Vaasan yliopisto
UNIVERSITY OF VAASA

Emil Makkonen

Utilization of Automated Guided Vehicles: CASE ABB Drives

School of Technology and Innovations
Master's thesis in Industrial Management

Vaasa 2020

UNIVERSITY OF VAASA
School of Technology and Innovations
Author: Emil Makkonen
Title of the Thesis: Utilization of Automated Guided Vehicles: CASE ABB Drives
Degree: Master of Science in Economics and Business Administration
Programme: Industrial Management
Supervisor: Petri Helo
Year: 2020 **Number of Pages:** 92

ABSTRACT:

Automation is increasing in manufacturing industry. It can help companies face the competition from low-cost countries. Today's rapidly changing technologies and shortening life cycles require flexible manufacturing which is enabled with automation. Automation is cheaper, safer, and more accurate than manual labour. Material handling is one area where automation can be efficiently used. Automated Guided Vehicles are transport equipment that are increasingly used in material handling. This research explains their technology, utilization and benefits. Future considerations for the use of Automated Guided Vehicles are also being discussed with Robots as a Service emerging as a potential breakthrough in automation.
This research is made to study the possibilities to implement Automated Guided Vehicles for ABB Oy Drives Production unit in Helsinki.
Theory about automation, material handling and Automated Guided Vehicles are being discussed in the research to build a coherent background for the automated solution for the case company. The literature used in this research is mostly online. The evaluation of the current state in the factory is made by empirical research. The automated solution is visualized and simulated with Visual Components 3D simulation software. Cost calculations to evaluate the financial profitability of the investment are made by Microsoft Excel.
The result from this research was a financially profitable automated solution for the case company and a general academic framework for implementing Automated Guided Vehicles. The automated solution for the case company was built on Omron LD-250 autonomous mobile robot.

KEYWORDS: Automation, material handling, automated material handling, automated guided vehicles, autonomous mobile robots, robots as a service, simulation

Preface

I would like to thank my supervisors Petri Helo and Rayko Toshev from University of Vaasa and my colleagues Timo Rissanen and Sami Mustonen from ABB for helping me in every part of this research. The greatest appreciation belongs to my girlfriend and family because without you this process would have been much harder.

Table of contents

List of Tables

List of Figures

1. Introduction

1.1 Background

Manufacturing industry in Europe sees automation as a weapon for competition on global markets. It is a way to meet the competition from low-cost countries. It can also be the answer for today's rapidly changing technologies and shortening product life cycles. Automation can help companies to adapt to changes by adding process flexibility. However, it does not necessary result in increased benefits if it is not implemented and utilized correctly. (Frohm et al. 2016).

The aim of automation is to increase the productivity, reliability, and safety of processes. Automation is often best used in simple and repetitive tasks as they can be done faster and with better accuracy than using manual labor. Automating such functions also allows the human staff to focus on tasks that require complicated work and problem-solving skills. Material handling is one area where automation is often successfully utilized. It consists of the transportation of items for long distances and is repetitive and simple.

One of the fastest growing technologies in automation is Automated Guided Vehicles (AGV). AGVs can increase the efficiency and productivity in material and product handling. AGVs use real time information to deliver materials or products to the exact place at the exact time with minimal efforts from the human staff. This is possible because they are controlled by a software that can be integrated to the company's information systems to communicate autonomously with each other.

1.2 Objectives and limitations

The objective of this research is to create a solution for the implementation of Automated Guided Vehicles for ABB Drives Production unit in Pitäjänmäki. I have provided four research questions and below each research question I have written the specific tasks that I have completed to find out the answer to the questions.

1. Which processes in the production lines are most suitable for the use of AGVs?

   Empirical research and process analysis

   - Evaluate the current state of production lines
   - Find out the problems and bottlenecks
   - Choose the most suitable processes for the AGVs

2. Which AGV model is the most suitable for the specific production lines?

   Search for information and product analysis

   - Search information about AGVs
   - Compare different AGV manufacturers and models
   - Choose the most suitable option for the specific production lines

3. Are the AGVs able to serve the production lines efficiently?

   Production simulation

   - Simulate the production with the AGVs
   - Use analytical methods to support the simulation
   - Compare process times and other valuable data

4. Are the AGVs financially profitable for the company?

   Cost calculations

   - Identify the costs and profits that the investment generates
   - Use different methods to calculate the financial profitability
   - Compare financial numbers to other similar investments in the industry

Previous models for implementation of AGVs are being used as a framework with the help of literature and research of the issue. The focus in this research is in the Corinth R6, R8 and R11 product families and their production. It can be used as a framework for other AGV related researches but is not straightforward transferable to other production lines. However, the idea of the research by improving the problem areas of the current state of production with automation is usable.
This research will cover shortly other areas of automation also but is not a general framework for automation as it is mostly focusing on the utilization of Automated Guided Vehicles and their abilities. This research is focusing on the improvements on the factory floor but does not cut other areas unless it has a straight impact to the use of AGVs.

1.3 Methods

This research has been formed by mixed methods, both qualitative and quantitative methods, and the research question is more practical than theoretical. Qualitative methods has been used in the thesis with empirical research in the factory by interviewing, exchanging thoughts and brainstorming with other colleagues and suppliers. Quantitative methods have been used in the thesis with data analysis by simulating the production with Visual Components software and calculating the financial profitability with MS Excel. This research has utilized both primary and secondary data. Primary data has been used in all parts except in literature review where secondary data from previous researches has been used. The time horizon in this research is longitudinal meaning that the study has an extended time period and the research approach is more inductive than deductive meaning that observations are presented in the beginning and theories are proposed in the end based on the results. Research philosophy used in this research is somewhere between positivism and realism where the topic is observed and described from an objective viewpoint meaning that the studied phenomena is not being interfered or challenged theoretically.

Table 1. Research methods

Research method	Primary/ secondary	Qualitative/ quantitative	Participants	Reason
Literature review (Internet)	Secondary	Both	Researchers	To gain better understanding of automation and robotics, material handling, AGVs, investment evaluation etc.
Case study	Primary	Both	Case company	To gain better undestanding and in-depth knowledge of implementing AGVs in practice
Interview (Notes)	Primary	Qualitative	Colleagues& suppliers	To gain better understanding of production line processes and AGVs
Observation (Timer)	Primary	Both	Production line workers	To gain better understanding of production line processes and measure process times
Data analysis (Visual Components and MS Excel)	Primary	Quantitative	Author	To measure the efficiency and financial profitability of the AGVs

1.4 Structure

The structure of this work is constructed so that it begins with an introduction chapter where the background, objectives and limitations, methods, and structure of the topic are being introduced. The case company introduction is also presented in the first chapter.

Second chapter begins the literature review by describing automation in manufacturing industry. The basic principles of automation are presented alongside with a Delphi survey from a case study found in the existing literature. It is there to highlight the importance of understanding where automation is most suitable to use. Chapter three discusses material handling in manufacturing industry and presents the ten most important steps that must be considered when implementing a material handling system. This is important to understand because AGVs are material handling equipment. Other important material handling equipment are also presented in the chapter.

The fourth chapter presents a more thorough look into Automated Guided Vehicles and the technology behind them. Different navigation, steering and zone control methods in AGVs are being discussed. This chapter also presents their utilization in manufacturing industry and discusses their major advantages and disadvantages.
Chapter five discusses Autonomous Mobile Robots as an option for the traditional AGVs. It is explained why AMRs are an improved version of the traditional AGVs and how the market for them has been exploding. Robots as a Service and Lean Automation concepts are also introduced.
The sixth chapter discusses automation investments and their evaluation. Productivity can be evaluated with different methods such as simulation and several analytical methods. Cost calculations is a way to financially evaluate the investment. Investment also always include risk and uncertainty.
Chapter seven is the empirical part of this thesis. It begins by describing the production in the factory and evaluating the current state and its problems. After that, an automated solution is made to address the problems of the current production with a general overview of issues that must be considered when implementing the solution. A simulation report with pictures is presented to illustrate the behavior of the vehicle in the specific case company facility. Queuing theory is also used to evaluate and calculate the service process of the vehicle. Cost calculations are made to calculate the financial profitability of the investment. Cost calculations consists of net present value (NPV), payback period, and return on investment (ROI). Future considerations for the use of AGVs are also presented.
The final chapter presents the results and conclusion of the thesis with an overall evaluation of the solution. Challenges and problems that might occur in the implementation phase are also being discussed. References are presented in the end.

1.5 Company introduction

ABB is a Swedish-Swiss industrial corporation located in Zurich, Switzerland. It was created in 1988 when the Swedish and Swiss companies, ASEA and BBC, merged into one larger company. ABB operates in over 100 countries and employs approximately 147 000 workers. ABB reported a revenue of 27,662 billion dollars in 2018. ABB operates in around 20 locations in Finland with factories concentrated in Helsinki, Vaasa, Porvoo and Hamina. ABB employs approximately 5 400 workers in Finland and is the largest industrial employer in the metropolitan area. (ABB 2020).

ABB focuses mainly in electrification, industrial automation, motion, robotics, and power grids. ABB's Electrification offers a large portfolio of products, digital solutions and services enabling a safe, smart and sustainable electrification. Their offerings in electrification include solutions such as solar inverters, modular substations, power protection, distribution automation, and wiring accessories. ABB's Industrial automation business offers solutions for process and hybrid industries with industry-specific integrated automation, control technologies, software services, and digital measurement and analytics solutions. ABB's Motion business provides electrical motors, generators, drives and services. ABB's Robotics focuses on value-added solutions in factory automation with artificial intelligence. ABB's Power Grids offers power and automation products across the distribution chain. (ABB 2020).

ABB in Pitäjänmäki focuses mainly in motors, generators and drives. Almost 70 percent of industrial electrical energy goes into powering electric motors. The frequency converters, that are manufactured in the Drives Production in Pitäjänmäki, are especially important in efficient energy use since they are designed to run the motors based on need and demand rather than running them at full speed and wasting energy. (ABB 2020).

2. Automation

Gupta and Arora defines automation in their book “Industrial Automation and Robotics” as a process in industry where various manual production operations are converted to an automated or mechanized process. (Gupta & Arora 2013: 1).
Industrial robotics is the most visible part of automation. They are modern automated processes mostly controlled by computer programs. The use of computers ensures that the process is accurate and effective. (Gupta & Arora 2013: 2).
The biggest advantages of automation are the increases in productivity, safety, control, and quality of processes and products. The current emphasis in automation has changed from increasing production to maximum and reducing costs to minimum into a more quality centered approach where process flexibility also plays a large part. Today’s markets demand the ability to easily switch the production from one manufacturing product to another without drops in quality or productivity. (Gupta & Arora 2013: 3-7).
A modern manufacturing system consists of a wide range of activities including both human and technological resources, as well as procedures, software and facilities. All this is connected to each other in a complex combination that requires proper management skills to be effective. The correct level of automation can be achieved in a situation where the relation between human and technology in terms of task and function allocation is balanced. (Frohm et al. 2016).

2.1 Automation suitability

Frohm et al. (2016) constructed a preliminary study with a Delphi survey from 16 respondents from seven medium-sized to large companies. The respondents were asked to what extent different activities in the production systems were being automated. The available answers were; 1) *very low, 2) low, 3) high* and *4) very high.*
To better illustrate the answers, they simplified the answers to **low usage** and **high**

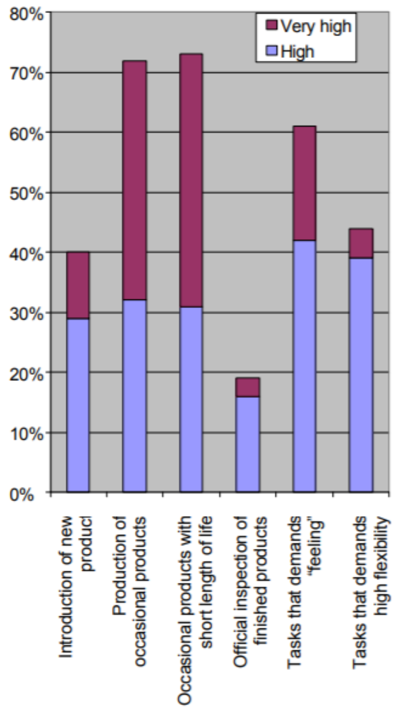
usage. It is also important to notice that if an activity has the same answer in both automatic and manual, such as material supply with **high usage** in both, this is because the answers are not from the same person or company. If the automated part is high, the manual part is low according to the study.

Based on the survey they concluded that machining, manufacturing, controlling, material handling and material supply are all automated to a larger extent than assembly, packaging and maintenance. Assembly, packaging and maintenance often require more complex work and are suitable for automation only to a certain point. Whereas the other areas are more repetitive and can be automated with less effort.

Table 2. To what extent is different activates automated or manual (Frohm et al. 2016).

Activity	Automated	Manuel
Assembly	Low usage (56%)	High usage (75%)
Machining	High usage (50%)	Low usage (44%)
Manufacturing	High usage (31%)	Low usage (25%)
Material handling	High usage (56%)	High usage (62%)
Controlling	High usage (75%)	Low usage (62%)
Information	High usage (75%)	High usage (56%)
Material supply	High usage (56%)	High usage (73%)
Supervision	Low usage (37%) High usage (37%)	High usage (50%)
Packaging	Low usage (69%)	High usage (62%)
Maintenance	Low usage (50%)	High usage (81%)
Change-over	High usage (56%)	High usage (60%)

This leads to the next issue in their study which is the specific tasks that benefit the most with automation. The tasks are divided suitable for either automated or manual work. Tasks can be suitable for either work to a **high** or **very high** extent. They concluded from the table that tasks that include heavy lifting or monotonous working operation, hazardous materials, big volumes, high repetition, or high accuracy are more suitable for automation. Tasks that include high flexibility, occasional products, inspection, or “feeling” are not suitable for automation and is better to do manually. (Frohm et al. 2016).



,

Figure 1. What tasks are suitable for automation? (Frohm et al. 2016).

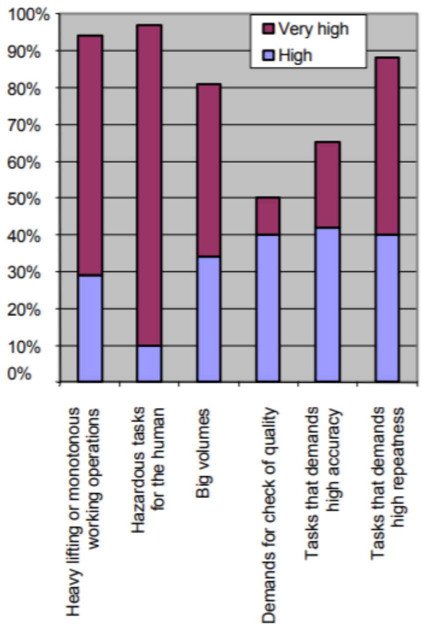


Figure 2. What tasks are not suitable for automation? (Frohm et al. 2016).

The biggest advantages of automation based on the answers from the respondents are cost reductions, increased efficiency, and overall better competitiveness and productivity. However, they also agreed that automation can lead to production disturbances because of more complex production systems that are more difficult to handle. They either do not have enough time to plan the usage of automation or train the operators and staff to handle the new investments. The variance in production and the adaptation to automatic production can also cause difficulties. (Frohm et al. 2016).

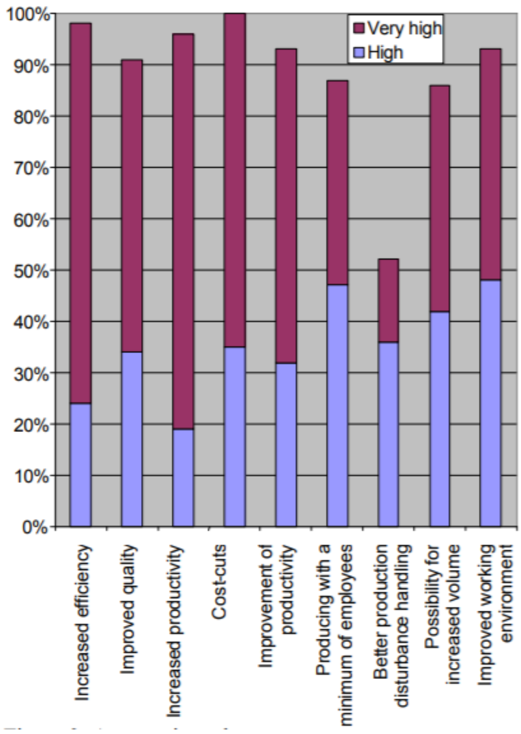


Figure 3. Automation advantages (Frohm et al. 2016).

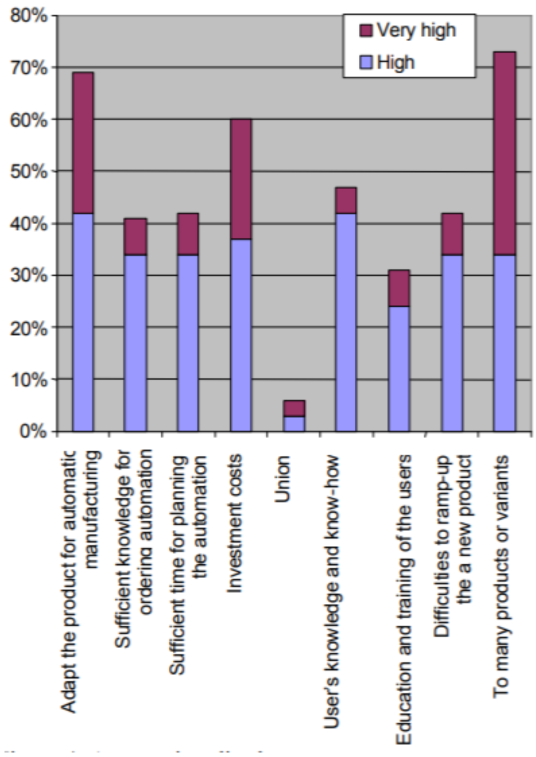


Figure 4. Automation disadvantages (Frohm et al. 2016).

