Automated Guided Vehicles: Investment and Implementation

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Degree Thesis for Novia (Bachelor of Business Administration)

Degree Programme in International Business

Vasa, 2022

DEGREE THESIS

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Degree Programme: Business administration, Vasa
Specialization: International business
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Title: Automated Guided Vehicles: Investment and Implementation

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Date: 17.4.2022 Number of pages: 39

Abstract

This thesis was written for Wärtsilä Oyj, which has made an investment of over 200 million euros in a technology center called Smart Technology Hub (STH) in Vaskiluoto, Vaasa. Wärtsilä has said that STH is a place for state-of-the-art production, first-class research, development, and engineering. This investment includes a logistics center that will use the latest technology in logistic and automation solutions. This is where automated guided vehicles (AGVs) step in. The AGV market has seen a lot of growth in recent years and has become a valid and reliable option for more companies to invest in.

The purpose of this thesis was to research automated guided vehicles and the surrounding factors that must be considered for investment and implementation. The theoretical part has gathered different factors that are connected to AGVs, which were technological, financial, employee, and warehouse factors. The research has been done through interviews with employees from both Wärtsilä and DHL who are involved with the development of the new logistics center and smart technology hub at Vaskiluoto. The interview questions were based on the factors from the theoretical part.

The result showed lots of connections with the other studies that have been done. It also brought up interesting facts about AGVs strengths and weaknesses. AGVs have come a long way since they began with lots of new capabilities, technologies, and innovations. Despite these innovations, they are still in an early stage of becoming more frequent in warehouses.

Language: English Key Words: agv, factors, investment, implementation, growth

EXAMENSARBETE

Författare: Alexander Björk
Utbildning och ort: Företagsekonomi, Vasa
Inriktning: Internationell handel
Handledare: Linda Jönn

Titel: Automatiserade styrda fordon: Investering och implementering

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Datum: 17.4.2022 Sidantal: 39

Abstrakt

Detta examensarbete är skrivet för Wärtsilä Oyj, som har gjort en investering på över 200 miljoner euro i ett teknikcenter kallat Smart Technology Hub (STH) som är beläget vid Vasklot i Vasa. Wärtsilä har sagt att STH är en plats för toppmodern produktion, förstklassig forskning, utveckling och teknik. I denna investering ingår ett logistikcenter som kommer att använda den senaste tekniken inom logistik- och automationslösningar. Det är här automatiserade styrda fordon stiger in. AGV marknaden har haft en stor tillväxt under de senaste åren och har blivit ett giltigt och pålitligt alternativ för fler företag att investera i.

Syftet med examensarbetet var att undersöka automatiserade styrda fordon och de kringliggande faktorer som måste beaktas för investering och implementering. Den teoretiska delen har samlat olika faktorer som är kopplade till AGV: er, som var tekniska, finansiella, anställda och lagerfaktorer. Forskningen har gjorts genom intervjuer med medarbetare från både Wärtsilä och DHL som är involverade i utvecklingen av Smart Technology Hub (STH) och ett nytt närliggande logistikcenter vid Vasklot. Intervjufrågorna baserades på faktorerna från den teoretiska delen.

Resultatet visade många kopplingar till tidigare studier som har gjorts. Det kom också upp intressant fakta om AGV:s styrkor och svagheter. Dessa fordon har kommit långt sedan starten med massor av nya funktioner, tekniker och innovationer. Trots dessa innovationer är de fortfarande i ett tidigt skede av att bli vanligare i lager.

Språk: Engelska Nyckelord: agv, faktorer, investering, implementering, tillväxt

OPINNÄYTETYÖ

Tekijä: Alexander Björk
Koulutus ja paikkakunta: Liiketalous, Vaasa
Suuntautumisvaihtoehto: Kansainvälinen kauppa
Ohjaaja: Linda Jönn

Nimike: Automatisoidut ohjatut ajoneuvot: Investointi ja toteutus

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Päivämäärä: 17.4.2022 Sivumäärä: 39

Tiivistelmä

Tämä opinnäytetyö on kirjoitettu Wärtsilä Oyj:lle, joka on investoinut yli 200 miljoonaa euroa Smart Technology Hub (STH) -nimiseen teknologiakeskukseen Vaasan Vaskiluodossa. Wärtsilän mukaan STH on paikka huipputason tuotannolle, ensiluokkaiselle tutkimukselle, kehittämiselle ja tekniikalle. Investointi sisältää logistiikkakeskuksen, joka käyttää uusinta teknologiaa logistiikka- ja automaatioratkaisuissa. Tässä automaattiset ohjatut ajoneuvot (AGV) astuvat sisään. AGV-markkina on kasvanut paljon viime vuosina, ja siitä on tullut pätevä ja luotettava investointivaihtoehto useammalle yritykselle.

Opinnäytetyön tarkoituksena oli tutkia automatisoituja ohjattuja ajoneuvoja ja niitä ympäröiviä tekijöitä, jotka on otettava huomioon investoinneissa ja toteutuksessa. Teoreettinen osa on kerännyt yhteen tärkeimmät tekijät, jotka liittyvät AGV:hin. Nämä ovat teknisiä, taloudellisia, varasto ja työntekijöihin liittyviä tekijöitä. Tutkimus on tehty haastattelemalla sekä Wärtsilän että DHL:n työntekijöitä, jotka ovat mukana kehityksessä Vaskiluodon uudessa logistiikkakeskuksessa ja älyteknologian keskuksessa. Haastattelukysymykset perustuivat teoreettisen osan tekijöihin.

Tulos osoittaa paljon yhteyksiä muihin tehtyihin tutkimuksiin. Se tuo esiin myös mielenkiintoisia faktoja AGV:n vahvuuksista ja heikkouksista. AGV:t ovat edistyneet pitkälle verrattuna niiden alkuun, ja niissä on paljon uusia ominaisuuksia, tekniikoita ja innovaatioita. Näistä innovaatioista huolimatta AGV:n yleistyminen on vielä varhaisessa vaiheessa.

Kieli: Englanti Avainsanat: agv, tekijät, investointi, toteutus, kasvu

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1 Introduction

This thesis is made for Wärtsilä Oyj. Some background to this is that Wärtsilä is currently in the middle of building its new Smart Technology Hub (STH) at Vaskiliuoto, Vaasa. The Smart Technology Hub will include an office, factory, and logistic center. Wärtsilä states the STH is a place of state-of-the-art production, top-notch research, development, and engineering. Wärtsilä has decided to start using automated guided vehicles for their operations at the factory and logistics center.

1.1 Objective

The objective of this thesis is to research AGVs, and the surrounding factors needed to be considered before investment and implementation. Research is done on the factors that are connected to AGVs and what they will have an impact on. AGVs are a complex subject, which is why this thesis does not do a deep dive, but rather gives a broad overlook of lots of factors. Therefore, it includes many different factors such as technological, financial, employee, and warehouse factors.

The thesis aims to support the investment and implementation process for Wärtsilä. This thesis could also work as a sort of guide for future AGV investments from other departments at Wärtsilä worldwide. This thesis also benefits other companies with an interest in AGVs.

1.2 Background to AGVs

Thanks to the internet, countries and their people are more interconnected with each other than ever before. This interconnectivity has affected the international marketplace in a way that any person is able to buy products from around the world with little to no restrictions. This and many additional reasons have led to the need for larger supply, demand, and increased productivity.

In the Automated Guided Vehicles (AGVs) history they have made tremendous technological advancements when compared to their start. Now in recent years, they have become a valid and reliable option for more companies to invest in. The AGV market has seen a lot of growth and studies suggest it is only going to grow more. The global AGV market is valued at $5,2 billion and is projected to reach $13,5 billion by 2027. (Sonipimple, Mutreja, 2020)

Companies have become a lot more interested in AGVs, especially companies looking to expand current facilities or build new ones. AGVs are the logical next step when wanting to increase productivity. They have become safer to implement, more accurate, and increased in flexibility.

1.3 Problem formulation and Delimitations

This research aims to answer the following research questions. The questions I have formulated are:

What factors to consider when wanting to invest in AGV?

What are the advantages and disadvantages of investing in AGV?

The research is done through Wärtsilä with data collection being done by interviews. These interviews are with employees associated with the logistics and smart technology hub team. The research will mostly be connected to AGVs in industrial use and warehouse operations.

2 Wärtsilä Oyj

Wärtsilä is a Finnish company that originates from the sawmill industry back in 1834. They began as a sawmill, but thanks to industrialism they replaced the sawmill with an iron factory. Almost 200 years later Wärtsilä has developed and become a leading power source provider in the energy and marine market. They build and develop engines powered by fuels like heavy fuel oil and natural gas but also renewable fuels such as biogas and biofuel. In 2020 they have planned to supply Finnlines with hybrid engines as well.

These engines are applied for the energy- and marine sector, which ranges from cruise ships to powerplants. In recent years Wärtsilä has emphasized lots on sustainability, efficiency, and data analytics, wanting to maximize the economic and environmental performances of its customers

In 2021 Wärtsilä operates in over 70 countries and 200 locations. They have around 18000 employees with the majority of them being in Europe, Asia, and the Americas. Wärtsilä has a big presence in Finland with around 3500 employees. They operate in three cities, which are Helsinki, Turku, and Vaasa. Helsinki is the location of their head office. Turku is the location of offices and a training center. Vaasa, which employs the most consists of offices and engine manufacturing.

In 2018 Wärtsilä announced that the Smart Technology Hub is going to be built. The location is Vaskiluoto located in Vaasa, which is close to the sea and ports. This means that all operations at the location in Onkilahti, Vaasa are going to be moved there. The new technology center is going to be consisting of research, development, and production. In addition to the center, there is going to be built a logistics center adjacent, which will be connected to the smart technology building.

