Vaasan yliopisto
UNIVERSITY OF VAASA

Olli Karvonen

Implementation and Usability of Automated Guided Vehicles: A Case Study of Wärtsilä Sustainable Technology Hub and Logistics Centre

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Author: Olli Karvonen
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Supervisor: Dr. Emmanuel Ndzibah
Instructor: Ari Mäkelä
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ABSTRACT:

Automated Guided Vehicles (AGV) are one concrete illustration of the Industry 4.0. AGVs are expected to increase the predictability, reliability, efficiency and safety of different logistics processes, and are capable of transporting different kinds of loads on predefined routes. They are increasingly implemented in a wide range of organizations globally and have achieved broad visibility over the past decade. However, a relatively limited number of case study -research exists in the context of AGVs implemented in the Finnish industry. Wärtsilä is implementing an AGV-system in its state-of-the-art facility, the Sustainable Technology Hub (STH).

To create knowledge in the context of the implementation of the AGVs in the STH, a research question was defined: *How can AGVs be implemented and utilized in an ever-changing corporate landscape?*

This thesis is written for Wärtsilä Finland Oy, which at the time of writing was establishing operations in the Sustainable Technology Hub in Vaasa. AGVs have a crucial role in the internal logistics of the facility, transporting predefined loads from the Logistics Centre to various locations of the STH. The study considers the implementation of the AGV-system in the facility, with four topics of research*: implementation, uninterrupt edness, responsibilities in problem situations, and lessons learned.* Also, the purpose was to identify the aspects leading to a successful implementation of an AGV-system. The information was collected through a literature review, interviews carried out from the personnel involved in the project, in addition to observations made as a member of the project team. The research process started after the innovative technology had been decided to be implemented, and therefore, the phases leading to the decision are not considered in this study.

As a result of the research, eight factors were discovered benefitting the implementation of an AGV-system. The interviews and observations helped identify the most likely reasons for interruptions in the AGV-system, thus helping the project team and other support staff to proactively avoid such interruptions. More so, such identification would lead to down time minimization of the individual AGVs thus maximizing their overall utilization rate.

KEYWORDS: System Implementation, Automated Guided Vehicle, Industry 4.0, JIT, Logistics Management, Wärtsilä

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TIIVISTELMÄ:

Vihivaunut (Automated Guided Vehicle, AGV) ovat eräs Teollisuus 4.0:n ilmentymistä. Vihivaunujen odotetaan kasvattavan logististen järjestelmien ennustettavuutta, luotettavuutta, tehokkuutta ja turvallisuutta, ja ne kykenevät kuljettamaan erilaisia kuormia ennaltamääritellyillä reiteillä. Vihivaunujärjestelmiä otetaan käyttöön enenevissä määrin erilaisissa organisaatioissa maailmanlaajuisesti ja ne ovat saavuttaneet laajaa näkyvyyttä viimeisimmän vuosikymmenen aikana. Kuitenkin, varsin rajallinen määrä tapaustutkimuksia on olemassa AGV:iden käyttöönotoista suomalaisessa teollisuudessa. Wärtsilä on ottamassa vihivaunujärjestelmää käyttöön huipputason tutkimus-, tuotekehitys- ja tuotantokeskus Sustainable Technology Hub:ssa (STH).

Tiedon tuottamiseksi vihivaunujärjestelmästä STH:ssa, tutkimuskysymys määriteltiin seuraavasti: *Miten AGV:t voidaan käyttöönottaa ja hyödyntää jatkuvasti muuttuvassa yritysympäristössä?*

Tämä diplomityö kirjoitettiin Wärtsilä Finland Oy:lle, joka kirjoitushetkellä aloitti toimintaansa STH:lla Vaasassa. AGV:illä on keskeinen rooli keskuksen sisälogistiikassa, kuljettaen ennalta määriteltyjä kuormia Logistiikkakeskuksesta useisiin eri kohteisiin STH:lla. Tutkimukseen sisältyy AGV-järjestelmän käyttöönotto neljän painopistealueen näkökulmasta: käyttöönotto, keskeytyksettömyys, vastuut ongelmatilanteissa sekä opitut asiat. Lisäksi tunnistettiin menestyksekkääseen AGV-järjestelmän käyttöönottoon liittyvät tekijät. Tiedot kerättiin kirjallisuuskatsauksen, käyttöönottoprojektissa mukana olleiden haastatteluiden, sekä projektitiimissä mukana olleen tekemien havaintojen kautta. Tutkimusprosessi alkoi innovatiivisen teknologian käyttöönottopäätöksen jälkeen, joten siihen johtaneita tekijöitä ei käsitellä työssä.

Tutkimuksen tuloksena tunnistettiin kahdeksan AGV-järjestelmän käyttöönottoa hyödyttävää tekijää. Haastattelut ja havainnot auttoivat tunnistamaan todennäköisimpiä syitä katkoksille AGV-järjestelmässä, auttaen projektitiimiä ja tukihenkilöstöä proaktiivisesti välttämään katkoksia. Lisäksi, tunnistaminen auttaisi minimoimaan yksittäisten AGV:iden toimintakatkosten kestoja sekä maksimoimaan järjestelmän käyttöastetta.

AVAINSANAT: Järjestelmän käyttöönotto, Vihivaunu, Industry 4.0, JIT, Logistiikan johtaminen, Wärtsilä

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Abbreviations

AGV	Automated Guided Vehicle
CPS	Cyber Physical System
CSF	Critical Success Factor
EWM	Extended Warehouse Management system
FAT	Factory Acceptance Test
HCI	Human-Computer Interface
IoT	Internet of Things
JIT	Just in Time
LNG	Liquefied Natural Gas
PC	Personal Computer
RTIS	Real-Time Information Sharing
SLAM	Simultaneous Localizing and Mapping
STH	Sustainable (Smart) Technology Hub
VNA	Very Narrow Aisle
WFH	Working from Home

1 Introduction

1.1 Background of the Study

Wärtsilä is building and starting operations in its ground-breaking production-, product research and innovation centre, the Sustainable Technology Hub (STH). An essential part of the STH facility will be the Logistics Centre, which will take care of the internal logistics of the facility. The facility will also include a Smart Partner Campus, where instances such as universities and other companies will have the opportunity to work and innovate together with Wärtsilä.

The facility will utilize an Automated Guided Vehicle (AGV) system, which has never been used in Wärtsilä premises in Finland. When the AGV system will be in place in the Sustainable Technology Hub facility, it will be a new situation and a new working environment for all the facility’s employees, with new processes and ways-of-working. This will require the employees to learn to work and operate in a completely new environment, which is to be taken into consideration in the implementation phase.

With the AGVs being implemented into the daily operations of the facility, the amount of huma-robot interaction will increase. This will require the employees to learn new sets of skills, one example being moving safely in the facility, where AGVs, manual forklifts and employees will share the same environment. Safety is one of the most important points of consideration in the entire facility and closely related to usability, to which strong focus will be given in this thesis. If a system or a facility is not safe, its usability can be considered highly questionable.

The new processes and ways-of-working highlight the importance of successful implementation of the system. Successful implementation will create foundations for first achieving the processes and ways-of-working to become routine for the people involved, and after that, developing and optimizing the process to support the principles of Continuous Improvement in the facility.

Because of the scale of the change, having proper change management in place is vital. As Tamilarasu (2012) describes, change management is a structured, proactive process to enable a group's (a team or an organization, for example) movement from the original state to a future state, which is presumably more suitable or preferable compared to the original one. In Wärtsilä context, this change refers to, for example, moving the operations from the Delivery Centre Vaasa to the STH and utilizing the new ways-of-working there. Properly managing this change is a necessityW to make the change a success.

On its website, Wärtsilä (2021e) describes itself as *"a global leader in innovative technologies and lifecycle solutions for the marine and energy markets"*. In Marine, the company mentions on its website (Wärtsilä, 2021b) that it has offerings to Yachts, Ferries, Offshore wind and Cruise, Merchant, Navy, Offshore, Fishing and Special vessels. This highlights the complexity of the company's offering and the possibilities of the company's technologies. A large amount of the products produced for the marine industry will in the future be produced in the STH, which acts as the physical context of this thesis.

In Energy, Wärtsilä (2021a) points out the transition to future with 100% renewable fuels. The solutions offered by the company in energy sector include power plants to enable grid balancing and energy storage, along with entire power plants operating on fuels that are 100% synthetic or carbon neutral. The company also mentions that it is working on creating a solution based completely on hydrogen. As with marine products, many of the products of this sector are currently produced in Delivery Center Vaasa and the production will be moved to the STH in the future. Notable is, that the process of moving the production to the STH is on-going at the time of writing this thesis.

Wärtsilä currently has over 17 500 employees working in over 70 countries. Of the total number of employees, 21% were located in Finland in 2021. The employees in Finland are located in Helsinki, Turku and Vaasa, where the Sustainable Technology Hub -facility is being built. The company has over 76 GW of installed capacity in 180 countries globally and its headquarters is in Helsinki, Finland.

1.2 Research gap, question and objectives

Research gap analysis was carried out selecting 20 databases to which I had access using my University of Vaasa -student account. Each of the search terms "Systems Implementation", "Automated Guided Vehicle", "AGV", "Industry 4.0", "JIT", "Logistics Management" and "Wärtsilä" were searched from the selected data bases and the number of hits calculated. The timeline was selected to be 01.01.2017 – 31.12.2021. "Just-in-Time" and "JIT" were combined, since in the context of logistics, they essentially refer to the same concept and from the perspective of this thesis, using the words independently and separately will not create any additional value. No other limitations to the searches were made.

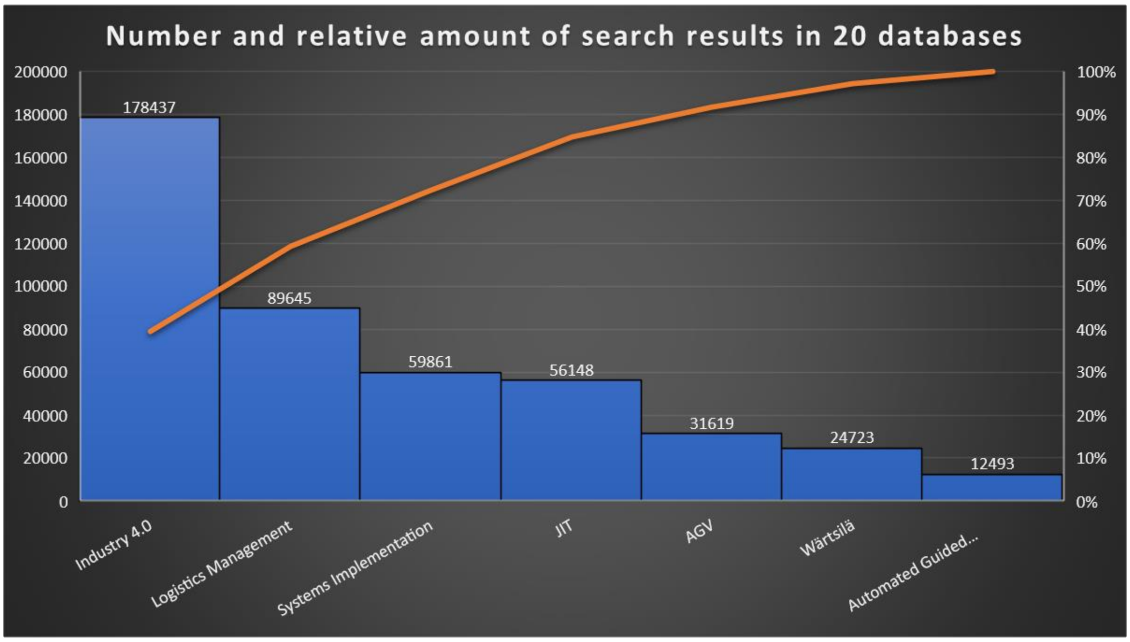

Figure 1: Number and cumulative percentage of search results

From Figure 1 it can be seen, that among the selected search terms, "Industry 4.0" received the largest number of results, whereas with "AGV" and "Automated Guided Vehicle", there were the second-least search results, together slightly more than Wärtsilä.