They concluded their study by saying that the idea and benefit of automation is to perform functions and processes more efficiently, more reliable, more accurately and with lower costs then human operators. The higher reliability will eventually lead to safer systems (Frohm et al. 2016).

However, some functions are still better to perform manual and companies should remember that rather than trying to add as much automation as possible, they should think where the automation is best used. Trying to automate everything is often too expensive and complex, or the system is filled with flaws. It is smart to automate functions that are simple and often repetitive and do not require the intelligence and problem-solving skills that the human staff obsess. Automating such functions allow the human staff to focus on more value-added work.

2.1 Automation types

1. Low-cost automation

Low-cost automation is created around the already existing equipment, tools and methods with standard components available in the market with relatively low investments. It automates and simplifies the processes without changing the basic set up. It is easy to benefit from as it increases labor productivity with low costs. LCA also supports wide range of activities such as loading, feeding, machining, assembly, and packing. (Gupta & Arora 2013: 5).

2. Fixed Automation (Hard Automation)

Fixed automation, also known as hard automation, is often associated with high production rates as it relatively difficult to change once implemented to the system. It is efficient only when product designs are stable and product life cycles long. Fixed automation enables a very high efficiency and low unit costs but is inflexible and the initial investments can be large. (Gupta & Arora 2013: 6).

3. Programmable Automation

Programmable automation is suited for production of batches as the equipment is designed for specific product changes and cycles. Reconfiguring the systems for a new product can be time consuming as they need to be reprogrammed with new set ups for the machines. Programmable automation has a higher flexibility then fixed automation but also higher unit costs because of the product changes that reduce the efficiency of the system. (Gupta & Arora 2013: 6).

4. Flexible Automation (Soft Automation)

Flexible automation, also known as soft automation, is made for production that requires the manufacturing of a large variety of products. With flexible automation system it takes little time to change from one product to another or even introduce a new product line. Its downsides are large initial investments and high unit costs. (Gupta & Arora 2013: 6-7).

3. Material handling

Stephens & Meyers (2013) state in their book "Manufacturing facilities design and material handling" that manufacturing facilities design and material handling has one of the largest impacts to productivity and profitability of a company from all decisions. It is the planned use of the company's physical assets such as people, material, equipment, and energy and includes the design of facility locations, buildings, factory layouts, and material handling systems. This research focuses on material handling and how it is affected by layout planning. Issues such as facility locations or building designs are not further discussed in this paper. However, material handling is so much depended on the factory layout that these two issues must be discussed in the same topic. Effective material handling requires proper layout design.

Material handling is simply the movement of materials to the right place at the right time with right amounts. (Stephens & Meyers 2013: 2) It includes the movement, protection, storage, and control of materials and products throughout every process of manufacturing. It includes equipment and systems that support logistics and supply chains. Implementing them helps with process management, inventory management and control, production planning, resource allocation, forecasting, and customer delivery and service. (MHI 2019).

Stephens & Meyers (2013) also say that the issue that has most positively affected to work design and ergonomics are the improvements in material handling. Material handling equipment has made the work easier for the staff but every expense and investment in business must be cost-justified. This means that in every case of an investment, there must be cost reductions elsewhere. They can come from reduced labor and materials, or overhead costs. (Stephens & Meyers 2013: 3).

The general rule is that improving the flow of materials companies automatically reduce production costs. Layout planning is very important here since the reductions correlate directly to the distance of the material flow; the shorter the material flow is through the factory, the larger the cost reductions are. Material handling is set to be accounted from 40 to 80 percent of all operating costs and 50 percent of all industrial injuries. The cost of material handling equipment is high but properly designed and implemented, they can have good return on investment numbers. Many industrial problems can be eliminated with a proper use material handling equipment and it is the one area that has developed the most in the industrial history. (Stephens & Meyers 2013: 3).

Today's material handling systems are equipped with the latest technology. The newest systems can automatically capture data, track items, control inventory, and inspect quality and productivity. (Stephens & Meyers 2013: 3).

Material control systems are a necessity in modern material handling systems. Location systems, part numbering systems, inventory control systems, lot sizes, order quantities, safety stocks are only some of the abilities that are included in a modern material handling system. (Stephen & Meyers 2013: 232).

The variations on how to move materials are limitless and the right combination emerges from cost calculations. The correct choice of material equipment is essential for the material handling to be effective. The right kind of equipment will most likely reduce the cost of production and improve the quality of work. As material equipment are expensive, the lowest overall cost per unit must be calculated. A very expensive equipment might still be a good purchase if it reduces the unit costs enough. The long-term safety considerations must also be accounted. (Stephens & Meyers 2013: 232-233).

3.1 Material handling principles

It is important to use the best practices when implementing a material handling system and there are 10 principles of material handling that need to be considered in modern material handling systems. By implementing these principles, the system will lower overall handling costs in manufacturing, transportation and distribution. They will improve customer service, shorten delivery times, and reduce inventory. The 10 principles stated by MHI (2019) are:

1. **Planning:**
   Define the needs and strategic performance objectives of the system and the functional specifications of the supporting technology.

2. **Standardization:**
   Standardize all equipment, software, control, and methods so that they can perform a variety of tasks.

3. **Work:**
   Simplify and shorten the material movement and workflow by eliminating unnecessary movement.

4. **Ergonomics**
   Improve the working conditions and safety by reducing repetitive and uncomfortable manual work.

5. **Unit load**
   Move more items at a time by using pallets, containers and other platforms.

6. **Space utilization**
   Maximize the efficient use of space by organizing the work area and utilizing overhead space.

7. **System**
   Coordinate all processes in material movement with a modern material handling system.

8. **Environment**

   Consider the environmental impact and energy use by reusing and recycling materials as much as possible.

9. **Automation**

   Improve the efficiency, predictability, productivity and safety by automating material handling processes in correct places such as in tasks including repetitive movement.

10. **Life cycle cost**

    Analyze the life cycle cost of an investment by considering the capital investment, installation, setup, programming, training, maintenance, repair, and disposal costs. (MHI 2019).

3.2 Material handling equipment

There are several material handling equipment and technologies for companies to benefit from. This equipment can be divided into five major categories:

1. Transport equipment

   Transport equipment are used to move materials or products from one place to another. The major subcategories of transport equipment include conveyors, cranes, and industrial trucks. Conveyors are efficient when material is being moved frequently between previously set points. Cranes are useful when needed to move material over variable paths in a previously set area. Industrial trucks are the most flexible option of the three as they have no restrictions in their movement area. Industrial trucks include vehicles such as automated guided vehicles. (Kay 2012).

2. Positioning equipment

   Positional equipment is used to control material at a specific location. It is often used direct materials or products to a correct position at a single workplace. Lift tables and manipulators are good examples of positioning equipment. (Kay 2012).

3. Unit load formation equipment

   Unit load equipment is used to form materials or products so that it is possible to move more units at one time. Often used equipment in this area are pallets and boxes. Pallets are commonly made from wood and they have space underneath their top surface so that they can be picked up with forklifts. The standard pallet in Europe is called the "Euro-Pallet" and it has the parameters of 1200 x 800 mm. Pallets are an easy way to transport larger single items or many smaller items at one time so that they are stacked into one unified package. Boxes are often used to move smaller components for in-process handling. (Kay 2012).

4. Storage equipment

   Storage equipment is used to hold materials for an extended time period. Single-deep racks are the most popular type of storage racks where the pallets are supported between beams. In single-deep racks there is a single position slot for each pallet. (Kay 2012).

5. Identification and control equipment

Identification and control equipment collect and communicate the data and information that is required to control the material flow. Often used system for identification today is radio frequency identification (RFID). The antenna within the tag picks up a radio wave and sends it back to the reader when its being scanned. The tag number is then the primary identifier for the item and all information about the item is linked to the specific number. (Borowik 2020).

3.3 Automated material handling (AMH)

Automated material handling (AMH) involves robotics or other computerized devices for moving materials or products whereas manual material handling (MMH) uses physical force of human labor. (HHI, 2019).

Table 3. Automated material handling (AMH) vs manual material handling (MMH).

	MMH	**AMH**
Technology	Simple	Advanced
	Hooks, slings and manual cranes	Automated Guided Vehicles (AGV)
	Pallet jacks and trucks	Robotic delivery systems
	Forklifts	Mechanized loaders
Flexibility	Slow and rigid	Fast and agile
	Lacks scalability	Easily scalable
	One operation at a time	Multiple operations
		Repetitive tasks
Accuracy	Inaccurate	Accurate
	Errors	Precise machines
	Relies on human labor	
Costs	Low initial investment costs	High initial investment costs
	Increased labor costs	Decreased labor costs
Productivity	Lower productivity	Higher productivity
Safety	Prone to accidents from errors	Less prone to accidents
Training	Easy	Challenging
	Safety training	Operators with technical skills

Automated material handling has several benefits comparing to manual material handling. It is safer, accurate, productive, and flexible. However, as it is technologically advanced it also have higher initial costs and require proper training.

4. Automated Guided Vehicles (AGV)

AGVs are computer-controlled load carriers without onboard operators or drivers. They have predetermined routes that are developed by a combination of software and sensor-based guidance. AGVs are a safe way to move loads since they have precisely controlled acceleration and deceleration and can detect obstacles with sensors. They are usually battery powered with charging stations within the facility. AGVs are typically used in support of manufacturing production lines with the transportation of raw materials, work-in-process or finished goods. (MHI 2019).

There are several types of AGVs such as automated carts, unit load AGVs, tugger AGVs and automated forklift AGVs. Automated cart is the simple model with minimal features and cost. Unit load AGVs are typically customized for pallets, bins, carts, and roll-handling AGVs are specialized for heavy rolls of steel or paper. Tugger AGVs are made to pull loads upon non-motorized trailers. Automated forklift AGVs are unmanned forklift trucks. (MHI 2019).

The guidance in AGVs can include several technologies such as floor-surface mounted magnetic tape or bars, lasers, optical sensors, and magnet or gyroscope based inertial guidance. These technologies enable a fast and easy way to change the routes or expand the AGV system if necessary. (MHI 2019).

An AGV system consists of multiple vehicles and a computer-based software which collects data from each vehicle for real-time control and monitoring. The specific instructions for the vehicles are directed with wireless communication via radio frequency. These instructions include stops, starts, reverses, speed limits, lifting, lowering, turning and interfacing with other equipment. (MHI 2019).

AGVs are used in several industries such as automotive, manufacturing, warehousing and distribution, foods, beverage, chemicals, hospital, pharmaceutical, commercial printing, newspaper, paper, and plastics industries. They are used in various tasks such as assembly, kitting, transportation, staging, warehousing, order picking, and transfer.

The benefits of using AGVs are increased accountability, automated line balancing, cost control, facility maintenance, flexibility, fewer restrictions, reduced operating costs, reduced product damage, repeatability, safety, and scheduling. (MHI 2019).

4.1 Technology

4.1.1 Navigation

The advancement and better use of navigation technologies are one of the main reasons behind the increased use of AGVs in manufacturing industry. There are seven different navigation technologies that are generally used:

1. Wired navigation

   Wired navigation uses wires that are built in the factory floor. The wires transmit signals to the AGVs via antenna or sensors (Taglic 2020). It is a relatively easy yet inflexible navigation method.

2. Magnetic navigation

   Magnetic navigation uses magnetic tape to guide the path for the vehicle. It is easier to remove and relocate compared to wired guidance and it eliminates the expense of restructuring the floor of the facility. However, the paths need to be carefully defined by the tape and the vehicle cannot pass obstacles until those have been removed out of the way. (Lydon 2018).

3. Laser-guided navigation

   Laser-guided navigation has the advantage compared to magnetic navigation that it does not require any floor work. Instead, it uses triangulation to determine its position with the help of reflectors on the surrounding walls of the facility, functioning similar to electronic eye. (Lydon 2018).

4. Vision-guided navigation

Vision-guided vehicles (VGVs) use different sensors, such as optic, speed and laser sensors to navigate. The software then builds a 3D map of the facility with the use of the sensors. VGVs have a high flexibility in their use since they do not require any infrastructural modifications. (Lydon 2018).

5. Inertial (gyroscopic) navigation

Inertial navigation controls and navigates the AGVs with transponders that verify the course of the vehicles. The transponders are embedded in the factory floor similarly as in wired guidance. (Taglic 2020).

6. Geo-guidance

Geo-guidance is similarly flexible as vision-guided navigation that it does not need changes in the infrastructure. Geo-guidance enables vehicles to recognize objects in their environment to navigate their location in the facility. (Taglic 2020).

7. Natural navigation

AGVs with natural navigation systems use light detection and ranging (Lidar) as their navigation methods and are easy to install as they do not require any markers or reflectors (Lydon 2018). Lidar tracks the distance of the target with a laser light that measures the reflected light with a sensor.

4.1.2 Steering

There are three different solutions available for steering in AGVs. The first one is differential speed control, the second one is steered wheel control while the third one is the combination of the first and second:

1. Differential speed control

   Differential speed control is the most common steering type in AGVs. It uses two independent drive wheels. When the vehicle is going forward or backwards the two drive wheels are driven at the same speed. However, if the vehicle is turning, each wheel is driven at different speed. It is also the simplest steering type as it does not require additional steering motors or mechanisms. AGVs with differential speed control are commonly used in tight spaces. (Taglic 2020).

2. Steered wheel control

   Steered wheel control works similarly than the steering in cars or trucks where the drive wheel is the turning wheel. It is more precise than differential speed control and it helps the vehicles to turn smoother. It is often used in towing applications. (Taglic 2020).

3. Combination steering

   Combination steering is the combination of differential speed control and steered wheel control. AGVs with combination steering have two independent steer motors on diagonal corners and swiveling castors on the other two corners. The vehicles can then turn in any direction but also drive in differential steering mode in any direction. (Taglic 2020).

4.1.3 Traffic control

Traffic control in AGVs can also be executed in three different ways. The first option is zone control, the second is collision avoidance and the third is the combination of both:

1. Zone control

   The idea of zone control is that a specific area is set with a wireless transmitter that sends signals to the AGVs. AGVs pick up the signal with its sensors and sends it back to the transmitter. Another option is to equip AGVs with transmitters that sends signals to other AGVs entering the zone. Zone control is often used traffic control method because its simplicity to install. (Taglic 2020).

2. Collision avoidance

   Collision avoidance idea is that AGVs are equipped with sensors that transmit a signal and then wait for a reply to figure out whether there is an object in front of the vehicle. The sensors can be sonic or optical. Both sensors work in a similar way as a radar. Bumper sensors are also another type of collision avoidance sensor and are often used a fail-safe option. Bumper sensors signal the vehicle to stop in case of a physical contact. (Taglic 2020).

3. Combination control

   Combination control offers collision avoidance in all situations. AGVs with combination control can use zone control as a primary traffic control method but also have collision avoidance sensors as a backup if the first one does not function properly for some reason. (Taglic 2020).

4.2 Utilization

AGVs are used in the manufacturing industry to increase productivity and to improve process flexibility and production flow. AGVs with advanced navigation methods that are integrated within the company's enterprise resource planning (ERP) and manufacturing execution system (MES) are becoming vital parts of a synchronized and well-structured manufacturing systems. (Lydon 2018).
Typical functions of an AGV in manufacturing industry include work-in-process movement, production parts delivery, pallet handling, finished product handling, and trailer loading. Work-in-process movement was one of the first functions where AGVs were used. The vehicles can be used to transport raw material from warehouse to the production line and to move the product between different processes or stations within the production line. AGVs can also deliver the necessary production parts and tools to the workstations. The finished products can then be transported to the storage or shipping from the production line. AGVs can also be used for pallet handling since the repetitive movement of pallets is often necessary in manufacturing. The most advanced vehicles can even pick up the pallets from conveyors or staging lanes and deliver them directly to trailers in previously set loading patterns. (Lydon 2018).

4.3 Benefits

AGVs have many advantages in manufacturing but also some issues that need to be accounted before implementing AGVs into the manufacturing process:

1. Safety

   One of the most important aspects in manufacturing is safety. AGVs reduce damage caused by human-operated forklifts and eliminate the threat of people with handcarts as those always rely on human input and can be compromised in many ways. They also reduce product and facility damage and can be utilized in extreme conditions with hazardous materials.

2. Profitability

By replacing the human worker, AGVs reduce labor costs as ongoing costs such as healthcare coverage, payroll taxes, salary increases, vacation times are no longer an issue. Costs will also be more stable since there is less fluctuation (Taglic 2020). AGVs will eventually reduce costs in long term, however, they might have a high initial investment. In the beginning they are likely going to be more expensive than hiring personnel or other equipment. AGVs also require routine maintenance checks and occasional repair which will increase their costs. (Benevides 2019).

3. Productivity

Productivity is increased because AGVs deliver materials and products to the exact spot at the exact time, saving time compared to manual material movement. They also reduce work-in-process movement for the staff which increases production volumes.

4. Predictability

Process predictability is improved as AGVs provide material visibility and traceability as they are electronically tracked with ERP-systems. They also have accurate use of key performance indicators (KPI) with real-time connection to information systems. This further improves visibility and predictability to material handling process.

5. Flexibility

AGVs provide flexibility to the process as they are easy to integrate to infrastructure and layout changes. Non-functioning vehicles are also easy to change to another unit. (Lydon 2018). AGVs have a modular system element so that it is easy to add additional vehicles if operations expand. (Benevides, 2019).

The implementation of AGVs require staff training and time for them to get used to the vehicles working alongside them in the factory. AGVs are best used at dealing with repetitive tasks as non-repetitive tasks are probably done faster by the staff. And even though AGVs add flexibility as they are easy to integrate within the system, human-operated equipment might be faster in some situations where rapid changes are necessary. (Benevides, 2019).

