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Degree project

Simulation and Implementation of Sustainable Automated Robotics at Volvo CE

Ergonomic and Economic Analysis of Automated Logistic Processes.

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Abstract

The development of advanced manufacturing opens new possibilities regarding cooperation between robots and humans, leading to a more sustainable industry. The study aims to research how automated processes with collaborative applications can be implemented in manual production systems and analyse the economic and ergonomic consequences this leads to. The process examined in the thesis is the de-labelling of wooden pallets conducted at the case company Volvo Construction Equipment in Braås, Sweden. Both quantitative and qualitative methods have been used. The study started with an analysis of the current situation regarding process design and the ergonomic aspect. The equipment needed to design the robot cell for testing had to be evaluated before a simulation of the automated process was done. Finally, the concept was tested in a laboratory environment. The result of the study shows that it is possible to automate if the removal of the labels is carried out completely perpendicularly. The economic analysis shows that the automated solution becomes a cheaper alternative after one year and four months. When the current manual process consists of unsustainable ergonomic elements, an automated solution will lead to improvements and more sustainable physical and organisational ergonomics.

Keywords: Industry 4.0, Industry 5.0, Automation, Simulation, RobotStudio, Collaborative Robot, Cobot, ROI Robot, Ergonomics, Pallet Handling, Pallet Dismantling, Logistics

Sammanfattning

Utvecklingen av avancerad tillverkning öppnar upp för nya möjligheter med samarbeten mellan människa och robot, vilket leder till en mer hållbar industri. Denna studie syftar till att undersöka hur automatiserade processer med kollaborativa applikationer kan bli implementerade i manuella produktionssystem och analysera de ekonomiska och ergonomiska konsekvenserna detta leder till. Processen som granskats är avtagandet av etiketter från träpallar som genomförts på fallföretaget Volvo Construction Equipment i Braås, Sverige. Både kvantitativa och kvalitativa metoder har använts. Studien började med analys av den nuvarande situationen gällande design av process och den ergonomiska situationen. Utrustningen som behövdes för att designa robotcellen utvärderades innan en simulering av den automatiserade processen gjordes. Seden testades konceptet i laboratoriemiljö. Studiens resultat visar att det är möjligt att automatisera om avtagandet av etiketter genomförs helt vinkelrät från pallen. Den ekonomiska analysen visar att den automatiserade lösningen blir ett billigare alternativ efter ett år och fyra månader. Om den nuvarande manuella processen består av ohållbara ergonomiska element, kommer en automatiserad lösning leda till förbättringar och en mer hållbar fysisk-, kognitiv- och organisatorisk ergonomisk situation.

Nyckelord: Industri 4.0, Industri 5.0, Automation, Simulering, Robotstudio, Kollaborativ Robot, Cobot, ROI Robot, Ergonomi, Pallhantering, Pallplock, Logistik

Preface

This study was initiated by Volvo Construction Equipment by contacting the Smart Industry Group at Linnaeus University. The project was to research how the pallet breakdown process can be automated. This thesis was done as a pilot project by removing the labels from the pallets. Since there is no published research regarding this, the concept created in this thesis is a benchmark for the whole industry.

We would like to express our gratitude to our supervisors, Osama Ziada, Jetro Kenneth Pocorni and Carl Sigfridsson for their commitment and support. We would also like to thank Anton Trollmåne for your guidance at the case company, and Gunay Toptas and Linnea Böhn for the help with handing out the questionnaires. A big thank you to Nicklas Jermstam from Universal Robots for letting us lease a tool and to Yaskawa for your support with the robot used in the tests. Thank you to *Smart Industry Group – SIG* for letting us test this concept in your lab.

The work has been divided equally between the authors and decisions have been made jointly.

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1. Introduction

1.1. Background

The globalization of the world has led to increased competition between companies. There is no longer a large competitive advantage to be geographically close to the customer. Instead, the customers choose the products with the best quality for the lowest price on a global market. This has resulted in companies moving their production to low-income countries to keep the products affordable (Poldahl 2016) which also has raised voices regarding sustainability.

For Germany to maintain their competitive advantage in the market, the German Federal Government introduced Industry 4.0 in 2011 with central aims to increase productivity and flexibility within the industry. Industry 4.0 consists of interaction between different elements to improve real-time data collection and decision making which leads to optimization of the production (De Propris & Bailey 2020). This concept applies to other countries with high production costs due to high salaries. Industry 4.0 also improves the working conditions for the operators since dangerous tasks can be automated and executed by machines (Matt, Modrák & Zsifkovits 2020). Some claim that a new revolution, Industry 5.0 is currently taking place where the focus is on human and robot collaboration, meanwhile, others state that this is part of Industry 4.0.

The new technologies and the interaction between technologies and humans result in a new type of production system and new processes. Simulation of these new systems can be used as a tool to plan for the new technologies. Analyses can also be made from the simulations to measure the efficiency of the process and compare it with other options (Choi et al. 2020).

1.2. Problematization

To stay competitive, manufacturing companies request automated solutions to implement into their current processes. Traditional industrial robots could be difficult to implement since they must be placed in separate cells with safety fences. The new technologies in Industry 4.0 have made it possible for human operators to collaborate with robots. Since collaborative robots do not require a separate robot cell, they become more flexible which facilitates the implementation into manual processes (Matt, Modrák & Zsifkovits 2020).

Automated solutions could be difficult to implement into a flexible process since well-defined steps and rules are required (Tripathi 2018). Lack of standardisation in a manual production system can lead to difficulties regarding the implementation of automated processes. Automating one part of the process could lead to an easier implementation due to the smaller change it requires. However, when the process still consists of manual workstations, the lack of standardisation can lead to lower reliability. Therefore, it is important to study how an automated process should be implemented and what changes are required.

1.3. Purpose and Research Questions

The purpose is to study how to implement an automated process into a manual production system. As well as analyse the ergonomic and economic effects of an automated process. The process studied is the de-labelling of wooden pallets.

1. How can a manual process be automated with a collaborative application?

2. How can an automated solution be implemented in an existing manual production system?

3. What are the ergonomic and economic effects of an automated process compared to a manual process?

1.4. Relevance and Previous Research

This study is relevant in the context of introducing automated solutions to current manual processes where automation can be implemented. The introduction of new technology could contribute to a sustainable ergonomic situation for the operators as well as economic improvements for the companies. Since there is a lack of published information in the area of automated de-labelling processes, the concept created is seen as a benchmark for the industry.

1.5. Delimitations

- Find a suitable tool for this concept.
- The label removal from wooden pallets is tested in a lab.
- The concept of camera recognition will be tested, but not connected to the controller.
- The external sensor will be a part of the robot cell, but not connected to the robot or its controller.
- The process will be simulated in ABB’s software RobotStudio.
- The ergonomic situation will be analysed, and an economic calculation conducted.

2. Theory

The *Theory* chapter consists of a literature review of the research area as well as theories covering The development of the industry, Automation, Ergonomics, Simulation and Costs of implementing robotics.

2.1. Literature Review

A literature review within the research areas The development of the industry, automation, simulation and the costs of implementing robotics were conducted to obtain an overview of the field. The searches were primarily made in the database OneSearch which Linnaeus University provides. Physical search at the library in the *Technology* section in the categories *Manufacturing* and *Management of Production* as well as the section *Social Sciences* in the category *Organizations of Production*. Since the research area is affected by continuous technical development, recently published literature was prioritized. The studied literature is shown in Table 2.1: The references used in the literature review.

Table 2.1: The references used in the literature review.

Author/s	Year	Title	Keywords
Adithan	2007	Process planning and cost estimation	Process planning
Duda	2010	Robot ROI: how to properly calculate the payback or return on investment of a robot installation into the mold build process	ROI Robot
Tripathi	2018	Learning Robotic Process Automation: Create Software Robots and Automate Business Processes with the Leading RPA Tool-Uipath	Automation process
Lantz, Löfsten & Isaksson	2018	Industriell ekonomi – Grundläggande ekonomisk analys	Organizations of production
Bilberg & Malik	2019	Digital twin driven human-robot collaborative assembly	Digital twin
Groover	2019	Automation, production systems, and computer–integrated manufacturing	Management of production
De Propris & Bailey	2020	Industry 4.0 and regional transformations	Industry 4.0
Matt, Modrák & Zsifkovits	2020	Industry 4.0 for SMEs: challenges, opportunities, and requirements	Automation Ergonomics
Smith	2020	Calculating a Robot's ROI: Determining the total cost and return on investment of an industrial robot is not a straightforward evaluation.	ROI Robot

Choi, Crump, Duriez & Trinkle	2021	On the use of simulation in robotics: Opportunities, challenges, and suggestions for moving forward	Simulation robotics
Margherita & Braccini	2021	Managing Industry 4.0 Automation for fair ethical business development: A single case study	Automation industry
Mourtzis	2021	Simulation in the design and operation of manufacturing systems: state of the art and new trends	Simulation manufacturing
Grabowska, Saniuk & Gajdzik	2022	Industry 5.0: improving humanization and sustainability of Industry 4.0	Industry 5.0

2.2. The Development of the Industry

Throughout history, there have been industrial revolutions leading to major changes. During these changes, new technologies, approaches and perspectives have been introduced to improve efficiency and profit within manufacturing. The first industrial revolution (1760 – 1840) introduced machines and changed the view on factory systems. This is followed by the second industrial revolution (1840 – 1914) which first introduced electrification and synthetic chemistry and later the perspective on standardisation which made mass production possible. The third revolution (1970 – 2011) introduced electronics and computers to the industry where automation now became a possible solution how to improve manufacturing systems (De Propris & Bailey 2020). When robots first were introduced during the third industrial revolution, the purpose was to replace human operators, especially for unsafe tasks. However, traditional industrial robots require a cell and are inflexible (Matt, Modrák & Zsifkovits 2020). The fourth industrial revolution, Industry 4.0, is a development from the third, where the combination of different technologies, data sharing and data collection are central (De Propris & Bailey 2020).

Matt, Modrák & Zsifkovits (2020) claim that human and robot collaboration is a part of Industry 4.0. Meanwhile, Grabowska, Saniuk & Gajdzik (2022) argue that human and robot collaboration is part of a fifth industrial revolution, Industry 5.0. The aim of Industry 5.0 is to change the focus back to humans and how improved cooperation with robots will lead to more sustainable production systems which will utilize the strengths of both humans and robots. Regardless if the revolution is a part of the fourth or, a new, fifth revolution, the future development requires extensive data handling. Investments are needed in IT infrastructure to be able to handle the digital change. To achieve this, management and the culture at the company must understand the possibilities of the development, which both businesses and individuals will benefit from (De Propris & Bailey 2020).

2.2.1. Automation

Production systems consist of the people, equipment, and operations of a manufacturing company. The trend in modern production systems is to increase automation, which leads to increased productivity if implemented correctly. An automated system is when human participation is reduced, which can be done to different degrees, semi-automated and fully automated. A semi-automated system needs some assistance from an operator in the production cycle, meanwhile, a fully automated system does not need manual operation for several cycles (Groover 2019).

Everything should not be automated; humans and machines have different strengths and weaknesses and should therefore execute different tasks. Machines are superior when it comes to the execution of repetitive tasks with high accuracy and can handle large amounts of data (Groover 2019). The ability to do repetitive tasks with high precision increases the quality and minimizes errors. Since everything is logged, it is easy to track errors when they occur (Tripathi 2018). Automation can also lead to increased safety since machines can execute tasks and processes which are dangerous for humans. However, humans are needed when it comes to creating new solutions and abstract problem-solving. Automation is not always a suitable option and should not be done for new products or other products with unknown demand since it could be difficult to scale the volume after implementation. A large capital is needed to automate a process and should not be done if the products are temporary (Groover 2019). The differences between machines and humans allow for efficient collaboration where they complement each other. The robot can do the lifting and the operator can execute tasks that are difficult to automate (Matt, Modrák and Zsifkovits 2020). Margherita & Braccini (2021) highlight the problem that new knowledge is needed when automating manual processes. However, the previous workforce has to be educated about automation to prohibit that knowledge about the processes is replaced with knowledge about automation. Margherita & Braccini (2021), Tripathi (2018) and Groover (2019) all emphasise that one large advantage of automating is that dangerous tasks could be executed by robots or machines.

Groover (2019) describes three different approaches when introducing automation, *The USA principle, Ten strategies for automation and process improvement* and *Automation migration strategy*. *The USA principle* consists of three steps, where the first step is to understand the process with its inputs, outputs and value-adding activities which can be illustrated with a flow chart. The second step is to simplify the process and remove unnecessary steps. The last step is to automate the process. *Ten strategies for automation and process improvement* are used as a checklist for possible improvements. It covers the following areas: specialised equipment or flexible equipment, analyses of the number of workstations, productivity control, automated material handling and more. *Automation migration strategy* consists of three phases, where phase one is manual production. Phase two is when single cells are automated and operate independently. The third phase is when the operations are integrated. Tripathi (2018) states that if the steps in a process are known it could be done by a robot as well.

2.2.2. Ergonomics

Work studies are when relatively small changes are made to a current process where the methods of working are analysed. The purpose of a work-study is to improve operations and use human effort more efficiently. Ergonomics are developed from work studies and consist of human interaction with other humans, equipment as well as the working environment. The layout of the workplace has a large impact on the ergonomics and should if possible be designed for the operator. If it is not possible to customize the workstation it should be designed for the average person and be adjustable (Adithan 2007).

Matt, Modrák and Zsifkovits (2020) describe three types of ergonomics, physical, cognitive, and organizational ergonomics. Physical ergonomics involves anatomy and physiology and focuses on working posture and repetitive movements with the purpose to prevent musculoskeletal disorders. The purpose of cognitive ergonomics is to minimize work stress and mental workload and focuses more on perception, stimulation and reasoning. Organizational ergonomics consists of job satisfaction and employee commitment where teamwork is important.

Margherita & Braccini (2021) emphasise the importance of ethical business development which not only focuses on economic growth but also business ethics and labour welfare. Many studies focus on the economic benefits of introducing Industry 4.0, however, if implemented correctly, Industry 4.0 can result in a more sustainable work environment. If the only goal of implementing new technologies is to increase the margins, it can be done at the expense of labour welfare. Industry 4.0 contributes to increased stimulation in the workforce which improves organizational and cognitive ergonomics. The case that Margherita & Braccini (2021) studied implemented collaborative robots into the assembly line which enriched the tasks for the operators as well as the feeling of increased responsibility. To succeed with this implementation, workers have to be involved in the development of the company. The introduction of Industry 4.0 requires new competence, the authors believe that the current personnel should be trained for this, instead of only hiring new personnel. It is important to keep the current knowledge regarding the process and add knowledge regarding automation, instead of it being replaced.

2.2.3. Simulation

Before the implementation of robots in a production system, physical testing is required. However, with the use of simulation, the quality of the physical testing and its cost-effectiveness can increase (Choi et al 2020). There are four main tasks connected to simulation development and activities before the implementation of a process; simulation modelling, conceptual modelling, model coding and experimentation. These activities are all affected by different objectives e.g., clients and stakeholders, as well as resources needed, e.g., software, budget, project team and hardware (van der Zee 2019). Simulation is essential to review new behaviour before actual realisation and therethrough avoid mistakes regarding implementation. The tools available for simulation are constantly evolving which leads to the possibility to create more efficient manufacturing processes at a lower price (Choi et al 2020).