Figure 1 illustrates the popularity of research about Industry 4.0 and in this research gap analysis, it got nearly 90 000 more search results than Logistics Management, which was the second on the list.

In this research gap analysis, “Just-in-Time” and “JIT” were combined into one search in a way that only “JIT” was used, because “JIT” is essentially an acronym of “Just-in-Time”, and they refer to the same concept. With search term “Just-in-Time” an unnecessarily large number of search results were gotten, due to which it was removed from Figure 1. Having “Just-in-Time” in the list would have also de-emphasized the differences among the other search terms used, thus decreasing the informative value of Figure 1.

Figure 1 illustrates, that there is little existing research published about topics of AGV, Automated Guided Vehicles and Wärtsilä. It is also notable, that Systems Implementation was only the third on the list describing, with which search term the most results were found. This indicates on the one hand the relatively small amount of research existing about these topics and on the other hand the need for such a research.

Database	Number of results
ScienceDirect	2744486
ABI/INFORM Collection	214267
Google Scholar	191930
SpringerLink	46749
Taylor & Francis eBooks	44076

Table 1: Number of search results per each database

The selection of data bases was done based on their relevancy concerning the topic of this thesis. The five data bases with the most results were in descending order ScienceDirect, ABI/INFORM Collection, Google Scholar, SpringerLink and Taylor & Francis eBooks. An interesting finding was, that in ScienceDirect, there were almost 13 times as many search results with the selected keywords as in the second one, i.e., ABI/INFORM Collection. The numbers of search results are illustrated in Table 1.

This thesis will be formed around the central research question: *"How can Automated Guided Vehicles be implemented and utilized in an ever-changing corporate landscape?"*. As will be described in this thesis, the current operating environment for companies is highly dynamic and competitive, which sets various and high requirements for the successful operations of the companies. AGVs and their implementation is a relatively new area and a limited number of studies exist concerning the topic. During the research process it became clear, that few case studies about the topic exist and that a large relative amount of the existing research about the topic is simulation-based, in which many unexpected, uncontrolled situations are inevitably left without attention. This thesis intends to cover the mentioned topics and offer concrete examples of the topics that were come across during the implementation process.

There are five main objectives in this study. The first objective is to describe the overall functionality of the Sustainable Technology Hub and Logistics Centre. Secondly, I will identify the most important aspects and components leading to a successful implementation of AGVs. The third objective is to identify the direct and indirect roles of employees in the AGV process. Fourth, the I will identify co-user ability features of AGV systems from an end-user perspective. Fifth objective is to identify the employees' reaction when being introduced with AGVs.

From the company perspective, four main focus points were set to the case study -part: implementation, uninterruptedness, responsibilities in problem situations and lessons learned after the project. All these focus points are directly linked to the reliable operations of the system where issues are solved without any unnecessary delays and where responsibilities are clear in every situation. As with any large-scale project having widespread effects, it is highly important and valuable to ask after the project: "What did we learn from this?". In each project I have been involved in during my career in the company, various lessons have been learned and those lessons have helped me in later project's I have been involved in and my everyday work in multiple ways.

1.3 Definitions and limitations

Systems implementation, according to Pataki et.al. (2003), means deploying a system for the use of the intended user group and ensuring the system stays operative. When the system is operative, the users will carry out any necessary maintenance. *System implementation* includes ensuring all the requirements in terms of data, users' level of skill and the infrastructure, are met. Pataki et al. (2003) point out, that *System implementation* is divided into three phases: *preparing for system implementation*, *deploying the system* and *transitioning the system to the performing organization*.

In the context of this thesis, *systems implementation* is limited to bringing the AGV system into use and available for users in the Sustainable Technology Hub and Logistics Centre. All other AGV-related areas, such as designing the system, selecting the types of the AGVs or estimating the cost of operating the system are excluded. They are described only to the extent to which it is required to maintain the coherency of the thesis and enable the reader to understand the topic.

Confessore et. al. (2013) define AGVs as vehicles moving independently while carrying loads of various types and sizes. The vehicles are guided with various methods, one of which is guiding the AGVs with laser beams. AGVs have no human employees operating them, which from one perspective offers opportunities of various kinds, such as the elimination of human errors, but from another perspective, raise the concern of actions in cases of malfunctions and the safety of the system.

In the context of this thesis, AGVs will be described only in the context of the Sustainable Technology Hub and Logistics Centre. In the theoretical part of this thesis, the basics of AGVs will be described only to the extent to which it is required for the user to understand the Case-part. In the Case-part, the implementation process, usability and basic elements of the AGVs used in the Sustainable Technology Hub and Logistics Centre are discussed further.

Industry 4.0 has gained wide visibility among scholars and industries globally in recent years. It is often referred to as The Fourth Industrial Revolution, which highlights its significant effects on industries and businesses worldwide. However, as Culot et al. (2020) point out, the concept lacks a commonly accepted definition and rather has a commonly known set of features. The lack of common definition has made researching the topic more complex.

Of all Industry 4.0 -related aspects and topics, this thesis only concerns the concept and its features in the context of the Sustainable Technology Hub and Logistics Centre. In both of these facilities, commonly recognized features of the Industry 4.0, such as the importance of efficient data-processing, real-time information sharing, autonomy (of which the AGVs are a clear example) and process integration, have a key role in the daily operations. Also, the changing role of the human employee stands out.

Just-In-Time (JIT) refers to a production strategy, that originates from Japan and was first invented by Toyota. According to Munro et al. (2015), the concept considers all unnecessary storage of materials to be essentially waste. This means, that unnecessary inventory creates unnecessary costs, which is a form of waste that should be eliminated from the process. The concept of JIT encourages organizations and managers in the organizations to keep all the storage and inventory to the minimum. As pointed out by Cambridge Dictionary (2022b), the delivery in the context of JIT takes place at the exact moment of need, thus avoiding the unnecessary storing and processing of materials. This is supported by Singh & Singh Ahuja (2014), according to whom, decreasing the number of inventories is one of the aspects in which JIT can support. It should still be noted, as Emde & Boysen (2022) mention, one purpose is to ensure manufacturing has all the component it needs at all times.

In the context of the Sustainable Technology Hub and Logistics Centre, JIT is limited to on-time deliveries with right amount of intended materials meeting the quality requirements within the Sustainable Technology Hub and Logistics Centre. The thesis also discusses the intermediate storage locations, such as pick-up and drop-off points, to and from where the AGVs will take the pallets containing various materials. Thus, only internal logistics are concerned, and material movements and deliveries to and from the facility are excluded, despite their role in the overall material flow in the company.

At the centre of all logistics operations is the Logistics Management. According to Anagnostopoulou et al. (2019), having proper logistics management in place is vital in terms of success of companies in a world more global than ever. Calixto (2016) points out, that Logistics Management has a key role in Supply Chain processes, and it includes the flow and storage of products and services along with information throughout the process from the initial starting point of the process to its end. Council of Supply Chain Management Professionals (2022) also bgring out an important and relevant aspect of Logistics Management to optimize all operations and activities concerning logistics. Optimizing is closely related to reducing waste in various processes, thus increasing the amount of value created.

In this thesis, Logistics Management is limited to the context of internal logistics taking place in the STH and Logistics Centre, utilizing the AGV system. In this context, the purpose of Logistics Management is to manage and optimize the operations of the AGVs as part of the entire internal supply chain of the facility. Each time a pallet is transported from the Logistics Centre to the STH, information is moved between the AGV and the operating system, thus having the proper and constant information flow about the locations and statuses of the pallets and transports is of essence in terms of smooth material flow.

Wärtsilä is a Finnish company operating in the Marine and Energy sectors. According to the company's website (2021e), the company currently operates in 200 locations worldwide and has 17 500 employees. The company also mentions (Wärtsilä, 2020), that it is listed on Nasdaq Helsinki. According to Finder (2021), In Vaasa, Wärtsilä Finland is the biggest company providing revenue (2 billion Euros) and is also the biggest employer with its 3176 employees located in the city.

All the operations of Wärtsilä taking place elsewhere but in the Sustainable Technology Hub and Logistics Centre excluded from the scope of this thesis. Also, as this thesis only concerns the internal logistics of the facility, operations like production and business development are excluded. Only the activities, facilities, processes and employees directly or indirectly operating in the AGV-context are concerned in this thesis.

1.4 Research design

In this research, the main focus of the data is in its quality. At the very beginning, a brief interview was carried out with an employee of another company, which has the same supplier's AGVs in use as the ones that are implemented to the Sustainable Technology Hub and Logistics Centre. The purpose of this interview was to find out the possible challenges in implementing an AGV system, things that stood out during the implementation project, the most important aspects in the implementation, the most important aspects in the usability and measuring the results of the project. This interview acted as the starting point for this study.

To establish a foundation for the basic understanding of the overall concept, a theoretical framework was formed in this thesis. The purpose of the theoretical framework is to enable the reader to better understand the case study -part, where the knowledge gained in the theoretical part is utilized in practice and real-world case study. The study is mostly based on interviews carried out for the people involved and observing the project as an active member of the project team. Together, the aim was to establish a holistic understanding of the implementation project.

1.5 Structure of the study

This thesis is structured as follows: first, in the Introduction-part, the I have familiarized the reader with the topic, the scope and limitations, the objectives of the research and the objectives of the case-study.

The second chapter is about familiarizing the reader to the case company, its history, current operating environment and the future logistics management in an environment, where AGVs are part of the operations. The case company has a long history starting in Karelia in the 1800s, and a lot had happened by the time the STH-facility was opened.

Chapter 3 contains the literature review carried out for this study. The most essential concepts related to the study are presented and a scientific perspective is taken when connecting these theoretical concepts into the reality of the STH-facility. This is to offer the reader a better understanding of the steps taken in the implementation and commissioning phase.

Chapter 4 is about the empirical study of this thesis. As this thesis is essentially a case study, this chapter discusses the various phases of the implementation and commissioning of the AGV-system in the STH-facility, including the testing of the system and training of the employees. The interviews are also discussed in this chapter along with comments and insights from the respondents. The empirical study is carried out from a perspective of an active member of the project team, offering an inside-look into the project.

Chapter 5 brings out the lessons learned throughout the entire implementation project. Lessons learned is a highly important and relevant part of any successful implementation project and can create a large amount of valuable information and feedback from the participants of the project. The information gained during this phase can enable the participants to utilize this information in their future projects. I will also utilize my knowledge gained in my hobby, aviation, where there is a saying: “Each flight is flown three times”, endorsing the importance of proper planning, execution and debrief. I consider each flight to be essentially a project; a flight flown with a two-seat airplane has a surprisingly large number of similarities compared to an industrial implementation project.

Finally, in the conclusions-part, I will summarize the study, and revise the most important findings. Also, the possibilities for future research are described and discussed. As the time period of this thesis ends when the system has been implemented, a large number of future research possibilities exist, including financial aspects of the operations, possible changes in the overall safety of the facility and the entire new level of human-robot interaction taking place.

2 Case company background

2.1 Wärtsilä: History from the beginning to the STH

The history of Wärtsilä goes back more than 180 years to 1834. That year in Karelia, a sawmill was founded in Tohmajärvi. According to the company (Wärtsilä, 2022h) 64 years later, in 1898, the company was renamed Wärtsilä. In the years that followed, the company acquired other companies operating in machine and bridge construction along with shipyard companies located in Helsinki and Turku.