5. Autonomous Mobile Robots (AMR)

Traditional AGVs are now being challenged by the new, more flexible and cost-effective AGV technology of autonomous mobile robots (AMR) which are basically enhanced versions of the traditional AGVs. (MiR 2019).

Traditional AGVs require supporting infrastructure such as wires, tapes or markers whereas AMRs navigate with maps that it builds on-site or based by pre-loaded facility drawings. It creates the most direct paths based on the maps to pick up or drop parts. The map is built by its built-in sensors and laser scanners with a software that detects its surroundings. The algorithms that enables the navigation and localization for the robots are called SLAM (Simultaneous Localization and Mapping) algorithms (Crossco 2019). AMRs can also create alternative paths in case of an obstacle whereas traditional AGVs need to wait until the obstacle is removed. (MiR 2019).

Traditional AGVs are limited to following the strict routes and tasks that it has been programmed to execute, or at least changing those is expensive and complicated. AMRs only require simple software changes to alter its missions and the same robot can perform a variety of tasks in different locations making it a much more flexible option for companies. The software also allows changes to be made to multiple robots with its fleet management control. As the missions and tasks are easy to change, the staff can focus on high-value work that contributes to company success. (MiR 2019).

The flexibility of the AMRs allows them to be adaptable to an agile production environment. If the facility is changed so that production cells are moved or new cells are added, a new map of the facility can be easily be uploaded to the robots. The company can focus on making their facility as productive as possible with the help of robots and not so that their layout is restricted to a certain pattern because of the robots. (MiR 2019).

Even though AMRs consists of much more advanced technology they are less expensive to implement. This is because they do not require any specific infrastructure building. They are quick to get up and running and add efficiency to production almost immediately. The fast optimization of processes leads to better return on investment and cost-efficiency for companies. (MiR 2019).

Table 4. Automated Guided Vehicle (AGV) vs Autonomous Mobile Robot (AMR).

	AGV	**AMR**
Navigation	Infrastructure:	No infrastructure:
	Wired guidance	*Trackless navigation*
	Reflective markers	
	Radio frequency ID etc.	
Obstacles	Stop	Alternative routes
Flexibility	New infrastructure	Remapping with software
Expandability	New tracks or units	Fleet management with
		software
Charging	Docking station	Docking station
Cost	High initial investment	Lower initial investment
	Slow implementation	Fast implementation

The AMR market is one of the fastest growing hardware markets that ARC, the leading technology market research firm in several industries including manufacturing, has ever seen. Major reasons to this are the increasing flexibility that AMRs can deliver which is further fueled by the boom in e-commerce but also the fact that it is currently difficult to hire workers for warehouses and factories in Europe and North America. (ARC Advisory Group 2019).

AMRs can be based on either fleet management or picking optimization system. Fleet management solution is more popular with bigger payloads as it routes the robots all the way from an origin to a destination. Picking optimization system deals with smaller payloads as they integrate the movement of machines and people in the process flow while increasing picking throughput. The latter one is the faster growing segment. (Banker 2019).

One of the largest suppliers of AMRs based on picking optimization system, 6 River Systems and its cofounder and co-CEO Jerome Dubois, reported that their booking were nearly 6 times greater in 2018 than what they were in 2017, and that their staff has grown by 150%. (Banker 2019).

Fleet management segment is also growing steadily. The Vice President of Sales for the Americas for MiR, Ed Mullen, reported a 160% growth for the company in 2018. According to Mullen, many large multinational companies such as Toyota and Honeywell first tested one or two robots in a single plant and then went on to buying a full fleet up to 20 robots. He also mentioned that they do not see too many limitations for the market growth. One aspect that would further fuel the growth is Robots as a Service (RaaS). It would allow companies to adopt the technology with more flexible payment options such as leasing. (Banker 2019).

Flexibility is the major reason behind the growth of AMR industry. They are easy to implement into facilities and are adaptive to layout changes. It is also easy to build different modules on top of the robots to support the specific production of the plant.

5.1 Robotics as a Service (RaaS)

For more than 30 years industrial robotics market has been operated with the classical capital equipment product design and sales business model. Product are sold to customer as a capital asset purchase. Customers own the equipment and are responsible for its maintenance, repair, and disposal. However, the business model is rapidly evolving and with the success of Software-as-a-service, autonomous mobile robot companies are now also seeking alternative options to sell their products with Robots-as-a-service (RaaS). (Mobilerobotguide 2020).

Robotics-as-a-Service (RaaS) is a business model based on renting or leasing robots as a full service rather than purchasing the robots and owning them. The payment is a subscription fee based on the results in factory floor. ABI Research estimates that the installed base for RaaS will grow from 4 442 units in 2016 to 1,6 million in 2026.

Expected annual revenues for RaaS providers will grow from 217 million US dollars to 34 billion US dollars in the same time. (Twentyman 2018).

RaaS allows customers to scale up and down the consumption of automation. Additional robot usage can be acquired during peak seasons and then idle or halt during quiet or slow periods. The purchasing cycle is also simplified and shortened. Typical capitals asset purchasing cycle varies from 3 to 18 months and issues such as capital budget request submissions must be considered. Investing for an expensive fixed asset often requires many levels of management approval. With RaaS companies can pay for the automation directly from their operational budget which often is not required for a capital approval within the organization. RaaS provides an opportunity to better utilize the company capital while also making it easier to acquire and implement automation. (Mobilerobotguide 2020).

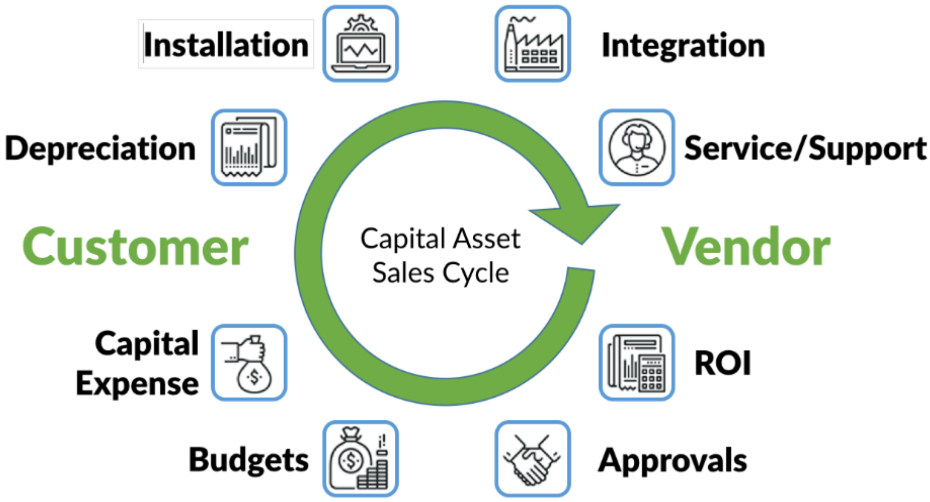


Figure 5. The capital asset sales cycle (Mobilerobotguide 2020).

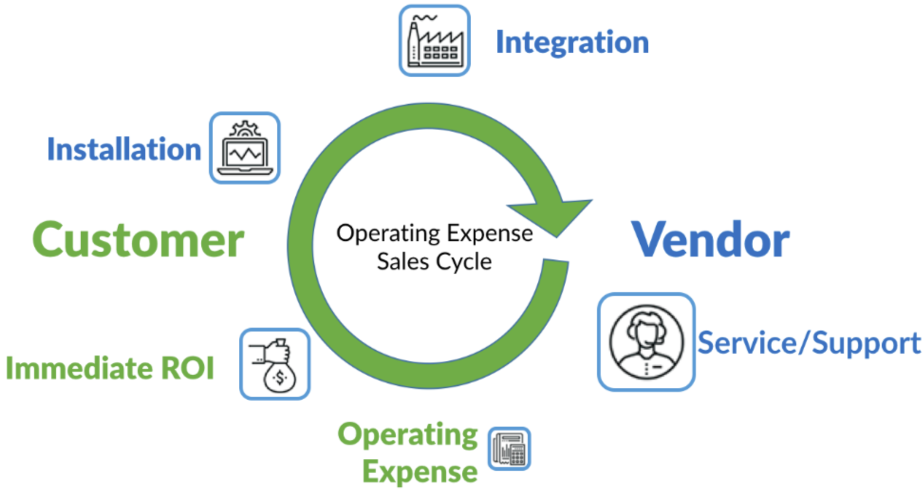


Figure 6. The operating expense sales cycle (RaaS) (Mobilerobotguide 2020).

Companies are increasingly interested in RaaS because of its flexibility, scalability, and lower cost of entry than traditional robot programs even though adaptations and customization of the robots to match the customer's needs might longer the implementation window. Regardless of that, RaaS will still be a useful solution for many organizations. (Marr 2019).

RaaS also cannot be automatically implemented in every situation since there are requirements which much exist for a RaaS solution to be viable. Three important requirements are:

1. Scalable automation problem

   The problem must be measurable by at least some Key Performance Indication (KPI). The KPI must also be effectively reported and invoiced by the supplier. Example measures could be hours of operation where the company would pay for every hour that the AMR is operating. Another option could be the number of picks in operation where the company would pay for every package transported through the facility. (Mobilerobotguide 2020).

2. Chargeable to Operating Expense

   The RaaS solution must be funded by an operating expense since the hardware will not be capitalized. It eliminates the need to seek higher level approval. (Mobilerobotguide 2020).

3. Guaranteed throughput

   RaaS enables companies to scale up and down during peak and slow periods but it requires a guaranteed throughput to be used effectively. (Mobilerobotguide 2020).

5.2 Lean Automation

Lean Production principles are widely accepted since their first wider appearance in the 1990s. The concept was originally created by Toyota in the 1950. It is a technology-independent way to organize production processes to reach the shortest lead times. Its key principles include continuous improvement by focusing on value adding activities by avoiding waste. It is simple and effective way for companies to increase productivity even up to 25 per cent. Its simplicity and effectiveness are the reasons why it became so famous and why companies are still utilizing it today. However, it seems that Lean Production has reached its limit on how it has been used thus far (Kolberg & Zuhlke 2015).

Today companies are facing a new challenge in the strong deviation in market demands alongside the need to maximize capacity and production volumes. Even though Lean Production supports a high variance in products, the principles are not meant for single-item production. Therefore, the suitability for shorter product life cycles in the future is limited with Lean Production. (Kolberg & Zuhlke 2015).

Industry 4.0 is an approach where smart machines and components can communicate with each other in a standardized network. Industry 4.0 is offering companies new areas and opportunities to benefit from Lean Production. It aims for optimization of value chains by implementing an autonomously controlled and dynamic production with the help of real time information and networked systems. All this in enabled by Cyber Physical Systems (CPS) which can work autonomously and interact with the production environment by using its microcontroller, sensors and communication interface. Lean Automation focuses on combining the benefits from Lean Production and automation technology with Industry 4.0. (Kolberg & Zuhlke 2015).
Industry 4.0 enables companies to develop smart factories equipped with smart operators, machines, products and planners. The technical installations in smart machines can help employees to avoid mistakes. Employees can become smart operators by equipping technology that notifies them immediately if a failure has occurred. Smart products collect process data to be analyzed after production. Smart planners can help companies to find the optimum between highest possible capacity utilization and continuous flow of goods. (Kolberg & Zuhlke 2015).
Andersen et al. (2017) tested the benefits of integrating collaborative robotic manipulators with autonomous mobile platforms. They named the systems as Little Helper 6 (LH6) and it consisted of a MiR100 autonomous mobile robot, UR5 collaborative robot arm and a Robotiq 3-Finger Gripper. These components are controlled by a software called Skill Based System (SBS). Little Helper 6 demonstrated the capabilities and possibilities of skill-based programming, 3D QR based calibration, part feeding, mapping and dynamic collision avoidance. The LH6 was used as an automated part-feeding system for a single module which in this case was a tray containing 12 printed circuit boards (PCB). The autonomous mobile platform drove to the location where the tray is picked up and the collaborative robot arm calibrates the imprecisions of the navigation of the mobile platform. The calibration of the position was made possible by inserting the system with a 3D camera that obtained information from a fixed QR-code. Once the full tray is inserted, a signal is sent to the programmable logic controller (PLC) that the tray has been fed. They concluded that an

essential part of the system was the ability to move with the MiR100 autonomous mobile robot. (Andersen et al. 2017).

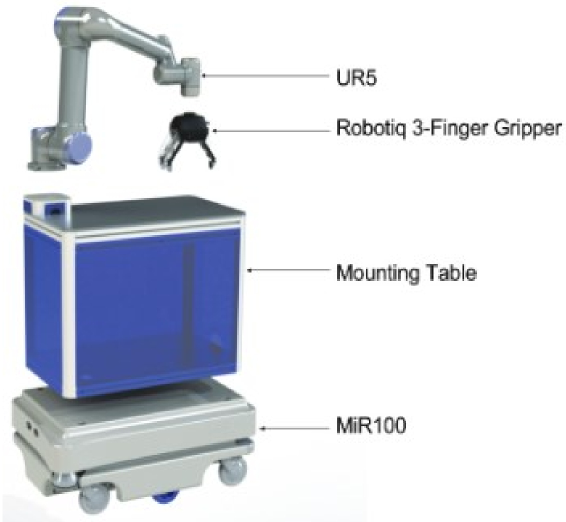


Figure 7. The main components of LH6 (Andersen et al. 2017).

6. Automation investments

Before investing in automation it is important to evaluate its efficiency and financial profitability. The investment must be based on theory and have scientific proof that it will improve the company's processes.
There are several ways to measure the improvement that automation has on production and productivity. Simulation enables companies to evaluate the investment before implementing it in their production. Different analytical and mathematical methods can also be used. Cost calculations are made to ensure the financial profitability of the investment. Investment always has risks and uncertainty.

6.1 Simulation

Simulation is creating and experimenting a real-world process with a computerized mathematical model. Mourtzis et al. (2014) says that simulation is especially important in today's manufacturing environment which is affected by the current megatrends of globalization and product customization. Decentralization of manufacturing requires real-time information of different processes in a product development life cycle. However, product development and production processes are becoming more complex because the increasing degree of product customization creates different product variations. Simulation modelling and analysis can help companies to gain insight into these complex systems by testing the new investments and systems virtually before implementing them. Simulation also enables them to gather information and knowledge without interrupting the actual production system. (Mourtzis et al. 2014).
Simulation can help companies with their layout planning, process planning, material flow, product data management, knowledge management, and supply chain management. The visualization of the simulation can be further enhanced with 3D models and with the use of virtual and augmented realities. (Mourtzis et al 2014.)

Production simulation software in manufacturing is a process where the actual manufacturing is mathematically represented on a computer in a 3D world with a software. It allows companies to test and try out different layouts and functions to efficiently utilize their manufacturing systems. It enables companies to make experiments and analyze manufacturing systems digitally which makes it easy, fast, safe, and cost-efficient. It encourages companies to try new things, invent better production systems and functions, and become more innovative overall.

6.2 Analytical methods

There are also many analytical methods to support simulation methods when designing a production system. Analytical methods include mathematical techniques such as queuing theory, integer programming, heuristic algorithm, and Markov chains. (Sezen 2003).

6.2.1 Queuing theory

Queuing theory is the mathematical study of congestion and delays of waiting line. It includes the arrival process, service process, number of servers, number of system places, and the number of customers. (Kenton 2019).
For example, company X wants to optimize their number of service desks so that their customers do not need to be waiting in a line. Their average service process time is 30 minutes. Their number of customers in the working hours of a day (8am to 4pm) is 64. That means that there are 8 customers per hour (64/8=8). If they have 8 customers per hour and their service process time is 30 minutes, they need to have 4 service desks (8*0,5=4) to reach zero time of waiting in line.

6.2.2 Markov chains

Markov chains, or Markov analysis is a forecasting method to evaluate the value of a variable which provides the possibility or likelihood of a future action to occur. It is based on only its current state and circumstances surrounding the variable. (Kenton 2019).
For example, the likelihood of company X to have 2 500 defective products is 50% next year given that company X manufactures 5 000 defective products this year based on the state of their equipment. The likelihood of manufacturing 2 500 defective products for the both next two years is then 25% (0,5*0,5=0,25).
Markov chain Monte Carlo simulation is a method that produces the probability of different outcomes by using continuous random variable, standard deviation and variance. It can be done with MS Excel or similar programme. (Kenton 2019).

6.2.3 Integer programming

Integer programming, or zero-one integer programming, is a mathematical method where a series of binary answers (yes=1 and no=0) is being used. It can be used when deciding where to invest or which product to manufacture. (Kenton 2019).

6.2.4 Heuristics

Heuristics is a problem-solving method in a situation with limited time or resources. It is a flexible technique based on quick decisions often associated with complex data. Decisions can be made with intelligent guesswork or trial-and-error. Heuristics might lead to poor decision making, however the speed and quickness of decisions can sometimes cover the losses. Representative heuristics focuses on mental shortcuts based on past events in a similar situation (Chen 2019).
For example, company X can imitate company Y's successful manufacturing strategy in country Z without researching if the same strategy applies for their own business model. Country Z might not possess the natural resources needed to manufacture

their products which would have occurred in a research study based on quantitative and qualitative data. However, it might also be so that they have a market niche just right for their products and being first in the market was crucial to their success.

6.3 Cost calculations

Cost calculations one of the most important issues when deciding whether to make new investments. The new investment will have to be financially profitable for the company meaning the profits must at least match the cost of the investment. However, as money lose its value with time and the money today is not worth the same as it will be a year from today. Issues such inflation and cost of capital must be accounted.

It is also very important to thoroughly design the new investment and consider different options since the design phase will eventually define the costs. It is difficult to make changes regarding cost savings when the investment is already in the implementation phase. In the implementation phase the focus is to make sure that the new investment is ready according to schedule. The delay of schedule might be even worse than going over the budget. (Yritystulkki 2020).