Robotic simulation differs from classical simulation, which is characterized by statical scenarios, where robot simulation instead is placed in a dynamic environment with interdisciplinary elements. A dynamic environment is affected by external factors such as unforeseen movements, human interaction, and unstructured behaviour. It is difficult to foresee all these factors in simulation software. This leads to unpredictability within the simulation, where the robot rarely is aware of its operational surroundings and stimulus (Choi et al 2020). However, human involvement in the industry is required since it impacts the cycle time and safety of an operation. Here simulation can emphasise the ergonomic situation for the operators. Through simulation of tasks and workplace situations, the planning of improvement can be facilitated, and areas of risk can be highlighted and avoided before implementation takes place. The ergonomic situation for the operator and the simulated situation can also be compared, and areas of improvement be found (Mourtzis 2019).

Furthermore, a digital twin can be a tool to improve the collaboration between humans and machines. A digital twin is a virtual copy of a physical system for intelligent control of complex systems. A human-robot environment is characterised by high complexity, and it leads to a higher degree of automation. At the same time, it increases flexibility, productivity, and efficiency within manufacturing companies. With cooperation between humans and machines, the safety of the worker can also be ensured. Digital twins can be used in offline disconnected mode and thereby not constantly exchange information between the virtual world and the real production environment. This offline mode is especially useful during the design phase of different situations, such as layout planning, reachability, and ergonomic assessment for operators (Bilberg & Malik 2021).

The procedure within offline programming of a simulation contains key targets that are applied to the robot. Often time disturbances between both humans and other equipment will occur which leads to further modifications. This results in offline programming being time-consuming work. A further challenge within this area is the synchronisation between the virtual world and production environment which not yet is as accurate as requested to be able to use to its utmost (Bilberg & Malik 2021). These factors lead to the importance of simplification within simulation modelling. A successful simplification will result in an increase in utility e.g., ease of use, flexibility and visualization, and feasibility e.g., time, resources and data. At the same time, a simplification must not impact the validity of the simulation model. The need for simplification also depends on where in the development process the project is. During verification, it is central that the model is easy to code and debug while a fast implementation is more important during experimentation. There are however risks with the simplification of complex systems. A model that is too simplified might not be acceptable where details that are needed for model credibility are left out. Where simulation is the basis for decision-making, the simulation has to be detailed to function as a cost-benefit analysis. To prevent unnecessary complexity in simulation models, *Evolutionary development* can be a tool to use. It follows the rule that the model starts basic, where only the essential needs of the process are taken into consideration. The simulation is continuously added with details until it becomes suitable for its intended use (van der Zee 2019).

2.3. Costs of Implementing Robotics

A varying degree of automation leads to different levels of fixed and variable costs. Companies with a high degree of automation where robots execute most of the value-giving tasks and the labour force is minimized are characterized by high fixed costs and low variable costs. In companies where most of the tasks are manual, the variable costs are higher and the fixed costs lower (Lantz et al 2018).

When a company decides to invest in a robot it is of utmost importance to conduct an estimation of the potential cost savings that will occur. A higher degree of automation will lead to increased engineering, programming, equipment, installation and operator training costs. However, there will be reductions in the area of labour costs consisting of salary, overtime, taxes and benefits (Duda 2010). A model of cost estimation is difficult to conduct since there are unforeseen events as well as fluctuations in prices and costs. The Boston Consulting Group reports that the price of an industrialized robot should be multiplied by three to take all fixed costs into account. There are also variable costs such as labour, energy and maintenance which must be calculated where maintenance with all probability will increase with the ageing of the robot. An estimation of the labour cost for an automated system is approximately 25% of the costs of a manual system (Smith 2020).

3. Methodology

The *Methodology* chapter consists of the research design of this thesis as well as a section regarding the method selection where the chosen methods are accounted for.

3.1. Research Design

The research design is the plan of how to answer the research questions as well as ethical issues, constraints, and the research quality. A research plan should cover how data will be collected and how it will be analysed which can be illustrated as a “Research onion” as seen in Figure 3.1 (Saunders, Lewis & Thornhill 2019). Each layer of the “Research onion” is described in sections 3.2.1 – 3.2.6.

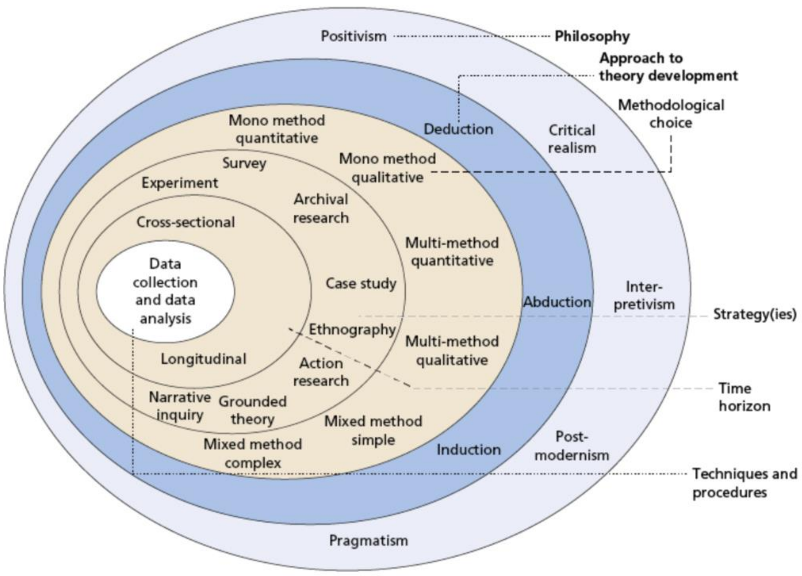


Figure 3.1:Research onion (Saunders, Lewis & Thornhill 2019).

The research design of this thesis is illustrated in Figure 3.2 with the following areas: idea, experiment, and evaluation.

The first step was to formulate the problem which was followed by analysis and the current situation and theories, these two steps are done iteratively. Thereafter research was done to find suitable equipment to accomplish the task.

This was followed by the implementation phase where firstly the equipment was discussed with companies within the area. When suitable equipment was found, a simulation of the process was made before it was tested in a lab to study if it was applicable in this case.

Lastly, the analysis begins with a comparison of the models created and the current situation. This was followed by the conclusion of the work and presentation of the results as well as suggestions for the company and future work.

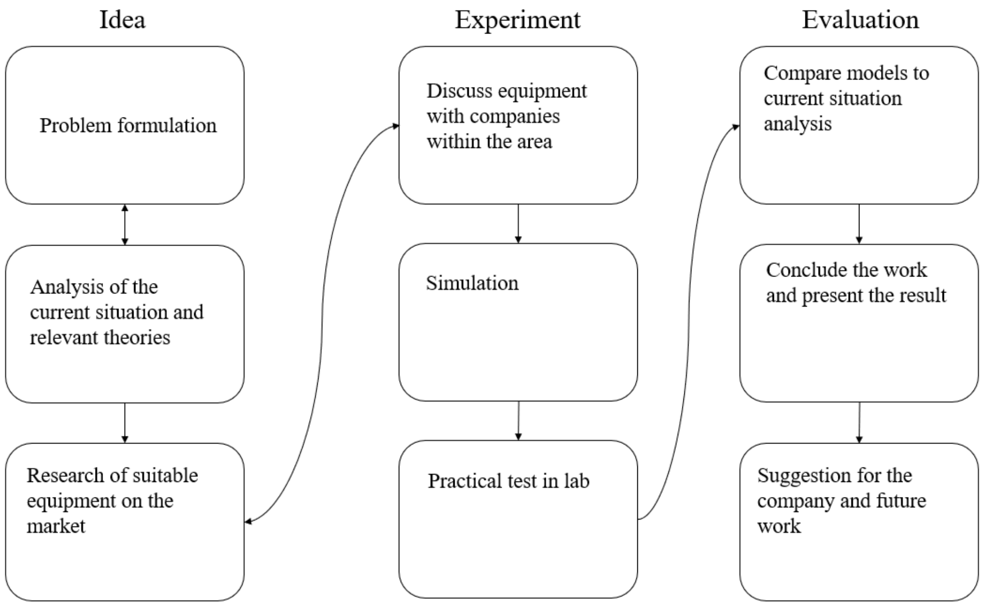


Figure 3.2:Research design.

3.2. Method Selection

The method selected for this thesis is illustrated in Figure 3.3 with a ”Research onion” similar to the one described in Chapter 3.1 *Research Design*.

Figure 3.3: Research onion with the selected method.

3.2.1. Research Philosophy

Research philosophy consists of different perspectives on the development of knowledge that occurs during studies. Predetermined assumptions regarding human knowledge, realities and values of influence will affect how the findings are interpreted. Different philosophical approaches influence the interpretation (Saunders, Lewis & Thornhill 2019). In Positivism, the reality is objective and independent of the observer and the knowledge gathered is based on empirical phenomena and measurable facts. Critical Realism sees, just like Positivism, the reality independent of the observer but to understand the studied phenomenon it must be linked to a theoretical framework. The Pragmatic philosophy emphasises a problem in reality, and knowledge is seen as a tool. The practical consequences of a theory or idea must be tested (Säfsten & Gustavsson 2020). The philosophy of this study was Pragmatism where the empirical problem was the focus and tested based on the theory.

3.2.2. Approach to Theory Development

The relationship between theory and reality can be either deductive, inductive, or abductive. A deductive approach means that conclusions of empirical phenomena are based on general principles and existing theories. An inductive approach is based on the empirical evidence from which the theory then is formulated. The abductive approach is a combination of deductive and inductive. Its starting point is empirical where a theory is created which then is tested in reality. From there the theory created can be developed and more general (Patel & Davidson 2019). This thesis followed an abductive approach where an empirical problem was described with theories which were tested and analyzed.

3.2.3. Methodological Choice

Methods used for studies can either be quantitative or qualitative. A quantitative method choice consists of numerical data and data analysis of graphs and statistics. For data collection, often one or more questionnaires are used. A qualitative method consists of non-numeric data and can be collected through interviews. A mixture of mentioned methods is commonly applied (Saunders, Lewis & Thornhill 2019).

To compare the process from different points of view, both qualitative and quantitative data were collected. A qualitative method was used to gather information on the operators' views on the ergonomics of the current process. A quantitative method was used for collecting data regarding the ergonomic situation as well as the economic aspect.

3.2.4. Research Strategy

Research strategy is the plan of how the research goal will be achieved. There are several different strategies, and it is important to choose a strategy which is coherent with the purpose and methodological choice. It is possible to combine strategies to fulfil the research goal. Some common research strategies are experiments, surveys, and case studies (Saunders, Lewis & Thornhill 2019).

A case study is when a phenomenon or topic is studied in depth with real-life context. The case study should answer what is happening and why, the case could be a person, a group or a business. The real-life context creates many unknown variables which makes it impossible to study one isolated phenomenon with its causes and effects. Case studies are often used for exploratory, descriptive and explanatory purposes and are often used with a deductive research approach. Both qualitative and quantitative data can be collected in a case study and the number of cases studied varies. However, there are often one or a few cases studied which result in a small sample size, therefore the result is not applicable to every case and should not be generalized (ibid).

To evaluate and compare the processes the suitable research strategy is a case study due to the complexity of industrial environments. This thesis focuses on how to plan for automation which makes it necessary to study within the real-life context of a case study.

3.2.5. Time Horizon

The time horizon for a study can either be cross-sectional or longitudinal. A cross-sectional study consists of a specific problem or area and is studied during a specific time. These types of studies are typically academic courses which are time constrained. Longitudinal studies are carried out over a longer period which makes this type of study suitable for analysing the changes and development within an area (Saunders, Lewis & Thornhill 2019). The time horizon for this thesis was cross-sectional since it consisted of a specific problem which was studied during a specific time.

3.2.6. Data Collection

There are several different data collection techniques where observations, measurements, interviews, and questionnaires are some frequently used ones. Data collection could be divided into the following two layers, data access and type of data, which are illustrated in Table 3.1. Data access describes the source of the data and is divided into primary data and secondary data. Primary data is when the data is collected from the original source. Secondary data is collected for other purposes and often by someone else, when using secondary data, it is important to include source criticism. The type of data is whether it is naturally occurring (e.g., observations and interviews) or artificial (e.g., simulations) (Säfsten & Gustavsson 2020).

Table 3.1: Types of data (Säfsten & Gustavsson 2020)

		Type of data		
Naturally occurring data				Artificial data
		Phenomena in reality	People's perceptions and experiences of reality	Reconstructions of reality
Access to data (source, access and proximity)	Primary data	Observation Measurement	Interview, Workshop Questionnaire	Simulation data
	Secondary data	Document study, source criticism		

Observations are described by some as the basis for all human knowledge. However, in order to conduct reliable observations, it has to be executed correctly and carefully documented. Observations are useful when studying a phenomenon or human behaviour since what is happening is studied, not what someone says. This makes it a suitable data collection method for case studies, experiments, and action research (ibid).

Measuring is when a number is assigned to the observation and is described as data collection from a real phenomenon. When using measurements as a data collection method it is important to analyze what is measured, how it is measured and the accuracy and precision of the measurement (Säfsten & Gustavsson 2020).

Questionnaires are usually not used in exploratory or descriptive research since those purposes often require more open answers. Therefore, it is more common in descriptive and explanatory research. Questionnaires could be used as the only data collection method, but it is often combined with other methods. A questionnaire can be conducted in several different ways, some are, telephone, web, and postal. There are two types of questions in a questionnaire, open and closed questions, and both types are often used. Closed questions are when the respondent has two or more fixed options to respond to, the advantage of these questions is that it requires less time but are on the other side easier to misinterpret. Open questions allow the respondents to formulate their answers and are often used in exploratory research if the alternative answers are not known (Saunders, Lewis & Thornhill 2019).

The data collection phase followed the work process presented in the research design (Figure 3.2: Research design). The idea phase consisted of information gathering of current theories from articles and books as well as market analysis of available equipment. Questionnaires were done to understand the operators' views on the situation. The main reason for using a questionnaire instead of interviews was the aspect of anonymity to receive honest answers. To increase the number of participants in the questionnaires, the number of questions was kept to a minimum and formulated in a simple way. Some of the questions were closed and quantified to make them easier to answer. However, to receive the operators' views on the situation some questions had to be open and qualitative. Observations were done to understand the current situation and how the process can be automated. This led to the experiment phase where the concept was simulated and tested. Observations and measurements were collected from the physical test as well as the simulation.

3.2.7. Research Ethics

Within degree projects it is expected to act according to ethics and the author and collector of information must behave ethically correctly, as well as use the correct references. There are codes of ethics called "Swedish Research Council´s principles of ethical research for the humanities and social science" that have been developed to provide a framework on how to behave correctly (Blomkvist & Hallin 2015).

- The collection of information, meaning the people that have taken part and contributed to the study in interviews and surveys, need to be informed of the aim of the study and what it is to be used for.

- Consent, meaning that the people that have been studied have agreed upon taking part in the study.

- Confidentiality, meaning that the material collected or created is not to be shared but must be handled confidentially.

- The good use of the material, meaning the material that has been collected or created only is to be used what it beforehand has been informed about (Blomkvist & Hallin 2015).

This thesis followed the ethics framework provided by the "Swedish Research Council´s Principles of Ethical Research for the Humanities and social science" as well as a signed contract with the case company.

3.2.8. Research Quality

Säfsten and Gustavsson (2020) discuss four areas of research quality: objectivity, validity, reliability, and trustworthiness. To obtain objectivity, the writer has to be unbiased and fact-based. Some believe it is impossible to be totally objective. However, it is important to be aware of objectivity and subjectivity. High validity is when what is intended to be studied actually is studied and within what context the result is valid. To strengthen the validity triangulation could be used, by using more than one source and method. Reliability is when it is possible to repeat the study and receive the same results. Trustworthiness consists of four segments: credibility, transferability, dependability, and confirmability. However, these segments are also components of reliability and validity.

The contract with the case company did not decrease the objectivity of this thesis since the case company inquired an objective result. High validity was obtained with data triangulation described before by having several participants in the questionnaire. The economic data was gathered from three different suppliers and thereafter a mean value was calculated which increases the validity.