The technology and infrastructure used in the new logistics center are going to be built and developed in collaboration with DHL Supply Chain. They are going to make use of the newest logistical and

automation technologies available. This will strengthen the long-term partnership that Wärtsilä has together with DHL Supply Chain.

Figure 1: Wärtsilä logo

3 What is AGV?

This chapter is going to give an overview of automated guided vehicles and the factors surrounding them. This chapter gives insight into what AGV is, the different models that are available, and the properties of the vehicles. You also get an overview of the surrounding factors of AGVs, which are sustainability and the Internet of things. These can be sorted as motivators to acquire AGVs.

3.1 Description of AGV

AGVs or automated guided vehicles are autonomously working wheel-based load carriers that are used for transportation in factories and warehouses. The main purpose of AGV is to move parts and products from one place to another. AGV does not require anybody onboard to steer it like traditional forklifts. They are instead connected wirelessly and controlled by a computer. (Logisnext, u.å.)

Automated guided vehicles have improved massively since their introduction in the 1950s. Thanks to today's evolved technology AGVs have become safer, more productive, more cost-efficient, easier to implement, and more sustainable. This technological evolution has affected the gain in the usage of AGVs by companies today. According to Grand View Research (2021), The AGV market size is growing and will continue to grow at a rate of 13.0% annually from 2021 until 2028. This shows us the actual size of the AGV market and that it will only continue to grow in the next decade.

(Industrial Quick Search, u.å.)

At the beginning of AGVs history, they traveled by having a sensor underneath and installing wires in the floor. The sensor connected with the wire using radio frequencies. Today AGVs are surrounded by different sorts of sensors and scanners, which ensures that their tasks are done precisely, carefully, and safely. (Logisnext, u.å.)

3.2 Different Models

There are several different AGV models available on the market. The most common AGV type is the Unit Loader (1), which transports objects on top of itself. This is usually in smaller quantities. Then there is the Towing AGV (2), which as the name suggests is used to tow carts with objects instead of carrying them on top. The towing AGV works much like a train with multiple wagons. The next model is the Pallet truck AGV (3), which is equipped with a lifting system. It is made to be able to lift pallets and objects that are on top of them. There is also a Forklift truck AGV (4), which also is made to lift and transport objects on pallets. The main difference is that this model usually is made to lift heavier objects. The next one is the Heavy burden carrier (5), which is used for heavy objects that regular vehicles can not handle. These are usually large-scale objects. Then we have the Hybrid vehicle (6). As the name suggests this type of AGV can be operated autonomously and manually by a human. This AGV type offers great flexibility. (Industrial Quick Search, u.å.) (Grand View Research, 2021)

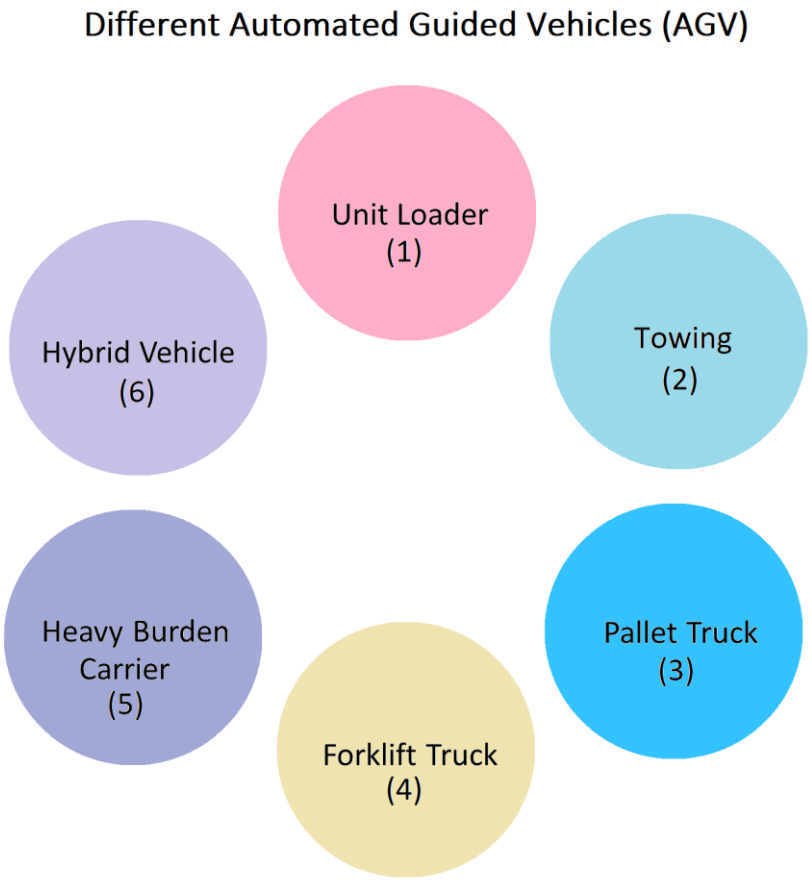

Figure 2: Different AGV models

Lastly, the most technologically advanced automated vehicle is the Autonomous mobile robot (AMR). The AMR transporting capabilities are mostly the same as an AGV. The main difference between AGV and AMR is the navigation and pathing system. It is like comparing a train with a taxi. AGVs follow a guided path set by the software, while AMRs can navigate freely, avoid obstacles, and set a new route around. AMRs are the most autonomous vehicle. (Industrial Quick Search, u.å.)

3.3 Properties

The properties of AGVs are split into two groups. This is because not every model of AGV operates the same way. The groups are universal and model-dependent capabilities.

The universal capabilities are common functions that most of today's AGVs can perform. An example of universal capabilities can be navigation and traffic control. These capabilities are enabled by the multiple scanners and sensors that the AGVs are equipped with. This allows AGVs to do their tasks in tandem with humans in a productive and safe manner. Another universal capability is when the AGV runs low on power or does not have a task to perform. They can drive to a charging station and connect themselves to the charger. These are universal capabilities that can be performed by most models. (Industrial Quick Search, u.å.)

Model-dependent capabilities are functions that only specific types of AGVs can perform. These can for example be the towing ability, which only the towing AGV is built to do. Another one can be the heavy burden carrier, which has a special ability to carry heavy-duty items. These AGVs are specially built to have these abilities. (Industrial Quick Search, u.å.)

3.4 Sustainability

Sustainability amongst companies plays a vital part in being environmentally friendly in today's industry. The definition of sustainability is "development that meets the needs of the present without compromising the ability of future generations to meet their own needs." (Jarvie, 2016).

The three pillars of sustainability found in figure 3 are a tool that shows us each important factor that is needed to achieve sustainability. The pillars can be used as a guide to show companies if a certain product supports sustainability. The three pillars consist of environment, economic, and social. To have something sustainable, all these three criteria must be met.

(University of McGill, 2013)

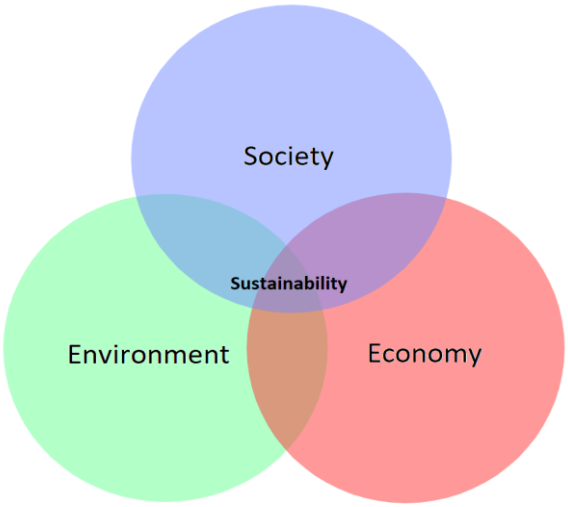

Figure 3: The three pillars of sustainability (Bruntland, 1983)

Automated guided vehicles support all these three factors when comparing them to the three pillars of sustainability. AGV is environmentally friendly because they run on electricity. Instead of its counterpart the regular forklift most often runs on diesel or petroleum gas (LPG). Electricity is good because it can be obtained from renewable energy sources. AGVs are also economical. This is due to AGVs having higher productivity and efficiency and reducing the cost of labor. Lastly AGVs social aspect. AGVs affect safety, since AGVs are robots, the possibility of human errors occurring is greatly reduced. This is due to AGVs being smart vehicles that can detect and stop if something is in their trajectory.

3.5 Internet of Things

The way that we in today's environment can have objects be so interconnected with each other is thanks to the development of the Internet of things (IoT). IoT stems from the creation of the internet, which Dave Evans (2011) says is one of the most important and powerful creations in all human history. IoT is defined by the Cisco Internet Business Solutions Group (2011) as the point in time when there are more things connected to the internet than actual people. The context of the definition means that the creation of IoT can be traced. Cisco IBSG (2011) estimated the time to be between 2008 and 2009. This estimation is due to the fact that this was the time when there were more connected devices than humans. estimation was done in 2020, which suggests the 2008/2009-time frame to be true. (Evans, 2011)

How is then AGVs connected to IoT? This connection exists because the technology behind today's AGVs works due to the development of IoT. The meaning of IoT is not only to be connected through

the internet. It also means a connection between other systems. AGVs use scanners and sensors so that they can do their task efficiently and safely. For this to work there needs to be communication between the vehicle, sensor, and software. The AGV sends information from the sensor to the software controlling it, which in return decides how the AGV is going to move. (Evans, 2011)

4 Factors of AGV

This chapter is going to go through the four main factors of AGVs. This includes technological, financial, employee, and warehouse factors. There are four main factors that a company must consider when investing in automated guided vehicles.

4.1 Technological Factors of AGV

This chapter goes through the technological aspects of AGVs. It covers the load capacities, dimensions, and navigation technology of AGVs. This chapter also goes through a method for measuring a company's readiness for AGVs and industry 4.0.