There are several methods to use to calculate the profitability of a new investment. Often used methods are net present value (NPV), internal rate of return (IRR), return on investment (ROI), and payback period.

6.3.1 Net Present Value (NPV)

Net present value (NPV) is a method where the profits and expenses are being discounted to present day. Inflation and cost of capital are accounted with a discount rate, or an imputed rate of interest, that is generated to get an accurate result from the calculations. Investments with positive NPV are financially profitable and investments with negative NPV are not (Kenton 2020).

(1)

$$NPV = \sum_{t=1}^{n} \frac{Rt}{(1+i)t} - RO$$

where *Rt = net cash flow at time t*

RO = cost of acquisition

t = the time of the cash flow

i = discount rate (imputed rate of interest)

For example, company X is investing 1000 euros into new equipment so the cost of acquisition is 1000. The lifetime of the machine is 3 years and it will generate net cash flow of 500 euros, 600 euros, and 700 euros at the end of years 1,2, and 3. The discount rate, or the imputed rate of interest, is 10%. The NPV of the investment is:

$$NPV = \frac{500}{(1{,}10)} + \frac{600}{(1{,}10)^2} + \frac{700}{(1{,}10)^3} - 1000 = 1476{,}33$$

NPV can also be calculated with the NPV function in MS Excel.

6.3.2 Internal Rate of Return (IRR)

Internal rate of return (IRR) is a method where marginal efficiency of investment is identified. The idea of the method is to compare the internal rate of return to a standard discount rate. If the IRR is greater than the discount rate, the investment is financially profitable. (Yritystulkki 2020). The IRR relies on the same formula as the NPV (Hayes 2020).

$$0 = NPV = \sum_{t=1}^{n} \frac{R_t}{(1+IRR)^t} - RO \qquad (2)$$

where *Rt = net cash flow at time t*

RO = *cost of acquisition*

t = *the time of the cash flow*

IRR = *internal rate of return*

IRR must be calculated with trial-and-error or with software such as with the IRR function in MS Excel. (Hayes 2020).

6.3.3 Return on Investment (ROI)

Return on investment (ROI) method is a simplified model of internal rate of return (IRR) method (Yritystulkki 2020). ROI is a percentage that compares the amount of return of an investment to its original costs (Chen 2020).

$$ROI = \frac{Current\ Value\ of\ Investment - Cost\ of\ Investment}{Cost\ of\ Investment} \tag{3}$$

For example, company X invests into new equipment which current value is 8000 euros. The investment cost 5000 euros. The ROI of the investment is:

$$ROI = \frac{8\ 000 - 5\ 000}{5\ 000} = 60\%$$

ROI can be calculated in MS Excel with the help of NPV function. ROI is simply NPV divided by the cost of investment.

6.3.4 Payback period

Payback period, or payback time shows how long it takes for the investment to pay back its original cost for the company. (Yritystulkki 2020). It expresses the time it takes for the investment to reach its break-even point. (Kagan 2020).

(4)

$$Payback\ period = 1 + n_y - \frac{n}{p}$$

where n_y = *The number of years with the last negative value of cumulative cash flow*
n = *The value of cumulative cash flow of the last year of negative value of cumulative cash flow*
p = *The value of cash flow of the first year of positive value of cumulative cash flow*

For example, company X invests into new equipment which costs 5000 euros. The investment generates a cash flow of 2000 euros, 2000 euros, and 2000 euros in years 1,2, and 3. It can be calculated that after two years the investment has generated 4000 euros and the cumulative cash flow is still 1000 euros negative. On the third year it turns positive so the break-even point comes in the third year. Payback period of the investment is:

$$Payback\ period = 1 + 2 - \frac{1000}{2000} = 2{,}5$$

Payback period can also be calculated in MS Excel from the point where NPV equals to zero.

6.4 Risk and uncertainty

Risk and uncertainty always exist with investments. The longer and far-sighted the investment is, the greater is the risk and uncertainty. Risk and uncertainty are, however, separate issues and must not be confused to one another. Risk can be measured based on its probability. Uncertainty is always unknown. Therefore, risk is uncertainty that can be measured. Risk and uncertainty in investments can be prepared with several different calculations and methods. (Yritystulkki 2020).

7. Implementation of AGVs: CASE ABB Oy

ABB Drives Production in Helsinki focuses on the production of frequency converters. They want to automate their processes to increase productivity and safety. This research is made to discover the possibilities to implement Automated Guided Vehicles (AGV) into their production of Corinth R6, R8, R11 product families. The first task is to evaluate the current state of the factory. Automated solution with AGVs is made to address the problems that occur in the current state. The automated solution is simulated with a simulation software to evaluate its capacity and efficiency in the environment. Cost calculations are made to evaluate the financial profitability of the investment.

7.1 Current state

There are four different Corinth products. The R11 and R10_11 are the larger products and are made in the same production cell in the factory. The R10_11 is not yet in the production but will be in near future. The R8 and R6 are smaller products and are made in the same production cell.

The production is done in phases. The R11 has eight different work phases and a full capacity of eight workers. The R6&R8 have three or four different work phases and a full capacity of four workers each. The production is done in two shifts. The morning shift begins at 6.00 am and ends at 2.00 pm. The evening shift begins at 2.00 pm and ends at 10.00 pm. Therefore, there are 16 working hours over the course of one working day. Working days are Monday to Friday with occasional overtime work during weekends.

Even though there are industrial robotics and automation is some areas of the production, currently all movement related to material or product handling is done either with human-operated vehicles or manually with carts. The production basically consists of four processes which all have their own sub-processes:

1. Materials

Both production cells have single deep racks where the materials are brought with EUR pallets. The material handling is outsourced to DHL. They currently deliver the materials from the docking station to the production line with human-operated forklifts. DHL is also responsible for the switch of empty pallets to full pallets in the production line. Empty pallets are stacked to a specific location.

2. Assembly

The first worker starts to build the product from an empty frame by adding the required components. Once the worker is ready with his work phase, he moves the product manually with a cart, or slides it on the conveyor line for the next worker in the production line. Manual carts are used in R11 production to transfer the product to the next workstation but R6&R8 production line is equipped with a line of conveyors. The workstations are located next to each other

3. Testing

Once the product is ready the final worker in the production line delivers it to the testing area. The testing area is located next to the production lines. This movement is done manually with the same carts that are used in assembly. The worker in the testing area lifts the product from the cart to the tester pallet with lifting equipment.

4. Packing

Once the product has passed the test it is delivered to packing area. Packing is partially outsourced to Transval. This movement is also done manually with the same carts that are used in assembly.

7.2 Automated solution

Automated solution is made for the work-in-process movement of products. Manual transportation of products from the production lines to testing area and from testing areas to packing area takes valuable time off production. The functions are very repetitive and simple, and therefore suitable for automation. The idea is to automate these work phases with automated carts. The robot should be based on fleet management system since there is a need to transfer bigger payloads from an origin to a destination. There are several suppliers for autonomous mobile robots based on fleet management but not that many that are able to carry the weight of the Corinth R11 products. Omron is one of the few suppliers that have such models in their catalog. Omron is a Japanese mobile robot manufacturer. The Omron LD-250 model has a maximum weight capacity of 250kg which is required. The model is also available as an electrostatic discharge (ESD) version.

Omron mobile robots are easy to install as they do not require pre-programming. The mobile robots are managed with the MobilePlanner PC-software. The software builds and distributes maps for the robot and provides configuration tools for it to adjust its parameters, program sensors and cameras. With the software the user can also assign jobs and schedule routes for the robot. The first mobile robot will have to be driven around its environment with a joystick as the vehicle will use its on-board lasers to scan the environment and generate a map to navigate later. This navigation map can also be edited later via the MobilePlanner to add pick-up and drop-off locations and restriction zones. The robot also has an ability to adapt to more frequently changing factories as it provides an additional light map that identifies overhead lights. The Omron mobile robots are safety rated and have front bumper sensors, and side and lower lasers alongside LiDAR lasers. It also uses sonar (sound navigation ranging). (Omron 2019).

Fleet management and coordination for multiple vehicles is handled by Enterprise Manager network appliance. With the network appliance the user can distribute jobs so that the best-suited vehicle to do the job is selected. Communication is easier as it can be integrated within the company's MES or ERP system or used with just a single point of contact. The Enterprise Manager can be used to optimize traffic flow of the vehicles. The mobile robots are charged in charging stations in the factory. (Omron 2019).

Table 5. Omron LD-250 technical information (Omron 2020).

Family	Omron LD-250
Technical filters	
Max. payload	250 kg
Max. Speed	1.2 m/s
Dimension	
Length	963 mm
Height	718 mm
Width	383 mm
Running time	13 h

Figure 8. Omron LD-250 (Omron 2020).

The vehicles can be modified quite easily to match the needs of the specific factory. Touch screens, conveyor modules and other extra attachments can be added to the robot. The conveyor module and other attachments to the mobile robot is made by Dimalog.

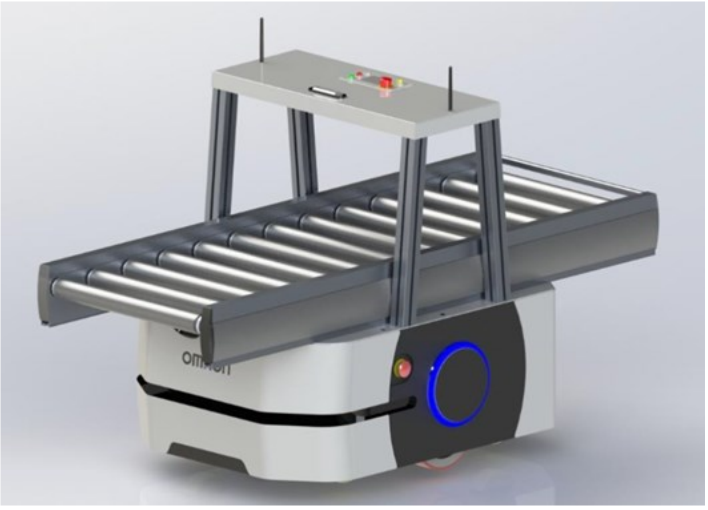


Figure 9. Omron mobile robot mounted with a conveyor module.

The mobile robot attaches straight to the conveyors. The height of the conveyor module is made to match the height of the conveyors in production so the workers can slide the product directly between the conveyors and the conveyor module. The conveyor module is equipped with protective rims and brakes to prevent any chances of the product dropping off the conveyor. The conveyors and conveyor module could also operate automatically without the worker sliding the product. It would save time since the workers could leave the product on the conveyor and start the next product while the conveyor automatically moves it on to the robot.

The testing areas and packing area will require additional conveyors. The product will have to be delivered on a conveyor in the testing area since it is not currently possible to deliver it straight to the tester pallet. It will also have to be picked up from another conveyor once it has passed testing for the same reason. Tester pallets could be modified so that the robot could deliver the product directly there. It would eliminate unnecessary conveyors in testing area and any need of lifting equipment. It would save time and is also safer since lifting equipment can malfunction.

Packing area requires a conveyor where the products are finally delivered.

Commands for the mobile robot are made with computers and a touch screen attachment. Workers would signal the mobile robot to pick up a product from an origin with a software in the computers they have in production lines and testing. The

destination is defined with a touch screen attachment mounted on the robot once it has picked up the product.
The mobile robot would use the same routes that are currently in use with the manual carts since the aisle width is large enough for the robot. It can be instructed with speed limitations in certain areas on its route and restrictions for other areas in the facility if necessary. The mobile robot would also have a waiting point next to the R6&R8 production lines when it has completed its tasks. Charging station would be located next to the waiting point.

7.3 Simulation report

The software that is used in this research course is called Visual Components. Visual Components is founded in 1999 by a team of simulation experts. It is now a leading developer of 3D manufacturing simulation software and solutions and it is recognized as a global leader in the manufacturing simulation industry and trusted technology partner to many leading brands. Visual Components offer machine builders, system integrators, and manufacturers an efficient way to design and simulate production lines to discover better solutions for manufacturing design, sales, and application development (Visual Components 2020).
This simulation report illustrates the production of Corinth R6, R8 and R11 product families. The production lines including the testing areas and packing area are built to the 3D world to match the actual distances in the factory. Only the final conveyor is being presented of the production lines since the focus in this simulation is in the movement of the mobile robot rather than the assembly of the products. The simulation will demonstrate the production rates in both production lines based on the actual production times. The testing areas are covered with fences as they are in real life. The testers are set to match the production rates so that there are no bottlenecks. The packing area is built with extra conveyors which represents the shipping of the products.

The routes and movement for the mobile robot are made with AGV Pathway and AGV Crossing components. The AGV Pathways are set up with arrows that define the movement of the AGV. AGV Crossing components are the dark grey squares which enables the AGV to turn and alter its direction in the 3D world. AGV also requires an AGV Controller which is the black circle on the left of the AGV Pathway. The simulation always requires a Works Task Controller which can be seen on the left side of the Human.

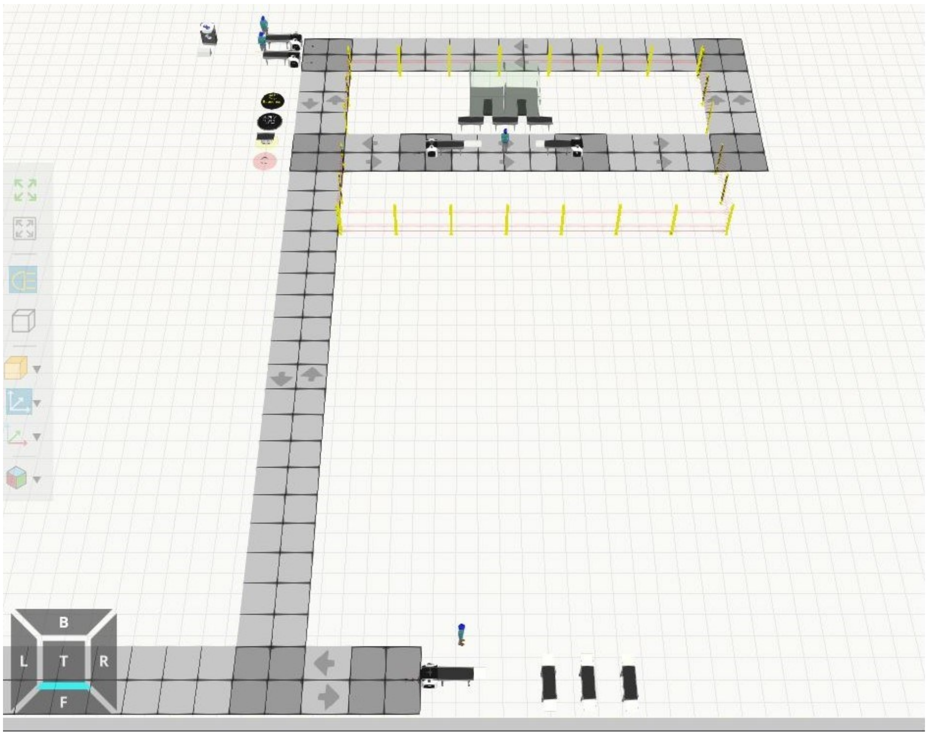


Figure 10. 3D model of the R6&R8 production lines including the testing area and packing area.

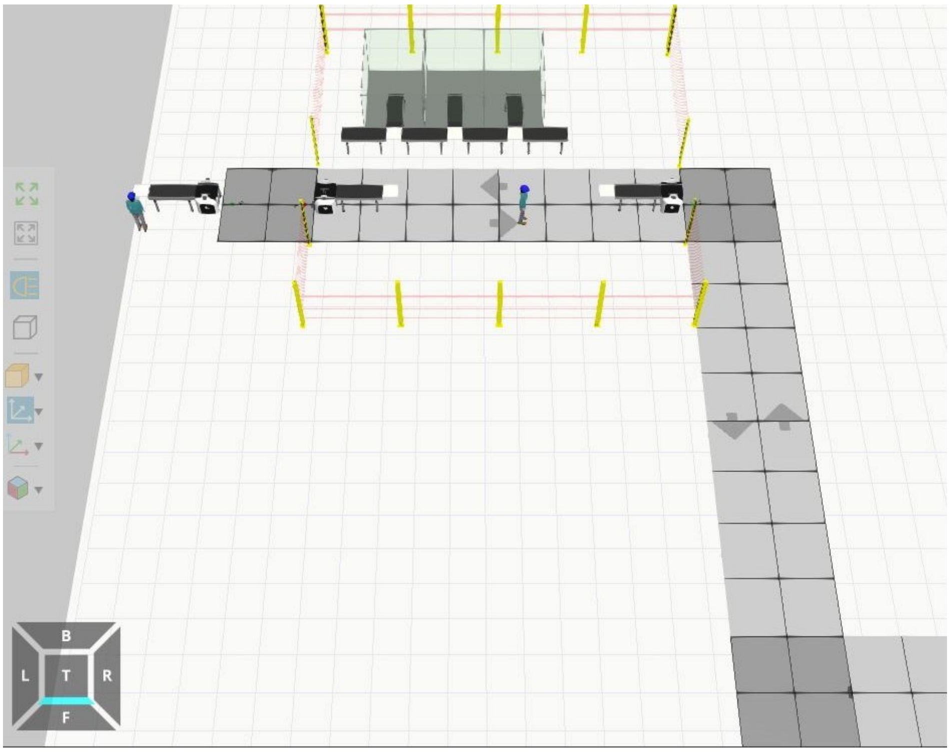


Figure 11. 3D model of the R11 production line including the testing area.