Since the study consists of one case company, the result cannot be generalized to the whole industry. High reliability is obtained by creating a structured method which is easy to follow. The survey gives the study high reliability since the same questions are asked to every operator.

4. Situation at the Case Company

This chapter describes the current state at the case company, including the process which is studied as well as the internal ergonomic guidelines.

4.1. Process Description

The pallet handling process at Volvo CE is currently a manual process and the station is shown in Figure 4.1. Each day, approximately 700 pallets are handled. Firstly, the pallets are transported with forklifts to the start of the conveyor belt, the pallets can be stacked on top of each other or placed separately. The conveyor belt moves the pallets automatically from start to point 1. There is a machine located at point 1 which de-stacks the pallets and places them one by one on the conveyor belt. The pallets move automatically from point 2 on the conveyor belt. While the conveyor belt is moving, the labels and remaining trash are removed by an operator. Thereafter the pallets are dismantled, and collars and pallets are stacked separately. The conveyor belt at the station is 510 mm high.

a) b)

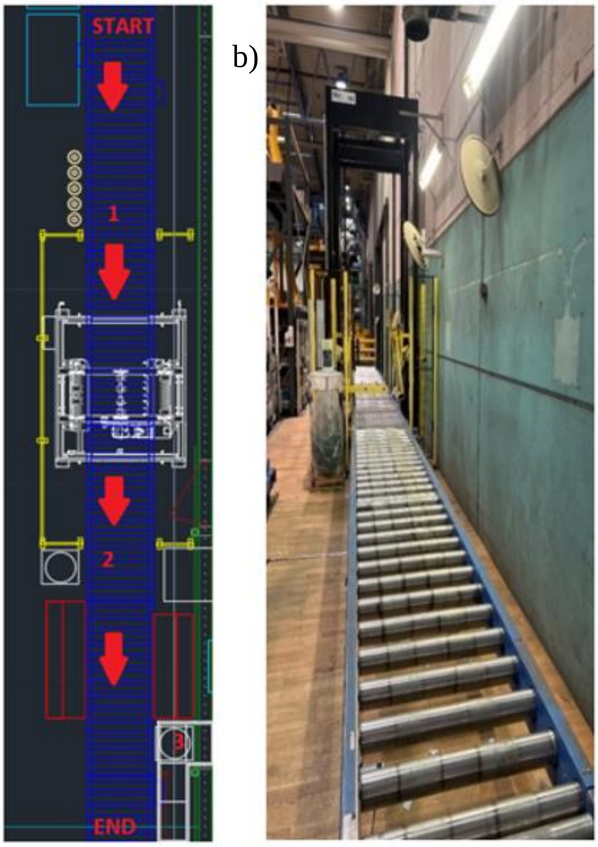


Figure 4.1:a)Drawing of the layout of the current station. b)Picture of the current situation taken from "END".

The station where the labels are removed is usually staffed with two operators during the day shift and one during the evening shift. However, one operator does not spend an entire shift at the station, they have a rotation where they move between several stations. Figure 4.2 a) shows one of the authors at the station, removing a label from a pallet.

There are two types of labels on the pallets which are shown in Figure 4.2 b). The white label is the external label which is used when transporting the material to the plant and is therefore placed by the supplier. The external labels can be either A4 or A5 size, can be paper, plastic/plastic pocket and attached by staples or glue. They can also be attached anywhere on the bottom collar. The pink one is referred to as internal the label which is used for the internal handling of the material and is always of size A4. According to Volvo CE standardisation, the internal label should be placed on the bottom collar to the left, with five staples. There is no standardisation of the position of staples on the label. However, the standardisation is not always followed where the number of staples per label and pallet differ which is shown in Figure 4.2 b).

a) b)

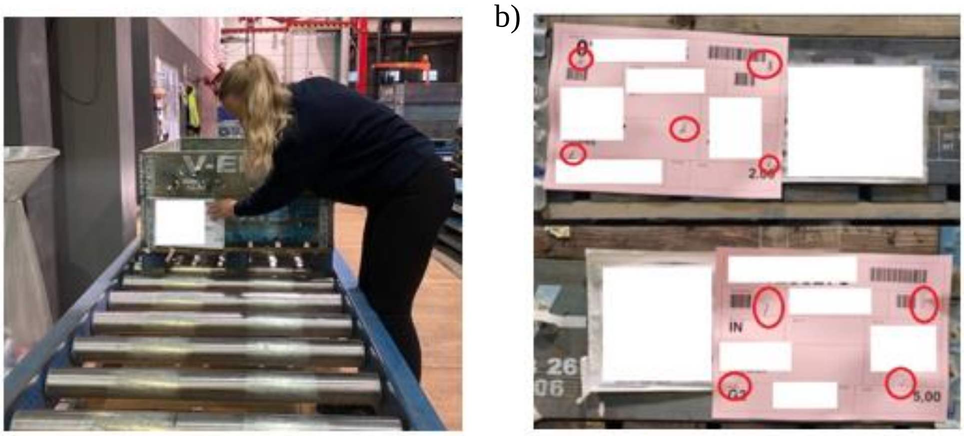


Figure 4.2:a) Picture of one of the authors at the station. b) Examples of the labels and the position of the staples.

4.2. Ergonomic Guidelines

For Volvo to maintain ergonomic sustainable workstations, they work accordingly to an internal ergonomic policy. In the policy, the movements of the operators have been analysed and divided into three categories: green, yellow and red. A movement in the green area is an approved movement, the yellow area is a critical movement, and maintaining movement in the red can lead to major pain issues, see Figure 4.3 (Volvo 2023).

LOW IMPACT Acceptable Further investigation not nededed	MEDIUM IMPACT Measures shall be planned and executed when possible Further investigation needed	HIGH IMPACT Measures shall be planned and executed immediately Further investigation needed
The level of physical and / or cognitive workload means that **no one or few employees** are exposed to risks within both short and long term.	The level of physical and / or cognitive workload means that **several employees** are exposed to risks within both short and long term.	The level of physical and / or cognitive workload means that **most of the employees** are exposed to risks within both short and long term.
Further investigation could be necessary for pregnant women or minors. General measures not needed but individual adjustments of workstation can be necessary.	Further investigation needed and measures shall be planned, executed and followed up.	Further investigation needed both immediate and long term, measures shall be planned, executed and followed up.

Figure 4.3: The green, yellow and red movements and postures (Volvo 2023).

How different movements and postures can be divided into the green, yellow, and red ergonomic areas can be seen in Figure 4.4. The recommended working zone for back flexion is between 0 – 60 degrees with support and 0 – 45 degrees without support. When working at a table, it is recommended to have an adjustable height, if it cannot be adjustable, it should be 1195mm (Volvo 2023).

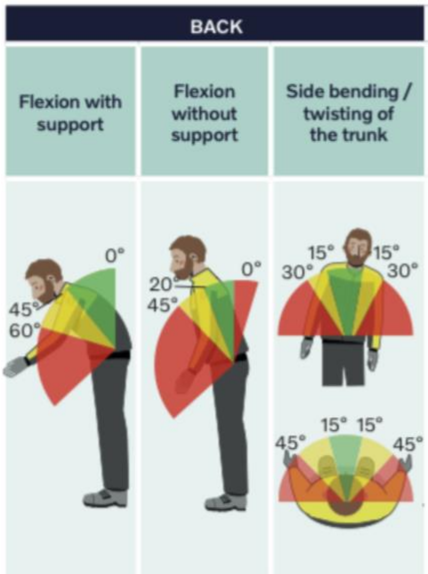


Figure 4.4: The ergonomic areas of movement of the back (Volvo 2023).

Postures categorized as yellow or red are divided into green, yellow, and red areas, as shown in Figure 4.5. The postures can either be dynamic or static and this affects allowance of frequency and occurrence. A yellow posture can be allowed for a short period, while a red posture first needs to be validated by an ergonomist. When in the yellow area, both red and yellow postures need to be part of a rotation, or the workstation needs to be improved. The red area is never approved (Volvo 2023).

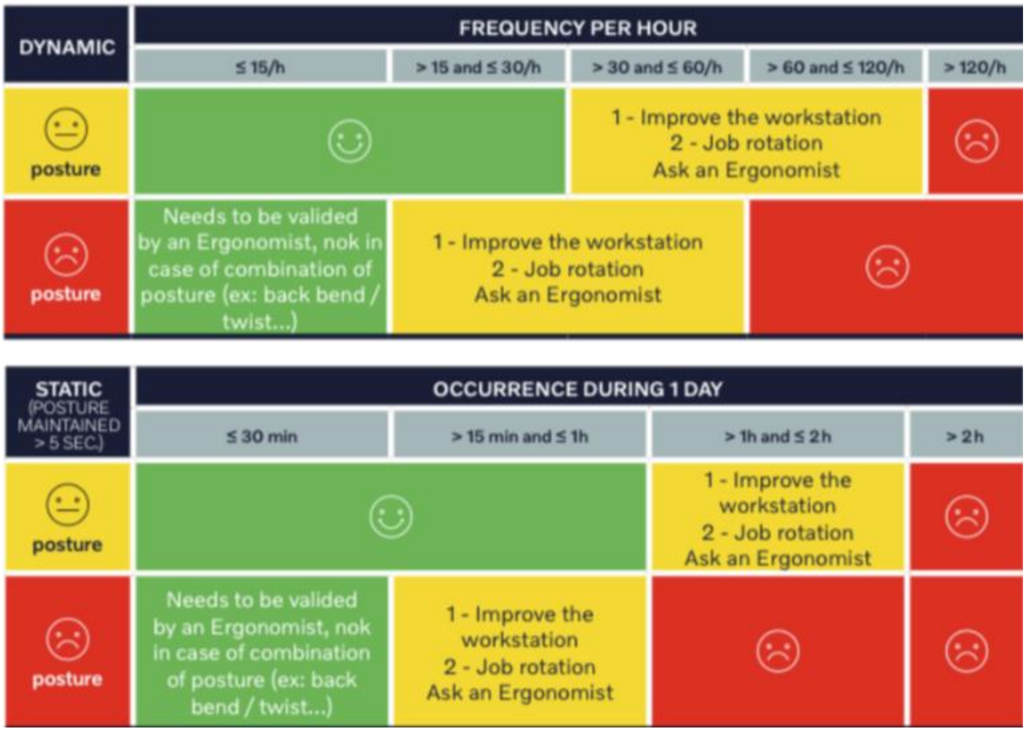


Figure 4.5: Green, yellow and red area for frequency and occurrence of movements and postures (Volvo 2023).

5. Robotic Cell

The chapter Robotic Cell describes the equipment used to set up the robotic cell, how it is implemented at the case company, the simulation as well as how the tests were conducted.

5.1. Design of Robotic Cell

The equipment used in the robotic cell is shown in Figure 5.1. Two different types of paper were also used in the tests.

Figure 5.1: Shows all the equipment used in the set-up a) Yaskawa HC10 b) YRC1000 HC10 c) VGP20 d) SICK S300 Mini e)OpenMV h7 plus R3 f)ComputeBox e)Hammer Tacker g)Staples

The equipment was connected according to Figure 5.2 where the camera detects the label. The position of the label is described as a function of the coordinates and the time when it should be removed which is analysed in a computer. A signal with the position the robot should move to is then sent from the computer to the controller of the robot. The computer sends a signal to the Compute box which activates and de-activates the tool. Then the physical process starts. The SICK-Sensor is connected to the controller and stops the robot in case an object enters its range.

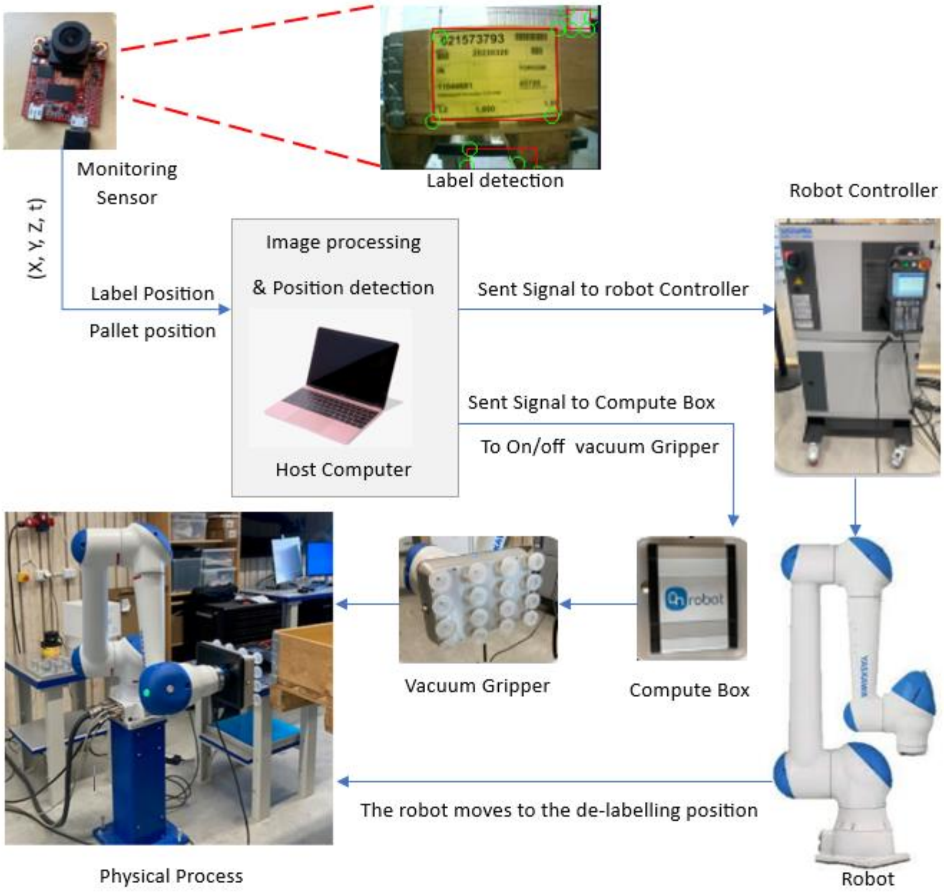


Figure 5.2: Wiring diagram of the robotic cell

5.1.1. Robot and Controller

Both Volvo CE and Linnaeus University had robots which could be used to test the application. The options are listed in Table 5.1 with the advantages and disadvantages of each option.

Table 5.1: Accessible robots with advantages and disadvantages.

Robot	Advantages	Disadvantages
Universal Robots-UR10e	Collaborative application	Located far away, No prior knowledge of the brand
Yaskawa HC10	Located at the University, Knowledge at the University, Collaborative application	
ABB IRB 1600	Located at the University, Knowledge at the University	Non-collaborative

The robot from Universal Robot is located at Volvo CE in Hallsberg which is four hours away from the University. This option would be sensitive to unpredicted difficulties since the test time would be limited to a couple of days. There is also no previous knowledge of this brand and there would not be anyone to assist if problems occurred. Therefore, it was chosen to use a robot accessible at the university, either ABB IRB 1600 or Yaskawa HC10. Due to the collaborative applications for HC10, this option was chosen. The controller connected to this robot is the YRC1000 HC10.

5.1.2. Robotic Tool

Since there is no other published solution for automating the de-labelling of wooden pallets, the process to find a suitable tool started with brainstorming and discussions with supervisors. This was then combined with research on the current state of the market. Both tools available, and what the industry successfully implemented before this thesis were investigated. The research did not show any automated processes of removal of pallet labels, however, similar processes were found and studied and the result of possible tools for this application from brainstorming and research is found in Table 5.2. After compilation of the tools and their advantages and disadvantages, a vacuum tool seemed like the most suitable option for this concept.

Table 5.2: The results from the brainstorming, research, and discussions with supervisors.