4.1.1 Readiness of AGV and Industry 4.0

The broader use of the internet, new technologies, and increased use of intelligent machines and equipment are leading us to a new technological revolution. This revolution is known as Industry 4.0, which implies that this is the fourth industrial revolution that humanity has entered. Zoubek and Simon (2020) describe factories shifting into "smart factories" thanks to the implementation of industry 4.0.

Zoubek and Simon (2020) say industry 4.0 is companies shifting into and implementing intelligent equipment and storage systems that are interconnected with each other. Implementation of Industry 4.0 also means the use of automation and automated guided vehicles. AGVs are connected to industry 4.0 as a leading technology system. As a result of this AGVs can be used and implemented in a much larger capacity than before. Other systems that are also included in Industry 4.0 are IoT, RFID, Smart Sensors, and more.

Capability Maturity Model Integration (CMMI) can be used to determine the readiness of AGVs and industry 4.0. This model can be used to evaluate a whole company’s readiness or just for a specific process within. There are several different iterations of CMMI models available. The models made are either made to fit a general category or a more specific industry. You can expect to get a better result from the models that are made with a specific industry in mind. (Grufman & Lyons, 2020)

Industry 4.0 readiness, which is a type CMMI model done by Lichtblau, Stich, Bertenrath, Blum, Bleder, Millack, Schmitt, Schmitz & Schröter (2015). The readiness model was made by reviewing literature and conducting a workshop. The workshop was done together by IW consult, FIR, and companies that had experience in using Industry 4.0. These companies were from the mechanical engineering industry. The reason behind the workshop was to assess success factors involving Industry 4.0.

This readiness model is made in the context of smart operations and is characterized by five dimensions ranging from level 0 to level 5. To measure readiness, a company needs to assess how they rank in each category. In model 1 each level and the criteria are seen as what is needed to move on to the next level. Once the final level of each dimension is determined you now have a final score. The final score can be used to see how the company ranks in model 2. This model determines the level of readiness that a company has. The readiness model dimensions and levels can be found in figure 4 and 5. (Lichblau et al., 2015)

Smart operations

Dimension	Level 0	Level 1	Level 2	Level 3	Level 4	Level 5
System-integrated information sharing	No system-integrated information sharing	Beginnings of in-company, system-integrated information sharing	In-company information sharing partially system-integrated	Some in-company and beginnings of external system-integrated information sharing	Predominantly in-company and partially external system-integrated information sharing	Comprehensive in-company and partially external system-integrated information sharing
Autonomously guided workpieces	Autonomously guided workpieces not in use	Autonomously guided workpieces not in use	Autonomously guided workpieces not in use	Autonomously guided workpieces not in use	Experiments in test and pilot phase	Use in selected areas or even cross-enterprise
Self-reacting processes	Self-reacting processes not in use	Self-reacting processes not in use	Self-reacting processes not in use	Self-reacting processes not in use	Experiments in test and pilot phase	Use in selected areas or even cross-enterprise
IT security	No IT security solutions in development or implemented	Initial IT security solutions planned	Multiple IT security solutions are planned or initial solutions are in development	IT security solutions have been partially implemented	Comprehensive IT security solutions have been implemented, existing gaps are being closed	IT security solutions have been implemented for all relevant areas
Cloud usage	Cloud solutions not in use	Cloud solutions not in use	Cloud solutions not in use	Initial solutions planned for cloud-based software, data storage, and data analysis	Initial solutions implemented	Multiple solutions implemented

Figure 4: Readiness model Dimensions (Lichblau et al., 2015)

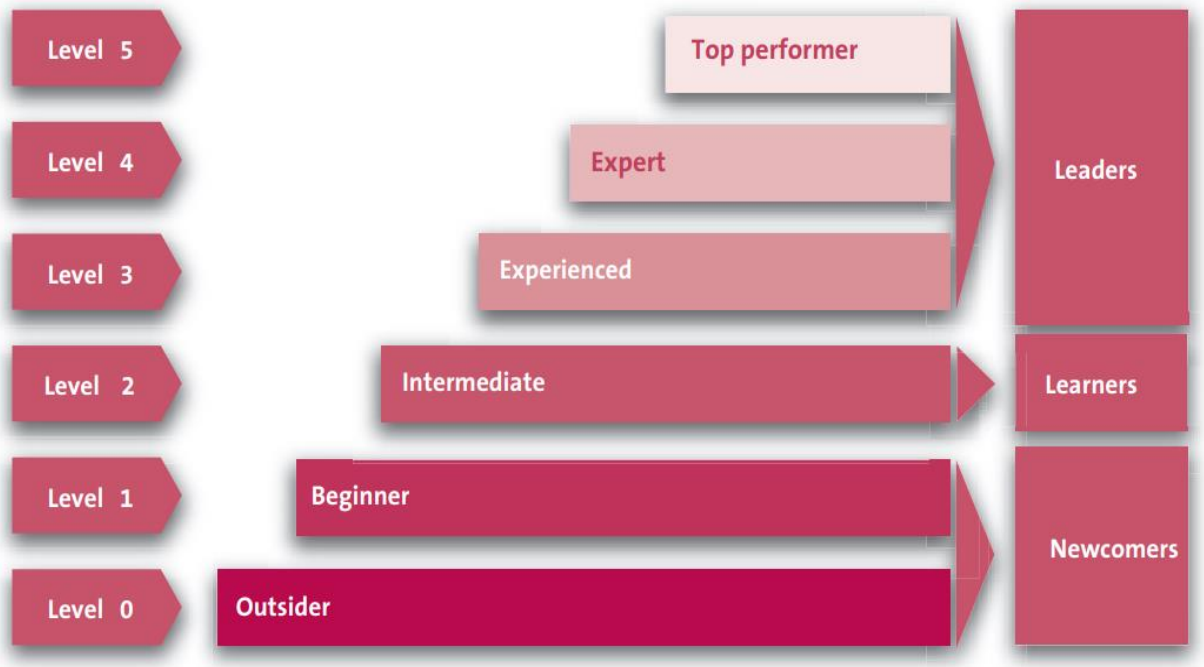

Figure 5: Readiness model levels (Lichblau et al., 2015)

The connection between the use of AGVs and Industry 4.0 is that in order to successfully implement AGVs you need to have a high level of readiness for Industry 4.0 since the criteria are linked to each other in the readiness model. (Grufman & Lyons, 2020)

4.1.2 Load capacities

Load capacities of the AGVs are determined by the weight of the maximum number of products they can carry. This depends heavily on what types of products are going to be transported. The weight of different items can vary a lot and can become quite heavy if it is carried out in bulk. The product's dimensions also matter. Bigger products are going to need more space when being transported. This affects the maneuverability of the AGVs when they are between the aisles of the warehouse. (Industrial Quick Search, u.å.)

4.1.3 Dimensions

The dimension of the AGVs and the warehouse space needs to be measured. These are connected since the AGVs must be able to travel and load on products in between the shelves. The proper dimensions and curves come down to what type of AGV is used and what they are transporting. You either fit the AGV to the warehouse or the warehouse to the AGV. (Hrusecka, Lopes, Jurickova, 2018)

AGVs are equipped with different types of rolling bases. Since there are different types of AGV models and different manufacturers means that they are not necessarily equipped with the same rolling

base structures. The rolling base of the AGVs determines how they will maneuver throughout the warehouse. The turning radius and the size of the AGV need to be measured. This is to ensure that there will be enough space for the AGVs maneuvers in between the shelves and throughout the warehouse. (Hrusecka, Lopes, Jurickova, 2018)

The dimension of the space itself also needs to be correctly measured. The layout of the operating space should be thought out and efficient. Enough amount of space ensures that the AGV can operate both efficiently and safely.

The layout needs to be designed together with what is going to be operating in it. This will ensure that the space is efficiently used and that no space goes to waste. (Gu, Goetschalckx, McGinnis, 2009)

4.1.4 Navigation Technology

The navigation technology used should be decided based on if the warehouse has only AGVs or a combination of AGVs and regular forklifts. This is going to matter when choosing the navigation system. The two most common ones used are the magnetic strip and the optical reader.

(Industrial Quick Search, u.å.)

Regular forklifts are equipped with rubber tires, which can leave rubber marks on the floor. These marks have an effect on the ability of the AGVs optical readers to correctly read and track its pathway. (Industrial Quick Search, u.å.)

There are several different types of navigation systems. There are AGVs equipped with all sorts of different navigation technologies. There are simpler navigation systems like the wire, optical and magnetic strip, and -spot, which are usually seen on older AGVs. There are also newer technologies that can be used. These are LGV (Laser Navigation), LiDAR, and Vision navigation.

(Industrial Quick Search, u.å.)

The wire navigation technology works through a pathway in the floor that the wire from an AGV is connected to in order to guide the vehicle. The wire sends a signal to the AGV, which allows it to follow. This technology is what the first version of the AGVs used. (Industrial Quick Search, u.å.)

Then there is the magnetic tape and -spot navigation type. The magnetic tape works by having magnetic sensors equipped, which can read the pathway set by the tape. The magnetic spot system uses embedded sensors that can be placed in the floor. The AGV is able to move from one spot to the other. You can have a CAD drawing to set the desired pathway with help from sensors, gyros, and encoders, which will steer the AGV. (Industrial Quick Search, u.å.)

Optical navigation uses a highly sensitive camera that guides the AGV path by reading tape or painted pathways. (Industrial Quick Search, u.å.)

LiDAR is also known as light detection and ranging. This technology maps the environment using different sensors and cameras that the AGV is equipped with. It then calculates the data that it has acquired in order to know its location and position. (Industrial Quick Search, u.å.)

Vision navigation is a technology that uses vision sensors to determine its location and pathway. It does this through a camera that records its programmed route and compares it with a map to navigate through the workspace. (Industrial Quick Search, u.å.)