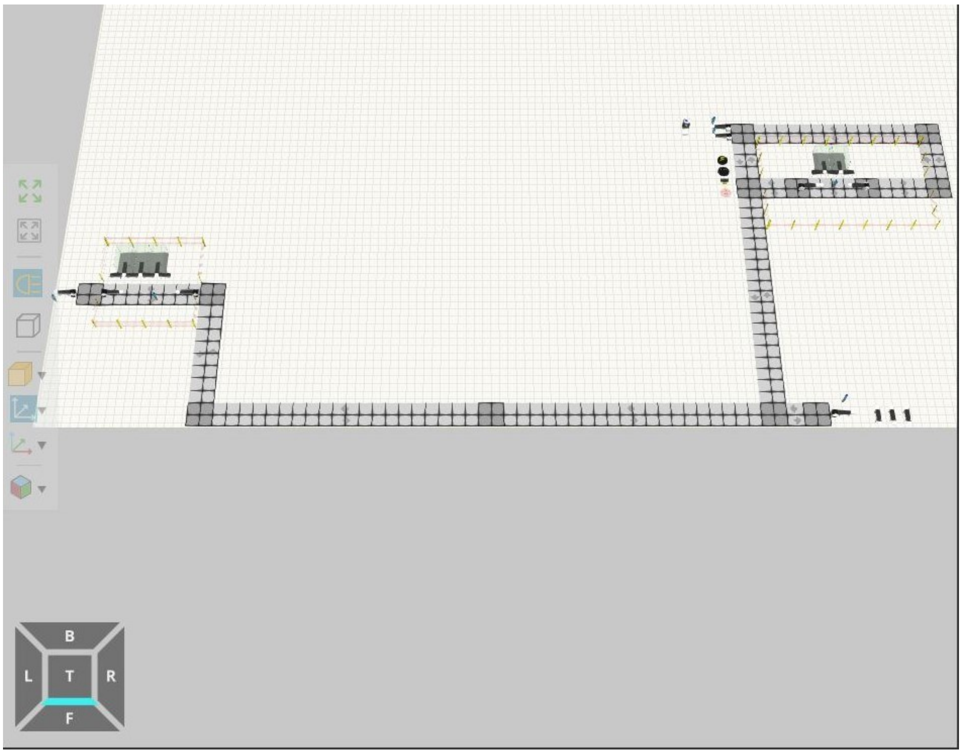


Figure 12. 3D model of both production lines.

The AGV model that is used in the simulation is the Omron LD-60. The LD-250 is not available in the simulation so the speed of the LD-60 is changed to match the speed of the LD-250. The AGV is also mounted with a conveyor module which enables it to receive the products directly from the final conveyor in the production line. Before the AGV can move in the simulation it must have its Charging station set up in the 3D world. In this case, the Charging station is placed next to the production lines. Next to its Charging station there is also its Waiting station where the robot returns to wait for a signal.

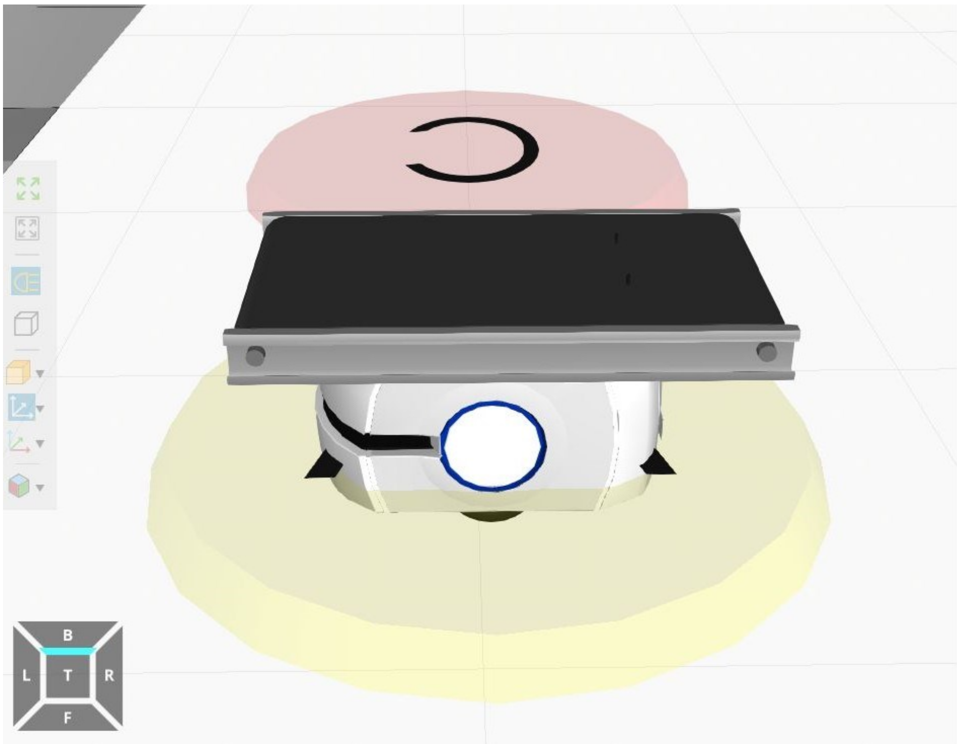


Figure 13. The Omron LD-60 mobile robot mounted with a conveyor module on its waiting point next to its charging station.

The white object that is attached to the conveyors is called a Works Process. It can be given different tasks to complete, and in this simulation, it creates a box with a Create task. The box represents the product that is assembled in the production and the conveyor represents the final conveyor in the production line. Second task for the Works Process is Human Process which represents the actual assembly of the product.

The time of the Human Process is made to match the production rates. Once the Human Process is ready and the product has been assembled the Works Process will complete its next task which is Transport Out. It means that it transports the box for the AGV Pick Location via the conveyor. This task represents the phase when the product is ready and the AGV is ready to pick it up.

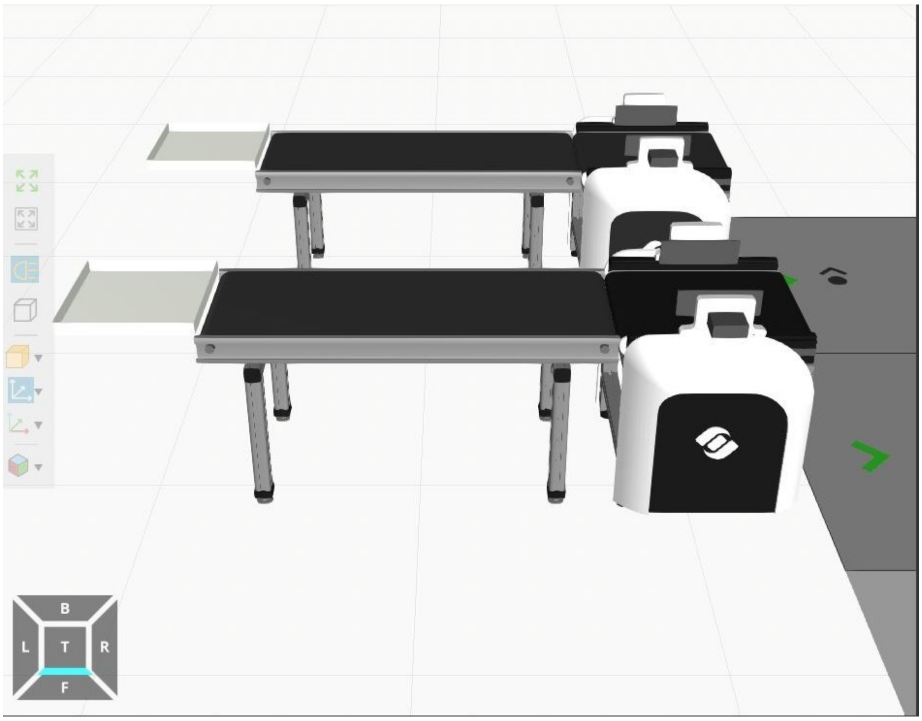


Figure 14. AGV Pick Locations in the end of the R6&R8 production lines.

The box has now been created and the human workers are assembling the product. The AGV is waiting for a signal once the product is ready to be picked up. Picking up and dropping off products is made with AGV Pick Location and AGV Drop Location components. All location components are being attached to a conveyor. These location components automatically adjust to the load height of the conveyor module of the mobile robot and act as an intermediary between the conveyors and the mobile robot. In real life the mobile robot conveyor module is made to match the height of the other conveyors and can attach straight to the conveyors. The AGV serves both production lines so it completes the same tasks in both production lines. The AGV drops the product for the AGV Drop Location in the testing area.

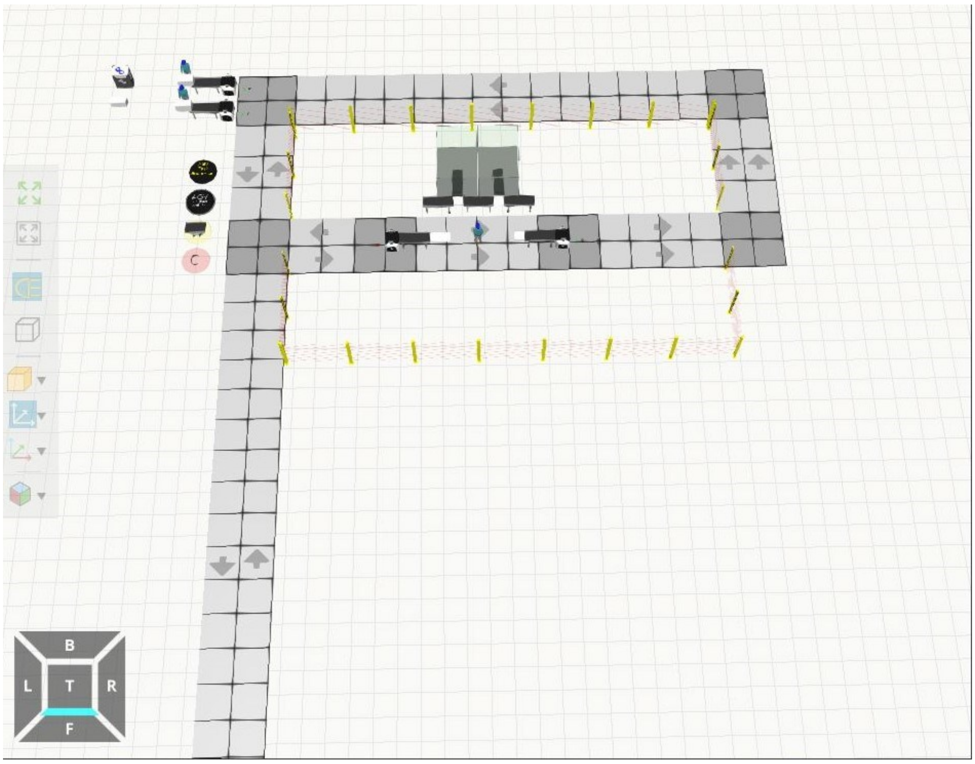


Figure 15. The mobile robot is on its waiting point waiting for a signal.

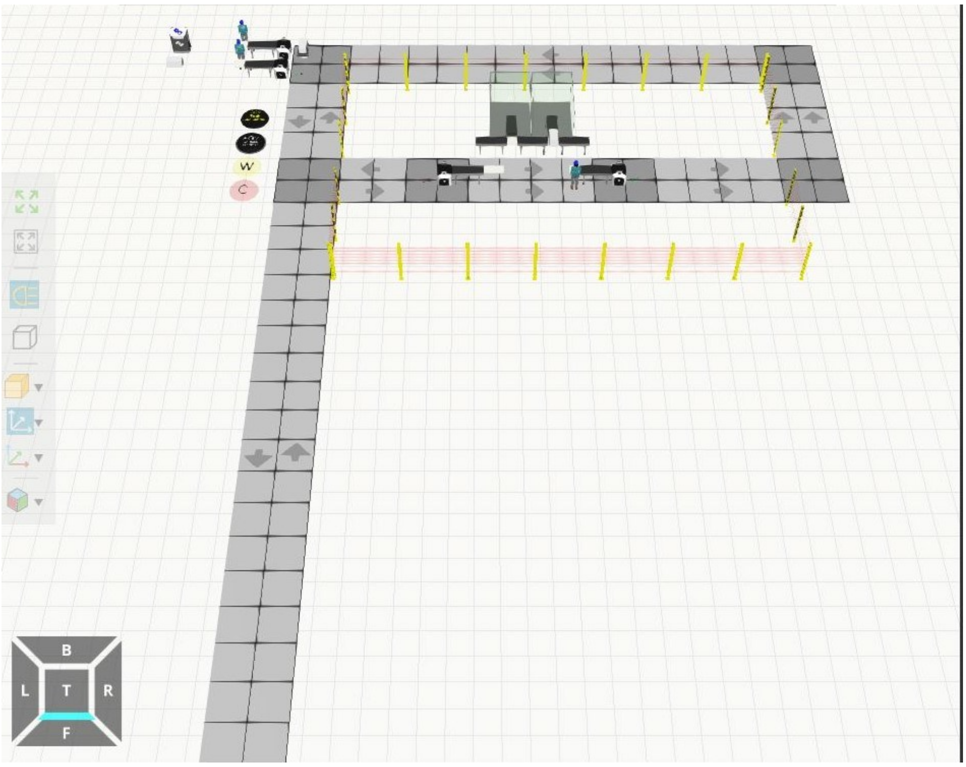


Figure 16. The mobile robot received a signal and is picking up a product from the AGV Pick Location in R6&R8 production line.

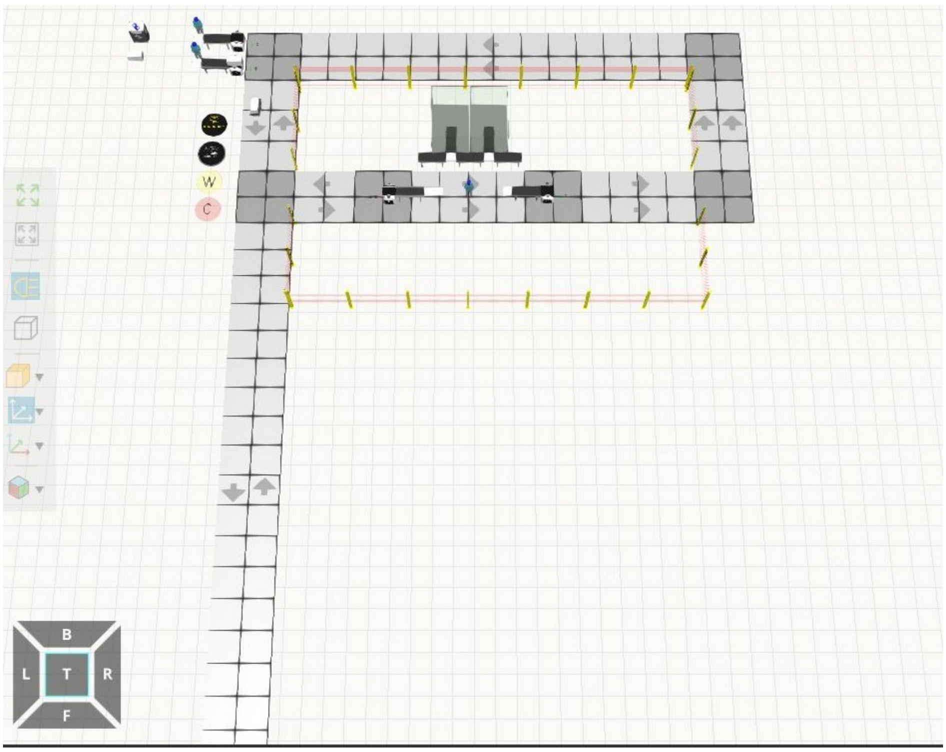


Figure 17. The mobile robot is delivering the product to the R6&R8 testing area.

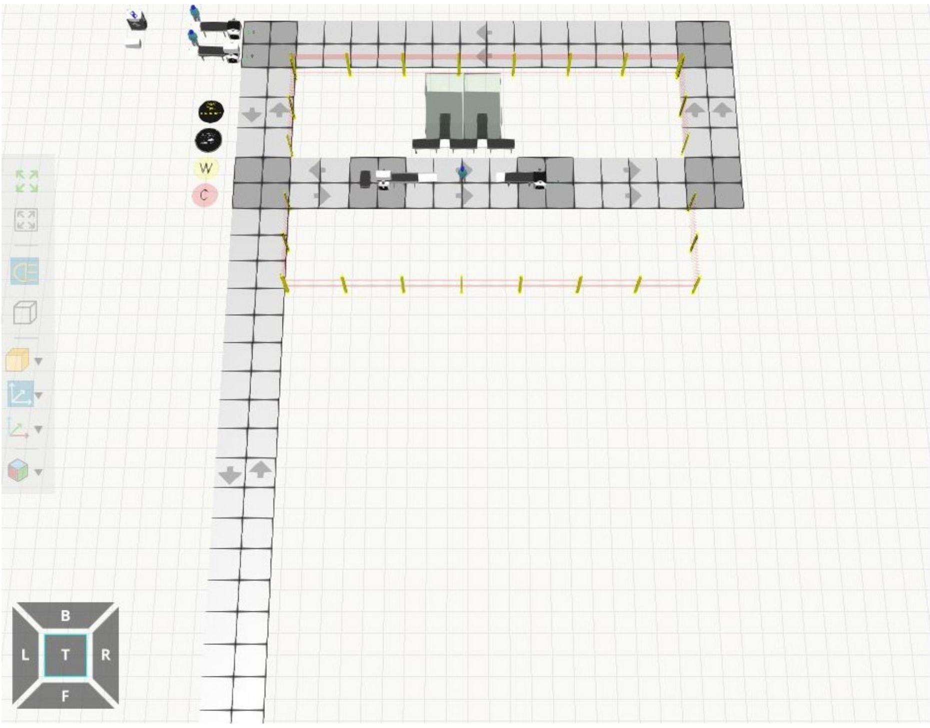


Figure 18. The mobile robot is dropping off the product on to the AGV Drop Location in the R6&R8 testing area.