According to Wärtsilä (2022h), the company made the decision to start operating in Vaasa in 1954. The first diesel engine designed and constructed by the company was completed five years later, in 1959. The engine was a Wärtsilä Vasa 14 with three cylinders. The 14-series engines were the first to be used commercially in ships and the first such engine was installed to a ship being operated by Silja Line between Finland and Sweden. Approximately two decades later, in the 1970s, the Vasa 32 (later renamed Wärtsilä 32) was invented. This engine later became the most-selling engine and with its high versatility, the engine is used in a wide range of ships of different sizes and purposes.

In the book *"Of Machines and people"*, one of the things discussed by Wärtsilä (2019 p. 18 - 20) is the development of the cooperation between employees and the management level changed in the 1960s and 1970s. In the 1960s, the hierarchical way of management was evident, but the culture was renewing. In 1978, the *Acts on Cooperation within Undertakings* was set into force and in the 1970s, the employees working as chief shop stewards on the factory floor started getting invitations to the headquarters in Helsinki. This gave the employees an opportunity to express their experiences, which was also valuable for the top management of the company.

The next major milestone described by Wärtsilä (2022h) was when the company started building a shipyard in Turku. The entire Turku shipyard was moved to the location in 1983. Another such milestone can be considered getting the majority holding of a Swedish business, which essentially started the international operations in manufacturing for Wärtsilä. In 1984, the company became the first Finnish company “*being quoted on the London stock exchange”* (Wärtsilä, 2019, p. 99). During the 1980s, also communications started taking on a bigger role, which was visible in many ways (Wärtsilä, 2019, p. 19): the employee magazine saw the light of day and there were info boards on the factory floor containing information about that particular engine and its final location, for example.

Another major event that took place in the 1980s was, when a group of employees working in Vaasa understood, that not only could the company’s engines be used in ships, but also on land in electricity production. This effectively was the first initiative towards the energy business in which the company also operates today. As the company describes (Wärtsilä, 2019, p.71), the knowledge gained was a strong enabler in building floating powerplants, that could be transported to destinations far away. This then again was an enabler for decentralized energy production, which is increasingly discussed today in the ongoing work against climate change.

In the 1990s, Wärtsilä (Wärtsilä, 2022h) was merged with a company named Lohja. The newly founded company got a name Metra Oy Ab, which focused on diesel engine business and work related to building. In 1996, the European Works Council was founded and in the same year, several companies in the diesel engine industry were merged and finally named as Wärtsilä NSD Corporation. The need of communications also increased in the 1990s as everyone, including employees and investors, were informed about things happening in the company (Wärtsilä, 2019, p. 25).

During the 1990s, there was a global recession. However, according to Wärtsilä (2019, p. 78) it managed to cope with the circumstances and one major factor was the speed at which it could deliver its Wärtsilä 32 engine. The company points out, that whereas its competitors took close to a year to deliver an engine, the Wärtsilä 32 could be delivered in approximately five months, meaning a delivery time of only 50% of that of the competitors, which was a major competitive advantage on the market and helped the company succeed in those times.

In 2000, Metra was renamed Wärtsilä (Wärtsilä, 2019, p. 143) and in the years that followed, the company expanded its scope to biopower and ship propellers. The story in Asia continued with an agreement with Hyundai Heavy Industries in 2007 to establish a joint venture to produce dual-fuel engines to ships carrying liquified natural gas (LNG). A year later, the company started a joint venture with Metso. In this joint venture, Heat & Power business of Metso and Biopower business of Wärtsilä were combined, with Metso as the major shareholder. The same year, Wärtsilä established operations in various countries and locations worldwide, including Namibia, Madagascar, China and Dubai. The next major milestone towards sustainability was achieved in 2009 when the company was selected to the list of 100 most sustainable corporations worldwide. Essentially, the start of the millennium marked the transformation of Wärtsilä into a global corporation.

Despite the start of the focus on maintenance services in the 1980s, the service operations got scaled up in the beginning of the 2000s. According to Wärtsilä, the company understood, that *“Where the signing of the contract had previously been the end of the journey, it now became the midway point”* (Wärtsilä, 2019, p. 150), indicating how the company shifted from selling just products to being a lifetime partner for the operator or the owner of their product. The company also expanded their offering into services, where the customer could with a monthly fee get a promise from Wärtsilä, that their engine will operate according to expectations and the engine is constantly monitored and managed. This enabled the possible problems to be noticed and solved proactively, increasing the effective time the engine is used.

As Wärtsilä (2022h) describes, numerous large events took place in 2010s. The list includes installing fuel cell units to a vessel, signing a contract of supplying a tri-fuel power plant in Jordan (being the largest such facility in the world), launching of the Wärtsilä 31 engine, which was recognized by the Guinness World Records for being *"the world's most efficient 4-stroke diesel engine"* (Wärtsilä, 2022h), stepping to the solar energy business in 2016, testing and succeeding in remote ship control, and in 2018, opening two Experience Centres in Vaasa and Helsinki. In 2018 the STH investment was published, and that facility forms the context of this thesis.

2.2 Current operating environment of Wärtsilä

At the time of writing, there was a large amount of uncertainty present in the world. According to Lazarova et al. (2023), COVID-19 was declared a pandemic by the World Health Organization and the pandemic has had massive effects on the operations of various companies worldwide. As Rahaman et al. (2022) mention, the geopolitical uncertainty has increased, the supply chains are faced with disruptions and the world is still recovering from the Covid-19 pandemic. All these factors make the operating environment -thus the corporate landscape- more uncertain. This inevitably has effects on the companies operating globally.

Lazarova et al. (2023) divide the changes in the global work into three categories, *societal level changes*, *organizational level changes* and *individual level changes*. The changes in the societal level concern efforts paid to sustainability- and health and safety -related aspects, whereas organizational level changes refer to the possibly increased amount of remote work and employee engagement, and finally, individual level changes concern i.e., self-development in terms of skills required to perform well in the current world. All these factors will have an effect on the environment and circumstances in which companies operate and also concern the case company, which has already for a substantial amount of time taken extensive efforts to operate sustainably and of which the STH facility is a clear example. A notable aspect here is, as mentioned by Miroshnychenko et al. (2017), that *green supply chain management practices* are currently also appreciated by the market, which indicates, that sustainable operations and ways-of-working can be also financially feasible and beneficial.

As the current corporate landscape keeps changing, there is a need for companies to have readiness to change and reconfigure their operations if needed. As Maganha et al., (2018) mention, reconfigurability refers to adjusting and changing manufacturing systems in a cost-effective manner. This means, that the companies have the ability to change their operations to better fit the corporate landscape and their operating environment, thus have the ability to succeed better in the marketplace. The changes in this context can take place in the manufacturing environment, containing both the physical and virtual infrastructure. One concrete example of this kind of change are the AGVs, which bring an additional component (the physical devices) and their operating system (in a virtual environment) to the manufacturing system.

A massive and global trend in the corporate landscape at the time of writing was sustainability. As Lazarova et al. (2023) point out, companies are facing increasing expectations to act and operate sustainably. Wärtsilä, for example, has included sustainability to be at the essence of its strategy and purpose (Wärtsilä, 2022g). The company aims to develop solutions that are feasible both environmentally and economically in both marine and energy sectors. The company (Wärtsilä, 2022g) also recognizes the ongoing transition in energy systems, mentioning that the industry moves towards more sustainable energy systems. A concrete example of the focus on sustainability was renaming the Smart Technology Hub into Sustainable Technology Hub at the beginning of June 2022.

Wärtsilä has also put a specific sustainability strategy in place (Wärtsilä, 2022f). The strategy is based on three aspects: economic, environmental, and social performance. The focus on sustainability goes beyond its products and solutions; Wärtsilä also wants to operate in an ethical and safe way in all its operations. Related to the strategy, Wärtsilä has an extensive list of sustainability targets (Wärtsilä, 2022f). By 2030, the company wants to be carbon neutral in its own operations and have a product portfolio completely ready for zero-carbon fuels. By 2022, the company wants to use electricity, that has been produced with 100% renewable energy sources. The sustainability targets are reviewed by the Board of Directors and the Board of Management, highlighting the corporate-level efforts on the topic.

The COVID-19 pandemic has had massive effects on companies worldwide. This is also the case for Wärtsilä. The company describes in their quarterly and half-year financial reports (Wärtsilä, 2022b) and (Wärtsilä, 2022c), that the new Covid-19 infections worldwide have decreased the pace at which ships have been reactivated. China, for example, has a zero-Covid policy, which has resulted in lockdowns, causing congestions in its ports, significantly affecting global logistics. Also, some shipyards in China have had to declare force majeure due to the restrictions. As the company mentions, infections have affected the operations of factories, causing further effects on the availability of spare parts and raw materials, for example.

Wärtsilä is changing its role from being only a supplier of products into being an active partner in its customers' operations (Wärtsilä, 2019, p.150). According to the company, they want to coordinate and be actively involved in operating the products manufactured by Wärtsilä. This strengthens the relationships between the companies and changes the mindset from the traditional supplier-customer -way of thinking. A strong customer relationship is also highly beneficial in long term.

In the current operating environment, Wärtsilä recognizes the importance of cooperating with different instances, such as large companies, start-ups, and universities (Wärtsilä, 2019, p.190). In the Sustainable Technology Hub, a Smart Partner Campus has been established to offer a platform for co-creation along with developing and testing ideas and innovations together, which will benefit all parties. According to the company (Wärtsilä, 2022d), with mutual learning, the results can be achieved quicker. This is especially important in the era of the climate change, where innovations and rapid actions are needed to achieve the global targets to reduce emissions.

Currently, Vaasa is the biggest operating location for Wärtsilä (Wärtsilä, 2019, p.190), having around 3000 employees working in the city area. The company describes the Vaasa region as *"a leading Nordic hub of energy technology"* (Wärtsilä, 2019, p.190), highlighting the relevancy of the location in its operations. A major step was taken in the company's operations in Vaasa when the Smart Technology Hub -project was announced – later named Sustainable Technology Hub.

There are, however, various factors effecting the operating environment of Wärtsilä. According to the company's Half year financial report 2022 (Wärtsilä, 2022b), uncertainty is clearly and widely present in the market in terms of price volatility, volatile geopolitical situation, Covid-19 pandemic, disruptions in supply chains and the availability of components. This has caused uncertainty to investments made by countries and companies due to the increasing regulations. Cyber threats are also playing an increasing role, forcing companies to take constant and increasing actions to ensure a safe way of operating.

The movement towards renewable and more sustainable energy production is also a relevant part of the operating environment. As the company (Wärtsilä, 2022a) mentions, there are ambitious decarbonization targets set, causing investment strategies to be updated, resulting in delays in investment decisions. However, despite the challenges, the increasing decarbonization targets can also offer possibilities for the company in terms of need for balancing power for energy systems using renewable energy. The company has a wide range of products and solutions in the category of storage and optimization.

In the marine business, the company (Wärtsilä, 2022b) sees that an increasing number of cruise ships have been reactivated as the Covid-19 restrictions are decreased. There is also an increasing amount of activity in the container shipping market in terms of amount of freight transported and vessels ordered. Also, an increasing demand exists for offshore construction vessels operating in wind power -related activities. An effecting factor to this is the increasing number of offshore wind farms being built. However, the price of crude oil has increased significantly.

Overall, there is a large number of aspects effecting the operating environment of Wärtsilä. These include the Covid-19 pandemic, the volatile geopolitical situation, volatility in prices of components and raw materials, uncertainties in availability of components and raw materials, the movement towards more sustainable ways of producing energy, the increasing amount of renewable energy being installed and the increasing efforts to decarbonize the marine industry. In this environment, Wärtsilä (2022c) highlights its desire to offer lifecycle solutions and deliver guaranteed performance to its products and solutions.