Tools	Advantages	Disadvantages
Vacuum	Does not damage the pallet, Removes the whole paper	Difficult to program for different sizes.
Gripper	Does not damage the pallet, Removes the whole paper	Time-consuming
Brush	Quick, Easy to use	Damage the pallet, Noisy, Garbage in small pieces
Staple remover	Removes the whole paper, Does not damage the pallet	Not existing design, Difficult to program

Several companies in the field of robotic tools were contacted concerning the tool to receive their opinions and if they have any current solutions for this problem. The following companies were contacted through e-mail or their website: Stöger Automation, United, Atlascopco, Fanuc, Schunk and

Universal Robots. None of the companies had a current solution for this and a majority of them thought it would be difficult to solve. However, Schunk and Universal Robots were interested in finding a solution for this and gave their feedback on how it could be solved through a Teams meeting. The result from the research was presented to the companies as options for how the problem could be solved. After the discussions, both companies offered to lease tools to test if they can remove the labels. Both Schunk and Universal Robots thought a vacuum gripper would be the most suitable tool which corresponded to the previously conducted research.

Universal Robots suggested two different vacuum tools to test the concepts, shown in Figure 5.3. The tool from Schmalz is a pneumatic gripper and needs to be connected to external airflow, which was not a possibility in the test. The tool from OnRobot is an electric vacuum gripper and has an integrated air supply, therefore this tool was chosen. There is larger reliability to pneumatic grippers, therefore if the electric gripper works, it should work with the pneumatic as well.

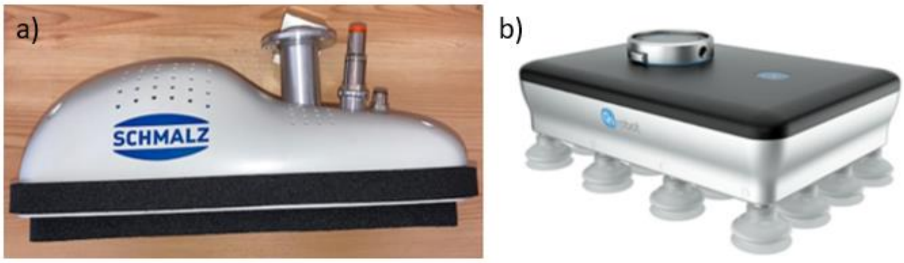


Figure 5.3: The tools borrowed, a) Tool from Schmalz b) Tool from OnRobot which was used in the test (OnRobot n.d.).

5.1.3. Sensor and Camera

The robot is designed to work side by side with the operators and has integrated sensors that will make the robot stop in case of a collision with an object. Still, for safety reasons, additional sensors are needed to reduce the speed of the robot when an object or operator is near the robot. In the set-up, the sensor SICK S300 Mini is used, see Figure 5.4 a). The sensor was used due to it already being accessible at the university. The range of the sensor is 270 degrees and is divided into two colour-coded areas depending on the distance to the object, see Figure 5.4 b). When an object or operator enters the yellow area, the speed of the robot will be reduced and in the red area, it will completely stop.

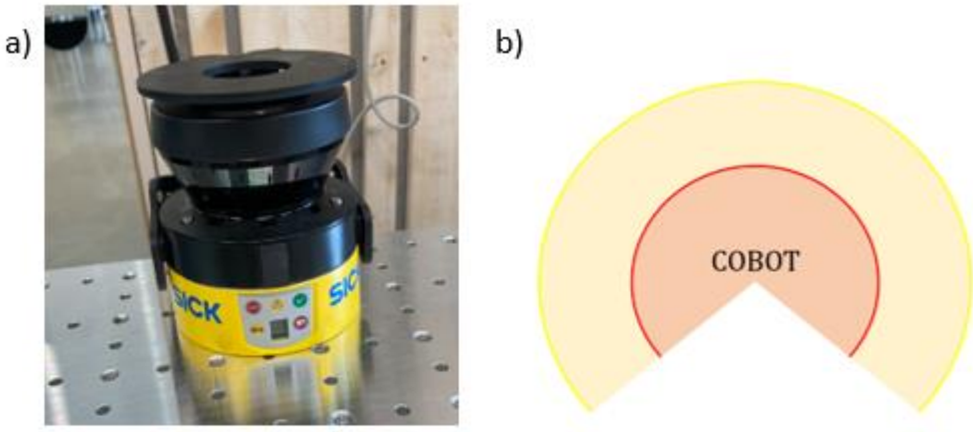


Figure 5.4:a) The sensor SICK S300 Mini. b) Safety zones for the sensor.

The camera used to detect the label is OpenMV h7 plus R3. The camera was chosen due to it already being accessible at the university. The vision of the camera can detect geometry, see Figure 5.5, and therethrough update the robot of the exact location of the label.

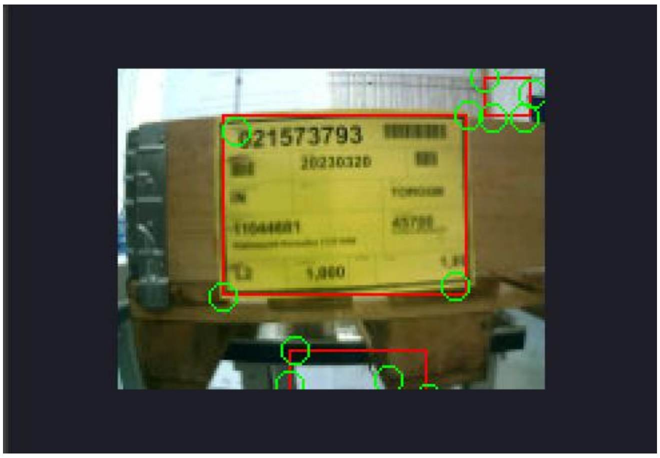


Figure 5.5 Camera detects geometries.

The camera was connected to the software OpenMV IDE, see Figure 5.6. In the software, the already existing code tells the camera to search for rectangles. Due to the sensibility of geometries, the outer edges of the label had to be thicker, see Figure 5.7. When the placement of the label is registered by the camera, a signal should be sent to a computer which will tell the controller of the robot where it should move and place the tool.

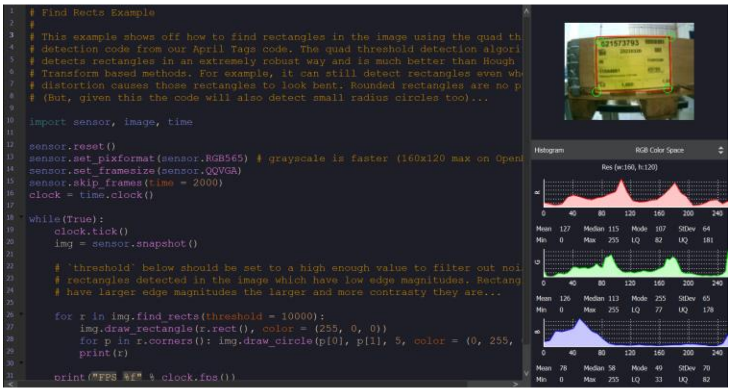


Figure 5.6 OpenMV IDE and camera detection.

Figure 5.7 Thicker border of the label

5.1.4. Label, Hammer Tacker and Staples

To replicate the current process, labels, hammer tacker and staples were borrowed from Volvo CE. The paper currently used as labels is A4 and weighs 120 grams/m^2, thinner paper of 80 grams/m^2 was also tested. The staples and the Hammer Tacker are of the brand Ironside, the staples are type L and 6 mm.

5.2. Implementation at Case Company

The end goal for the case company is to automate the whole pallet handling process. Following the *Automation migration strategy*, the first phase is the manual process, the second phase is automating single cells in the process and the last phase is to integrate the automated cells. The case company is in the second phase of this strategy where cells are automated. However, in this case, the project of automating the process is not done all at once. Therefore, to keep the process functioning during the *Automation Migration Strategy*, the automated cells need to be incorporated into the current manual process. This is done by placing the robot where the labels were removed manually in the current process. As in the current process, the pallets are de-stacked by the machine located between points 1 and 2 in Figure 5.8 a). After they are de-stacked the labels are removed by the collaborative robot placed at point 3 in Figure 5.8 a) & b).

a)

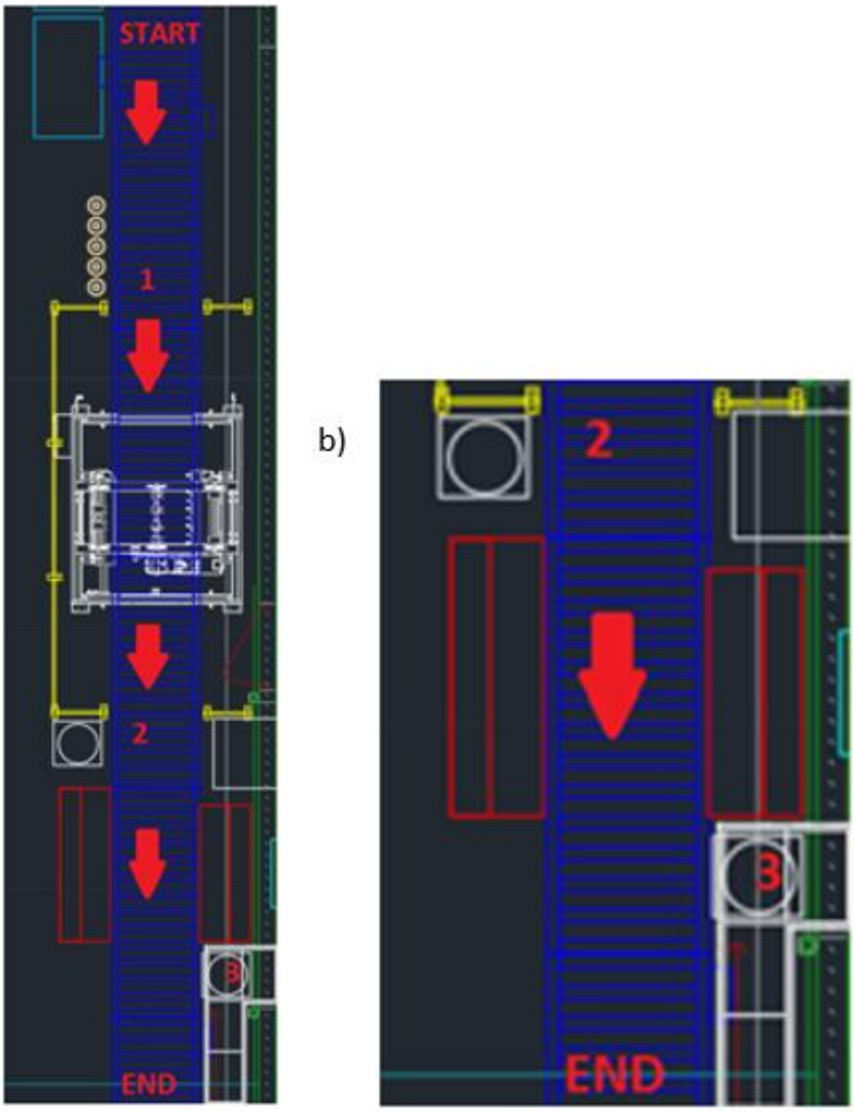


Figure 5.8: a) Layout when the automated cell is incorporated. b) Zoomed in layout of the placement of the collaborative robot.

5.3. Simulation of Robotic Cell

The simulations of the automated processes were done in RobotStudio which is used for offline programming and simulation of ABB robots. In the software, the code for offline programming can be modified with the language RAPID. The use of RobotStudio was carried out through previous knowledge combined with help from videos of similar simulations on the internet as well as discussions on the ABB Robotics User Forum. The robot selected for the simulation was Swifti CRB 1300 from the ABB gallery which can be used for collaborative applications. This robot was chosen due to its similar properties to the Yaskawa HC10 used in the physical tests. The conveyor belt was imported from ABB´s equipment library and the pallet, and the collar is according to EU standardisation and was downloaded from the website grabcad.com. These were then combined in SolidWorks to form one object. The paper was created as a geometry in RobotStudio. A 3D drawing of the vacuum gripper was downloaded from the OnRobots website and imported to RobotStudio. The simulation setup was created according to the design at the Volvo plant.

An object in RobotStudio can be assigned as a Smart Component which therethrough can react to certain triggers. The source is used to make the pallet appear, LinearMover is used to move the pallet and the sink is used to make the pallet vanish. Plane sensors are used to trigger LinearMover and Sink when the pallet arrives at a certain point. LogicSRLatch is used to set and reset output signals.

The robot is taught targets which are then added to the path. To be able to attach the paper to the tool, an I/O signal is needed. In the controller tab under configuration, a signal with the values 1 and 0 is created which then is connected to the “attach” and “detach” actions in the event manager tab. These are added as action instructions in the path. An I/O signal is also needed for an automated import of new pallets at the beginning of the simulation. The signal was connected to the controller via the RAPID code as SetPulse.

The creation of the simulation followed the evolutionary development where a basic set-up started as the foundation where details were added continuously to make it suitable for its intended use. The file for the final simulation in RobotStudio is found in the link below.

Link to simulation

The final set-up of the simulation is shown in Figure 5.9. The fence is from the de-stacking machine and the garbage bin is the blue box behind the conveyor belt.

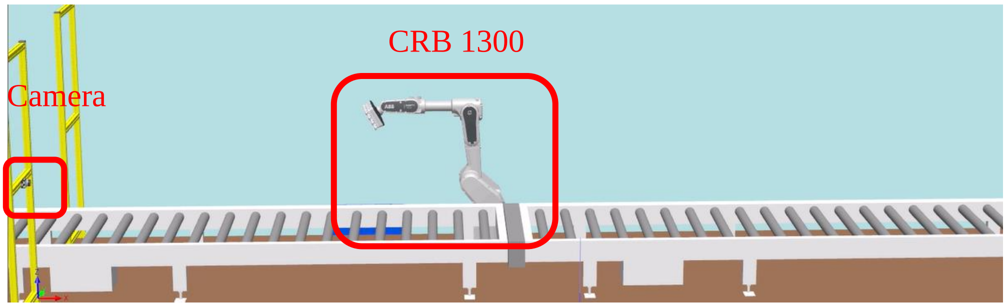


Figure 5.9: The final set-up of the simulation with the CRB1300 robot.

The pallet enters the conveyor which is shown in Figure 5.10 and Figure 5.11.

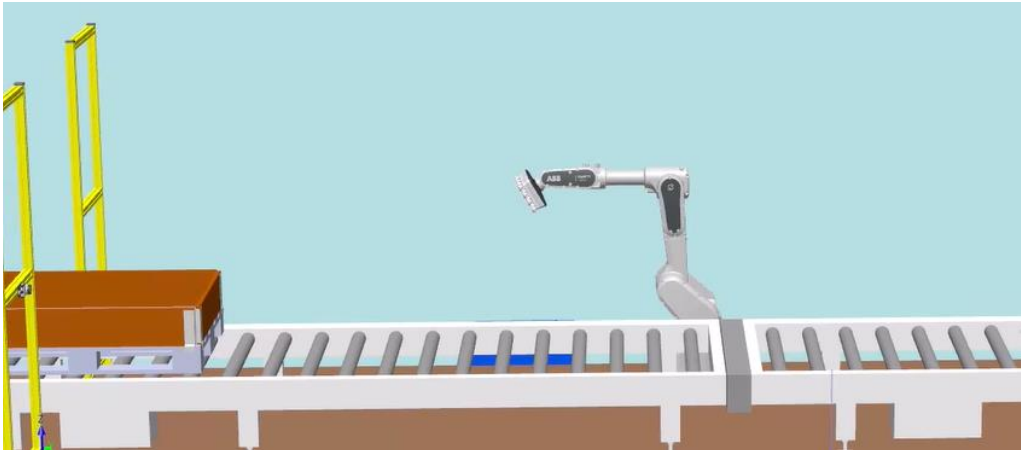


Figure 5.10: Front view of where the pallet enters.