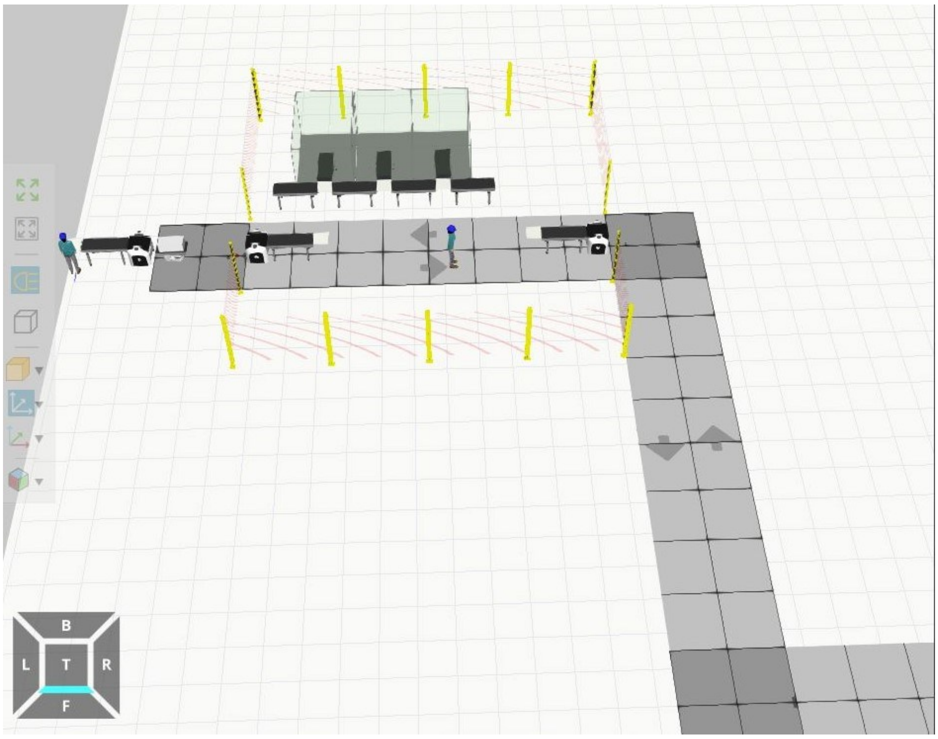


Figure 19. The mobile robot received a signal and is picking up a product from the AGV Pick Location in the R11 production line.

Once the AGV has dropped off the product in the testing area The AGV Drop Location then delivers the product via conveyor for the Human in the testing area. This is made with a Transport In task in the Works Process component that is attached to the same conveyor. Once the product is in the Works Process component, the Human will pick it up. This happens with a Pick task in the Works Process component. The testers in this simulation is being presented with a Works Process component attached to a conveyor and covered with a square shaped cage. Once the product is picked up it will be placed on the tester with a Place task. The Works Process will complete its next task which is Delay. The delay is set to match the actual testing times which are always made to match the product arrival rates so there are no bottlenecks in the production.

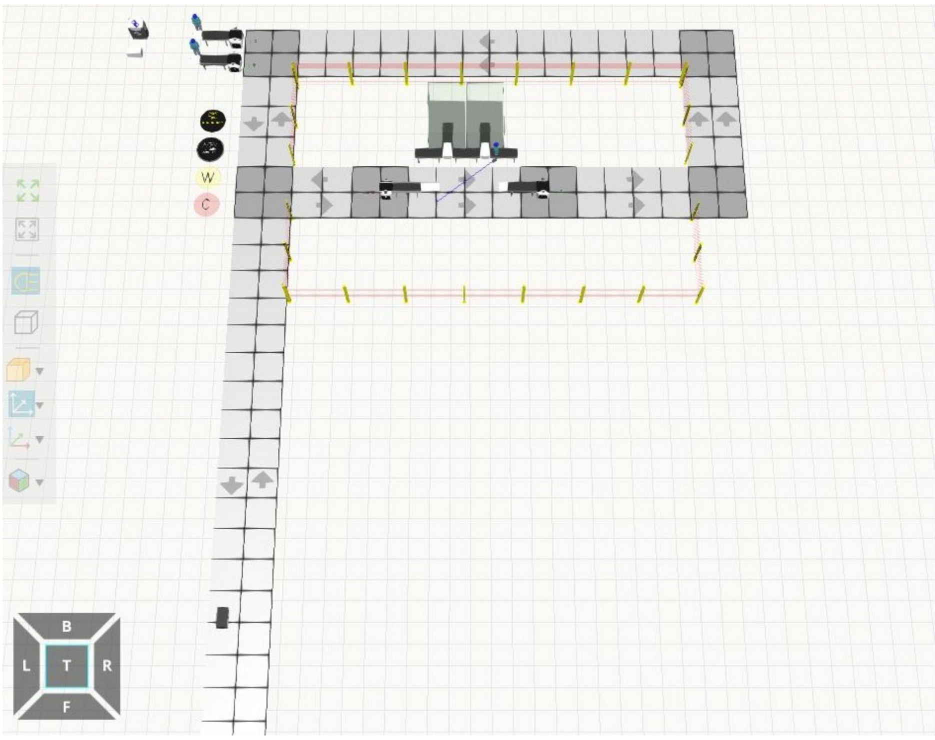


Figure 20. The human worker picks up the product from the conveyor and places it in the tester in the R6&R8 testing area.

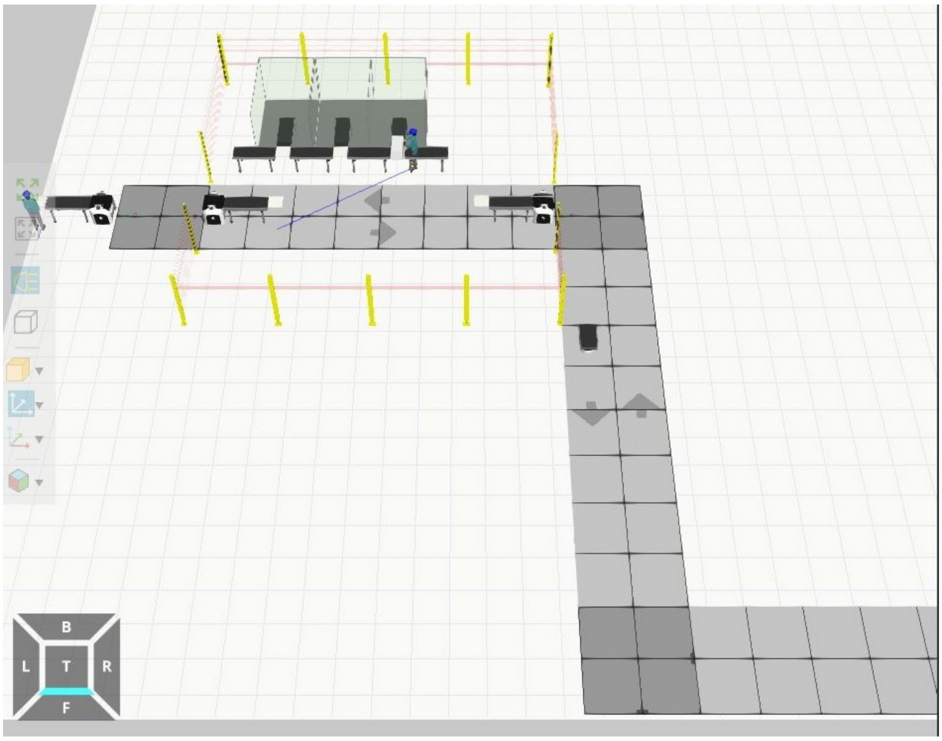


Figure 21. The human worker picks up the product from the conveyor and places it in the tester in the R11 testing area.

Once the Delay is completed the Human completes the next Pick and Place tasks to deliver the product for the next AGV Pick Location. The AGV picks up the product once it receives a signal from the AGV Pick Location in the testing area. Finally, the AGV drops off the product in the final AGV Drop Location in the packing area.

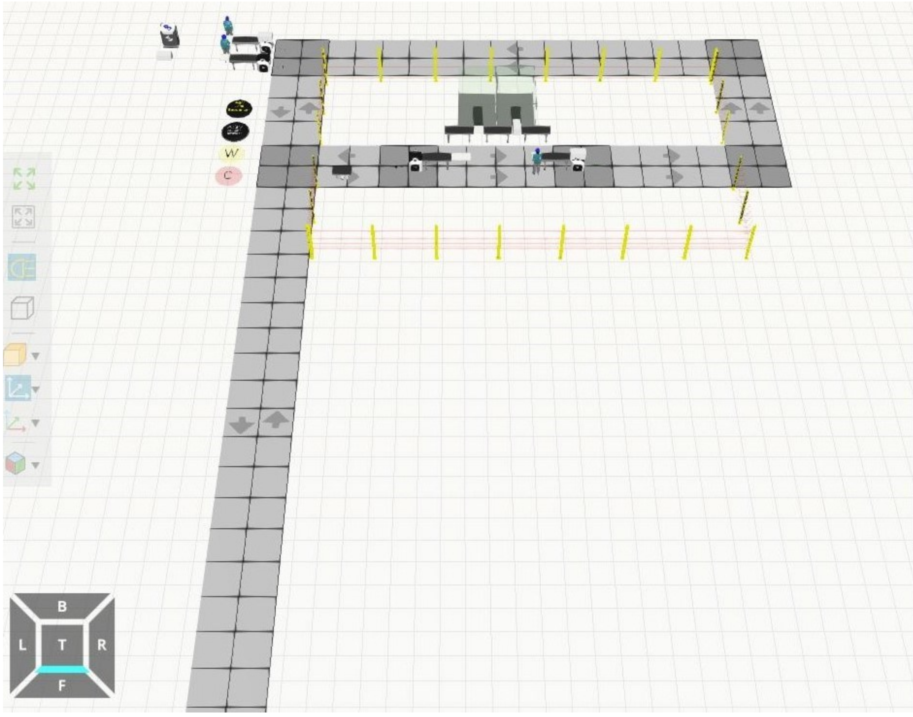


Figure 22. The human picks up the product after its testing and places it on the conveyor attached to the AGV Pick Location in the R6&R8 testing area.

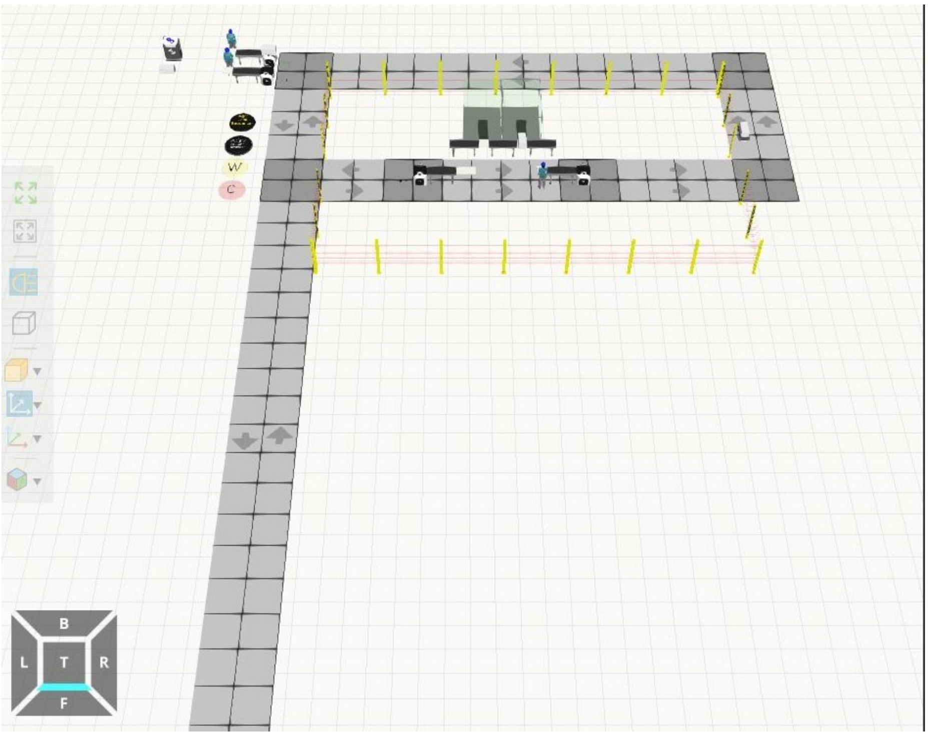


Figure 23. The mobile robot is delivering a product to the packing area.

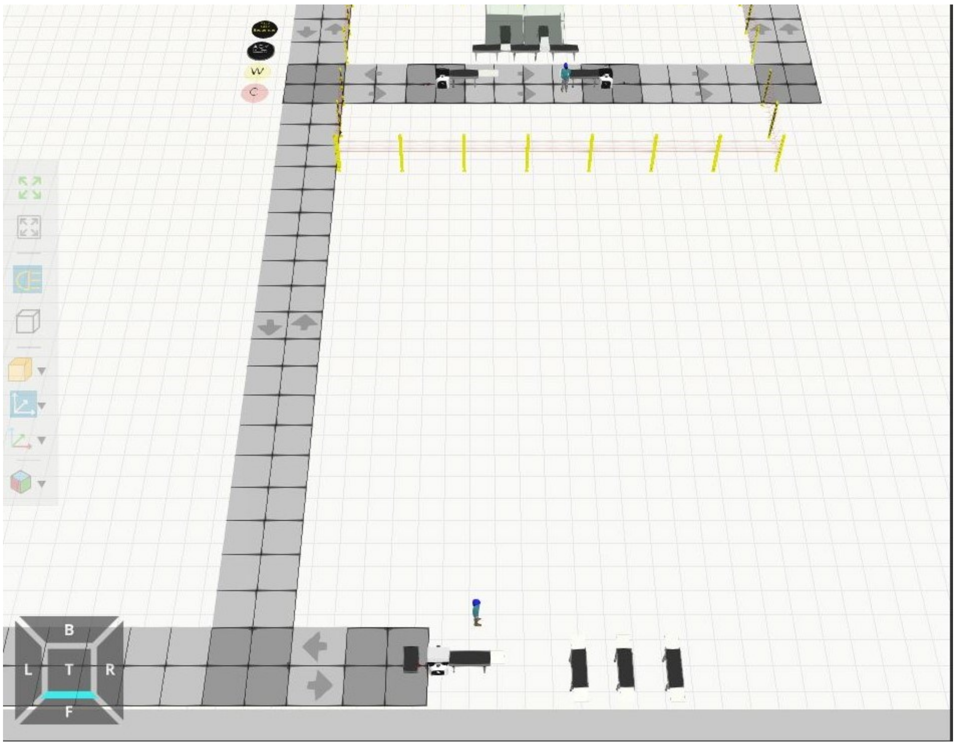


Figure 24. The mobile robot is dropping off a product to the AGV Drop Location in the packing area.

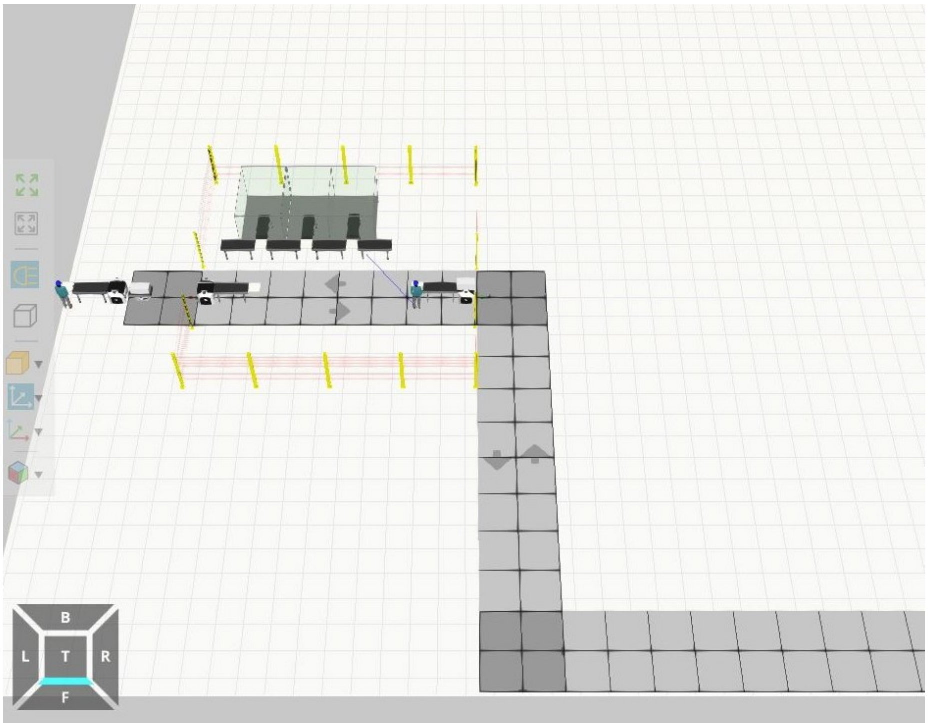


Figure 25. The human picks up the product after its testing and places it on the conveyor attached to the AGV Pick Location in the R11 testing area.