2.3 Future logistics management in the context of AGVs as part of Wärtsilä's logistics operations

Having logistic operations carried out in a coordinated and organized way is an integral part of the operations in the STH-facility. This, however, is a complex task, since according to Wärtsilä (2019, p.80), there are approximately 8000 parts in a Wärtsilä 31 -engine, for example, which is just one of the engines produced in the STH. The parts must be delivered to the various specified locations when the employees need them, in the right amount and without having caused any damage to the components during transportation from the Logistics Centre.

A distinguishing factor compared to the logistics operations in Delivery Centre Vaasa is, that in the STH-facility, also AGVs are present in the logistics activities. The AGVs set new requirements in terms of the physical infrastructure and the ways-of-working. Some of the shelves must be equipped with additional safety equipment and the corridor floors in the facility must be marked to ensure the cleanness of the routes used by the AGVs to avoid any risks of crashes and unnecessary stops. Therefore, logistics management takes an even bigger role in the new facility.

A core part of the operations in the STH facility is the principle, that whenever materials move, information moves. Different systems and interfaces are in place in the facility to serve the employees and the production in the most suitable way possible. One of the concrete examples is a user interface, where the employees working in production can order a set of materials to a specified storage bin. The production determines, when the materials are needed and to which storage bin they are delivered, thus supporting the pull-mentality in logistics and manufacturing, and helping the Material Management - business unit to better serve Production. This way also unnecessary storing of materials can be avoided, thus limiting the space needed for that purpose and being able to utilize the existing space more efficiently.

A significant change caused by the AGVs in terms of logistics management is, that all the movements go through the defined processes in the specified systems. On a very concrete level it means, that the employees can no longer verbally ask a forklift driver to deliver a certain pallet to a certain location, but on the other hand, the movements are highly predictable and reliable. This way-of-working also brings constant visibility to the situation, making it easier for everyone involved to gain a sufficient situational awareness of the overall situation in the facility.

Overall, the increased amount of automation and having AGVs involved will most likely cause changes in logistics management in the context of the STH-facility. These changes are to be prepared for and with that, the changes have a higher probability of being successful. Proper training and communication will be crucial, and the employees will have to be given opportunities to express their thoughts and possible concerns. Change resistance is a possible scenario, which must be prepared for. The increasing amount of data collected in the operations will also enable new tools for logistics management, including better visualizations of the operations and the possibility to find and thus solve root causes of problems.

Having proper logistics management in place in the modern operating environment of companies is highly important. Because of the increasing role of smooth logistics processes and the complexity of the modern supply chains and logistics overall, there must be proper management in place for logistics operations to make it successful. Proper and high-quality logistics operations can also act as competitive advantages for companies. The purpose of Logistics Management is, according to Westland (2019): *"finding more efficient and effective ways to move resources and products from conception to completion, and, finally, to the customer"*. Therefore, the goal of logistics is essentially serving customers.

Westland (2019) describes logistics management as *"a detailed process of organizing and implementing an operation"*. The flow of logistics, according to Westland (2019) consists of the flow of goods and information. It is once again pointed out, that very often the situation is, that if information doesn't move, goods and materials cannot move. This is also vital from the perspective of maintaining awareness of material levels to avoid situations where the company runs out of a needed material.

As Westland (2019) mentions, the focus of logistics management in business is essentially divided into two, first of which is *inbound logistics for internal functions*. Here, the focus is on ensuring that the internal actors of the organization have the resources they need to produce the goods or services needed. The second one is *outbound logistics for the external flow from the point of origin to the point of consumption*. It is notable, that the first one has a direct impact on the second: if the first one fails, it will have consequences to the second one, too.

Westland (2019) mentions four types of *logistics management*. Three of these are directly linked to the topic of this thesis, namely, *supply management and logistics*, in which the materials are transported and stored, and *distribution and material movement*, in which the materials are moved from place of origin to the place of need. Tracking of the materials is also included in the latter one. There are multiple attributes here, which are essential in the context of the STH and Logistics Centre: materials arrive from the original storage bin to the temporary one, from where the AGVs deliver them further.

The third topic included is *reverse logistics and product return*, which means the materials and components moving, for example, from the production and back to the storage facility.

There are various dimensions that effect the type and scale of the *logistics management* needed, as mentioned by Westland (2019). With simple operations with few phases and people, the requirements of the *logistics management* needed are not as high as in a facility such as the STH, where highly complex products are produced with large number of components and materials. This requires the *logistics management* to be well-planned and executed.

3 Literature review

The fourth industrial revolution is playing an increasingly important role in various industries. According to Zuin et al. (2020), as the constant change in the market environment forces companies to be capable of quick adaptations, automation is utilized in an increasing manner in production environments and factories. Leitão et al. (2016) agree by pointing out the need for production processes that are able to react quickly to the changing environment and where only minimum amount of waste is created.

This literature review is focused on topics directly or indirectly related to AGVs. Despite their potential in the logistics industry, they also have a certain set of problems. Zhong et al. (2020) have divided these problems into three main categories, including *AGV scheduling*, *AGV path planning and AGV control system implementation*. These issues are discussed in general, but especially in the STH-perspective, to connect the theory to the context of this study.

AGV scheduling is related to managing the AGVs in such a manner, that any failures in the system can be avoided. Saidi-Mehrabad et al., (2015) mention that the poor coordination and management of the AGV fleet might lead to negative consequences across the AGV system. This can cause threats to the productivity of the overall facility, since the material flow of the facility is affected, thus not being able to transport a sufficient amount of materials from the place of origin to the needed place.

AGV Path planning considers planning the vehicles' routes in a way, that there will be no deadlocks. Zhong et al. (2020) note, that the optimal route for AGVs is not necessarily the shortest one, which will increase the travelling time from the original pick-up spot to the drop-off point, where the AGV leaves the materials. Notable here is, that this will also increase the operating costs of the AGVs: the more the AGVs move, the more they consume energy and the more their parts wear, for example. The relationship between financial efficiency of the AGVs and their optimal routing and path planning are not studied in this thesis.

Six AGVs will be operating in the STH facility. The space in which the AGVs will operate is limited and shared with other vehicles and human employees. As pointed out by Liu et al. (2017), an essential part of successfully planning a multi-AGV system is to ensure that the paths of the AGVs are conflict and collision free. This relates to two of the basic problems in AGV systems: *scheduling* and *path planning*. In the STH-facility, the routes of the AGVs have been designed to avoid any collisions. Because of the routing, the number of locations where the AGVs will have only one lane to two directions is minimized. Scheduling is handled with the CWay-software in the AGV PC, and the software does the selection for an AGV to take a certain task, when it is given by the EWM.

On their website, Solving (2022) describes the overall layout of an AGV system. The layout is described in Figure 2. At the top of the hierarchy is the Customer Host system, which in the case of STH and Logistics Centre is the Extended Warehouse Management system (EWM). EWM gives the orders to the AGV System Controller or System Manager, which has a constant bidirectional communication with the AGV System Manager, which essentially acts as the brain of the system. It can also be considered as the bridge between the EWM and the AGVs in the sense, that it transports and distributes the tasks and their statuses between the EWM and the AGVs.

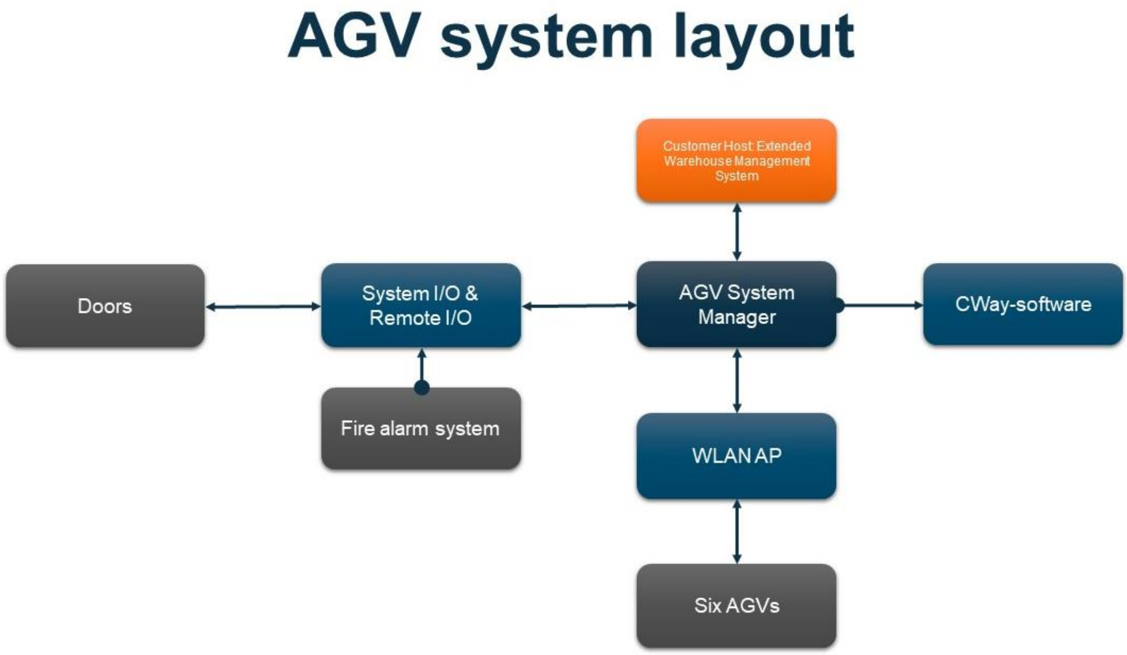

Figure 2: The layout of the AGV system

System I/O and Remote I/O are involved in transporting requests to doors, for example. This means, that whenever an AGV approaches a door, it sends an opening request to the I/O, which initiates the command for the door opening and once the door is opened, the AGV system and eventually the individual AGV receives the information of the door being completely open. This reduces the need for the AGVs to decrease their speed before the doors, reducing the lead times of the transportation tasks. A possible risk without this system is also, that a door would be half-opened, and the safety scanners would not be able to detect it, thus the crash between an AGV and the half-opened door would be evident. The System I/O and Remote I/O also enable the fire alarm system of the facility to be connected to the AGV system: whenever there is a fire alarm in the facility, the AGVs will stop, and all the doors will be closed.

The AGV System Manager is also closely linked to the CWay-software, which, according to Solving (2022), offers a visual user interface from which the users can see the statuses and locations of the AGVs in the facility, in real-time. The system constantly collects data and saves it to a log file, which the later-created AGV visualization is completely based on. From the usability perspective, the visualization is likely to offer possibilities for improvements in terms of uninterruptedness of the system.

3.1 Illustrations of Industry 4.0 in STH and Logistics Centre

Industry 4.0 essentially represents the *fourth industrial revolution*. AGVs are a clear visual illustration of the Industry 4.0. According to Ammar et al. (2021), the concept was first revealed in Hannover Messe 2011, which is a Trade Fair taking place in Germany. Ammar et al. (2021) mention, that with the help of the modern digital tools, optimizations can be made in inventory and reductions achieved in terms of material waste, which are to increase effectiveness of the companies' operations and increasing financial profitability. This is positive also from the environmental perspective: the waste created in the process has to be processed in some way, which inevitably creates direct and indirect emissions. Therefore, utilizing the tools enabled by Industry 4.0 has also numerous positive environmental effects.