4.2 Financial Factors of AGV

This chapter covers the financial factors of AGVs. This chapter explains what the market size of AGVs is around the world and on what trajectory it seems to go. This chapter also covers different ways to calculate investments for companies, which are essential when making a large investment like AGVs. Lastly, it goes through the financial advantages and disadvantages of AGVs.

4.2.1 Market size

The automated guided vehicle market is on a growing trajectory. According to Grand View Research (2021), the Asia-Pacific AGV market size was at an estimated value of $3.39 billion. The market is expected to expand at an annual rate of 13% from 2021 to 2028. Figure 6 done by Grand View Research (2021) shows us a visual interpretation of the expected trajectory. It also identifies each AGV category and its individual shares in the market. The top spot in the AGV market is occupied by the tow vehicle, which accounts for about 40% of the market share. Up and runners in second and third are the unit load carrier and pallet truck that are in the second and third sport. These three are the most common AGVs utilized by factories. (Grand View Research, 2021)

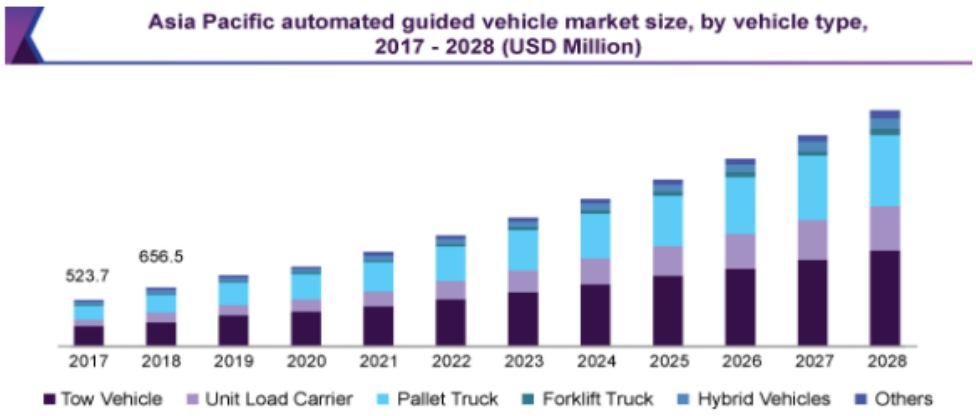

Figure 6: AGV market growth (Grand View Research, 2021)

4.2.2 Financial advantages of AGV

The reasoning behind why companies want to acquire AGVs for their operations is most often to increase profitability. This is the main reason for the investment and what it should accomplish. There are many factors that should lead to this. These are reductions in labor costs and increases in safety, productivity, and modularity. (Benevides, 2020)

Labor cost reductions happen by replacing the person operating a forklift with the AGV. With this replacement, the company's only payment is the initial investment of the AGV. They now do not have to pay the worker which requires salary, healthcare, and vacation time. (Benevides, 2020)

The increase in safety happens since the human is replaced with a machine. AGVs have more safety mechanisms applied to them than humans do. Humans are much more probable to perform human errors, which is excluded by the replacement. Another safety concern is that humans are more probable to become distracted, which might happen through fatigue or being unfocused. (Benevides, 2020)

The increase in productivity is also connected to the decrease in human errors. Since humans can get fatigued or tired, which leads to a more inaccurate workflow. It is only human nature to need brakes throughout the workday to stay efficient. AGVs are able to perform tasks continuously and could stay running as long as their battery allows them to. (Benevides, 2020)

Lastly the modularity of AGVs. The modularity of AGVs means that a company is able to start with five AGVs and increase the amount as time allows it. Companies are no longer beholden to buy 10 at once and only use them as a group without any future additions. (Benevides, 2020)

4.2.3 Financial disadvantages of AGV

We can not talk about the advantages without addressing the disadvantages as well. The disadvantages that are linked to finances are the high initial investment, maintenance costs, and decreased flexibility. (Benevides, 2020)

Automated guided vehicles made today do come at a hefty price point. According to Austin Weber (2015), the price of an AGV can range from $100 000 to $150 000. The price can vary with what capabilities or AGV model you choose. This is the price of only one AGV and most companies need multiple when wanting to invest. Looking at a logistic center they would probably need at least as many AGVs as they had manual forklifts beforehand. Let's say you need 10 AGVs for your operations. 10 AGVs make the initial investment cost of only the vehicles to be between $1 000 000 to $1 500 000. This price should not be a problem for larger companies, but the further you go down in company size more of a problem it becomes. (Weber, 2015)

Maintenance cost is another disadvantage of AGVs. AGVs are machines and machines need to be maintained if you want to prolong their lifespan and have them work properly. There are also occasional repairs that need to be done if something malfunctions or breaks. Proper and timely maintenance checks should reduce the potential repairs, but they are inevitable. Maintenance and repairs mean downtime, which leads to lower productivity for that time. (Weber, 2015)

4.2.4 Investment methods

This chapter will go through Net present value (NPV) and Payback time as investment methods. These methods give a company an overview of how long it will take to pay back investments and if the investments are worth it or not. Payback time is the simpler version, while NPV is the more complicated one. re

Net present value (NPV) is a method used to calculate if an investment will be worth it or not. To calculate the NPV you need to know the price of the initial investment, the projected cash flow, the discount rate, and the life span of the project. If the NPV is positive, means that it's a good investment. If the NPV is negative it means that the investment is bad. "We should invest in project X if its NPV is greater than Zero". (Brealey, Myers & Allen, 2011)

NPV takes a couple of things into account. NPV accounts for the time value of money, meaning that money today will be worth more than money tomorrow. This is important when dealing with investments over multiple years. Secondly, the NPV of one project can be compared with another as long as they have the same lifespan. This means that you can compare the NPV of multiple investments in order to see which one is most worth it. Lastly, you can take count of the investment risk by the use of the discount rate you apply. The percent of the discount rate comes from the rate of return the investment is expected to have. The formula for NPV can be found in figure 7

(Brealey, Myers & Allen, 2011)

$$NPV = \sum_{i=1}^{n} \frac{Cash\ Flow_i}{(1+r)^i} - Initial\ Investment$$

Figure 7: NPV Formula (Brealey, Myers & Allen, 2011)

Payback time or also referred to as the payback rule is described by Brealey, Myers, Allen (2011) as "the number of years it takes before the cumulative cash flow equals the initial investment". The payback time formula can be found in Figure 8. Payback time is a simpler and faster variant of the NPV. With payback time you only get the answer of how many years it will take before the investment is paid back. It does not account for the value of the money, which means that this method is not suited for longer-term investments. The decision if the investment is worth it relies on the company and how long they would allow the time to be. This is called the cut-off period. (Brealey, Myers & Allen, 2011)

When wanting to calculate the payback time you need to know the project's initial investment, projected cash flow, lifespan, and the time allowed set by the company. If the payback time is five years and the company only allows for three years, then you do not make the investment. (Brealey, Myers & Allen, 2011)

$$payback\ time = \frac{cost\ of\ insulation}{annual\ saving}$$

Figure 8: Pt Formula (Brealey, Myers & Allen, 2011)

4.3 Employee factors of AGV

This chapter goes over the employee factors, which are affected by AGVs. We go through employee productivity and what effect introducing AGVs will have on it. This chapter also covers safety aspects with an AGV environment and different safety standards in the form of ISO.

4.3.1 Productivity

Productivity is described as the effectiveness of a productive effort. From the perspective of employee productivity, it is high efficiency and quality work done by an employee (Satyendra, 2019). Productivity of employees is a key manner that every company wants their workers to have. It is measured by comparing the hours worked to the output. By measuring productivity, you get in a way the worth, which that employee has to the company. The disadvantage with measuring productivity is that it does not always fit. Calculating productivity by comparing output and hours worked is best suited for manufacturing work. Using the same methodology for problem-solving work tasks does not give a useable result since every problem is different and takes different amounts of time to solve. (Satyendra, 2019)

To achieve higher productivity, you need to take into account that it is a two-way street. To expect high productivity, you need motivators to do so. This can be done through ways like higher salary, job security, good work conditions, and more. It is all things that the employees value. Another way to achieve productivity is to set goals for the employees, which is supported by the goalsetting theory. (Satyendra, 2019)

The goalsetting theory argues that when wanting to increase productivity a company needs set goals or targets that are not easily achievable. Setting targets means that workers have something to strive for. It is important to note by hitting the required target, employees should be rewarded for their efforts. Otherwise, what is the point of the achievement? (Satyendra, 2019)

When wanting to implement AGVs in a company's operations it is a key motivator to increase productivity. AGVs are more efficient than having regular workers driving forklifts, but it is not that simple to just start using AGVs and get increased productivity. (Lindskog, 2012)

Systems theory or also known as systems thinking is described by Magnus Lindskog (2011) as seeing the wholes and interrelationships rather than single things. Systems theory argues that when wanting to increase productivity by implementing more efficiency at one stage does not mean that the others will follow. This could be used with AGVs as well. If employees in-between stages of AGVs cannot keep up with the new level of efficiency. This can lead to potential efficiency being wasted. (Lindskog, 2012)

4.3.2 Employee safety amid AGVs

The additions of AGVs and automation in general throughout factories should bring up how it will affect the safety of the employees. As warehouse technology evolves also means that safety standards need to evolve.