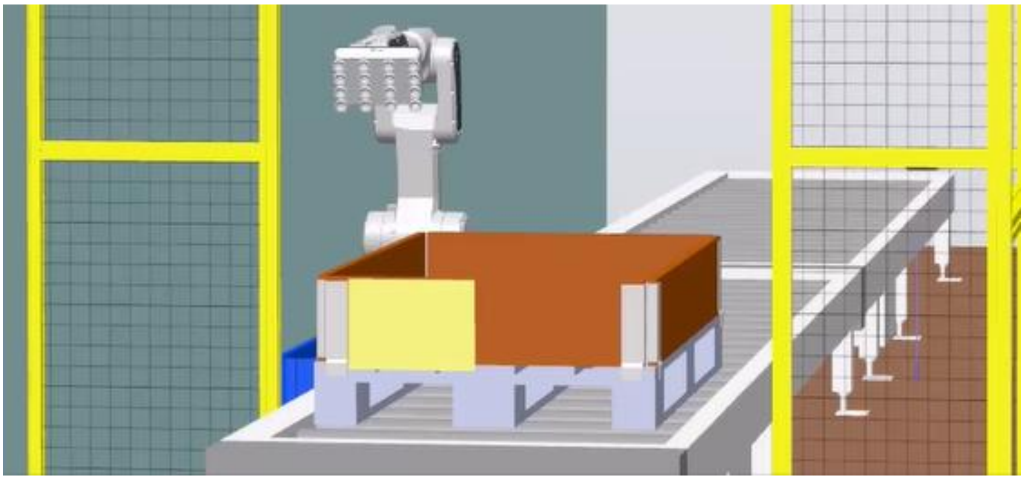


Figure 5.11: Side view of where the pallet enters.

The pallet stops in front of the robot. In the meantime, the robot moves to the start position, see Figure 5.12 and Figure 5.13

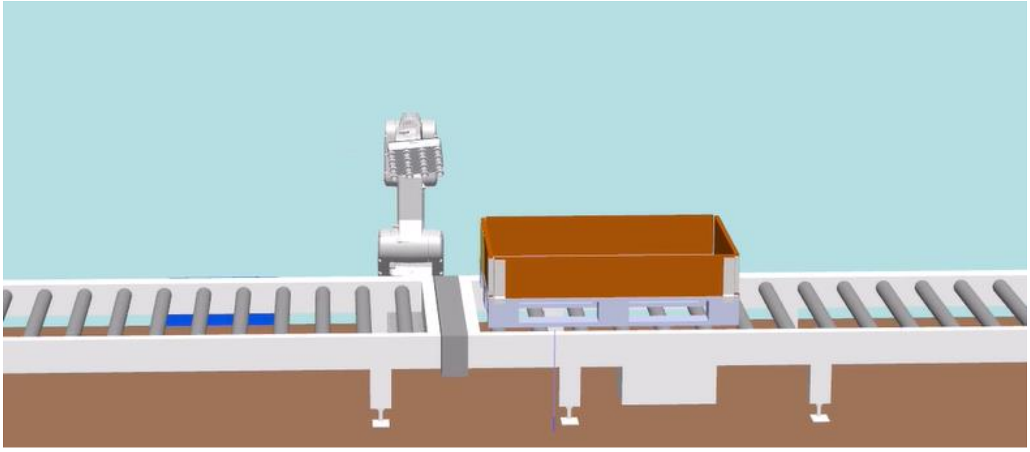


Figure 5.12: Front view of when the pallet is in front of the robot.

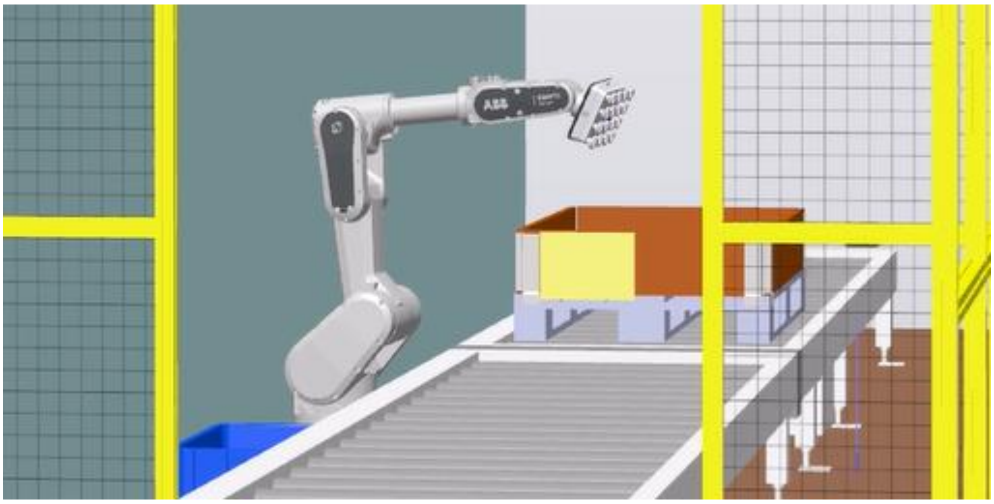


Figure 5.13: Side view of when the pallet is in front of the robot.

The robot approaches the pallet and removes the label, see Figure 5.14 and Figure 5.15.

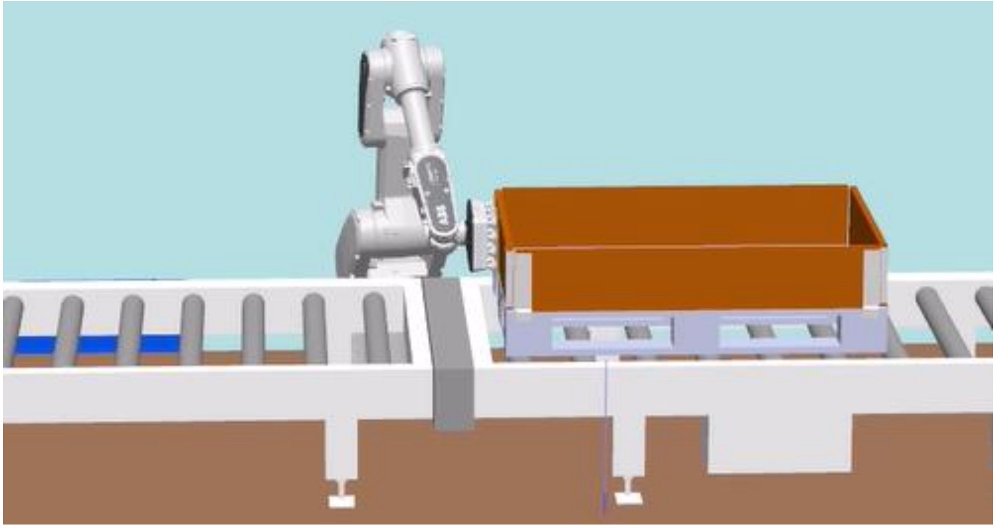


Figure 5.14: Front view of when the label is removed.

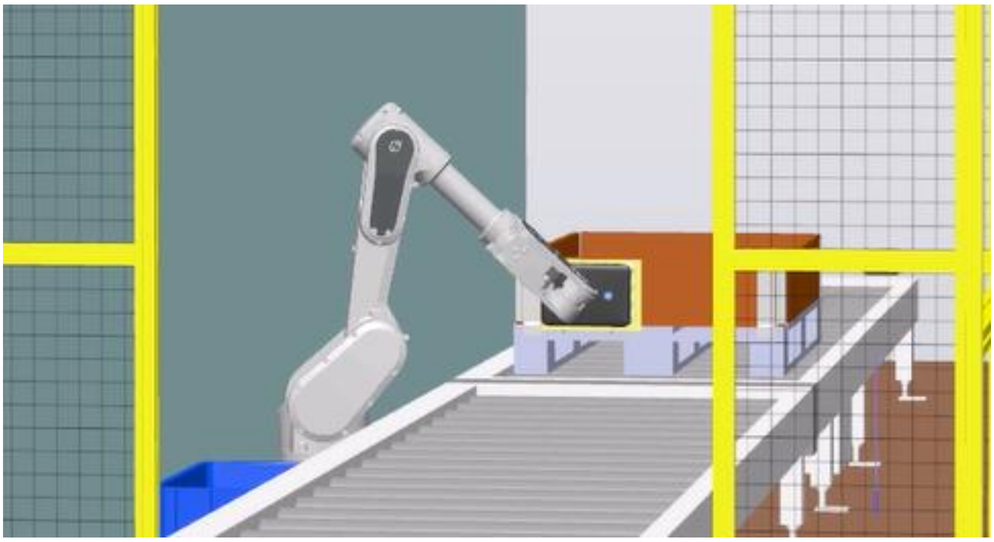


Figure 5.15: Side view of when the label is removed.

The robot puts the label in the garbage meanwhile the pallet moves away on the conveyor which is shown in Figure 5.16 and Figure 5.17.

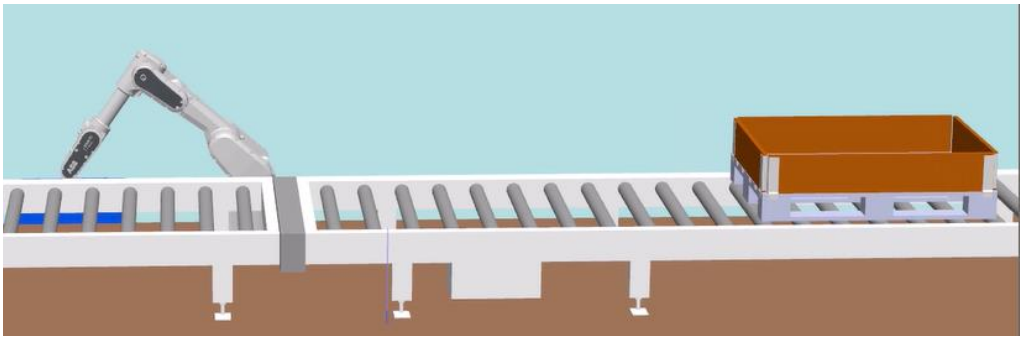


Figure 5.16: Front view of when the robot puts the label in the garbage.

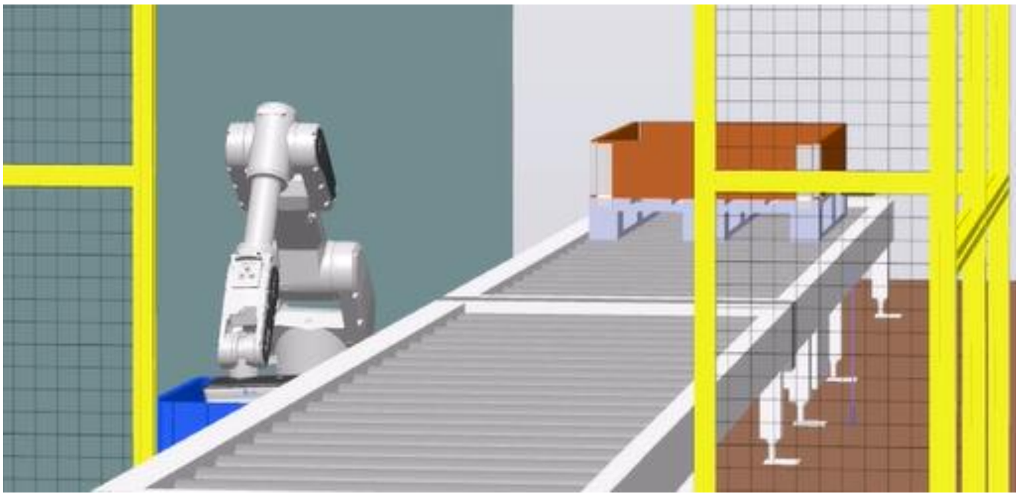


Figure 5.17: Side view of when the robot puts the label in the garbage.

5.4. Proof of Concept

The control of the tool during the testing phase was conducted in the web client of OnRobot, see Figure 5.18, which was connected to the IP 192.168.1.1. In the devices tab to the left, the VGP20 gripper was chosen and could then be monitored and controlled.

Figure 5.18: The OnRobot Web client

In the VGP20 tab, the values and state of the tool could be read. The tool is divided into four rows of channels: A, B, C and D, these are shown in Figure 5.19. The status and value of each channel can be monitored in the web client, see Figure 5.20.

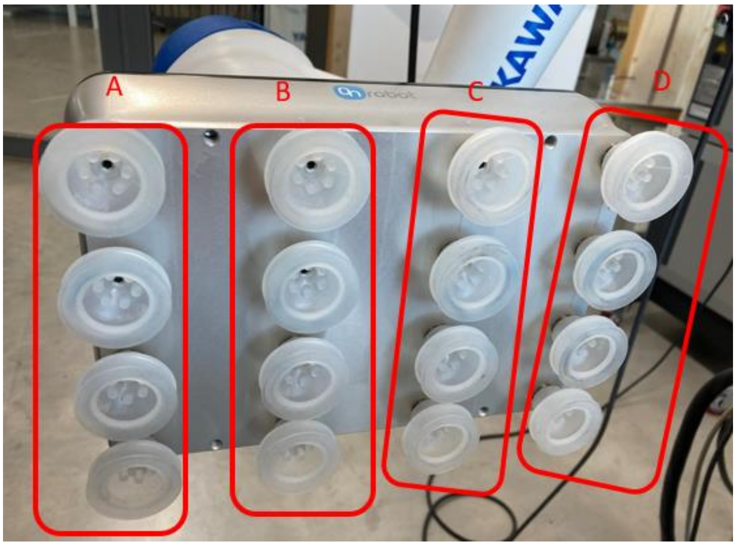


Figure 5.19: The columns of vacuum cups.

ACTUAL VALUES AND STATES

Busy ○

Channel	A	B	C	D	
Current vacuum	0	0	0	0	kPa
Grip detection	Not gripped	Not gripped	Not gripped	Not gripped	
Release status	Release ok	Release ok	Release ok	Release ok	

Figure 5.20: Monitoring of each row of channel.

In the device control of the vacuum gripper, either all channels can be chosen at once, or only the channels needed for the current situation. The target vacuum ranges from 5 to 60 kPa. The device control is shown in Figure 5.21.

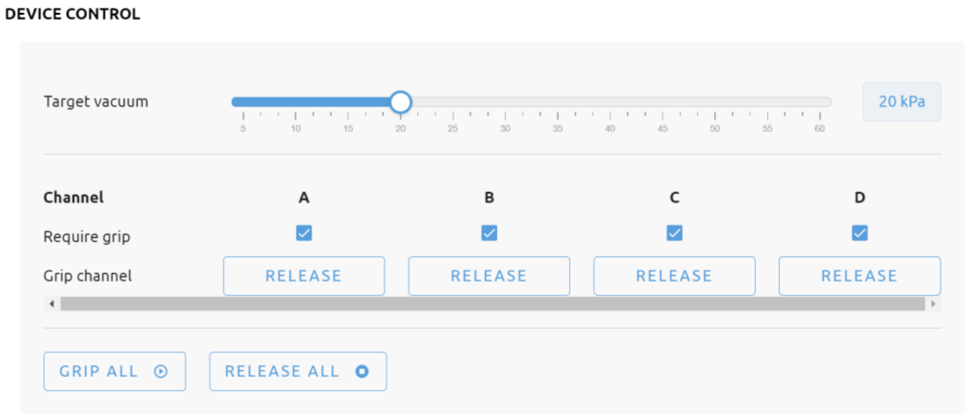


Figure 5.21: The device control of the VGP20 in the web client.