Despite the Industry 4.0 being increasingly utilized in various industries, its actual definition appears to be relatively abstract in many ways. This perspective is pointed out by Culot et al. (2020) and they point out that since there is no common and universal definition for the concept, it is problematic to construct theories upon it. Also, comparing theories is more difficult because of the poorly defined term. In the context of this thesis, it sets limitations on how I can describe the *automated guided vehicle system* in the context of Industry 4.0. However, the Industry 4.0 in the context of this thesis acts more as a theoretical framework and less as the concrete foundation on which this study is built upon. The actual context of this thesis is the STH-facility rather than the Industry 4.0 -framework.

Because of the poorly defined concept of Industry 4.0, Culot et al. (2020) describe three aspects of the concept, *key enabling technologies*, *distinctive characteristics*, and *possible outcomes*. They highlight data utilization and processing, physical-digital interface and network, which all are related to connectivity. Data utilization refers to an increasing amount of data being used in the operations of organizations, from shop floor to top management and everything in between. In the era of concepts like *big data* and *automated decision making*, data plays a vital role in companies' daily operations, such as monitoring material levels in storages or workloads in workstations. In a company like Wärtsilä, where the material movement takes place with high volumes, data is an essential part of operations taking place across the organization, for example in terms of knowing if a certain delivery from the Logistics Centre to the STH has been completed or whether one of the AGVs is in error state.

Culot et al. (2020) mention *"virtualization, real-time information sharing and autonomy"* as the characteristics commonly discussed in the context of Industry 4.0. Cambridge Dictionary (2021d) defines virtualization as *"the process of creating a virtual version or several virtual versions of a piece of computer equipment or software"*. This is supported by Verdouw et al. (2016), according to whom it enables the actors in the supply chain to manage and control the events taking place in the supply chain. It can also give the actors the opportunity to optimize the different processes in the supply chain, thus improving the overall functionality and efficiency of the supply chain. An important feature of virtualization is, according to Vedrouw et al. (2015), that it can eliminate the need of the controllers of the supply chain to be physically at a close range to the actions taking place, thus enabling remote control of the events. This is a significant improvement in terms of flexibility. Virtualization can also help in simulating past and future states of the system or the supply chain.

Virtualization has various benefits to it, including modelling and testing various processes and devices in a virtual environment, thus eliminating the risk of causing costs because of unnecessary testing with real materials, or worse, occupational accidents because of failed equipment or poorly planned tests. In the STH-facility, the entire AGV system including its storage bins and individual AGVs, is visualized in a separate software. Any changes needed can be carried out first in a virtual environment and only when the changes are approved, the changes would be carried out in the real environment.

Real-Time Information Sharing (RTIS) is related to Customer Relationship Management (CRM) and according to Ghouri (2019) means sharing the responses given by the customer after the delivery of the service provided by the company. In the STH facility, each transportation of materials is recorded. Whenever a transportation of a pallet is carried out, the transportation task is allocated to the resource (AGV, for example), after which the AGV executes the task and when the task is finished, the status of the task is marked 'Complete'. The employees working in the places where the pallets are delivered have a direct contact to the employees working in the internal logistics, thus are able to provide feedback and/or requests if needed.

In the context of the Industry 4.0, autonomy is one of its main features. Aoun et al. (2021) define the automatic decision-making process as one of the criteria of the concept. The various nodes of the industrial systems can monitor the status and condition of the system continuously and report them independently without human intervention, which helps noticing possible malfunctions in advance, thus reducing downtime costs, and increasing the amount of predictive maintenance instead of reactive maintenance. In the context of the AGVs operating in the STH-facility, the AGVs will independently move to recharging stations when their battery reaches a certain level and move a pallet to the error handling location called CarWash, if the information the AGV has read from a barcode in a pallet is not equal to the information in the Warehouse Task the AGV received from the EWM.

Possible outcomes listed by Culot et al. (2020) include increased flexibility and productivity, both of which can reduce waste from the overall process and operations of organizations. The increased flexibility can enable organizations and companies to better serve their customers in terms of customizing products, which used to be impossible or would have previously required a significantly larger amount of resources, thus making it financially less beneficial. Increased customization can increase customer satisfaction, which can strengthen the existing customer relationship and thus increase the threshold for the customer to change supplier. Therefore, it can be also financially beneficial for companies. Flexibility and productivity are also increased with the AGV-system in the STH-facility: the AGVs can operate 24/7 even when there are no human employees present at the site.

Ammar et al. (2021) note that there are three technological factors, that encourage the concept of the *fourth industrial revolution*, such as *connectivity*, *intelligence*, and *flexible automation*. Cambridge Dictionary (2021a) define connectivity as *"the ability of a computer, program, device, or system to connect with one or more others"*. In the context of Industry 4.0, communication and information sharing are vital parts, because several outputs of certain parts of a process can act as inputs to the next one and if the connection fails, the inputs for the next part of the process are not given or are given falsely and there is a risk of the entire process failing. As Issaoui et al. (2021) mention, in transportation, for example, with connectivity it is possible for different vehicles to communicate with each other and their environment. It should be noted, as Aktas et al., (2021) highlight, connectivity is also a key part in achieving flexible networks, which means, that the networks have the ability to react to various situations and scenarios.

The role of connectivity is evident in the context of the STH, where the AGVs receive their orders from the EWM, in which a human employee is at the very beginning of the overall process. This highlights the interconnectivity between machines, software-based systems and people. Connectivity in STH is also linked to the actual movements of the AGVs in the facility: without proper connections and communications between the AGVs and the surrounding infrastructure, the AGVs would not be able to operate.

Intelligence is a term often used in a number of contexts, but Cambridge Dictionary (2021b) defines it as *"the ability to learn, understand and make judgments or have opinions that are based on reason"*. These can be described as features of Machine Learning and Artificial Intelligence, for example, which are able to change their behaviour based on the inputs and feedback they receive. At the centre of this is the ability to make decisions. Kumar et al. (2022) discuss the potential of artificial intelligence in warehouse operations and point out, that artificial intelligence could be utilized in deciding, which type of cargo is transported with which kind of vehicle or when would be the most reasonable time to recharge the vehicles. This can offer potential for balancing the workload between different types of transportation vehicles and ensuring that the means of transportation is the most optimal for each type of load. The AGVs in the STH-facility can act as platforms for utilizing artificial intelligence and machine learning, but in the original state, they only act according to predefined settings.

Artificial intelligence can help the process to create more outputs with fewer inputs, which is can be considered as a process improvement. Despite intelligence being one of the embodiments of the Industry 4.0, it is left out of the scope of this thesis, because it is not considered as an essential part of this thesis; the AGVs used in the facility are not considered intelligent but only follow the commands of the CWay-software.

According to Zhong et al. (2018) Industry 4.0 utilizes Internet in industrial systems, such as in automation. Internet is largely a way of real-time communications between different parties, such as devices and people, in various systems. These communications can be in the form of instructions, commands or requests. Also, several platforms for data visualization and reporting are based directly on Internet, highlighting its versatility. In the Wärtsilä's Logistics Centre, locations and amounts of materials are listed in the EWM system, which is an Internet-based system. Also, the orders for the AGVs to take materials from the Logistics Centre to the STH are given in EWM and the barcode scanners in the AGVs are connected to a wireless network to send the read information to the EWM.

Despite the possibilities of Industry 4.0, it has its set of challenges. Aoun et al. (2021) divide the challenges of Industry 4.0 into three categories: technical challenges; economic challenges; and regulatory and social challenges. When it comes to the technical challenges, the exponentially increasing amount and use of data sets higher requirements for the technical devices in terms of data processing capabilities (such as RAM-memory). The employees must have an increased technical knowledge and skills to work with the new devices. The ways-of-working with the new systems and devices can significantly differ from those of the traditional systems, and it will inevitably take time for the employees to learn the new working models. This is visible in the STH-facility: the employees will use systems that were not used in the Delivery Centre Vaasa, they will work in an environment shared with AGVs, and all orders for pallets to be delivered to production are created in a specific system, whereas in the Delivery Centre Vaasa, the employees could verbally ask their colleague to deliver a certain pallet to a certain storage bin.

Related to the technical challenges of Industry 4.0 are the concerns about security. Since the amount of data collected, processed, and stored is bigger than ever, the risk of losing the data is relevant. Hackers and cyber criminals have an increasing number of tools and ways to unlawfully access systems, and cyber-attacks pose a massive challenge for companies of all sizes and industries. According to IBM (2021) a single data breach costs on average 4,24 million USD, highlighting their massive effects on companies of various sizes. The most common reason causing the attacks were compromised credentials, which is directly linked to the human-factor in the systems. The case company described in this thesis takes continuous and extensive efforts to maintain a high level of cyber security, i.e., by training employees on a regular basis.

According to Aoun et al. (2021), the main economic challenge of Industry 4.0 is the uncertain return on a possibly very high investment. This means that the implementation of Industry 4.0 technology can cause high costs to the company and the return on investment is uncertain and depends on a number of factors. Therefore, companies implementing Industry 4.0 technologies cannot be completely certain, whether the implementation project will financially be a success or a failure. Covid-19 pandemic has also widely increased uncertainty, which for many companies can further increase the threshold of investing to Industry 4.0 technologies.

The third challenge of Industry 4.0, according to Aoun et. al. (2021) contains the *regulatory and social challenges*. At the centre of this concern is data processing and especially data security. In EU, the General Data Protection Regulation (GDPR) was applied on 25th of May 2018 and, according to GDPR.EU (2022), it is globally the tightest law when it comes to privacy and security. Since the amount of data is currently larger than ever and keeps increasing, companies are forced to take significant actions to ensure their operations being lawful and in accordance with the various data protection and processing policies, of which GDPR represents an example. Many companies have designated legal departments to ensure their operations meet the current legal requirements and train their employees in the context of GDPR.

As the word *usability* in the subject of this thesis indicates, human factors are one of the core points of focus. As Cimini et al. (2020) highlight, the technological development needs also support from the human-aspect. Despite the already large and increasing amount of automation in various modern processes, people will still be an integral part in the process and affect and be affected by it, and for the technological part to succeed, it will require the human employees to enable and support it. This relates to the changes caused to employees, which can create change resistance, which is managed through change management.

The emerging technologies will require the current employees of companies to learn new skills. These skills are often related to IT technologies, Cyber-Physical Systems (CPS), automation and operating in an environment, where, for example, AGVs are actively present. As many of the people working in the STH facility do not have previous experience of AGVs, they have to develop their professional skills to operate efficiently and effectively with the system.

As Maganha et al., (2018) suggest in their research findings, new technologies that came along the Industry 4.0, such as flexible transformation systems, collaborative robotics and the analytics of big data, can help manufacturing systems' ability to be reconfigured to match the changing requirements in terms of service and production. Therefore, it seems evident, that not only does Industry 4.0 help companies better serve their customers already, but the concept also offers them possibilities to increase their level of customer service in the future. Therefore, the readiness to reconfigure and adjust operations in a cost-effective and timely manner, can be a competitive advantage and help the companies to better operate in their environment. The need for reconfigurability became apparent in the STH-facility, when an engine type not produced there before, had to be implemented for production.

The change brought by Industry 4.0 will widely effect employees also from the social perspective, effects correlating with various aspects, such as the position and current tasks of the employee; the employees with higher education and with tasks requiring human consideration are less likely to be affected by the change, but employees with possibly lower education and more routine tasks, such as packaging and delivering items and materials between different locations, have a lower threshold of being replaced by automation. The social aspect is a highly relevant one, because it relates to more societal phenomena such as (un)employment rates. This is supported by Lazarova et al. (2023), according to whom automation has already had visible effects on jobs with lower skill requirements and the replacement effect is already the reality in some cases. This, however, is not at the scope of this thesis, so it is left to minimum attention.