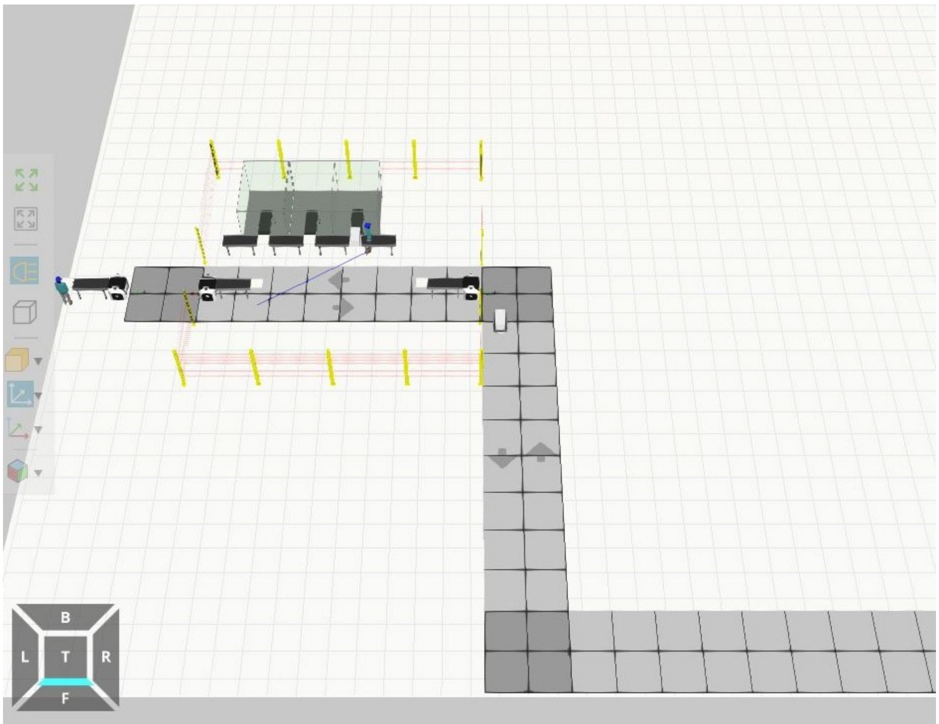


Figure 26. The mobile robot is picking up a product from the AGV Pick Location in the R11 testing area.

7.4 Analytical methods

Queuing theory is the most suitable analytical method to use for this research as it can be applied with the task and process times from the simulation software. In this case there is only one server which is the autonomous mobile robot. The arrival process is the amount of time that it takes to assemble the product from the staff. The service process is the amount of time that it takes for the mobile robot to complete its task. Number of customers here are the workers who are waiting for the robot to pick-up the product.

Before the implementation of the autonomous mobile robot its service process time must be known. The robot would be ideal to function in a way that the average customer in queue and average time waiting in line is zero. This means that the service rate per hour must at least match the arrival rate per hour. The autonomous mobile robot is wise not to run at a full capacity so it would be better that the service rate per hour would be faster than the arrival rate per hour.

Task times present the times that it takes for the AGV to complete a task. Tasks include loading and unloading a product and transporting a product from an origin to a destination.

Process times present the times that it takes for the AGV to complete a process. Processes include transporting the product from assembly to testing or from testing to packing. Processes consists of different tasks. Process times are calculated from the total time of the tasks included in the process. However, process times can vary since all tasks are not always included in the process. For example, the mobile robot can pick up a signal to pick up a product from R11 testing while it is still completing its previous task in packing. In that situation the robot can directly travel to R11 testing from packing. Process time is then much shorter since it does not need to return to its waiting point between processes.

Table 6. Process times for AGV.

Process	**Times**	
	R6&R8	**R11**
Assembly - Testing	**30,43 %**	**51,40 %**
Waiting point - Production line	*6,52 %*	*22,43 %*
AGV Loading time	*6,52 %*	*2,80 %*
Production line - Testing	*6,52 %*	*0,93 %*
AGV Unloading time	*6,52 %*	*2,80 %*
Testing - Waiting point	*4,35 %*	*22,43 %*
Testing - Packing	**69,57 %**	**48,60 %**
Waiting point - Testing	*8,70 %*	*19,63 %*
AGV Loading time	*6,52 %*	*2,80 %*
Testing - Packing	*30,43 %*	*15,89 %*
AGV Unloading time	*6,52 %*	*2,80 %*
Packing - Waiting point	*17,39 %*	*7,48 %*
Total	**100,00 %**	**100,00 %**

Product arrival rates present how often a product is completed in assembly. Different products have different assembly times and number of phases. Therefore, arrival rates vary between different products. AGV service rate presents the times that it takes for the AGV to complete both processes required for a product including transportation from assembly to testing and from testing to packing. AGV utility rate is calculated by dividing the service rate by the arrival rate. Different products have different utility rates and calculating the total utility rate of all products presents the total AGV utility rate. However, the total AGV utility rate can vary because, as said earlier, the process times can be shorter in certain situation. It means that the total AGV utility rate is probably also lower.

$$AGV\ Utility\ rate = \frac{AGV\ Service\ rate}{Product\ arrival\ rate}$$

Table 7. AGV Service and Utility rates.

Product	Arrival rate	AGV Service rate	AGV Utility rate
R11	100,00 %	34,13 %	34,13 %
R6	100,00 %	12,78 %	12,78 %
R8	100,00 %	19,17 %	19,17 %
All			**66,08 %**

Heuristics can also be used in this research to replicate the successful implementation of AGVs from other companies. The author of this research participated a mobile robot seminar in the fall 2019 where companies such as KONE presented their experience of implementing AGVs with some financial numbers also. Some of the practices learned from that presentation is also used in this case study, with changes made to suit the specific production of the case company, as it is believed that it will bring similar success.

Analytical methods that require software such as Markov Chain Monte Carlo simulation or integer programming is not used in this research as the focus is in the simulation software.

7.5 Cost calculations

Three costs calculation methods are used in this research to build a coherent entirety of the financial profitability of the investment. These methods are Net Present Value (NPV), Return on Investment (ROI), and Payback time method. Internal Rate of Return is not calculated since the ROI is already a simplified model of that.

The Net Present Value (NPV) can be calculated from the costs and profits with an imputed rate of interest. The costs include the cost of acquisition and the annual costs that appear from service and maintenance costs.

$$Costs = Cost\ of\ acquisition + annual\ costs$$

Profits come from the cost savings that the investment generates, more specifically from the number of products, hours saved per product and the hourly rate per worker. Hours saved per product presents the time that is saved with the automated solution compared to the manual solution.

$$Profits = Products \times Hourly\ rate \times Hours\ saved\ per\ product$$

Discounted profits can be calculated from profits and an imputed rate of interest.

$$Discounted\ profits\ = \frac{Profits}{(1 + imputed\ rate\ of\ interest)}$$

Net Present Value (NPV) can then be calculated with discounted profits and overall costs.

$$Net\ Present\ Value = Discounted\ profits - Cost\ of\ acquisition - Annual\ costs$$

Table 8. Net Present Value (NPV) of the investment.

Cost of acquisition				100,00 %
Annual costs				2,00 %
Imputed rate of interest				8,00 %
Hourly rate				0,066 %
Hours saved/product (seconds)				0,033
Year	**Products**	**Profits**	**Disc. profits**	**NPV**
0	0,00 %	-100,00 %	-100,00 %	-100,00 %
1	100,00 %	41,69 %	38,61 %	-63,39 %
2	109,57 %	45,68 %	39,17 %	-26,23 %
3	117,86 %	49,14 %	39,01 %	10,78 %
4	117,86 %	49,14 %	36,12 %	44,90 %
5	117,86 %	49,14 %	33,44 %	76,34 %

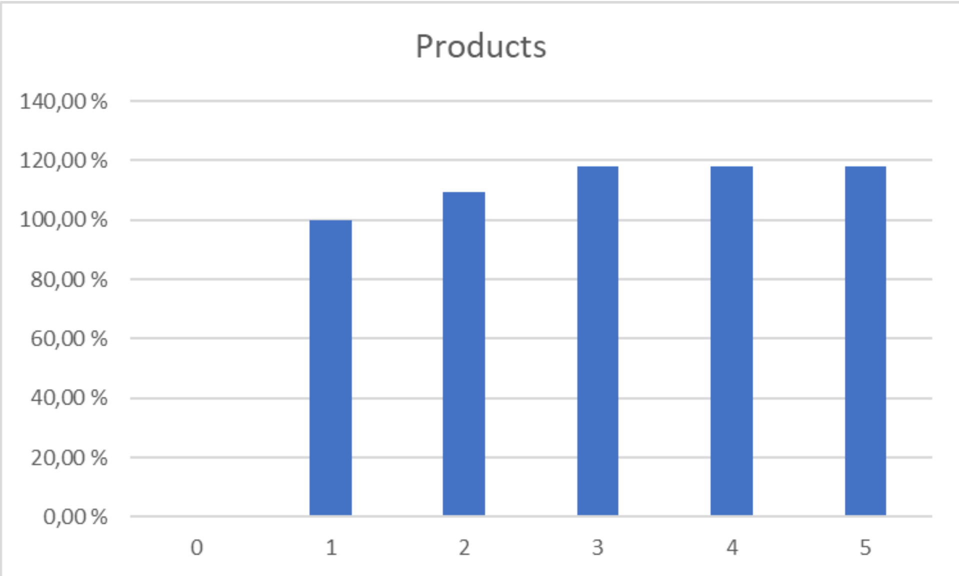


Figure 27. Forecast of manufactured products for every year.

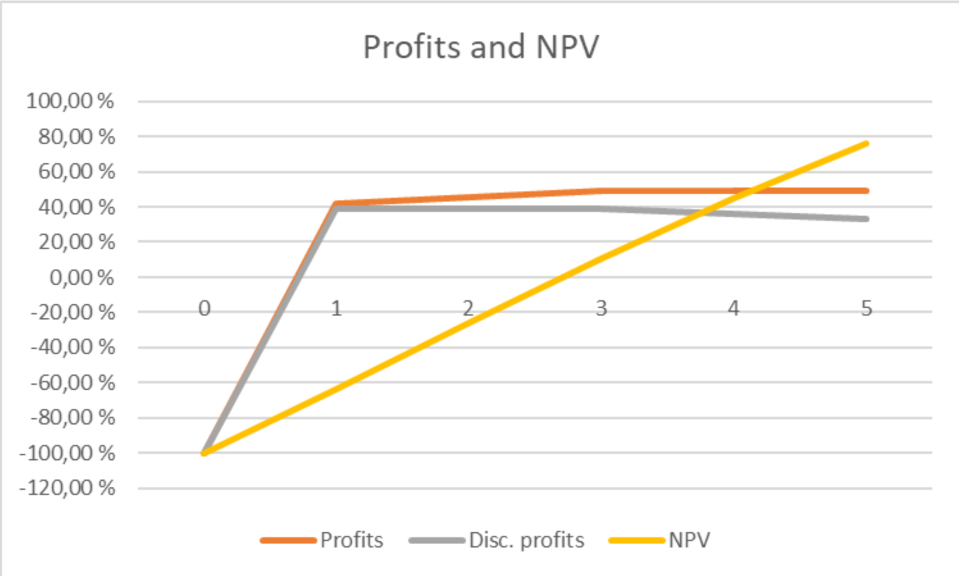


Figure 28. Profits from every year add value to NPV cumulatively.

As it can be seen in figure 25, the forecast of manufactured products is rising during years 1,2 and 3. It then stays the same during years 3,4 and 5. It is only natural that profits also grow at the same rate. However, discounted profits decline during years 3,4 and 5. It is because money loses its value as years go by. Money today is not worth the same that it will be in year 3 and the money in year 3 is not worth the same that it will be in year 5.

Discounted payback time can be calculated from the NPV. The number of full years can be calculated by adding every year when the NPV is negative.

$$Full\ years = sum\ of\ years\ with\ negative\ value$$

The final year can be calculated from the year when the NPV turns positive. The NPV from that year must be divided by the profit from that same year after eliminating the annual costs. That number eliminated from 1 is the final year.

$$Final\ year = \frac{1 - (NPV\ from\ first\ positive\ value)}{(Discounted\ profits\ from\ first\ positive\ value - Annual\ costs)}$$

Table 9. Payback time in years.

Full years	2
Final year	0,71
Payback time years	**2,71**

Discounted ROI can be calculated by dividing the net present value (NPV) from the cost of acquisition.

$$Discounted\ ROI = \frac{NPV\ from\ final\ year}{Cost\ of\ acquisition}$$

Table 10. Return on Investment (ROI).

Cost of acquisition	100 %
NPV	76,34 %
ROI	76,34 %

7.6 Risk and uncertainty

To consider the risks and uncertainty of new investments and equipment and their behavior and final costs, additional calculations and scenarios are important to be considered if some of the numbers are about to be different or change in the end. Let us, for example believe that the AGV has many technical problems that need fixing and so the annual costs are larger than first thought. Let us believe that the annual costs are double than was estimated.

Table 11. The NPV of the investment with doubled annual costs.

Cost of acquisition				100,00 %
Annual costs				4,00 %
Imputed rate of interest				8,00 %
Hourly rate				0,066 %
Hours saved/product (seconds)				0,033
Year	**Products**	**Profits**	**Disc. profits**	**NPV**
0	0,00 %	-100,00 %	-100,00 %	-100,00 %
1	100,00 %	41,69 %	38,61 %	-65,39 %
2	109,57 %	45,68 %	39,17 %	-30,23 %
3	117,86 %	49,14 %	39,01 %	4,78 %
4	117,86 %	49,14 %	36,12 %	36,90 %
5	117,86 %	49,14 %	33,44 %	66,34 %

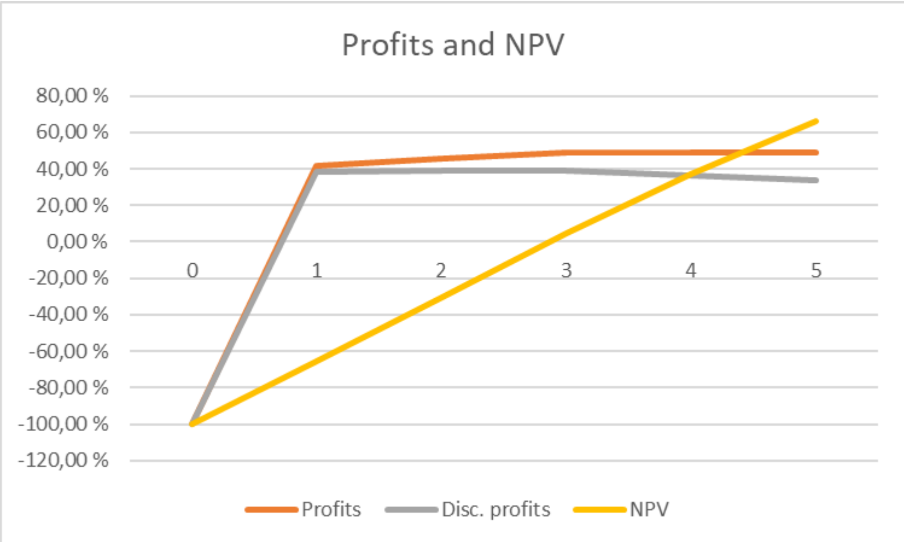


Figure 29. The profits and NPV with doubled annual costs.

Now as can be seen in Table 11 and Figure 29, the NPV, and the ROI, is now only 66,34%, therefore 10% lower than what was estimated. Because the NPV is lower, the payback period of the investment is also longer.

Table 12. Payback time of the investment with doubled annual costs.

Full years	2
Final year	0,86
Payback time years	**2,86**

Another important issue which can change if the AGV is not functioning correctly is the hours saved per product. Let us believe that the hours saved is only half of what it is estimated.

Table 13. The NPV of the investment with decreased hours saved per product.

Cost of acquisition				100,00 %
Annual costs				2,00 %
Imputed rate of interest				8,00 %
Hourly rate				0,066 %
Hours saved/product (seconds)				0,0167
Year	**Products**	**Profits**	**Disc. profits**	**NPV**
0	0,00 %	-100,00 %	-100,00 %	-100,00 %
1	100,00 %	21,10 %	19,54 %	-82,46 %
2	109,57 %	23,12 %	19,82 %	-64,64 %
3	117,86 %	24,87 %	19,74 %	-46,90 %
4	117,86 %	24,87 %	18,28 %	-30,63 %
5	117,86 %	24,87 %	16,92 %	-15,70 %

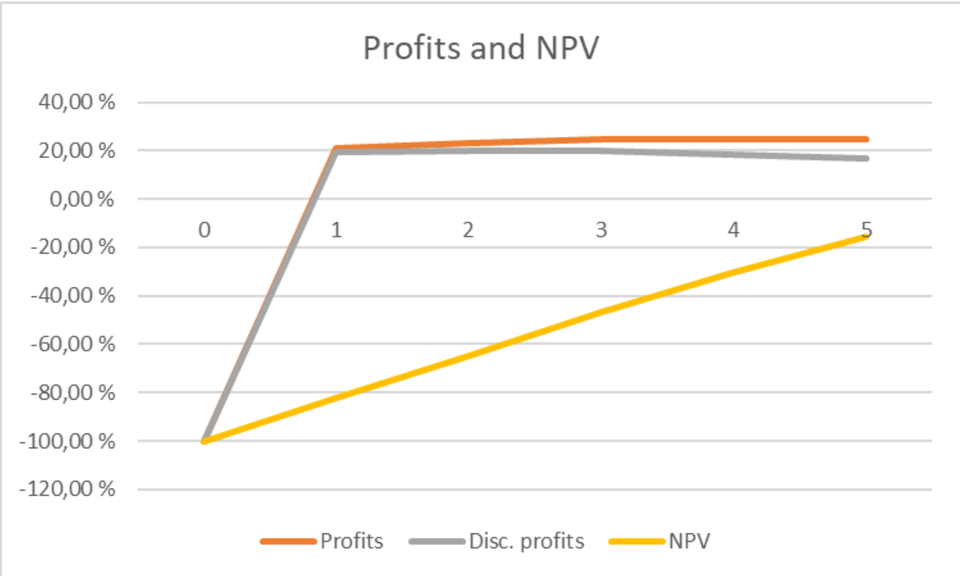


Figure 30. Profits and NPV from every year with decreased hours saved per product.