When executing the testing, a set-up was created in the lab in which changes were made to investigate what circumstances are needed for a successful implementation. The general setup is shown in Figure 5.22, different changes were made to the set-ups which are shown in Table 5.3.

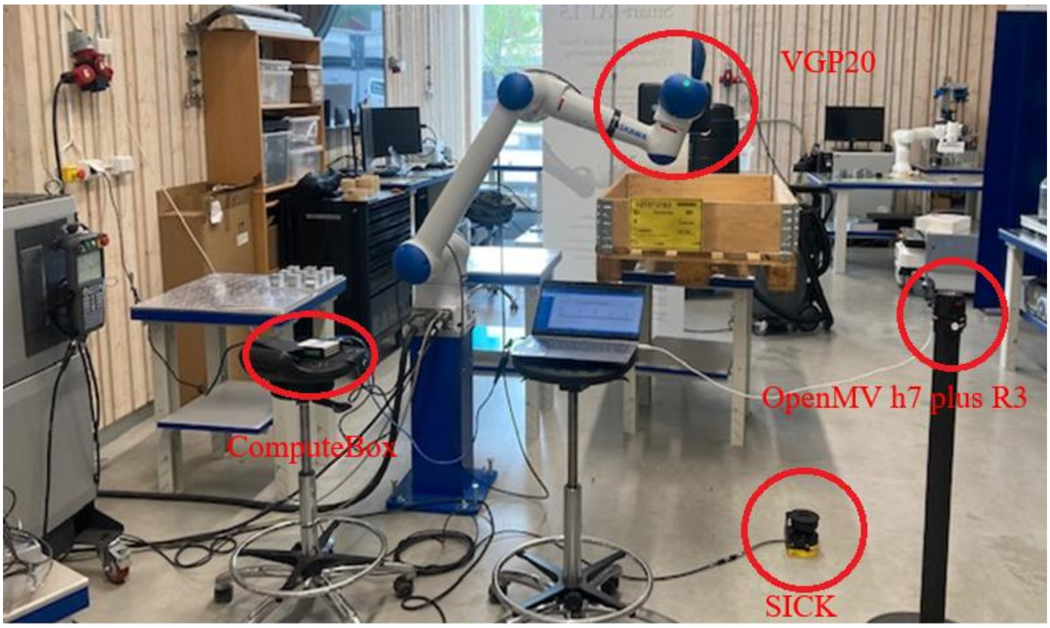
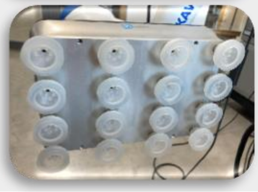
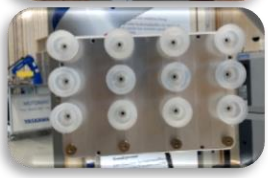
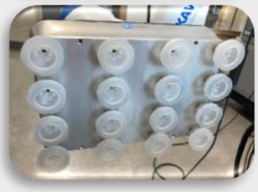
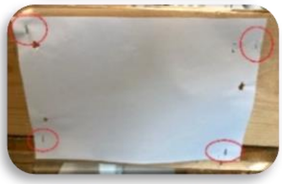


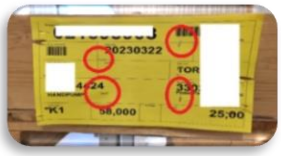
Figure 5.22: The set-up of the test with all the equipment used.

Table 5.3: The different set-ups which were tested.

SET-UP I	Pallet and robot	Beside the robot Robot moves one joint at a time	
	Label and staples	Thick paper One staple in each corner	
	Tool	All cups activated	
SET-UP II	Pallet and robot	Beside the robot, Robot moves one joint at a time	
	Label and staples	Thick paper, One staple in each corner	
	Tool	Three out of four rows of cups activated	
SET-UP III	Pallet and robot	Slightly twisted Robot moves one joint at a time	
	Label and staples	Thick paper One staple in each corner	
	Tool	All cups activated	

SET-UP IV	Pallet and robot	Slightly twisted, Robot moves one joint at a time	
	Position of staples	Thick paper, One staple in each left corner, one in the middle of the right side	
	Tool	All cups activated	
SET-UP V	Pallet and robot	Beside the robot, Pull the pallet	
	Position of staples	Thick paper, One staple in each left corner, one in the middle of the right side	
	Tool	All cups activated	
SET-UP VI	Pallet and robot	Beside the robot, Pull the pallet	
	Position of staples	Thick paper, Four randomly placed staples	
	Tool	All cups activated	

SET-UP VII	Pallet and robot	Beside the robot	
	Position of staples	Thin paper, One staple in each left corner, one in the middle of the right side	
	Tool	All cups activated	
SET-UP VIII	Pallet and robot	Beside the robot	
	Position of staples	Thin paper, One staple in each corner	
	Tool	All cups activated	
SET-UP IX	Pallet and robot	Beside the robot, Fully perpendicular pull by moving several joints of the robot	
	Position of staples	Thick paper, One staple in each left corner, one in the middle of the right side	
	Tool	All cups activated	

SET-UP X	Pallet and robot	Beside the robot, Fully perpendicular pull by moving several joints of the robot	
	Position of staples	Thick paper, Four randomly placed staples	
	Tool	All cups activated	

The results of the tests are shown in Table 5.4 and Table 5.5. The set-ups which failed are shown in Table 5.4 with a hypothetical reason for not working. Changes were made to the next set-up to solve the problem. The tests which successfully removed the label with high reliability are shown in Table 5.5.

Table 5.4: Unsuccessful set-ups

Situation	Pressure [kPa]	Removed Label	Hypothetical reason for not working
I	10	No	Pressure too low
I	20	No	Pressure too low
II	20	No	Pressure too low, not a perpendicular pull
II	30	No	Pressure too high for the robot's sensors
III	20	Sometimes	Not a perpendicular pull
IV	20	Sometimes	Not a perpendicular pull
VII	20	Sometimes	Could not grip the paper, air came through
VIII	30	Sometimes	Could not grip the paper, air came through

Table 5.5: Successful set-ups with a short explanation of each.

Situation	Pressure [kPa]	Set-up
V	20	Pull the pallet Three staples Thick paper All vacuum cups activated
VI	30	Pull the pallet Four staples Thick paper All vacuum cups activated
IX	20	Perpendicular pull from robot Three staples Thick paper All vacuum cups activated
X	30	Perpendicular pull from robot Four staples Thick paper All vacuum cups activated

Set-ups V and VI are not suitable for Volvo CE at the moment since there are several labels to remove from each collar. These set-ups would require the conveyor belt to move forward and then back again for the next label to be removed, which currently is not a possible solution to the problem. When set-up IX succeeded, it was also tested with four staples (set-up X) since it requires smaller changes to the current labelling process. Set-up X had a success rate of 100% when tested ten times.

6. Economic Analysis

The economic analysis compares the costs of the manual process and the automated process. Therefore, the differences between the processes are calculated, not the parts which are the same for the processes. For example, the cost of the conveyor belt is not taken into consideration since this is used in both scenarios.

6.1. The Costs of the Current Process

The costs of the manual process consist of the manual labour at the station. The station is occupied by two operators during the day shift and one operator during the evening shift. According to Statistiska centralbyrån (SCB) (2021), the average salary for a process operator is 30 900 SEK per month. With payroll tax and other employee fees, the monthly cost for one operator is estimated to be 47 260 SEK. The yearly cost of the manual labour is therefore 1 701 360 SEK. The yearly costs for the current manual process are shown in Table 6.1.

Table 6.1: The annual costs of the manual process.

Cost Manual Process	Fixed [SEK]	Variable [SEK]
Labor (2/day, 1/night)	0	1 701 360
		1 701 360

6.2. The Costs of the Automated Process

The cost bearers for the automated solution consist of both fixed and variable costs. The fixed costs consist of the robot, the tool, the sensor and the 2D camera. The cost of the robot is based on three comparable collaborative robots from three suppliers: ABB, Universal Robots and Yaskawa where also the tool and sensor were calculated in the price (the full calculations can be found in Economic Calculation. Then an average price was calculated, see Table 6.2. The camera used in the calculation is the MotoSight 2D from Yaskawa which will be used as a recommendation for the case company. To find the implementation cost for the robot, the estimation factor of three was used according to theory.

Table 6.2: Cost of the robot from three suppliers of comparable collaborative robots.

Robot, tool & sensor	Cost [SEK]
Swifti CRB 1300	542 350
Yaskawa HC10	479 580
Universal UR10e	535 975
Mean value	**519 302**

The variable costs for the automated solution are the energy, maintenance, and service cost as well as labour.

In the simulation, the energy consumption of the robot was approximately 2 kJ for two pallets of different sizes. The graph from the simulation of the Total Motor Energy and Total Motor Power is shown in Figure 6.1: Total motor energy and total motor power used for two pallets. Given the number of 700 pallets being de-labelled each day at the pallet handling station, this leads to 700 kJ being required for the process. Since 1 kWh is 3 600 kJ, the energy consumption during one day for the robot is:

$$U_{cons} = \frac{700\ kJ}{3600\ kJ} \approx 0{,}20 \text{ kWh}$$

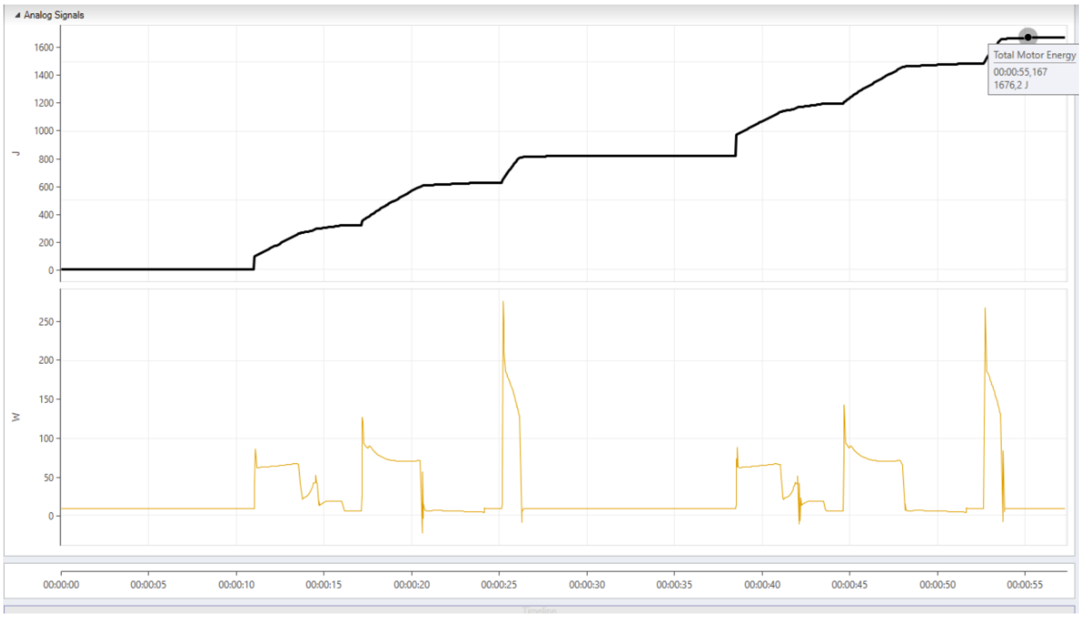


Figure 6.1: Total motor energy and total motor power used for two pallets.

The cost of the energy consumption is assumed to be negligible about the cost of the whole robot set-up. ABB offers a maintenance and service package for their robots, which was used to estimate the total maintenance and service costs for the automated solution. The cost of labour was calculated with the current cost of the manual process multiplied by the estimation factor of 0,25 according to the theory. The estimated fixed and variable costs for the automated concept can be seen in Table 6.3.

Table 6.3 Fixed and variable costs for the automated concept

Costs Automated Process	Fixed [SEK]	Variable [SEK]
Robot, tool, sensor and implementation	1 557 906	0
2D Camera	30 000	0
Maintenance and Service Cost	0	40 750
Labour	0	425 340
	1 587 906	**466 090**

6.3. Comparison of the Processes

The estimated cost for a period of five years for the manual and automated process was calculated and can be seen in the line chart in Figure 6.2. In the chart, the break-even occurs approximately one year and four months after implementation.

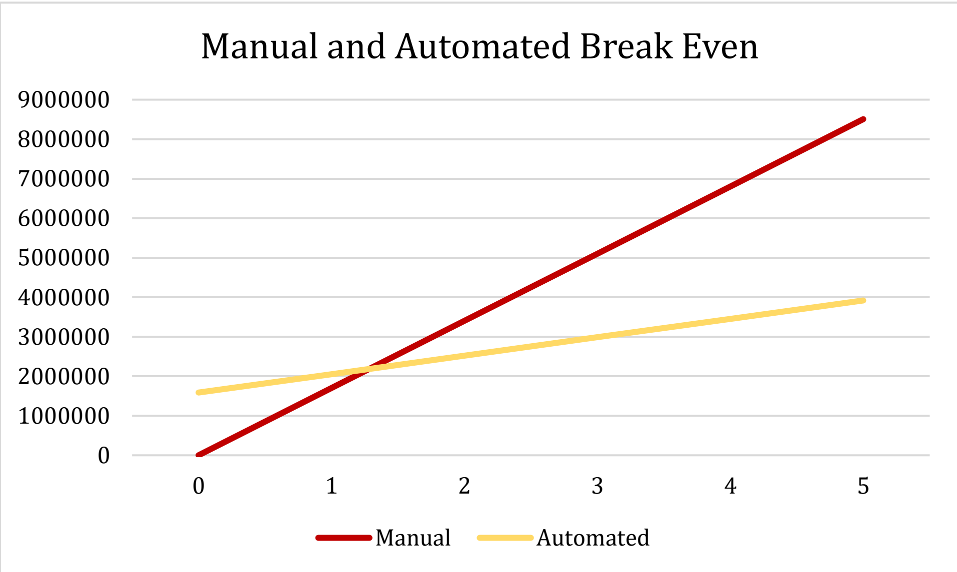


Figure 6.2 Estimated cost for five years for a manual and an automated.

In Figure 6.3 the difference in cost per year is shown where the automated process will be more expensive the first year, but where it the following year will lead to a lower cost.

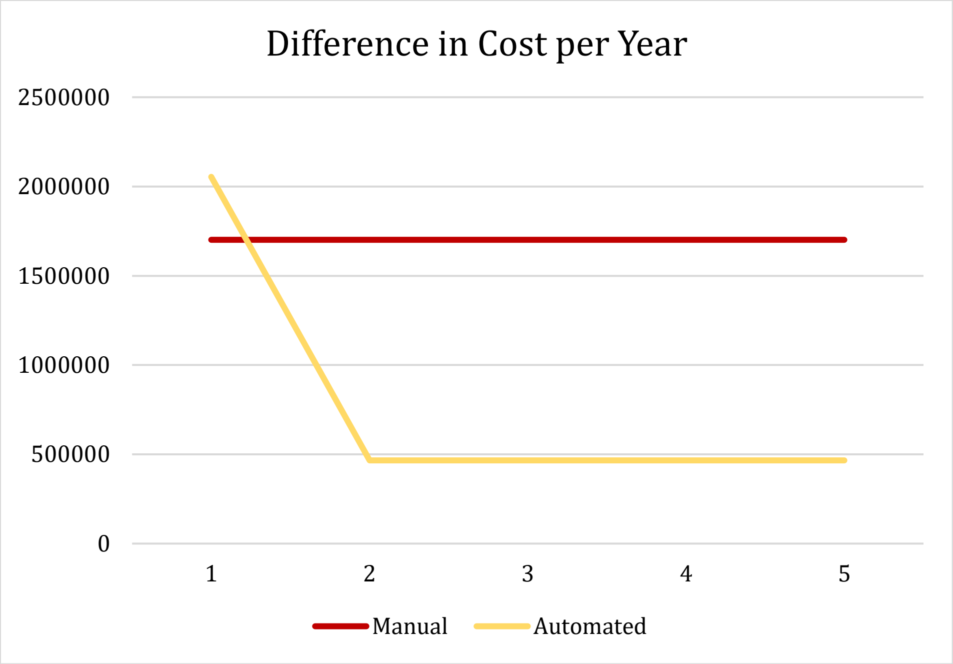


Figure 6.3 Cost per year for a manual and an automated process.