It is also notable, that not only does the Industry 4.0 endorse the movement towards an increased amount of automation, also the COVID-19 pandemic accelerates this transformation. This is clarified by Garretsen et al. (2021), who point out that robotization is more likely to be implemented in different companies and organizations. They add, that the effect on human employees is not entirely positive, however, but is of labour-saving nature, effecting negatively on all kinds of workers. This means, that while the requirements for the skills of employees change, the need for human employees is reduced, which can be considered negative in various ways and is closely linked to the social perspective mentioned earlier. This is, according to Ozkiziltan & Hassel (2020), especially relevant for low-skilled, low-educated labour, whose tasks are more easily replaced with automation.

Not only does automation replace some of the tasks previously carried out by human employees, but, according to Ozkiziltan & Hassel (2020), it also changes and even complements the existing ones. Thus, the contents of a large number of human employees' work will be changed and complemented in the way, that in addition to their existing tasks, in the future they will also have to work on non-routine tasks, such as problem situations. During the AGV-implementation project taking place in the STH-facility, a selected group of employees were trained to operate in and with the AGV-system, carrying out non-routine tasks that might occur both during and after the implementation project of the AGV system.

As Acemoglu & Restrepo (2018) mention, automation can also increase inequality. This is related to the tasks with low skill requirements being replaced by automation, thus narrowing the number and scope of tasks available for employees with a lower skill set. This is already visible in various modern warehouses and logistics facilities, where the amount of automation has increased, and the tasks of human employees has simplified. Here, however, it should be remembered, that while in some cases the tasks might be simplified, the employees must learn new skills, such as operating in complex virtual environments, such as warehouse management systems.

3.1.1 Supply Chain 4.0 in the context of the STH-facility

Modern companies and organizations do not operate in a vacuum; they compete against and cooperate with a number of different actors on global markets. At the centre of the cooperation taking place between various companies and organizations are supply chains. Cambridge Dictionary (2022a) defines supply chains as *"the system of people and things that are involved in getting a product from the place where it is made to the person who buys it"*. It should be noticed, however, that the "person" buying a product can also be a company or an organization and that the finished products made by one company and sold to another company, can act as inputs or raw materials to the lastly mentioned. An example of this is a factory making screws. For that company, the screws are finished products, but for a company making engines, they can be considered raw materials. An important point to notice is, that getting a product or service delivered always requires and includes logistics.

A crucial aspect in any supply chain is coordination to ensure the movements of the materials is controlled. According to Bassiouni et al. (2023), the network consisting of people, machines, and individual events and activities must be coordinated. Besides coordination, the activities and events taking place in supply chains must be planned to ensure that right resources, such as materials and people, are available at the right place, at the right time, in the right quality and quantity. This is a crucial part of the logistics operations taking place in the STH facility, where a large number of materials are delivered to a large number of locations across the facility. As Bassiouni et al. (2023) continue, a delayed delivery has negative consequences for production and in the worst case, to the customer. These situations must be avoided and therefore, having proper supply chain management in place is important.

The ongoing *fourth industrial revolution* has brought a concept called Supply Chain 4.0 along with it. According to Ferrantino & Emine (2019), supply chain 4.0 will have an influence on how companies design and plan their supply chains, as well as reverse logistics. They also point out, that in supply chain 4.0, the operations are more driven by customers, which is the case in Wärtsilä's STH-facility: the production will order materials from the Logistics Centre and only then will the picking and transporting of pallets take place, which can reduce unnecessary storing of materials next to the production area, increasing the efficiency of the utilization of storage space in those areas. As Ferrantino

& Emine (2019) mention, Supply Chain 4.0 will offer better visibility and automation to the warehouse processes overall. This is clear also in the STH-facility, where the consumption of materials will in some situations automatically create purchase requests for new materials, meaning, that the request to transport a pallet containing certain materials, will ultimately be the trigger to create a new purchase requisition for those materials. Since the products built by Wärtsilä are complex and contain a large number of parts and components, automating this process can be considered an efficiency improvement.

According to Alicke et al. (2017), Supply Chain 4.0 increases the amount of physical and planning tasks being automated. This will increase the efficiency of the overall supply chain. They describe also, how robots will increasingly take over the material handling. In the AGV system in the STH-facility, one concrete example of this is how the CWay-software allocates the transportation tasks to the individual AGVs and the AGVs carry out the given tasks. As Alicke et al. (2017) mention, the implementation of the autonomous vehicles can enable cost reductions and reduce lead times. As the AGV system constantly monitors the tasks it receives, the utilization rate of the AGVs is constantly maximized without human intervention required. This reduces the involvement of people in the overall process, transforming the role of the human employee from being a forklift driver into being a problem solver or a process coordinator, for example.

Wärtsilä, whose highly complex and tailored products are delivered across the globe to various locations on- and off-shore, must have a high focus on its supply chains, streaming both to and from the company. Because of the complexity of the company's products, a high variety of raw materials and components stream into the company from various partners. Wärtsilä (2022e) points out the importance of the value chain around its products and services. In the value chain, the company (Wärtsilä, 2022e) mentions the strength of the relations, proper lead times for the delivery of components, and information sharing as desirable aspects. This is easy to understand, because the proper and predictable lead times for the components can be seen as related to the lead times when manufacturing the final products, i.e. engines for various purposes.

Wärtsilä describes its supplier requirements on its website (Wärtsilä, 2022e) and mentions having more than 30 000 supplier accounts existing. The requirements for the suppliers are high and the company lists areas such as legislation, occupational health and safety management, and cyber security as general supplier requirements. The compliance is evaluated in all phases: selection, onboarding and on a continuous basis. The company also mentions having a specific tool, *Supplier Relationship Management tool*, for assessing possible new suppliers. The complete supplier assessment contains four individual phases. Therefore, it becomes apparent, how much value does the company pay to its suppliers and thus its supply chain.

It can be seen, that the STH-facility includes an internal supply chain, where goods and data are moved inside the overall facility, creating value inside the company, which is reflected to the end customer in the form of delivered goods and services. In this internal supply chain, a large percentage of materials and components used in production are transported from the Logistics Centre by means of manual forklifts and AGVs to the various locations in the STH and from where empty and in some situations, loaded pallets, are transported back to the Logistics Centre. Using the pallets several times is both cost-effective and environmentally friendly because the quality of the pallets is not likely to decrease significantly during each transport. However, the pallets are inspected each time they arrive in the Logistics Centre. Figure 3 illustrates *supply chain 4.0* in the context of the STH-facility.

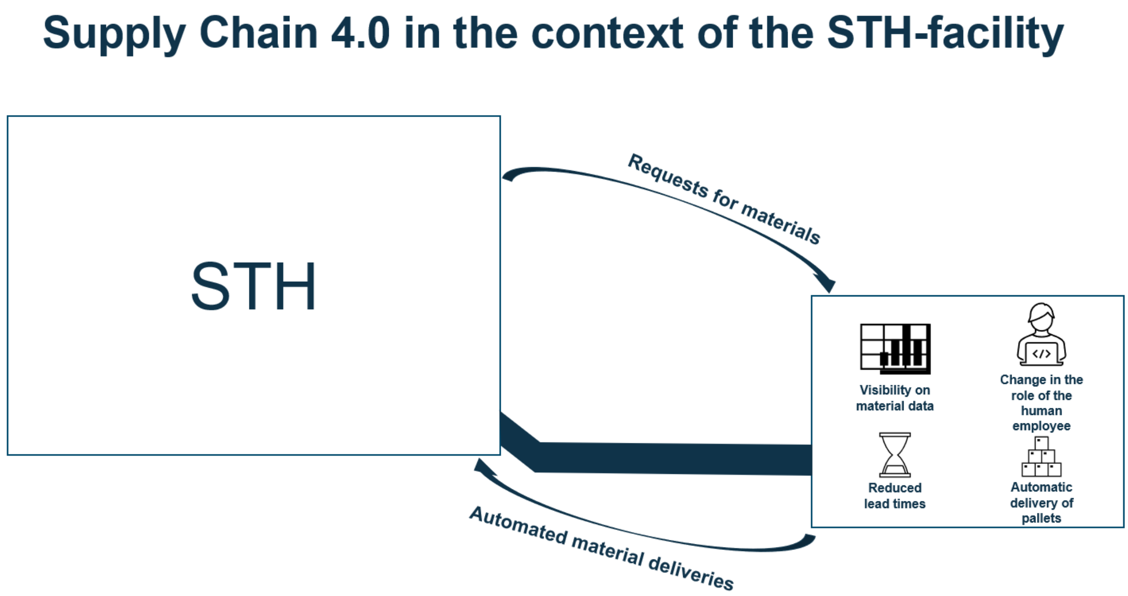

Figure 3: Supply Chain 4.0 in the context of the STH-facility

3.1.2 Logistics 4.0 in STH-facility

Industry 4.0 has gained a large amount of attention globally over the last decade. As pointed out by Winkelhaus & Grosse (2020), there is a need for strong connections between the service providers and their customers. It is important to notice, that terms "service providers" and "customers" also refer to companies' internal roles, since customer-supplier -relationships also exist inside companies. This has created the basis for a concept called Logistics 4.0, which according to Winkelhaus & Grosse (2020), is defined as: *"the logistical system that enables the sustainable satisfaction of individualized customer demands without an increase in costs and supports this development in industry and trade using digital technologies".* In the context of Wärtsilä, the contents of the pallets transported between the STH and Logistics Centre via the Hubway vary significantly and there will not be such thing as a "standard pallet" referring to their contents. Here, the Logistics Centre can be viewed as the supplier and the STH as the customer.

The definition of Logistics 4.0 contains multiple aspects supporting Industry 4.0 and the current, ever-changing corporate landscape, such as the varying customer needs, customization of the service experience offered to the customer, meeting customer demands in a sustainable manner, cost efficiency and digital technology. All of these aspects are closely related to the STH-facility, including the Logistics Centre, where meeting both internal and external customer demands and expectations sustainably and efficiently stand out. The facility will also include a significant amount of digital technology in various forms, such as the AGV-system, the Extended Warehouse Management (EWM) system and the highly automated Mini Load -system intended for the storing of smaller materials. Automation and modern technology are thus no longer illustrations of the future, but the current reality in the facility.

Even though Logistics 4.0 aims to increase efficiency and quality of various logistics processes, the concept does not aim to replace human employees in the overall logistics process, as pointed out by Barreto et al. (2017). As they mention, human employees are and will be needed in the concept of Logistics 4.0 in the process control and problem-solving situations, to which the current level of automation is not capable of. In the AGV system implemented in the STH-facility, there is a so-called CarWash-station, serving as a trouble-shooting station for various situations concerning the system. Here, a human employee will solve the possible issues occurred in the system, highlighting the need for people to be crucial players in the overall system and process.

Winkelhaus & Grosse (2020) recognize three dimensions, which form the basis for the concept of Logistics 4.0. The first one they have listed is the *external dimension*, including the need for high-quality customized products. They add that this dimension includes the inevitable effects on the way people work, to which the term “work-life balance” refers to. This dimension in itself is relatively broad and includes a wide variety of points. When it comes to Wärtsilä and more specifically, the STH facility, the company has the capability of customizing its products according to customer requests to a certain extent.

As Doh et al. had mentioned (Woshchank & Dallasega, 2021), Logistics 4.0 pushes organizations towards an increased amount of interaction between people and machines, and also towards ICT. This is the case also in the STH facility, where AGVs are constantly present in the workplace of the human employees, who have to consider the AGVs in their work. One concrete example of this is, that if a pallet is left on the route of the AGV, it will stop and give a sound signal, to which the human employees must react. The employees are also instructed to always walk only on marked routes to avoid getting onto the routes of the AGVs, causing unnecessary stops.