Safety standards for AGVs in Europe and United States are found in ISO 3691:2020 for the EU and ANSI B56.5-2019 for the US. These are not the same, but very similar. These standards cover both the vehicle and its system, but also the environment it will be used in. Manufacturers are obliged to manufacture their vehicles to these standards to ensure safety. EN ISO 13849-2015 standards sets the performance levels that AGVs are required to reach. These levels are set between PLa to PLe. (Tomatis, 2021)

EN ISO 13849-2015 sets that AGVs need to reach at least the PLd safety level. Seen in figure 9 PLd states that the system needs to have “Well designed safety systems with redundancy and/or checks”, “Single failure does not lead to loss of safety”, “Probability of dangerous failure to be 10^7 to 10^8 per hour”, “Architecture category 3 or higher” and “All safety lasers scanners”. (Kidman, 2020)

Performance level	PLa	PLb	PLc	PLd	PLe
System	Unmonitored safety systems.	Basic safety principles.	Well-designed safety, but no redundancy nor checks.	Well-designed safety system with redundancy and/or checks.	Advanced safety system with redundancy and feedback loop.
Failure effect		Failure can lead to loss of safety.	Single failure can lead to loss of safety.	Single failure does not lead to loss of safety.	Multiple failures do not lead to loss of safety.
Probability of dangerous failures	10^{-4} to 10^{-5} per hour	10^{-5} to $3x10^{-6}$ per hour	$3x10^{-6}$ to 10^{-6} per hour	10^{-6} to 10^{-7} per hour	10^{-7} to 10^{-8} per hour
Architecture category	Category B or higher	Category B or higher	Category 1 (principle), Category 2 (component) or higher	Category 3 or higher	Category 4
Examples	Lights, horn	SICK TiM-S (laser scanner)		All safety laser scanners (Hokuyo, Leuze, OMRON, SICK, ...)	SICK Flexi Soft (safety PLC)

Figure 9: EN ISO 13849-2015 safety performance levels (Tomatis, 2021)

4.4 Warehouse factors of AGV

This chapter covers the warehouse factors of AGVs. Here we go through things to consider in warehouse design when starting to implement and use AGVs. This includes locations, such as the home location of the AGV and the loading and unloading stations. The second one is the layout. This includes how many aisles, the orientation, length, width, and door locations. The third one is routing, which is the chosen pathway that the AGVs travel by.

4.4.1 Locations

The first order of business is the locations of the AGVs loading- and unloading stations. These should be set up away from the main area where the AGVs have the most traffic. This is so they do not interrupt the flow of the operation. The different loading stations should be in areas with low consumption. (Hrusecka, Lopes, Jurickova, 2018)

4.4.2 Layout

The layout design of a warehouse with regards to AGVs does have two main functions that need to be considered. The first one is the Pallet block-stacking pattern, which referrers the depths of storage lanes, how many lanes for each depth, the stacking height, and pallet placement angles. The second function is the storage department layout. This function refers to the warehouse aisle's orientation, length, width, how many aisles there are, and locations of entry and the exits. These functions will influence storage capacity, utilization of space, and the equipment used. The functions will also have

a cost effect on maintenance, construction, and material handling. (Gu, Goetschalckx, McGinnis, 2009)

Pallet block-stacking pattern, which includes the storage lane depth, number of lanes, and stack height are all crucial design elements of a warehouse. Depth, lanes, and heights that are used should be in proportion to how much storage is needed. Having too much space will add on unnecessary pickup times and not having enough space will not fit all the items. The capacity is also important to determine, so you know how many AGVs you need to operate the warehouse. The height should also be considered so that the AGV model chosen can with certainty lift and place products on the shelves in the warehouse.

(Gu, Goetschalckx, McGinnis, 2009)

Pallet placement angle, which is the required space between shelves for the AGV to be able to place products on the shelves. This needs to be measured so that the AGVs have the required turning radius for placing products on the shelves. Figure 10 is an illustration of the turning radius, which is determined by how much the wheels turn, where they are placed, and the size of the AGV.

(Gu, Goetschalckx, McGinnis, 2009)

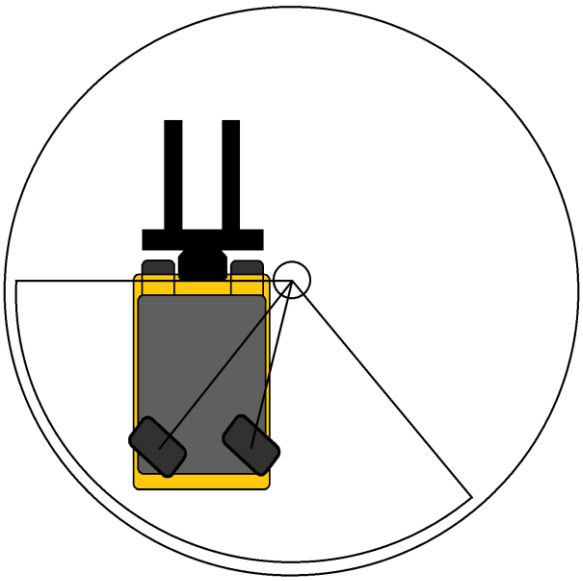

Figure 10: Forklift turning radius

Storage department layout refers to the aisle orientation, length, width, and quantity. The preferred shape of the warehouse should be either square or rectangular. According to (Erkemen and Topcubasui, 2018) a rectangular warehouse uses 18% more movement compared to a square warehouse. Warehouses are most often fitted to the land of the location, which means the shape can vary. (Gu, Goetschalckx, McGinnis, 2009)

The aisles inside should either be placed parallel or perpendicular in order to utilize the most space. The different orientations can be found in figure 11. This also depends on the shape of the warehouse. The bays inside of shelves should be identical for ease of use. (Gu, Goetschalckx, McGinnis, 2009)

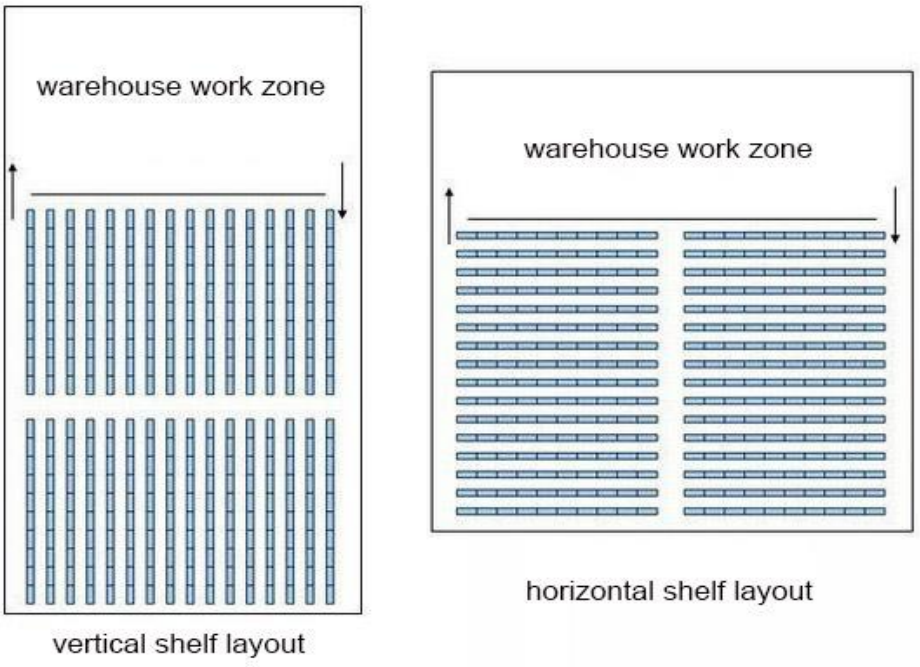

Figure 11: Warehouse shelf layouts (Beson Shelves & Racks, 2016)

Important to note is that there is a difference between a warehouse that maximizes storage efficiency compared to minimizing travel distance. Simulations are good tools when measuring storage layouts. They can be utilized to measure the most efficient storage configuration and travel distance. (Gu, Goetschalckx, McGinnis, 2009)

Lastly (Rooderbergen, Vis, 2006) "Calls into question the attempt to optimize storage department without knowing what the true material handling performance will be". He also mentions the need for more research into what the impact of the layout will be. (Rooderbergen, Vis, 2006)

4.4.3 Route

Routing is determining the path that the AGV is going to travel in the warehouse between shelves. When picking up items for an order you should always choose the fastest path, which results in higher efficiency.

Routing heuristics are a way to determine the pathway that we choose to take. Heuristics are in a way a thumb rule that determines which way we travel and pick up items. There are different heuristics to go by and even combinations of them. The choice of heuristics also needs to work in a combination of the warehouse design and layout. Figure 12 shows some commonly used routing heuristics. (De Koster, Le Duc, Roodberg, 2007)

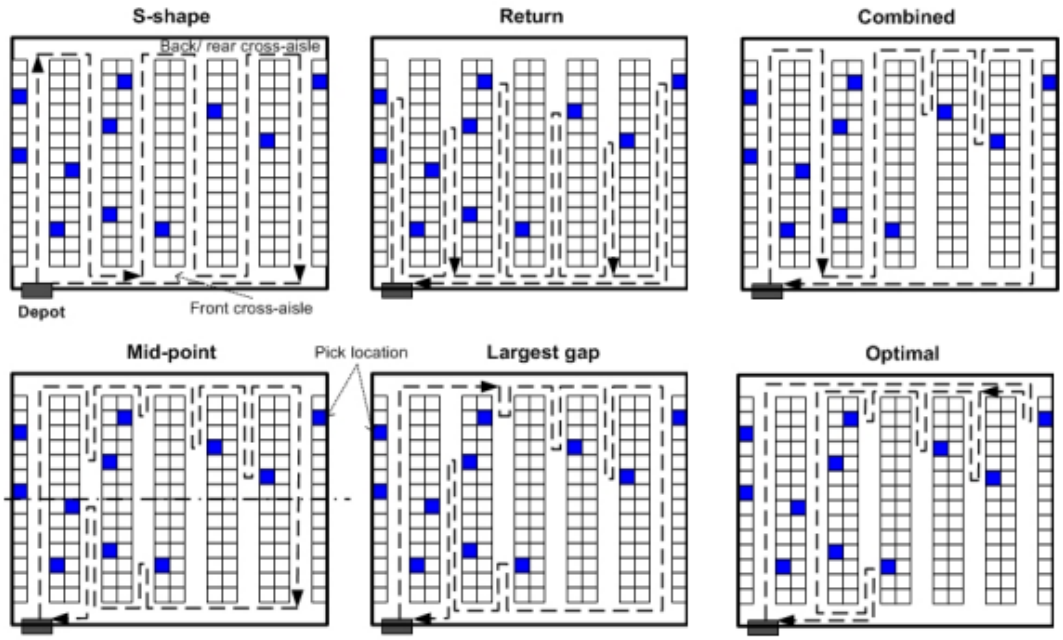

Figure 12: Routing methods for a warehouse (De Koster, Le Duc, Roodberg, 2007)