7. Ergonomic Analysis

In the chapter *Ergonomic Analysis*, the current ergonomic situation is presented as well as the answers from the questionnaire. The improvements regarding ergonomics by automating the process are analysed.

7.1. Current Ergonomic Situation

The operators working with the pallet handling were asked to participate in a survey regarding ergonomics and stimulation at the station. The questionnaire and a compilation of the answers are found in Appendix II: Questionnaire Regarding Ergonomics. The first question in the questionnaire was if the operators are starting to perceive or are already perceiving any ache in any of the following body parts: feet, knees, legs arms, hands, shoulders, back or neck. The operators had to rate from 1 (does not feel anything) to 10 (serious ache). The answers are presented in Table 7.1 where the answers from rate five and above are combined in the answer 5+. Figure 7.1 represents the lowest and highest value the operators answered for each body part, as well as the median value.

Table 7.1: Perceived aches in body parts.

Perceived Ache in Body Parts					
Scale	**1**	**2**	**3**	**4**	**5**
Feet	9	2	6	0	3
Knees	7	3	7	2	1
Legs	9	3	7	1	0
Arms	8	3	3	1	5
Hands	5	4	4	3	3
Shoulders	6	5	4	2	3
Back	4	1	5	3	7
Neck	8	5	2	2	3

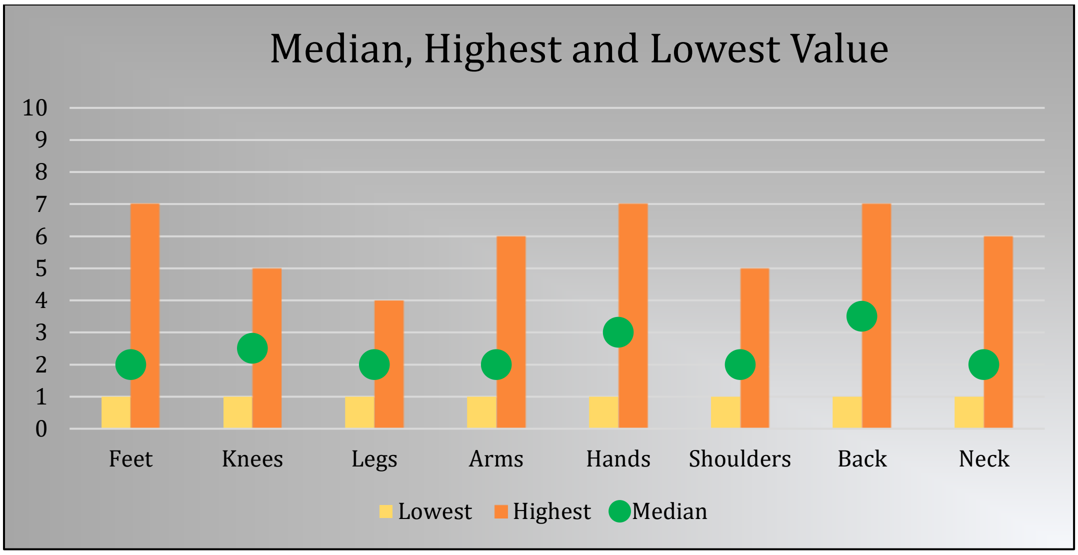


Figure 7.1 The lowest, highest, and the median value

When analysing the posture of the operator, it is noticeable that it is not sustainable. The degrees between the hip and the back are shown in Figure 7.2 and approximated to 45°, which is considered a yellow posture. To remove the label, a twist of the back is also needed which results in extra stress in the back. The operators were asked if they had any proposals of how the workstation can be improved regarding ergonomics, where eleven out of twenty participants gave ideas for improvements. Six operators answered the height of the conveyor belt as an area of improvement where it should be increased to simplify the task. Three gave automation and implementation of a robot as a possibility to improve the ergonomic situation at the station.

The conveyor belt could be compared to a standing workstation at a table, where there are recommendations that the height of the table should be adjustable or fixed at 1195 mm. The height of the conveyor belt is currently 510 mm which is almost half of the recommended table height.

Figure 7.2 Angle between hips and back at the workstation.

In the questionnaire, the operators were asked on a scale from 1 to 10 how stimulating the workstation is. The answers are shown in Figure 7.3 where more than half of the participants replies that the level of stimulation is 1 – 2 on a 10-point scale from non-stimulating to stimulating. However, one operator replies that they appreciate a station which is not as requiring as the rest in the rotation. 60% of the participants have a positive view regarding spending time on another task, which is shown in Figure 7.4.

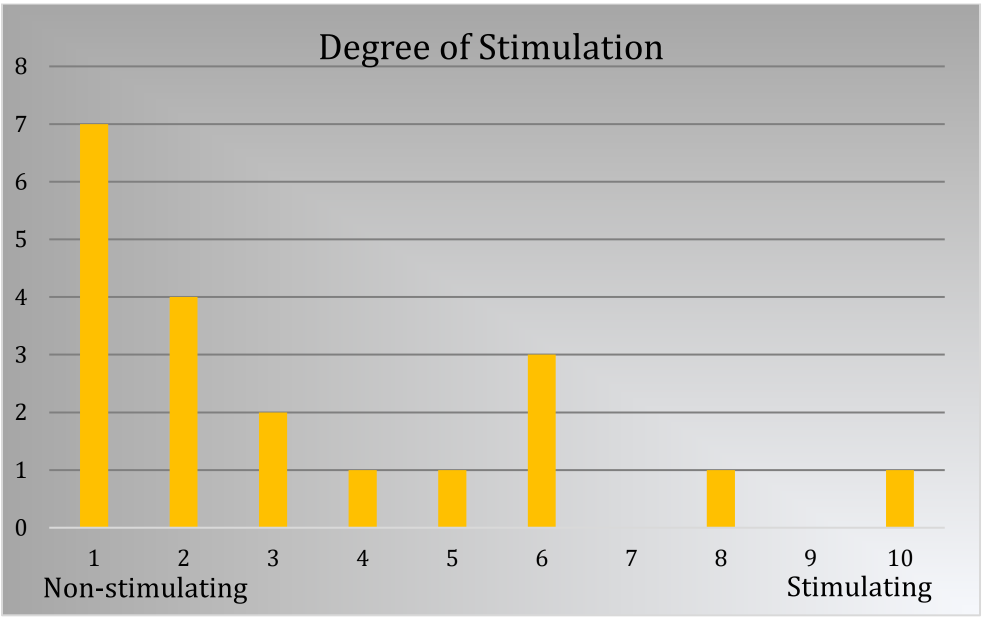


Figure 7.3 Degree of stimulation

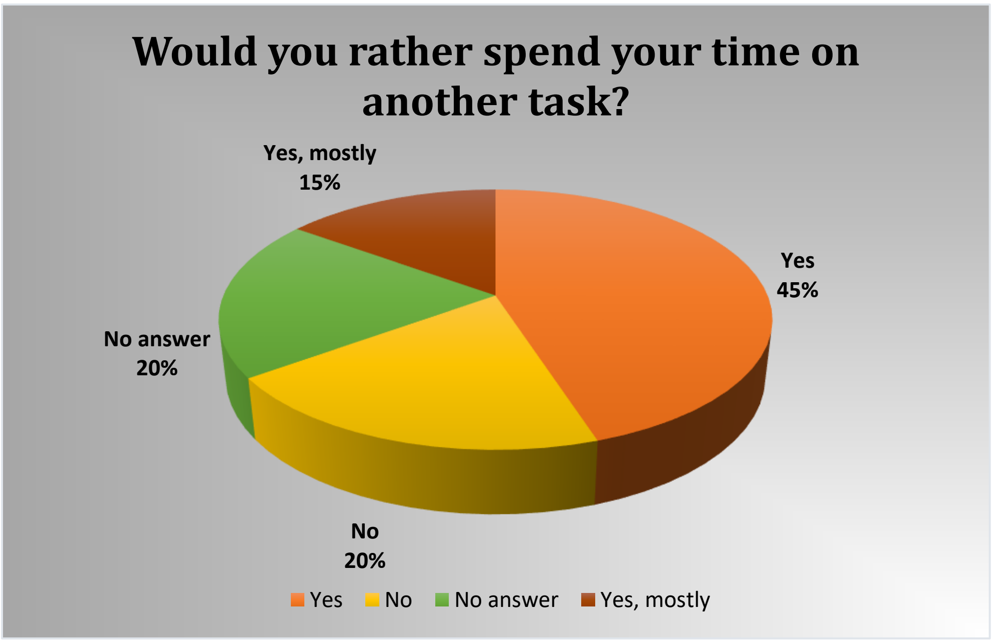


Figure 7.4 Answers regarding if the operators rather spend time on another task

85% of the participants answer the usage of too many staples is the biggest issue why the label cannot be removed. Another difficulty regarding the removal of paper that three of the participants highlight is when the internal and external labels are attached on top of each other.

The general opinion from the operators on the implementation of a collaborative robot to perform the de-labelling of pallets is shown in the chart in Figure 7.5, where 70% of the participants are neutral or positive about the usage of a collaborative robot. The median value of the responses is 6. Operators who answered 5 or higher commented that they are positive to the change if the robot operates without errors and flaws while the operators who answer 5 or less are negative due to the risk that the robot will be difficult to integrate and cause disturbances.

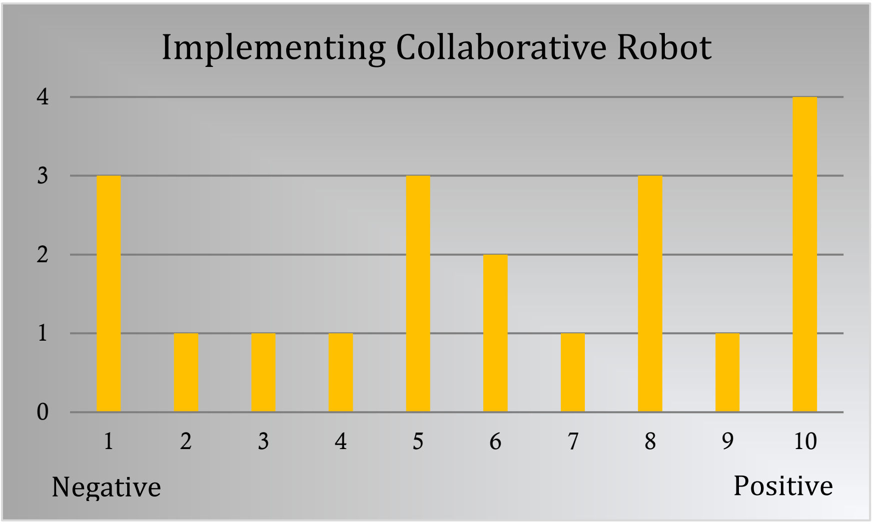


Figure 7.5: View in implementing a collaborative robot.

7.2. Ergonomics of the Automated Solution

The operators' answers regarding perceived aches in body parts were on a scale of 1 – 10 where 10 is serious ache. Since there is a problem before serious ache, the answers 5 – 10 were compressed to 5+. The largest problem areas are the back as well as arms, followed by feet, hands, shoulders and neck.

The answers to the surveys show that the operators' view on implementing a collaborative robot at the station is positive. However, many of the operators are concerned about the complications that might occur when implementing a robot. This could be handled by involving the operators in the development of the process. This was also mentioned by Margherita & Braccini (2021), that the workers need to be involved when working with developments as well as training the already existing personnel when implementing a robot. The operators who expressed in the surveys that they would like to spend their time on another task could be trained to operate the robot, this would also lead to increased stimulation at the workstation.

Automation of this process will improve physical-, cognitive- and organizational ergonomics by decreasing musculoskeletal stress as well as increasing stimulation, job satisfaction and employee commitment.

8. Discussion

By implementing the technologies of Industry 4.0, increased sustainability can be achieved. Automation of processes requiring postures which cause aches results in improvements in physical ergonomics. To succeed with the implementation, the workers need to be involved in the change, both to make them feel included and because they have valuable knowledge regarding the processes. Some workers who feel unsatisfied with the current manual labour can be educated in automation and operate the robots. This can lead to increased organizational ergonomics where the workers receive higher work satisfaction. Many workers fear that a robot will result in more complications and downtime, which can be solved by conducting extensive research before implementing it. During the implementation, the workers´ experiences are also needed to predict potential problems. If the operators are well trained, they can solve the problems with the robot when they occur, saving time and resources.

The result from the economic analysis can be seen as a foundation in the decision-making regarding investment in automation. Since the analysis is based on cost assumptions and calculated with estimation factors for industrialised robots, it should be seen as a guideline for investments rather than the exact truth. Some of the cost bearers in the analysis are also difficult to foresee where maintenance costs will most likely increase with time, and energy costs are fluctuating depending on area and season. Even though the estimated analysis shows a rapid break even and a clear cost difference between manual and automated processes, more factors play a role in the decision for automation, such as the ergonomic situation, repetitive work, as well as existing level of automation in the company. If the current degree of automation in a company is low, new knowledge also has to be gained to succeed with the implementation which will be time-consuming and expensive and affect the Return on investment. The company may decide to completely outsource the project, which also will lead to a change in Return on investment.

8.1. Methods Discussion

If several cases had been studied, the implementation of the automated process could be analysed in different environments. There are large differences between different companies which can result in different implementation processes. By conducting a longitudinal study, the actual effects of the implementation could be studied as well as evaluating the implementation process.

One method of data collection was by conducting questionnaires with the operators working with the current process. This method was chosen to keep the participants anonymous to receive honest answers. However, when the participants answer the questions, they might interpret the questions and the scales differently which decreases the validity. The questionnaires consisted of the same questions for every participant, however, some answers may need to be elaborated. This could be done by conducting semi-structured interviews and asking follow-up questions to receive a deeper knowledge about the operator's perspective.

8.2. Future Work

Before implementing an automated solution, a risk assessment must be conducted. Even though a collaborative robot has sensors and is created and implemented to work side by side with humans, all possible risks must be analysed and avoided, minimizing the risk of accidents.

The lack of standardisation makes the processes complicated to automate. If the placement of the labels were standardised, the camera would not be needed because then the robot would move to fixed coordinates. The variation in size and material of the external labels makes it difficult to remove. To increase the reliability of this solution, all the labels need to be of the same size, or a more flexible tool will have to be used which can handle the large variety of labels.

To optimize the process, the conveyor belt can continue moving while the label is removed, this requires high precision of the robot and tool. Also, the speed of the robot and conveyor belt might need to be adjusted to be able to synchronize the processes.

To make the process autonomous, a sensor is needed to activate and deactivate the tool, a wiring diagram for the process as shown in Figure 8.1 will have to be used. A recommendation for the company is to use the Motosight 2D from Yaskawa because of its better properties for this concept. The process starts with the camera detecting the label, which will send a signal to a computer where the image will be processed, and the position of the label detected. The analysed signals will be sent both to the controller and the compute box. The controller will tell the robot to start its path and the tool will be activated through the compute box. The robot will also be able to send updates of its coordinates to the computer. The computer will function as a learning tool for the system, where algorithms will learn and develop from situations that occur. The SICK-Sensor will be connected to the controller and stop the robot in case an object enters its range.