Not only does the demand for customized products cause challenges for the manufacturing department, also the transportation and logistics must take them into consideration, because they have to arrange transportations for products with different weights and dimensions, for example. This concerns both inbound and outbound logistics, as pointed out by Barreto et al. (2017). Wärtsilä, for example, has to be able to receive and process a large amount of different kinds of materials that are used in their products, and also to arrange transportations to a wide range of products going to customers of the company across the globe.

Related to the first dimension listed by Winkelhaus & Grosse (2020), Wärtsilä also gives high efforts for its employees in terms of the way the company's employees work and to the work-life balance of the employees. Examples of these include a possibility to work partly remotely, assuming the nature of the employee's tasks allow it, and offering an application by which the employees can get discounts on sport and culture possibilities. The company also puts significant resources into the continuous learning of the employees and offers them opportunities to develop. However, this aspect is left out of the scope of this thesis, since despite its importance, it is not directly related to the implementation and usability of the AGV system.

Technical dimension mentioned by Winkelhaus & Grosse (2020) include many of the aspects endorsing Industry 4.0. The technical aspects related to Industry 4.0 include i.e., processing of large amounts of data (Big Data processing) and cloud computing. These factors can be seen as endorsing both the concepts of Logistics 4.0 and Industry 4.0. In the STH and Logistics Centre, large amounts of data are processed daily as an integral part of the logistics operations. For example, with every material movement from the Logistics Centre to the STH, information about the materials being moved, source location and destination location are processed in the EWM.

The extremely large amount of data processed in modern logistics systems is also brought up by Barreto et al. (2017) and they mention, that having large amount of data offers a wide variety of opportunities concerning optimization and the efficient operations of the system, but also creates a threat in terms of data safety. According to them, the large amount of data combined with the relatively weak average knowledge and cyber security awareness among people will increase this type of risks further. It is known, that in the current digital environment, human is often the weakest link in terms of data safety. In Wärtsilä, employees must take cyber security trainings on a regular basis and are constantly encouraged to act safely and report any suspicious activities they notice.

With the increasing amount of data, operating in a cyber-safe manner is increasingly important for organizations. Since organizations are using an increasing number of constantly-developing sophisticated systems for various purposes and regularly processing confidential data, it is vital to have proper cyber security protocols in place. The consequences of a data breach can be severe in many ways: confidential information can end up to unauthorized parties, the attacker can sabotage even the physical environment through different systems causing danger to the employees and equipment of the facilities, and possibly cause a substantial amount of reputational damage.

The final dimension on Winkelhaus & Grosse's (2020) list is directly about logistics. They divide this dimension in three subpoints, namely: tasks, domains and human factors. Especially the human factors are highly relevant in the context of the STH and Logistics Centre, since despite the large amount of utilization of automation in the facility, human factors and human decision-making will have significant roles as the operators of the automation systems. Inevitably, human employees will also solve the possible problems and issues occurring in the system, because the automation in many of the systems in the STH and Logistics Centre have limited or no capability of autonomous problem solving themselves. However, automation can support the human employees in solving these issues.

A key aspect of the entire Logistics 4.0 concept is that logistics overall is combined with possibilities enabled by Cyber-Physical Systems (CPS). This is important to notice, because both are essentially individual illustrations of the broader Industry 4.0 concept. This relates to the pull-mindset instead of the traditional push-mindset in manufacturing and business environments: with the utilization and possibilities offered by Logistics 4.0, Industry 4.0 and CPS, positions of materials and their estimated arrival times to various points and locations in the systems can be forecasted more easily, which will help the overall process parts' operative planning. This can even reflect to the customer, as the overall process from the moment of purchase order creation to the moment of the delivery of the finished product is made in a more Lean manner.

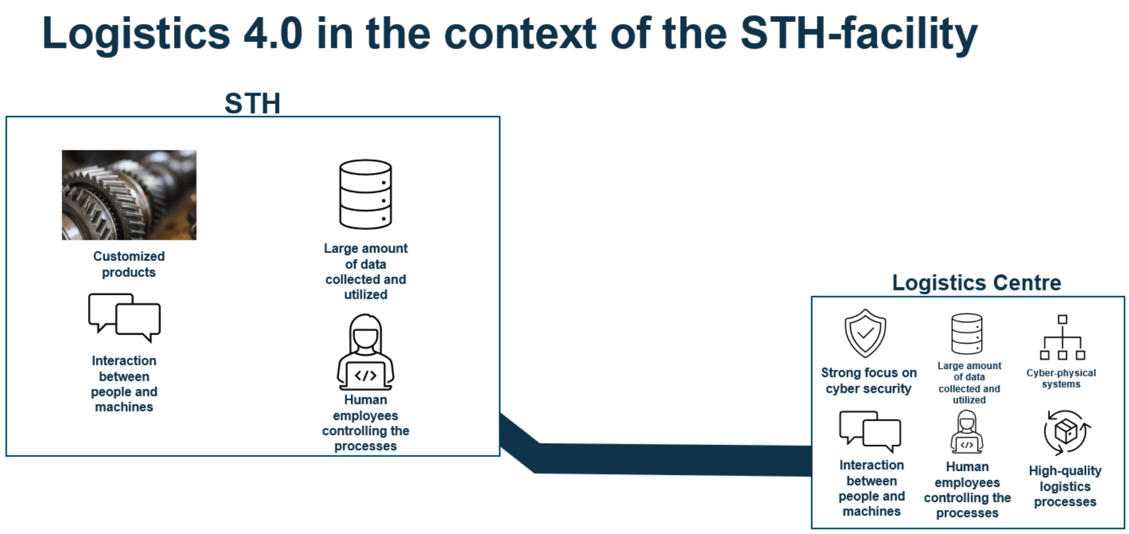

Figure 4: Logistics 4.0 in the context of the STH-facility

3.1.2.1 Extended Warehouse Management System in the STH operations

Extended Warehouse Management (EWM) is a system in which one can control their warehouse operations and have a high visibility on the events taking place in complex warehouse systems and environments. According to SAP (2021), user of the EWM system has real-time information of the locations of individual parts and components.

As computers and data processing become increasingly important parts of the daily operations in warehouses and factories, it is of high importance to have a proper interface in place between the human and the machine. The term describing this is defined by Turkle (2001) and according to the definition, it means the ways with which people interact with computers. Stefanou (2003) agrees and adds, that it is *"the visible part of the system to the users"*. In the context of the AGV-system in the STH-facility, these interfaces contain the AGV PC, through which the trained employees can view and manipulate the movements of the AGVs, as well as through the screens and buttons in each AGV.

Having a sufficient level of visibility allows warehouse managers and operators optimize and plan the operations in the warehouses and have the operations as efficient as possible. This relates to the Just-In-Time -principle, which, according to Kong et al. (2018) considers deliveries taking place more frequently, but in smaller amounts. Having smaller amounts delivered more frequently increases the level and opportunities for having the material flow as smooth as possible. With smooth material flow, forecasting in production will be easier, which will make it easier for the company to give its customers estimates about delivery dates or times, and react to any threats, that might affect its forecasts. Smaller batch sizes also decrease the consequences in a situation where one batch/pallet cannot for some reason be delivered.

One of the core parts of the modern warehouse management is traceability. SAP (2021) points out, that in EWM, the user can track down individual components down to storage bin level. This is of significant help in inventories, when there is real-time information available about the history and events that have taken place regarding the materials at various phases of the processes. In case of a broken or damaged material, the material and its movements can be traced to help find the time and place, where the material has been broken or damaged, to find the root cause of the issue and solve it easier. This is valuable in terms of eliminating waste (which damaged products and materials essentially are) and increasing work safety and efficiency. In the STH-facility, where the EWM is used, each material typically goes through several warehouse tasks. If the material is damaged in any of these, the availability of the movement data can help finding the root cause of the issue, thus avoiding similar situations in the future.

One of the most important features of EWM is Goods Movement. SAP states on their website (2021), that these movements cover various types of movements throughout the process and the list includes *goods receipt*, *stock transfers*, *automatic replenishment* and *management of dangerous goods*. Each of these can be considered regular and normal activities taking place in modern production facilities of various kinds. In the context of Wärtsilä, the both the workers and the AGVs get a large number of their work tasks either directly or indirectly from the EWM and to which they report the tasks as completed.

Another relevant aspect of smooth and agile warehouse operations is having the operations and activities planned. On their website, SAP (2021) highlights planning and monitoring being one of the features of the EWM. Planning relates to optimizing, which helps use the available resources in the most efficient way possible. EWM gives decision makers the possibility to see the near-future workload to avoid problems and challenges in advance and ensure that all the actions will be taken on-time. One example can be a situation, where the workload of Goods Reception will increase too high and the consequences can reflect to production, after which to customer, in the worst case.

3.2 Safety as the centre of internal logistics operations in Wärtsilä

One of the main concerns in the concept of utilizing AGVs in the STH is safety. Safety is a broad concept, but according to Cambridge Dictionary (2021c), safety means *"a state in* *which or a place where you are safe and not in danger or at risk"*. In an environment, where there are human employees and large, autonomous objects moving at relatively high speeds, the role of safety is vital. Safety, however, is a complex topic and as Fostra et al. (2018) discuss, it includes attitudes and actions among other things, of which the safety culture is one of the most essential. They add, that workload and both rewarding for positive actions and punishing for negative actions belong under transforming the safety culture into concrete development of behaviour in the organization.

Since the AGVs share the same working environments with human employees in the STH and Logistics Centre, safety is one of the corner stones of the process and something, that must always be considered with extreme caution. Therefore, several safety measures are in place in the facility: in the AGVs, there are several sensors constantly monitoring the vehicles' environment to avoid collisions with objects and people, the employees working in the facility have been trained to operate in this specific environment and the floors are marked so, that the employees always have the information on where loads and materials can and cannot be left.

According to Ammar et.al. (2021), forklifts are among the most common equipment that cause deaths of employees in industry. Forklifts of various sizes and purposes will be routinely used as part of the daily operations in the STH-facility. The AGVs, essentially forklifts, will be operating autonomously, meaning that no human is constantly operating them, thus the vehicles must have proper safety devices and sensors in place.

Another safety measure for the AGVs are their lights. The vehicles' direction is indicated with warning lights. There are also blue spotlights in place, which will help the human employees to see the AGVs sooner and easier. These lights will give a visual indication about the location and direction of the AGVs for the people working in the same areas with them.

An essential part of safety in the STH facility are doors and their functionalities. Various types of doors have been installed to the facility and their purposes and functionalities vary. Some of the doors are fire doors that are by default open and closed only, when necessary. Considering a human employee operating a forklift, the operator can visually detect the status of the door and react accordingly.

Since the AGVs will not have a human employee operating them, communications between the AGVs and the door system was considered a necessity. Events in which the AGV would crash the door could cause significant danger to employees. The accidents would also almost certainly cause unnecessary and avoidable costs. Accidents such as these could occur in situations, where the AGV falsely has the information that a certain door is open and hits the door at full speed. A smaller disadvantage of lacking communications between the AGV system and the door system is, that considering the AGVs safety sensors would be working, the AGV would have to slow down or completely stop before the door, which would increase the delivery time.

A solution to the door- and communication-related issue was to have the AGV send an opening request signal to the door system when approaching the door, the individual doors would have switches indicating that the door is completely open, after which a signal indicating the successful opening of the door would be sent to the AGV. This way, the AGV would not have to slow down at each door, but could maintain a high speed and thus, unnecessary delays in deliveries could be avoided and the same number of AGVs would be able to complete more deliveries in the same amount of time, thus increasing their operating efficiency. Figure 5 contains a simplified process chart of the door opening when operated by AGVs.