The two more simple heuristics are the s-shape and the return. The S-shape determines that you must completely travel through every aisle that contains an order item. This means that if an isle does not contain an order item it is skipped. When all the order items have been picked up you return to the depot. The Return method instead of traversing through every single aisle only travels from one side. You pick up the item for the order and then return it the same way that you started. This is useful if you have the shelves adjacent to a wall and the aisle can only be entered from one direction. (De Koster, Le Duc, Roodberg, 2007)

Two more heuristics are the mid-point and the largest gap. The mid-point heuristic sets the standard that the warehouse is divided into two sections. the AGV should never traverse the mid-point, not

even if the next item is on the same aisle. The largest gap is a modified version of the mid-point. If the items are adjacent to each other then the AGV can pick them both. If the items are in the same aisle but far away from each other then the items should be picked from separate sides of the aisle. (De Koster, Le Duc, Roodberg, 2007)

The choice of heuristics is a double-edged sword. With the more complex ones you get better performance, but they are harder to implement. The simpler ones are easier to implement but have worse performance. (De Koster, Le Duc, Roodberg, 2007)

5 Empirical research process

This chapter is about the research process and the factors that are included in carrying out the research. This will go through the different types of methodology, methods of data collection, the validity and reliability of research, and lastly the method of data collection that I am going to use, which is interviews and how to conduct them.

5.1 Research methodology

The methodology used in research is described as either qualitative or quantitative. The qualitative research method aims to create a deeper and more complete point of view. This method is used when you research factors that are not numerical. Instead, the focus lies on situations that can be described. The aim of the qualitative method is to explore and produce an understanding of the matter.

The quantitative research method is when you study a larger group of people. The data you gather is expressed in numerical form and should also be quantifiable. The quantitative method is mostly expressed in the form of tables, charts, diagrams, etc. The purpose of this method is to find explanations and generalize.

5.2 Data collection

There are two methods of data collection. These are case studies and surveys. These both serve the same purpose of data collection but have different ways of gathering information.

Case studies are a more in-depth way to get information. They can be conducted in several different ways, which are interviews, observations, documents, and databases. When conducting a case study, the researcher needs to be present and active. To get good information the researcher must interact with the responders. An example is when interviewing someone and they have an interesting answer the researcher can based on that do follow-up questions that might not be in the script.

Surveys are a more passive way to collect data. Opposite to case studies with surveys the researcher does not have to be present during the data collection. When conducting a survey, you need to prepare a questionnaire that the focus group will answer. The questions can be either closed-ended or open-ended questions. The preparation work for the questions in a survey is important, since a researcher is most often not present, which removes any way to be flexible. An example is if the one answering the question does not understand the question or what it is asking, a researcher is not present to better explain the meaning behind the question.

5.3 Validity and Reliability

Validity is referred to as consistency, while reliability is referred to as the accuracy of the research. Validity and reliability are crucial in data collection. To maximize the validity and reliability you need to have the right questions to ask. In surveys, it is also equally important to have the right answers if you use close-ended questions.

5.4 Interview methodology

Interviews, which are one of the most common methods for data collection for case studies provide an in-depth view. Interviews allow the individuals to express their experiences and opinions, especially if it is on sensitive issues. Interviews are also flexible since the researcher has the option to ask for more context.

Interviews are conducted in three ways, which are unstructured, semi-structured, and structured. The unstructured interview is done in a free-flowing manner with minimal control over the answers. The questions are also broad, which can lead the conversation in many different directions.

Semi-structured interviews have more control over what is asked. With this type, you have standardized questions. You also include questions that must be asked. This interview type is good to use when wanting to gather information about a specific topic and delve deeply into it

The structured type is the most controlled. This type uses strict questions, which are asked in a specific order. This type can almost be described as a survey in an interview format. In a structured format, the researcher is not allowed to ask for any additional information even if the respondent does not understand the question.

When conducting an interview different aspects need to be considered. During the interview you should gain cooperation between you and the respondent, this is so you get accurate and honest answers. Another important aspect is the ability to listen. You should never cut off the respondent and let him finish. Dependent on the chosen interview structure, if the respondent struggles to come up with an answer or describe something you can chime in and help. During the interview you should

also always be neutral, this is so that your personal opinions and views do not affect the answers of the respondent.

5.5 Capturing data

There are different ways to capture data during an interview. There is note-taking and recording. Recording the interview is the more passive way to gather data. With this method you just hit play and the data capturing happens out of the way. Recording the sound gives you the opportunity to focus on the interview and responder. Note-taking is the way, which requires more work. With this method, you simply just write down what the responder says. It is not that simple though. When taking notes, you need to be able to write fast and capture what the responder is saying. With notes, you are also able to capture non-verbal data. This data is the setting of the interview, the surroundings, and what is happening in the background.

5.6 Interview structure and implementation

I have chosen a qualitative research method. I have chosen to use interviews as my data collection method. The structure of my interview is unstructured. I wanted to have free-flowing conversations with the people I interviewed. The data capturing methods I used were recordings and taking notes. This would depend on if the person wanted to be recorded or not.

Unstructured interviews are also the most flexible type. This works best in my case since everyone I interviewed had different expertise and are involved in different capacitates. Free-flowing conversations work the best in this case since the topic I have about is so broad.

I used broad questions to gather as much data as possible from each person. Broad questions are good since it was hard for me to prepare how much information they have about thesis topics.

The questions I used in my interviews are compiled in the chart on the next page. Question 11 was not a direct question. I have compiled things that were said in the interview with person D, which fit into this category. Question eight is red for persons A and B since it did not get asked to them. This is because I thought of that question at a later stage when doing my interviews. Person D's high absence of answered questions is due to time constraints.

Questions		Persons	A	B	C	D
1	What features should AGV have?					
2	What are the weaknesses of AGV?					
3	Which AGV models would best suit Wärtsilä's needs?					
4	How do you think AGV affects productivity?					
5	How do you think AGV affects employees?					
6	What should be considered in the design of the warehouse when thinking of AGV?					
7	Do you think that the introduction of AGV is easy or difficult to implement?					
8	Why did Wärtsilä decide to acquire AGV?					
9	Do you think that more companies will start using AGV?					
10	Do you believe that AGV is the future of logistics?					
11	Financial obstacles of AGV?					

Answered question.	Yes	No

6 Result

In this part I will go over the interview I conducted and what answers I got from them. All the people I chose to interview have some involvement in the development of the new facilities at Wärtsilä. Some persons are more involved and others less. Most of the interviewees have logistical or development backgrounds.

I interviewed a total of four employees from both Wärtsilä and DHL. All the interviewees are connected to the development of the new Logistics Center at Vaskiluoto Vaasa. The interview duration was between 20 minutes to an hour. The time difference is a result of how much each person had answered. One interview was cut short because there was not enough time. The interviewees are named Person A, B, C, and D.

- Person A works at Wärtsilä and is a general manager of material management. He has over 16 years of experience in material management, purchasing, and logistics.
- Person B also works at Wärtsilä and is a senior project manager of the STH program and Logistics stream. He has 19 years of experience in purchasing and management.
- Person C also works at Wärtsilä and is a Senior Development Manager. He has over 20 years of experience in development.
- Lastly, Person D works at DHL and is a Senior Project Manager. He has over 20 years of experience in business development and supply chain management.

6.1 Questions related to Technological Factors

What features should AGV have?

Everyone brought up the importance of security systems through various sensors. This is a crucial feature and should be 100% dependable. The security systems must be in place for the security of employees working among the AGVs but also for the security of the transported products and infrastructure around the warehouse. Person A mentioned that the sensor should also be able to sense things at higher altitudes in case of other lifting systems or walls that can be in the way.

Person D brought up an important safety feature if the AGV loses connection. If this happens there needs to be safety features to stop the AGVs so that they do not continue in an unpredictable pathway until the connection is back.

When having employees and AGVs among each other in the same space you need to have specific lanes, which separate employees and AGVs from each other. This is a safety feature, but also a way to increase flow. In completely restricted areas AGVs can travel at higher speeds. The difference between restricted areas and areas among people is due to the connection between weight and braking power.

The software features were also something everyone brought up. The AGVs system must be integrated with a company's own warehouse management system. All AGVs from different manufacturers have their own system, which prior knowledge of another system does not necessarily help. The interviewees also pointed out that AGVs must be flexible enough for adjustments. This is for the implementation phase when proper routes are being coded. The flexibility also applies to scalability if you have the desire to expand your AGV fleet. Person C pointed out that AGVs also need good recovery. By this, he meant when problems occur AGVs need to be easy and quick to fix.

All the interviewees also mentioned logistical features, that AGVs need. These features are the proper lifting height and weight capacities. AGVs must be able to lift items to the needed height. They also must be able to carry and lift the required weight.

What are the weaknesses of AGV?

The main weakness mentioned in every interview was the lack of intelligence and flexibility. AGVs are so unforgiving in the way that minor problems can cause a system error. Person C mentions that AGVs need lots of data, which is not necessarily a weakness. AGVs need data about what it is going to

carry in the form of weight and dimensions. This means that if you do not have the proper information about specific items you have to acquire them. This enables companies to gather all the information about their products, which is a good thing in the long run.