As we can see, the NPV is now negative and therefore the investment would not be financially profitable at all for the company. The ROI would also be negative and the investment would not be able to reach the break-even point of its payback period.

That is why it is extremely important to design the implementation phase carefully and thoroughly and so that it can provide the hours saved per product numbers that it is estimated to do.

7.7 Future considerations

Material movement would be the next area where ABB Drives Production unit in Pitäjänmäki could implement AGVs. Automating the transport of EUR pallets from docking station to production lines with automated forklifts would save valuable time from DHL staff. They could focus on serving production lines in more complicated work.

Single deep racks in production lines can be high and aisles can be narrow in some areas. Therefore, the automated forklift should have a lifting height of at least few meters but also be agile enough to operate in tight spaces. It should also be able to operate with automatic doors and traffic around it. Radio frequency identification (RFID) is required for all materials brought in the facility from docking station.

One potential option would be Rocla's Automated Reach Truck. Rocla is a Finnish company that provides intelligent material handling solutions and services such as automated guided vehicles. Rocla ART Automated Reach Truck is a reach mast AGV that is designated to operate in an aisle width of 3 meters. It has better load handling speed than traditional AGV trucks because of a new and innovative software and sensor technology. It has three scanners that secure a safe operation alongside a dynamic stability control system that monitors its speed, load weight and height, and reach position. A pressure compensation system provides efficient lifting operation and collision avoidance ensure its safety. It also has an agile turning radius and can lift pallets and other materials up to 10 meters. Its load capacity is 1600 kg and maximum driving speed 2 m/s. (Rocla 2020).

There are two models available for the Rocla ART, the ART-N16 and the ART-M16. The M16 is a bit wider and larger overall and can lift pallets to 10 meters compared to the 7,5 meters of the N16. The N16 is more agile because of its smaller size. (Rocla 2020).

Table 14. Rocla ART Automated Reach Truck technical information (Rocla 2020).

Family	N16	M16
Technical filter:		
Max. Payload	1600 kg	1600 kg
Max. Lifting height	7500 mm	10000 mm
Speed		
Driving	2 m/s	2 m/s
Lifting/lowering (unloaded)	0,7 m/s	0,5 m/s
Lifting/lowering (loaded)	0,4 m/s	0,55 m/s
Dimensions		
Width	1250 mm	1420 mm
Height	2592 - 3282 mm	2592 - 4170 mm

Figure 31. Rocla ART Automated Reach Truck (Rocla 2020).

The Rocla ART is an efficient vehicle for large warehouses but also work-in-process storages. Its lifting height provides possibilities to reach even the highest shelves of most pallet racks. However, the vehicle is quite large and requires aisles of at least 3 meters which can be difficult in many factories that have limited space for work-in-process storages. It might require a layout restructure for some aisles if ABB were to implement the vehicle in their facility.

One major reason material movement is only included in the future considerations is the expense of automated forklifts. With Robotics as a Service (RaaS), ABB could seek to lower the high initial investment costs and use a subscription fee rather than fully obtaining the robot for themselves.

8. Conclusion

Automation can solve several problems that companies are facing today. With proper implementation and training, automation improves productivity and safety with less costs. High initial costs are justified with better efficiency and accuracy than human labor which leads to less errors and better throughput. Automation enables human labor to focus on high value-added work.

Automation is especially efficient in material handling. Automated Guided Vehicles, or Autonomous Mobile Robots, are an efficient way to organize material handling and in-door logistics. Improvements especially in navigation technology has generated a rapid increase in their use. They can also offer companies a good return on investment with proper payback time. Robots as a Service can even further increase their financial profitability in the future.

The idea of this research was to create a model to implement Automated Guided Vehicles for ABB Oy Drives Production. The current state of the production was being evaluated and the solution was made that the AGV would be smart to implement in the transport of work-in-process products between production, testing, and packing. AGVs automatize simple and repetitive tasks in production and enable human labor to focus on high value-added work. They improve productivity and safety of the processes by eliminating unnecessary work. AGV is a financially profitable investment with an excellent return on investment and payback time.

8.1 Results

The main benefits from the AGVs in the elimination of unnecessary work. The time that was used to manually transport the products can now be used in assembly. It directly leads to increasing number of products.

$$\textit{New number of products} = \frac{\textit{Current number of products} + \textit{Current number of products} \times (\textit{Hours saved per product})}{\textit{Product arrival rate}}$$

Table 15. Number of products per month

Product	Manual	Automated
R6	100,00 %	109,95 %
R8	100,00 %	106,77 %
R11	100,00 %	107,81 %
R10_11	100,00 %	100,00 %

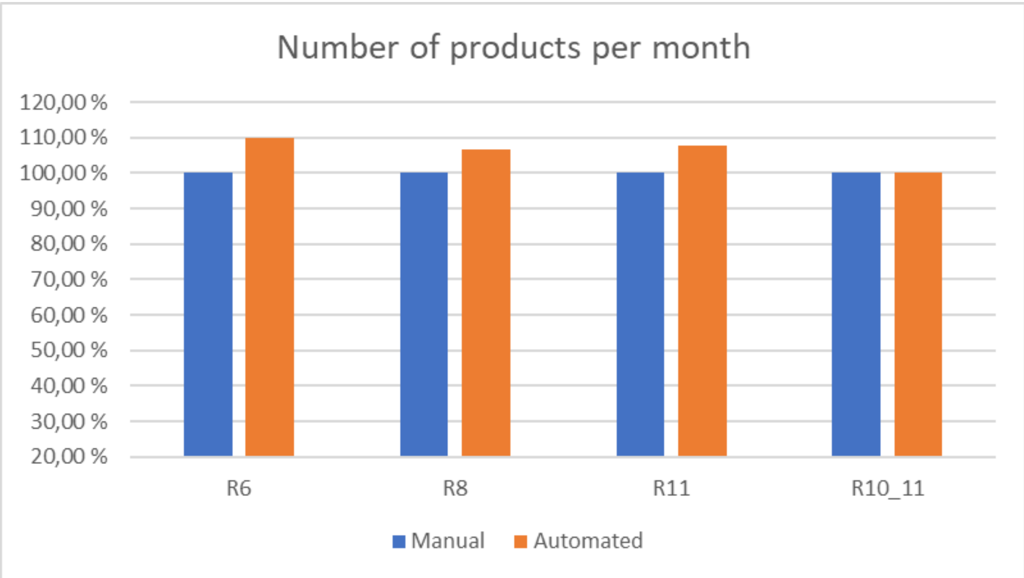


Figure 32. Number of products per month manually versus automatically.

The AGV is a reasonable investment after evaluating its productivity and financial effects. AGV is financially profitable with excellent Net Present Value (NPV), Return on Investment (ROI) and Payback time numbers.

Table 16. AGV financial numbers

Net Present Value	76,34 %
Return on Investment	76,34 %
Payback Time	2,71

It also adds safety, flexibility and predictability to the processes. Challenges with the current routes is the utility rate. The production lines are far away from each other so it could be wise to use different AGVs for each line. However, the utility rate would be too low for it to be efficient. One option would be to use different AGVs for different production lines so that their utility rates are increased with additional tasks in material handling.

References

ABB (2020). *ABB Suomessa.* ABB lyhyesti. [Online]. [Cited 22.1.2020]. Available: https://new.abb.com/fi/abb-lyhyesti/suomessa.

ABB (2020). *Energy efficiency: Using drives to control motors can lead to big savings.* Drives. [Online]. [Cited 22.1.2020]. Available: https://new.abb.com/drives/energy-efficiency.

ABB (2020). *Group reports.* Media. [Online]. [Cited 22.1.2020]. Available: https://new.abb.com/media/group-reports.

ABB (2020). *Our businesses.* About us. [Online]. [Cited 22.1.2020]. Available: https://new.abb.com/about/our-businesses.

Andersen, R. E., E. B. Hansen, D. Cerny, S. Madsen, B. Pulendralingam, S. Bogh & D. Chryostomou (2017). *Integration of a skill-based collaborative mobile robot in a smart cyber-physical environment.* Department of Mechanical and Manufacturing Engineering. Aalborg University. [Online]. [Cited 14.1.2020]. Available: https://www.sciencedirect.com/science/article/pii/S2351978917304171.

ARC Advisory Group (2019). *Autonomous Mobile Robots.* Market Studies. [Online]. [Cited 16.1.2020]. Available: https://www.arcweb.com/market-studies/autonomous-mobile-robots.

Banker, S. (2019). *The Autonomous Mobile Robot market is taking off like a rocket ship.* Forbes. [Online] [Cited 16.1.2020]. Available:

https://www.forbes.com/sites/stevebanker/2019/03/11/the-autonomous-mobile-robot-market-is-taking-off-like-a-rocket-ship/#560360bf1603.

Benevides, C. (2019). *The Advantages and Disadvantages of Automated Guided Vehicles.* Conveyco. [Online]. [Cited 27.11.2019]. Available: https://www.conveyco.com/advantages-disadvantages-automated-guided-vehicles-agvs/.

Borowik (2020). *What are the functions of RFID?* Articles. TechWalla. [Online]. [Cited 4.2.2020]. Available: https://www.techwalla.com/articles/what-are-the-functions-of-rfid.

Crossco (2019). *The difference between AGVs and Mobile Robots.* Resources. [Online]. [Cited 8.12.2019]. Available: https://www.crossco.com/resources/articles/the-difference-between-agvs-and-mobile-robots/.

Chen, J. (2019). *Heuristics.* Investing essentials. Investopedia. [Online]. [Cited 27.5.2020]. Available: https://www.investopedia.com/terms/h/heuristics.asp.

Chen, J. (2020). *Return on Investment (ROI).* Financial Ratios. Investopedia. [Online]. [Cited 26.5.2020]. Available: https://www.investopedia.com/terms/r/returnoninvestment.asp.

Frohm, J., V. Lindström, M. Winroth & J. Stahre (2016). *The industry's view on automation in manufacturing.* Chalmers University of Technology & Jönköping University. Gothenburg & Jönköping. [Online]. [Cited 9.1.2020]. Available: https://www.sciencedirect.com/science/article/pii/S1474667015330925.

Gupta, A. K. & S. K. Arora (2013). *Industrial Automation and Robotics.* Laxmi Publication Pvt. New Delhi. [Online] [Cited 12.1.2020]. Available:

https://books.google.fi/books?hl=en&lr=&id=Y7rgCP7iC18C&oi=fnd&pg=PA1&dq=automation+and+robotics+&ots=e4KX2Ah1h7&sig=SPYIJ4kUuA1oo5rgQTTKSxs4mTw&redir_esc=y#v=onepage&q=automation%20and%20robotics&f=false.

Hayes, A. (2020). *Internal Rate of Return – IRR.* Financial Ratios. Investopedia. [Online]. [Cited 26.5.2020]. Available: https://www.investopedia.com/terms/i/irr.asp.

HHI (2019). *Manual vs. automated material handling: knowing the difference.* News. Home. [Online]. [Cited 15.4.2020]. Available: https://www.hhilifting.com/manual-vs-automated-material-handling/.

Kagan, J. (2020). *Payback period.* Corporate Finance. Investopedia. [Online]. [Cited 26.5.2020]. Available: https://www.investopedia.com/terms/p/paybackperiod.asp.

Kay, M. (2012). *Material Handling Equipment.* North Carolina State University. North Carolina. [Online]. [Cited 26.1.2020]. Available: https://s3.amazonaws.com/academia.edu.documents/56980917/Material_Handling_Equipment.pdf?response-content-disposition=inline%3B%20filename%3DMaterial_Handling_Equipment.pdf.pdf&X-Amz-Algorithm=AWS4-HMAC-SHA256&X-Amz-Credential=AKIAIWOWYYGZ2Y53UL3A%2F20200126%2Fus-east-1%2Fs3%2Faws4_request&X-Amz-Date=20200126T152426Z&X-Amz-Expires=3600&X-Amz-SignedHeaders=host&X-Amz-Signature=0ea0c8ca5fde24a01aabe5ddf67356834d8f54b1aae16c85330f0921cde56147.

Kenton, W. (2019). *Markov Analysis*. Tools for Fundamental Analysis. Investopedia. [Online]. [Cited 27.5.2020]. Available: https://www.investopedia.com/terms/m/markov-analysis.asp.

Kenton, W. (2019). *Monte Carlo Simulation Definition.* Financial Analysis. Investopedia. [Online]. [Cited 27.5.2020]. Available: https://www.investopedia.com/terms/m/montecarlosimulation.asp.

Kenton, W. (2019). *Queuing theory.* Marketing Essentials. Investopedia. [Online]. [Cited 26.2.2020]. Available: https://www.investopedia.com/terms/q/queuing-theory.asp.

Kenton, W. (2019). *Zero-One Integer Programming Definition*. Business Essentials. Investopedia. [Online]. [Cited 27.5.2020]. Available: https://www.investopedia.com/terms/z/zero-one-integer-programming.asp.

Kenton, W. (2020). *Net Present Value (NPV)*. Financial Ratios. Investopedia. [Online]. [Cited 26.5.2020]. Available: https://www.investopedia.com/terms/n/npv.asp.

Kolberg, D. & D. Zuhlke (2015). *Lean Automation enabled by Industry 4.0 technologies.* Department of Innovative Factory Systems & German Research Center for Artificial Intelligence. Kaiserslautern. [Online]. [Cited 12.1.2020]. Available: https://www.sciencedirect.com/science/article/pii/S2405896315005984.

Lydon, B. (2019). *Automated guided vehicles improve production.* InTech. [Online]. [Cited 27.11.2019]. Available: https://www.isa.org/intech-plus/2018/dec/automated-guided-vehicles-improve-production/.

Marr, B. (2019). *Robots as a Service: A technology every business must consider.* Innovation. Forbes. [Online]. [Cited 5.4.2020]. Available:

https://www.forbes.com/sites/bernardmarr/2019/08/05/robots-as-a-service-a-technology-trend-every-business-must-consider/#7af7f59324ea.

MHI (2019). *Automated Guided Vehicles.* MHI Fundamentals. [Online]. [Cited 27.11.2019]. Available: http://www.mhi.org/fundamentals/automatic-guided-vehicles.

MHI (2019). *Material handling.* MHI Fundamental. [Online]. [Cited 20.1.2020]. Available: http://www.mhi.org/fundamentals/material-handling.

MiR (2019). *AGV vs AMR – What's the difference?* Resources. [Online]. [Cited 7.12.2019]. Available: https://www.mobile-industrial-robots.com/en/resources/whitepapers/agv-vs-amr-whats-the-difference/.

Mobile Robot Guide (2020). *Robotics as a Service is the future of automation.* News. [Online]. [Cited 4.4.2020]. Available: https://mobilerobotguide.com/robots-as-a-service/.

Mourtzis, D., M. Doukas & D. Bernidaki (2014). *Simulation in Manufacturing: Review and Challenges.* University of Patras. Rio Patras. [Online]. [Cited 16.1.2020]. Available: https://www.sciencedirect.com/science/article/pii/S2212827114010634.

Omron (2019). *Autonomous Mobile Robot.* Products. [Online]. [Cited 29.11.2019]. Available: https://industrial.omron.co.uk/en/products/autonomous-mobile-robot.

Rocla (2020). *About Us.* Home. [Online]. [Cited 28.2.2020]. Available: https://www.rocla-agv.com/en/about-us.

Rocla (2020). *ART brochure*. Sample files. Home. [Online]. [Cited 28.2.2020]. Available: https://www.rocla-agv.com/sites/default/files/sample-files/art_brochure_en_website.pdf.

Rocla (2020). *Reach Mast AGV.* Automated Guided Vehicles. Home. [Online]. [Cited 28.2.2020]. Available: https://www.rocla-agv.com/en/products/reach-mast-agv.

Rocla (2020). *Rocla AGV.* Sample files. Home. [Online]. [Cited 28.2.2020]. Available: https://www.rocla-agv.com/sites/default/files/sample-files/rocla-agv-2019.pdf.

Sezen, B. (2003). *Modeling Automated Guided Vehicle Systems in Material handling.* Dogus University Journal, Vol 4, No 2. Turkey. [Online]. [Cited 26.2.2020]. Available: http://journal.dogus.edu.tr/index.php/duj/issue/view/16.

Stephens M. P. & F. E. Meyers (2013). *Manufacturing Facilities Design and Material Handling.* Purdue University Press. Indiana. [Online]. [Cited 17.1.2020]. Available: https://books.google.fi/books?hl=en&lr=&id=khiyTWMHEv4C&oi=fnd&pg=PR1&dq=material+handling+in+manufacturing&ots=2r24e0pSCx&sig=_8ShQk3SdVRai2IjYZn_EjststU&redir_esc=y#v=onepage&q=material%20handling%20in%20manufacturing&f=false.

Taanila, A. (2012). *Excelin rahoitusfunktioita.* Haaga-Helia. [Online]. [25.2.2020]. Available: http://myy.haaga-helia.fi/~taaak/f/rahoi.pdf.

Taglic, N. (2020). *What are automated guided vehicles?* 6 River Systems. [Online]. [Cited 24.2.2020]. Available: https://6river.com/what-are-automated-guided-vehicles/.

Twentyman, J. (2018). *Manufacturing: How Robotics as a Service extends to whole factories.* Analysis. Internet of Business. [Online]. [Cited 4.4.2020]. Available: https://internetofbusiness.com/how-robotics-as-a-service-is-extending-to-whole-factories-analysis/.

Visual Components (2019). *Our story.* About Us. Visual Components Oy. [Online]. [23.1.2020]. Available: https://www.visualcomponents.com/about-us/.

Yritystulkki (2020). *Investoinnin kannattavuus*. Aloittava yrittäjä. BusinessOulu. [Online]. [17.2.2020]. Available: https://www.yritystulkki.fi/fi/alue/oulu/aloittava-yrittaja/suunnittelu/taloussuunnitelmat/investoinninkannattavuus/.