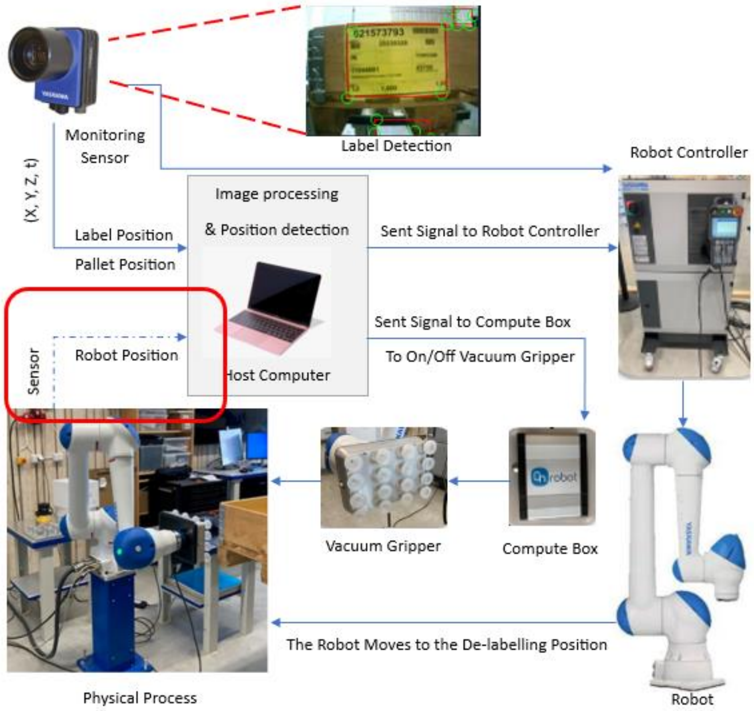


Figure 8.1 Wiring diagram of the future autonomous setup.

9. Conclusion

This thesis shows that a manual process can be automated with a collaborative application by first finding a suitable robot and tool. In this case, it was primarily focused on the robotic tool since no prior tests of this type of application were found. The concept should then be proven with a simulation before physical tests. The following step is to implement the collaborative application.

The solution was implemented by testing different set-ups which were evaluated. Each set-up was analysed, and changes were made to find a reliable solution. The changes were kept to a minimum to facilitate the implementation of the solution into the production system. The lack of standardisation in the production system was handled by adding vision detection to detect the labels as well as increasing the pressure of the tool. The changes needed to implement this solution in the manual production system are the number of staples as well as a thicker border on the label.

The return on investment of an automated process is estimated to be approximately one year and four months. It is mainly the reduced labour cost that leads to the automated solution being a more cost-effective alternative. The need for investments in equipment leads to a high one-time cost. However, the variable costs are lower than the manual process. The cost of maintenance and the level of automation and knowledge regarding robotics in an organisation also have fluctuating effects on the cost.

In the thesis, an automated solution is compared to a manual system. The results show that the automated solution leads to a more sustainable physical and organizational ergonomic situation. Repetitive postures and movements can be avoided by implementing a robot and improving physical ergonomics. Results also show that increasing operator involvement can improve organizational ergonomics.

10. References

10.1. Books:

Adithan, M. (2007) *Process planning and cost estimation.* New age international ltd

Blomkvist, P. & Hallin, A. (2015) *Method for engineering students.* Studentlitteratur

De Propris, L. & Bailey, D. (2020) *Industry 4.0 and regional transformations*. Taylor & Francis

Groover, M. (2019) *Automation, production systems, and computer-integrated manufacturing.* Pearson

Lantz, B., Löfsten, H. & Isaksson, A. (2018) *Industriell ekonomi – Grundläggande ekonomisk analys.* Studentlitteratur

Matt, D., Modrák, V. & Zsifkovits, H. (2020) Industry 4.0 for SMEs: challenges, opportunities and requirements. Springer Nature

Patel, R. & Davidson, B. (2019) *Forskningsmetodikens grunder, att planera, genomföra och rapportera en undersökning.* Studentlitteratur

Saunders, M., Lewis, P. & Thornhill, A. (2019) *Research methods for business students.* Pearson

Säfsten, K. & Gustavsson, M. (2020) *Research methodology for engineers and other problem-solvers.* Studentlitteratur

Tripathi, A. (2018) *Learning Robotic Process Automation: Create Software Robots and Automate Business Processes with the Leading RPA Tool-Uipath.* Packt Publishing

10.2. Articles:

Bilberg, A. & Malik, A. (2019) "Digital twin driven human-robot collaborative assembly" *CIRP Annals* Vol.68, Issue 1, Pages 499-502

Choi, H., Crump, C., Duriez, C. & Trinkle, J. (2021) "On the use of simulation in robotics: Opportunities, challenges, and suggestions for moving forward "*Proceedings of the national academy of Sciences"* Vol. 118, No.1

Duda, P. (2010) "Robot ROI: how to properly calculate the payback or return on investment of a robot installation into the mold build process" *MoldMaking Technology* Vol. 13, Issue 4

Grabowska, S., Saniuk, S. & Gajdzik, B. (2022) "Industry 5.0: improving humanization and sustainability of Industry 4.0" *Scientrometics* Vol. 127, 3117-3144

Margherita, E. & Braccini, A. (2021) ”Managing Industry 4.0 automation for fair ethical business development: A single case study.” *Science Direct* Vol. 172 Doi: 121048

Mourtzis, D. (2021) “Simulation in the design and operation of manufacturing systems: state of the art and new trends” *International Journal of Production Research* Vol. 58, No. 7, 1927–1949

Smith, N. (2020) “Calculating a Robot’s ROI: Determining the total cost and return on investment of an industrial robot is not a straightforward evaluation” *Foundry Management & Technology* Vol. 148, Issue 2

Van der Zee, D. (2019) “Model simplification in manufacturing simulation- Review and framework” *Computers and Industrial Engineering – Review and framework* Vol. 127, 1056-1067

10.3. Other:

OnRobot (n.d.) *VGP20* Obtained [2023.03.16] https://onrobot.com/sv/produkter/vgp20

Poldahl, A (2016) *Flytt av verksamhet till andra länder*. SCB

Statistiska Centralbyrån (2021) *Lönestatistik, Andra process- och maskinoperatörer.* SCB https://www.scb.se/hitta-statistik/sverige-i-siffror/lonesok/Search/?lon=operat%C3%B6r

Volvo (2023) *Ergonomic Guidelines Manufacturing*. Volvo Group

11. Appendices

Economic Calculation

Appendix II: Questionnaire Regarding Ergonomics

Appendix I: Economic Calculation

ABB

The cost of using a Swifti CRB 1300 from ABB is shown in Table 11.1. A sensor from SICK is included in the price of the robot.

Table 11.1: Calculations of the robot from ABB

ABB	
Equipment	**Cost [SEK]**
Swifti CRB 1300	451 000
VPG20 kit	68 100
Quick changer	
ComputeBox	
FlexPendant	23 250
Sum	542 350

Universal robots

The cost of using UR10e from Universal robots is shown in Table 11.2. A Compute Box is not needed for this solution.

Table 11.2: Calculations of the robot from Universal Robots.

Universal Robots		
Equipment	**Cost [EUR]**	**Cost [SEK]**
UR10e	38165	432027,8
Pendant Armor URE-series	345	3905,4
VPG20 Vacuum gripper	5079	57494,28
Quick changer	458	5184,56
Connection	78	882,96
SICK S300 Mini		36480
Sum		535975

Yaskawa

The cost of using HC10DTP from Yaskawa is shown in Table 11.3. Controller YRC1000 and TeachPendant are included in the price for the robot. This robot requires both a ComputeBox for the tool as well as a sensor.

Table 11.3: The costs of the solution from Yaskawa

Yaskawa	
Equipment	**Cost [SEK]**
HC10DTP	375000
YRC1000	
TeachPendant	
VPG20 kit	68 100
Quick changer	
ComputeBox	
SICK S300 Mini	36480
Sum	479580

Appendix II: Questionnaire Regarding Ergonomics

Ergonomi vid flaggborttagning

Dagens situation

1. **Får du ont eller börjar få ont i någon av följande kroppsdelar på grund av arbetssituation vid flaggborttagningen?**

Fötter:

1 (9)	2 (2)	3 (6)	4	5	6 (2)	7 (1)	8	9	10
Känner inget									Stora besvär

Knän:

1(7)	2 (3)	3 (7)	4 (2)	5 (1)	6	7	8	9	10
Känner inget									Stora besvär

Ben:

1(9)	2 (3)	3 (7)	4(1)	5	6	7	8	9	10
Känner inget									Stora besvär

Armar:

1(8)	2 (3)	3(3)	4 (1)	5 (3)	6(2)	7	8	9	10
Känner inget									Stora besvär

Händer:

1(5)	2(4)	3(4)	4(3)	5(2)	6(1)	7(1)	8	9	10
Känner inget									Stora besvär

Axlar:

1(6)	2(5)	3(4)	4(2)	5(3)	6	7	8	9	10
Känner inget									Stora besvär

Rygg :

1(4)	2(1)	3(5)	4(3)	5(2)	6(3)	7(2)	8	9	10
Känner inget									Stora besvär

Nacke:

1(8)	2(5)	3(2)	4(2)	5(2)	6(1)	7	8	9	10
Känner inget									Stora besvär

Annat:

- Nej
- Öronen
- Besvärligt när man måste sträcka sig för att nå flaggor som sitter olägligt eller extra hårt. Jäkla springande också för att hinna med att plocka flaggor! Det påverkar förmodligen mer än man vill/kan tro! (Kroppen alltså)

Den inringade flaggan kallar vi interna flagga

2. **Hur stimulerande upplever du att arbetsuppgiften är?**

1(7) 2(4) 3(2) 4(1) 5(1) 6(3) 7(0) 8(1) 9(0) 10(1)

Icke-stimulerande — Stimulerande

3. **Hur ofta krävs flera försök för att ta bort den interna pallflaggan?**

1(0) 2(1) 3(2) 4(3) 5(2) 6(4) 7(3) 8(2) 9(2) 10(1)

Aldrig — Hela tiden

4. **Vad brukar vara orsaken till att flaggan inte lossnar?**

Svar:

- Går sönder, sitter med för många stift. Klisterlappar sitter hårt
- Att den är häftad med överdrivet många stift
- Klister
- Allt för många stift
- Sitter för hårt eller för många lappar under
- Klister, flera papper i en hög
- 35 olika häftstift eller klister kan vara orsak till frustration
- För mycket stift/klister
- Den är för häftande
- För många stift
- Många stift/klammror i flaggan
- Fastklistrad, mycket klamrar i flaggorna
- För många stift, skulle räcka med hälften max 4
- Sitter för hårt
- Många stift
- För mycke stift
- För många häftklamrar, starkt klister, många lappar på varann
- Man får inte tag i den i ett svep
- Sitter fastklistrad istället för fastspikad
- Fast klistrad, för mycket nitar

5. **Hade du hellre ägnat dig åt en annan arbetsuppgift?**

Svar:

- Nja
- Ja
- Nej
- Ingår i rotation
- Ja
- Nej
- Jag gör det som förväntas av mig. Alla kan inte vara Zlatan !
- (Inget svar)
- Ja
- Ja om man inte är dödstrött och har världens sämsta dag för då kan det vara skönt!
- Ja
- Ja
- Det är ju inte roligt men det måste ju göras
- Ja
- Nej, ganska rogivande
- Ja
- Ja
- Efter ett tag, ja
- Ja
- Nej

Övrig kommentar:
- Behövs en "icke-tänkande" position som alternativ till mer krävande stationer.
- Rätt mysigt att stå med Operatör1
- Man ska utföra ett arbete, hur svårt är det
- Ingår i vårt jobb/rotation
- Fråga 2: Enormt stimulerande när man får loss skiten!
- Operatör1 gillar att ta lappar

Förbättringar

1. **Anser du att stationen kräver förbättringar?**

Svar:
- Ja
- Ja
- Nej
- Det går alltid förbättra
- Nej
- Nej
- Nej
- Ja lite
- Kommer inte på nåt just nu
- Nej
- Nej
- Ja
- Inte kräver men om det skulle finnas en standard för hur man fäster lappen så kanske den lossnar smidigare
- Ja
- Lite
- Ja, men allt är relativt
- Hjälpas åt mer
- Lite
- Ja
- Nej

2. **Om ja, vilka områden behöver förbättras?**

Svar:

- Roboten behöver förbättras. Den är för känslig i vissa fall eller känner inte av alls (syftar på pallnedbrytaren).
- Ergonomi- höjden på banan. Lättare att få bort lappar etiketter.
- Går ju förbättra allt, men jag ser inte behovet just där, bättre att förbättra stationerna med kragarna först.
- Nån slags lappborttagare
- Flödet, ordning på klossar, sopkärl etc.
- Färre stift
- Lättare att ta bort de
- Alltså, det här kan automatiseras lätt. 2 motroterande stålvalsar gnuggar eller river bort flaggor på nolltid!
- Jag tycker man skall hjälpas åt om man ser att det finns att göra
- Vet inte
- Lättare att städa runt NUSEN, under sensorerna. Ta bort en 10 cm av gallret runt NUSEN så man kan sopa under den

3. **Har du några förslag på hur ergonomin kan förbättras på denna station?**

Svar:

- Höjd på banan. Centraldammsugare för städning
- Gärna en robot som avlägsnar kolliflaggorna
- Nej
- Hade varit i så fall varit att höja bandet men det är stort ingrepp, vet inte om det skulle vara lättare att plocka lapparna när man plockat av krage för krage.
- Nej
- Nej
- Allt ska vara automatiserat
- Nej
- Nej, inte just nu
- Hjälpmedel att ta bort lapp som är fastklistrad
- Höj- och sänkbar bana. Såklart jävligt dyrt men i en perfekt värld så…
- Höja pallbanan lite grann
- Mja, jag skulle gärna se att banan höjd/går att höja så att etiketterna kan lossas enklare om man är 185 cm som jag
- Använda våra hjälpmaskiner som finns istället för att stressa och undvika dem
- Ergonomihandske, höja banan
- En till Operatör1

4. **Hur ser du på implementering av en kollaborativ robot för att avlasta stationen?**

1(3)	2(1)	3(1)	4(1)	5(3)	6(2)	7(1)	8(3)	9(1)	10(4)
Negativt									Positivt

5. **Motivera svaret på fråga 4**

- En robot innebär att arbetet flyttas till service/underhåll av den. Det kommer att krångla och det kommer stoppa flödet, vid manuell hantering åtgärdas/förebygger man stopp direkt.
- Skulle minska belastningar enligt punkt 1, samt även minska stress (8).
- Kan bli mycket fel på robotar (6)
- Lyckas man få till en robot som funkar så skulle det kunna bli bättre resultat och spara på många ryggar (10).
- Det är bra med robotar förutsatt att de inte strular (7)
- Känns som att det blir mycket krabb (2)
- Kan vara skönt att slippa plocka bort dem (5)
- Det beror på vad roboten ska göra, hur den fungerar och om det faktiskt hjälper. Jag tycker inte att det är en jobbig situation (5)
- Inget bra (3)
- Funderar på om den stoppar upp flödet (6)
- Den kan nog inte få ta i alla sorters lappar då vissa sitter mer limmat utan någon riktig flärp att dra i (1)
- Robotar krånglar mycket i en sådan här arbetsmiljö (1)
- Jag är allt för samarbete! Motroterande stålvalsar som river loss skiten! Måste funka! (10)
- All hjälpmedel som vi kan få är bra för vår framtid vi skall ju jobba till vi blir 75 år? (8)
- Förutsatt at den fungerar 100% (9)
- Det är bra för då slipper jag göra allt (8)

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