Both person B and C brought up complex tasks as a weakness. They both mentioned that there are lots of drop-off and pick-up points at various heights and locations, which can be difficult for AGVs. Person B said especially the coding phase can be a challenge for this aspect. This is also connected to the flexibility and lack of it for AGVs. Person B also mentioned the coding phase for routes and that new routes need to be coded if you change pathways.

What AGV models are best suited for Wärtsilä´s needs?

Person C says that the scale of usable AGV models is large at Wärtsilä. Person A and B both mention that the AGV model best suited for Wärtsilä is a model that can carry heavier items and large quantities. The models should also be equipped with a forklift for transporting pallets. They both also said that the AGV model should be equipped with a counterbalance, which aids in lifting heavier objects. Person C mentions the use of smaller and heavy burden AGVs. The heavy burden could be used for carrying larger machined parts. The smaller AGVs could be used for carrying objects to offices.

6.2 Questions related to Employee Factors

How do you think AGV affects productivity?

All the interviewees agreed that productivity should increase. Person A also mentioned that having AGVs doing simpler more tedious tasks allows human employees to do more challenging and complex tasks. Person A also added that AGVs have the capacity to work 24/7 without any breaks, which is something humans require to operate efficiently. Person C added the flexibility of drop-off and pick-up points. With AGVs you can code these to be at any location.

All interviewees also mentioned potential problems that can hurt productivity. The potential challenges are mostly prone to happen in the less integrated parts of the factory. Person C mentions the problems with calculating the flow correctly in factories. For example, how fast AGVs can transport products from place A to B. The challenges are to know where AGVs are amongst employees since AGVs must drive at lower speeds at these parts for safety reasons.

How do you think AGV will affect the employees?

Every interviewee mentioned something about the potential negative feedback from employees. This could be about employees getting replaced or the skepticism towards innovation. Firstly, imple-

menting AGVs allows employees to work with something more demanding and complex as mentioned earlier. There could also be worries about employees having to work more. Person C says that an increase in volume does not necessarily mean they need more recourses or working shifts. It just allows more flexibility for capacity.

Person B and C mention that innovation will always have some pushback in the beginning. This is heavily linked to how good or bad the AGVs will work. If there are lots of problems with a new system and processes are running less smoothly than before. This will cause negativity toward the new system, but on the contrary, it will also have positive effects if it works as intended.

An additional challenge mentioned by person A is communication. The communication flexibility for employees will be reduced due to AGVs being less flexible. The lack of communication abilities between employees and AGVs will be a challenge. Especially with changing and adapting in certain situations.

Person A also adds that the implementation of AGVs means a change in the production philosophy. From a flexible work way to a more systematic one.

6.3 Questions related to Warehouse Factors

What should be considered in warehouse design when thinking of AGV?

In every interview, everyone places high importance on having the right dimensions. AGVs need shelves and the floor to be aligned with each other. Person A mentions that there can not be any seams on the floor. Both person A and B says that the floor should also be flat without any down- or up hills. All interviewees mention that the dimensions of the pathways and between shelves need to be the appropriate size for the AGVs. Person A and C mention that the dimension of pathways where employees are among AGVs needs to be designed in a way that they do not cause interference.

All interviewees also mention how the drop-off and pick-up points need to be accurately designed. Person A, C, and D got more in-depth. AGVs are inflexible in the sense that they are coded to pick up something at a specific place. This means that pickup and drop-off points must be correctly designed. Employees placing pallets for pickup also need to place them accurately in the correct place at the right angle. If they are not, AGVs will struggle to pick up the pallets and waste precious time. Fortunately, there are ways to assist this process. Person D says one solution is to have rails in place, which forces pallets to be aligned in order to be placed correctly.

Person B and C mention the design of routes. Person B says that the routing needs to be straight, effective, and fast. You should have lots of straights and minimize turning. This is so you can utilize the

AGVs speed, which leads to higher efficiency. Person C also mentions turning radiuses and how they need to be considered when designing a warehouse.

Person C mentions slightly that you must consider design elements around the navigation system also. You need to think about what it requires and the design element around it.

Person D lastly says that warehouse design with AGVs is difficult because there is still very little "in real life" data.

Do you think that the introduction of AGV is easy or difficult to implement?

All the interviewees agree that the implementation phase is challenging and is not expected to be easy. The learning curve is steep, but you always hope that it will be as smooth as possible. Person C says that the beginning phase should not be too difficult. The more complicated tasks are where the issues are prone to be challenging. Person A mentions that AGVs are so unforgiving, which makes the implementation even more difficult.

The interviewees also have suggestions on what can make the implementation easier. Person A and B both suggest that the implementation should be done in different phases. This allows you to get one part working, and steadily start to expand it. Person A also adds that implementing AGVs is not easy and cannot be done overnight.

Person D talked about the implementation aspects in relation to the warehouse. With this, he mentioned that it is actually easier to implement AGVs into existing areas rather than new ones. He says that this is because implementing AGVs requires lots of data. With an old warehouse, you can more clearly consider all the factors that are going to affect the AGVs. When implementing AGVs into new areas you still have details that are unknown and difficult to predict.

Person D also adds factors about how to utilize the AGVs once they have been implemented. They should be used in repetitive processes, that are relatively stable. AGVs work the best and are the most cost-effective when there is a steady flow of products.

6.4 Questions related to Financial Factors

Financial aspects of AGV

Person D mentions the financial aspects of AGVs. AGVs require a large investment in advance and an approximately six-year investment horizon to be affordable. Person D adds that smaller companies have difficulty with the high initial investment and long-term investment horizons. This financial inflexibility is a major obstacle for smaller companies. For AGVs to be cost-effective they must replace at least two working shifts (~16 hours). Anything less than that will be difficult.

Because AGVs are still expensive and inflexible, it is difficult to find motivations for them in today's situation. Why not just have a flexible truck driver or conveyor belts that are cheap.

6.5 Questions related to Investment Motivators

Why did Wärtsilä decide to acquire AGV?

This question was only answered by person C and D. Person C mentions the usage and volume flexibility, and the flexibility for future visions and operations. He also adds that it is good timing for Wärtsilä since they are building a new factory and logistics center.

Person D mentions that Wärtsilä has a positive business case regarding AGVs. They have data, which shows more cost efficiency using AGVs, rather than using more traditional equipment. He also adds that conveyor belts for transportation would be impractical for their needs.

6.6 Questions related to Future

Do you think that more companies will start using AGV?

Do you believe that AGV is the future of logistics?

All interviewees agree that more companies will start using AGVs. Person A and B add that the industry is surely heading towards AGV solutions, and as it looks now, they are increasing. Person C and D mention that the increase in usage is connected to the cost of AGVs. Person D adds that AGVs are not smart enough and still too expensive. Person A says that there are mostly largescale industries that use AGVs.

AGVs are still being developed. Person B says that the development of the AGVs technology will affect the increase of usage. Person D adds to that by saying that users can increase if AGVs become more intelligent and cheaper.

"Do you believe that AGV is the future of logistics?" is more of a follow-up question to "Do you think that more companies will start using AGV?". All interviewees agree that the market is shifting toward these solutions and that they will be a part of the logistical future. Person C adds that the scale of AGVs will probably be wider. An example of this can be robotic arms attached to an AGV or drones that transport products.

7 Analysis

In this part, I will analyze the answers I received from my interviews and make connections with the theoretical part. In the beginning, I will have a brief summary of what was said in the interviews and then follow up with the analysis. I will also add my own thoughts in some cases.

7.1 Analysis of questions related to Technological Factors

What features should AGV have?

The answers to this question were about the importance of security, software, and the AGVs capabilities. The importance of safety and AGVs equipped with safety features is connected to the EN ISO 13849-2015 safety standards. These standards are required to be followed and state that AGVs manufacturers must reach at least a PLd performance level. This level clearly indicates the need for safety lasers and scanners. PLd also emphasizes the need that a single failure does not lead to loss of safety. This is connected to the features that AGVs must stop in case of a signal loss to prevent potential accidents.

The need for software integration clearly shows how interconnected the AGV needs to be with other systems in order to work properly. This is possible due to the development of IoT. AGVs communicate through the internet with management systems. IoT also allows the censors and scanners to work properly by communicating with the AGVs own system.

Weight and height requirements are connected to the load capacities. The load capacity needed is determined by what you are transporting. The height aspects are also connected to the Pallet block-stacking pattern, which mentions the need to have the proper shelving height in the warehouse. Both these factors determine what type of AGV is best suited for your needs.

What are the weaknesses of AGV?

The answers to this question were about lack of intelligence and flexibility. Data requirements for the AGV are connected to load capacities. This clearly indicates the AGVs need for data on the weight and dimension of what it's going to transport. As mentioned in the interview it might be a good thing for a company to finally gather data about all its products. This might be good to have for the future.

What AGV models are best suited for Wärtsilä's needs?

The answers to this question were about models that are best suited for Wärtsilä´s needs and also what additions could be useful in the future. The models suited for Wärtsilä are connected to the

properties factor. The forklift, counterbalance, and heavy burden are model-dependent capabilities since only specific models are equipped with these abilities. When comparing these models to the different AGVs in the theory part you can compare these with the heavy burden carrier and forklift truck. The forklift truck is equipped with counterbalance capability.

When comparing the most suitable AGV models to the market size chart you notice that both these two only take up a small portion of most common models. This could maybe be due to most companies needing to carry lighter items.

7.2 Analysis of questions related to Employee Factors

How do you think AGV affects productivity?

The answer to this question says that AGVs should increase productivity. There were also mentioning's about potential problems in the less integrated parts and challenges in calculating flow. Productivity is described as the effectiveness of a productive effort. The measurement of productivity is comparing hours worked to output. With AGVs as you can have them work around the clock if you so desire. The output can also be similar compared to humans. And as mentioned by interviewees AGVs do not require any breaks. Therefore, AGVs are ideal, since the increase in hours worked can be so large.

The fundamentals of goal setting theory can also be excluded completely with AGVs. Humans need targets to reach in order to achieve higher productivity. It also says that humans are more productive by having different motivators in place. These are for example having breaks and vacations. Humans are also more productive by having higher salaries and good working conditions. AGVs are machines and do not require any of these, which makes them ideal for having effective productivity all the time.

Challenges to increased productivity can arrive with the systems theory. Systems theory says that increasing higher productivity at one stage does not mean it will translate to the next one. So, this means that getting increased productivity through AGVs does not necessarily mean that the whole process will be more productive. If the next stage cannot handle the increase in an effective way.

How do you think AGV will affect the employees?

The answers to this question were about the potential negative feedback, innovation always having some pushback at the beginning, and less communication flexibility. Productivity can be connected to the way human employees have concerns about new innovations. What helps to increase productivity for employees are the different motivators such as higher salary, job security, and good working

conditions. Planning to introduce new innovations can cause productivity to get reversed. Let's say now employees do not know if they will have a job at all. If employees are in the unknown and think that their job security may be in jeopardy can cause productivity to decrease. This of course depends on what the innovation is.

The less flexible communication between AGVs and employees working around them is connected to the way AGVs work. AGVs use the implementation of IoT and communicate between their system and the warehouse management system. During the "old" days a worker could just talk to the forklift driver and make adjustments and changes on the fly, which is a more flexible way but less systematic.

7.3 Analysis of questions related to Warehouse Factors

What should be considered in warehouse design when thinking of AGV?

The answers to this question were about dimension, navigation, and the warehouse factors, which include warehouse design, layout, locations, and more. Firstly, the dimension of AGVs. All interviewees placed high importance on having appropriate dimensions surrounding the AGVs. This can be connected to the dimensions chapter which states that AGVs and the space around it need to be correctly measured. The design also needs to be thought out in an efficient way.

The interviewees also talked about the importance of having everything aligned, which they meant by having the floor and shelves aligned with each other, which is an accurate reason. The pallet placement angle in the theory part can be slightly connected to this. The pallet placement angle is more about the required space between shelves so that the AGV can place the pallets on the shelves. This is also an accuracy reason and having everything aligned makes it easier for the AGVs to keep the correct spaces in-between.

We have the drop-off and pick-up points which can be connected to locations. The locations part only explains where the points should be placed around a warehouse. From the interviews, we gathered more information about how they should be set up. The drop-off and pick-up points as mentioned need to be accurately set up with high precision.

The routes also come up by person B and C. This can be connected to the routing chapter. They say that the routing needs to be straight, effective, and fast. This statement matches with the theory part since you always should choose the fastest path for higher efficiency. The heuristics of routing did not get mentioned, but it still can be connected. There are many different heuristics to use in routing. The choice as stated is a doubled-edge sword. By this, it means that more complex routes can get better results but is harder to implement. All the interviewees have mentioned that it can be

challenging for AGVs to complete complex tasks. By this, you should probably stay to simpler routing heuristics.

Navigation also must be considered in the warehouse. There are many different navigation technologies, and they all have different requirements. Some have more, some have less. The technology used needs to be considered in the design phase of a warehouse when implementing AGV.

The three key factors which are efficiency accuracy and safety really summarise well what has been said in the interviews about warehouse design for AGVs.

Do you think that the introduction of AGV is easy or difficult to implement?

The answers to this question were about implementation and it being challenging. It should be done in steps for a simpler process. The implementation phase can be connected to all the factors that have with warehouse design, AGV models, and properties to do. This is because wanting to successfully implement AGVs you need to account for all the warehouse factors, and factors connected to the different models and their properties. If the warehouse is complex will also mean a more complicated implementation phase.

7.4 Analysis of questions related to Financial Factors

Financial aspects of AGV?

The answers to this question were about the need for a large investment in advance and a six-year investment horizon, which is a barrier for smaller companies. This can be connected to the financial factors of AGV. AGVs are expensive and cost approximately $100 000 to $150 000 depending on the model. Let's say you need five AGVs to manage your operations. This will increase the investment price to somewhere between $500 000 to $750 000. This only includes the cost of the vehicles and not potential maintenance or other expenses. There can be additional costs. This puts into perspective why it is a large investment for smaller companies to make.

7.5 Analysis of questions related to Investment Motivators

Why did Wärtsilä decide to acquire AGV?

The answers to this question were about usage and volume flexibility. The timing was also a key factor. Wärtsilä also has a positive business case regarding AGVs. This can be connected to the financial factors of AGV. AGVs are a $3.39 billion market (Asia-Pacific) and are estimated to grow. AGV is an expanding market, which is supported by the fact that big companies like Wärtsilä are acquiring them. The financial advantages are also supporting the reasons for Wärtsilä to acquire AGVs. These

were the reduction of labor costs, increase in productivity and safety, and lastly the modularity of AGVs.

7.6 Analysis of questions related to Future

Do you think that more companies will start using AGV?

Do you believe that AGV is the future of logistics?

The answers to these questions were about AGVs surely getting more usage in the future. Further development of the AGVs technology and price reduction will affect the increase in users.

This can be connected to financial factors. AGV is a growing market and is expected to expand at an annual rate of 13% from 2021 to 2028. The increasing number of companies using AGVs, which as mentioned by the interviewees is still affected by the technology and cost. The cost of a single AGV is still between $100 000 to $150 000. The price will of course vary due to different models and properties.

AGVs are expected to become more affordable. We are still in the initial phase of AGVs usage increasing. This will surely drive the innovation of the technology in this field forward, which in turn will drive the cost down and make AGVs more affordable.

8 Summary

The summary will include the conclusion from the result and analysis parts and also have a discussion part where I will go over the result, method, and further research that could be done in the future.

8.1 Conclusion

Now I will conclude with the key elements of each factor. Several things can be gathered and tied together with the research questions. The research questions were "What factors to consider when wanting to invest in AGV?" and "What are the advantages and disadvantages of investing in AGV?".

Firstly, we will start with technological factors. AGVs need to have proper safety measures. Mainly to ensure safety for workers, but also to protect the AGVs workflow. Software integration with the company´s own system needs to be done, which can be tricky. AGVs must be flexible for adjustments and have good recovery in case problems occur. You need to choose the right model for the right purposes. The AGV properties and capabilities need to fit your operations. The right models in Wärtsilä´s case are counterbalanced AGVs equipped with forklifts and heavy burden AGVs for heavier parts.

AGVs are weak to complex tasks. The more complex the task or the environment is will lower the flexibility of AGVs.

Then we have the employee factors. The implementation of AGVs means a change in the production philosophy. The change is from a flexible work way to a more systematic one. There will always be pushback and skepticism towards innovation at first. The view and mindset of employees hinge on if the innovation works or is a struggle.

Then we have warehouse factors. Warehouse design connected to AGVs relies on accuracy. Everything needs to be accurately designed in order to make it easier for the AGVs. Same things with routes, drop-off, and pick-up points. Accurate design and not too many complexities. Keep it simple.

Implementation will be challenging. It needs to be done in several phases to be an easier process. An interesting fact is that implementation of AGVs is easier in existing warehouses rather than being done together with a new one.

The last one of the factors is financial. AGVs require large investments in advance and an investment horizon of approximately six years. These are barriers for smaller companies. It is also still hard to justify the investment in AGVs. This is because they are still inflexible and expensive when compared to simpler ways, which are regular forklifts or conveyor belts. For AGVs to be cost-effective they need to replace at least two work shifts (16 hours). They also need repetitive tasks to be efficient.

Second, to last, we have investment motivators in general and for Wärtsilä. Motivators for Wärtsilä have been flexibility in usage volume, but also flexibility for future operations and visions. The timing is also good when considering new facilities at Vaskiluoto. Wärtsilä also has data that indicates that AGVs are the most cost-effective. Using older methods would also be impractical for their specific needs.

Lastly, we have future. AGVs will most likely be the future of warehouse operations and more companies will acquire them. Today barriers to flexibility, intelligence, and cost are still present. This should be solved by advancements in the technology of the AGVs, which will make them more flexible, smarter, and cheaper. Only time will tell.

8.2 Discussion

There were lots of theories that did not get brought up in the interviews at all. Reasons for this might be that AGVs are such a broad topic with so many details. When looking at each factor you surely could do a thesis on just individual factors alone. The result I got from my interviews were expected with some instances being unexpected. The most unexpected part was that it is harder to implement AGVs in a new factory. You could think that it is easier to design and build everything together from the ground up, but this is not the case. Additional research could be done into the technical aspects of implementation. It was mentioned in the interviews about coding. This would surely be helpful for companies to know more about. Overall, the results that I got in this thesis were interesting and will surely be helpful to Wärtsilä and hopefully to other companies looking into AGVs as well.

I think my method was a good choice. Having interviews with people that are involved with AGVs from both Wärtsilä and DHL gives different perspectives. Having the interviews be unstructured allowed me to gather lots of data and different perspectives on each question. Looking back, it would have been interesting to have done surveys with multiple companies. With these surveys, you could ask questions about interest in AGVs and get data on what the thought process about AGVs is. How interested are companies actually and what are their uncertainties? Surveys could also have been done with logistical employees at Wärtsilä. With this, I would have acquired information about what the regular employee's actual thought processes about AGVs are.

I would also have liked to interview people that were involved with specific factors. This would have been to have one person who was mainly focused on warehouse design and another who focused on financials as an example. This way I could have asked more in-depth and specific questions about the different factors. This is tricky with large companies like Wärtsilä when there are so many different employees doing multiple things.

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