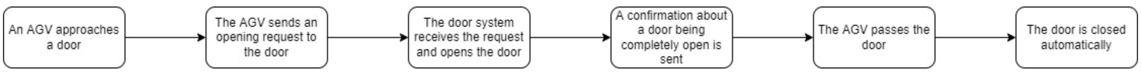

Figure 5: The door opening and closing process when an AGV passes through

In addition to the existing safety measures, the employees working in the facility have the possibility and are encouraged to report any safety observations including near misses. Any observation should be properly documented and reported, in order to proactively find solutions to avoid similar near misses or in the worst case, actual accidents in the future. Safety walks are also carried out and during the walks, the participants observe any potential safety risks. The risks are documented and reported forward, enabling the issues to be fixed.

3.3 Cyber-Physical Systems as part of the operations in the STH and LC

Cyber-Physical Systems (CPS) are taking an increasing role in industrial automation. According to Leitao et al. (2016), CPS combines the operations and functions of physical devices and computations performed by various applications. They mention that the cyber parts of the systems are the software and cloud services, for example, whereas the physical parts are the actual devices and hardware, for example. Examples of these systems exist in the STH-facility and these systems are taking an increasing role.

The structure of the CPSs is network-like, which essentially means that there are multiple components, both cyber-based and actual physical devices, in the overall system. Leitao et al. (2016) point out, that the concept of CPS is to be applied not only in industry, but also in smart buildings and grids, and industries such as healthcare. This highlights the on-going change, where automation and data processing are playing increasingly important roles in not only industrial context but also in the context of people's everyday lives. In the context of the STH and Logistics Centre, many of the work tasks to both people and AGVs come from a software-based system onto a physical device, such as a tablet or a handheld device, with which the employees carry out the tasks, do the necessary barcode scanning and reporting, for example. Another concrete example is, that a task is sent from the virtual system (the EWM) to the AGV (the physical part of the system), which completes the task. During the execution of the task, the AGV also communicates with the doors it has to pass.

Cyber Physical Systems being structured in the form of a network is what separates them from concepts like Internet of Things (IoT), where the structure is umbrella-like, and embedded systems. In CPS, there is a larger amount of communication between individual instances, such as computing applications and physical objects, like vehicles or sensors. The results and benefits are achieved through this cooperation and information sharing on the network-level, rather than only between an individual device and the host system.

3.4 Automated Guided Vehicles in Wärtsilä

AGVs are vehicles capable of travelling independently and according to pre-defined instructions from the AGV-system, within the limits of the routes defined to it in the design and implementation phase of the utilization of the system. Ali et al. (2010) describe AGVs as *"battery-powered driverless vehicles, centrally computer-controlled and independently addressable. They move either along wire guidepaths, or by magnetic or optic guidance"*. This definition describes on a high-level the basic functions of the individual AGVs and highlights the fact, that they operate independently, without a human employee driving them.

Since AGVs are battery-powered, they do not need a continuous power input from an external energy source. This on one hand increases their usability in terms of no power lines needed, eliminating the need for power tracks installed to roofs or floors, but on the other hand, sets limits to individual time windows when the AGV can be used before its batteries have to be recharged. During the recharge, the AGV is inoperable, which has to be taken into consideration in capacity calculations of the AGV system. However, the AGV-system automatically considers the AGV currently being recharged, and does not allocate tasks for it while the recharge is in progress.

As the AGVs move independently, without a human employee driving it, the risk of human errors is eliminated from the part of material transports. Also, the predictability of the AGVs position in the system at a certain point in time is higher, which will help planning the operations and utilizing the available resources in the most efficient way possible. However, the human-factor is present in the overall operations, since also manual forklifts operate in the STH-facility. Not only does predictability help estimating the arrival times of materials to various storage bins in production, but also the employees will learn, where the AGVs move and how to detect them, since they only use specified routes.

3.4.1 AGV Process Control in STH and Logistics Centre

The operations of AGVs are controlled in the AGV system, which is essentially a computer connecting the operations of the AGVs with EWM. EWM allocates the tasks to the AGV-system and a software in the AGV PC allocates the tasks to individual AGVs according to several factors, such as the battery charge status of the AGVs and their locations. Controlling the movements of the AGVs and the tasks they are allocated is vital, since it enables using the system in the most efficient way possible, thus minimizing the amount of waste created in the operations.

With the AGV Process Control, it is also possible to have a constant visibility on the overall situation in the AGV-system: the locations along with load statuses of each AGV, as well as the status of the communications and individual doors can be seen at all times. This helps the employees working with the system better understand, which tasks will be handled next, and detect any malfunctions for individual AGVs, for example. Additionally, as the AGVs act as just one actor in the overall logistics system, managing and controlling their movements stands out.

3.4.2 Connection and communications between AGV system and EWM

The AGV system is connected to the EWM system via a separate software, that was installed on the AGV PC. The purpose of the AGV PC is ultimately to serve as the ‘brain’ of the AGV system and monitor the statuses and conditions of the individual AGVs. The communication between the AGV software and EWM takes place with a TCP/IP protocol, using telegram-messages.

There is a large number of pick-up and drop-off points located in the STH and Logistics Centre. Each time AGV is ordered to deliver goods from the Logistics Centre to the STH, information is processed and distributed between the AGV System and the EWM system. As the number of deliveries in the facility is high and with each delivery, several individual messages containing varying sets of information are sent, the amount of data stored and moved in the system is high. The high amount of data creates challenges on the one hand in terms of data safety and efficient processing, but it also offers possibilities in terms of optimizing, controlling, and forecasting the overall functioning of the system. During the implementation project it was found out, that the amount of data could be utilized further to visualize the functions and operations of the overall system. This would enable employees to have visibility on various figures and values of the operations, such as the number of pallets delivered to various areas and how many stops had the AGVs do at different areas of the facility. This could act as an input for the employees and their supervisors to find reasons for the stops and solve them, thus enabling the system work more efficiently in the future.

However, without proper communications and a constant connection between the AGVs, the AGV PC and the EWM, the system would not work in the most efficient way possible. A malfunction could in the worst case lead to the system being temporarily inoperable, having direct effects on the material flows of the facility. Therefore, extensive efforts were taken already in the very early phases of the commissioning: the connection and possible malfunctions were tested to learn to detect them as soon as possible. Also, finding and fixing the root causes of the issues were considered essential skills of the employees involved.

3.4.3 AGV navigation in the STH facility

Various navigation methods exist for AGV navigation. The selection of the navigation method depends on numerous aspects, such as the complexity and size of the facility, complexity and length of the routes and how much the environment can change throughout the life cycle of the overall AGV system. Also, the costs play a role since there are differences among the prices of different navigation methods.

Hamlin (2020) categorizes the different AGV navigation methods into four different categories. It is notable, that some of these categories also include subcategories. In this subchapter, these navigation methods are briefly introduced, with most focus on the Laser Navigation since that was chosen to be implemented in the STH facility.

First navigation method to be presented in this context is the Magnetic tape -based method. This method, according to Hamlin (2020), is based on a magnetic tape installed to the floor surface of the facility. The AGV is equipped with a reader that detects the changes in the magnetic field caused by the magnetic tape. Hamlin (2020) adds, that these kind of AGVs can be equipped with RFID cards, enabling the vehicles to initiate stops, change their routes or to initiate battery recharging.

Another AGV navigation method described by Hamlin (2020) is based on optical vision. According to him, this method has three subcategories that are based either QR code recognition detecting QR codes installed in the facility, ground guidance using a recognition of a high-contrast layer of paint on the surface of the facility, or 3D cameras creating images of the surroundings of the AGV thus recognizing its location.

According to Hamlin (2020), it is also possible for AGVs to simultaneously localize and map, where they are at each particular moment. This is called the SLAM (Simultaneous Localization and Mapping) method, in which the AGV builds the map and moves through the map at the same time. This method includes complex algorithms, so it can be considered a more demanding method of navigation of AGVs.

Lastly, it is possible for AGVs to navigate using laser beams. As Hamlin (2020) mentions, the navigation scanners of this kind of AGVs send laser beams at very high frequencies (thousands of beams emitted each second) and these beams are reflected back to the AGVs from reflectors (tapes or cylinders) installed around the facility. The AGV's systems initiate calculations about the travelling time of the beams sent and the amount of time required to receive the reflected beams. Hamlin (2020) highlights the accuracy of this kind of navigation method. He also points out, that this kind of navigation system is very reliable, which is essential in a production facility, where the timely and predictable transportation of the needed materials is vital. The navigation method selected to the AGVs in the STH-facility was the laser navigation. This method is illustrated by Solving and is presented in Figure 6:

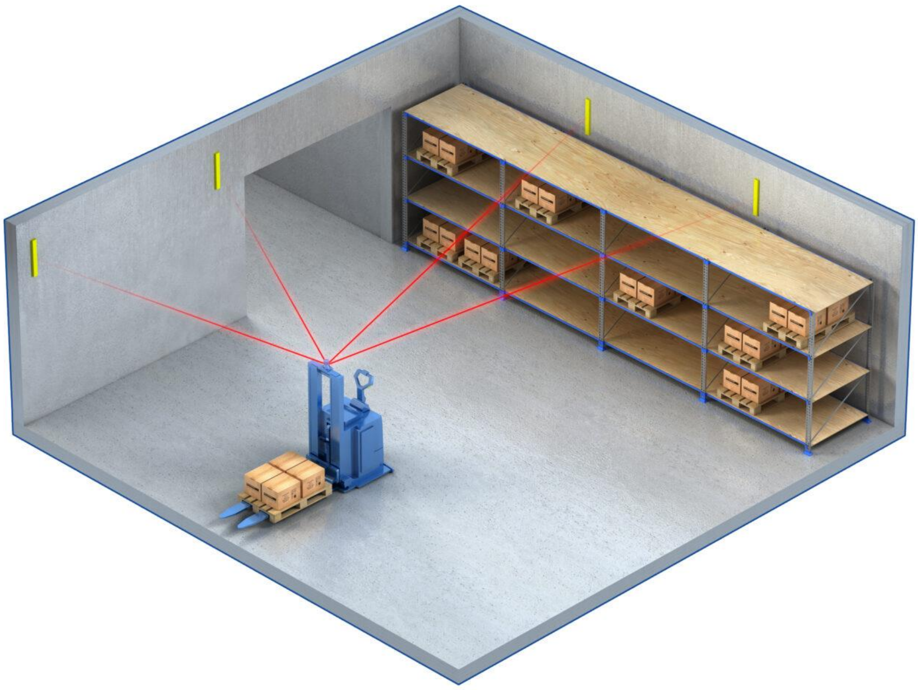

Figure 6: Visualization of the laser-guided method of AGV navigation. Image: Solving (2022).

3.4.4 Human-Robot interaction in the STH facility

As the AGVs and human employees operate in the same environments in the STH, a highly relevant aspect of the daily operations is the interaction between the two parties. The interaction can be either direct or indirect, meaning that in direct interaction, the human and the AGV are in direct physical contact, whereas in indirect interaction, the interaction takes place using an interface.

An example of direct interaction between an AGV and a human is a situation, where a human employee manually drives the AGV. The indirect interaction between AGVs and human employees takes place for example, when an AGV leaves a pallet to a drop-off point and a human employee picks the pallet up, taking it further in the process.

A situation where an AGV leaves a pallet to a shelf, and a manual forklift driven by a human employee picks the pallet up, can be considered one of the most typical examples of an indirect human-robot interaction in the facility. Here, the shelf acts as an interface between the human employee and the AGV. Another scenario like this is, when a human employee leaves an empty pallet to a drop-off location and an AGV picks it up to take it to the Logistics Centre to be cleaned and re-used.

In the STH's Common Labs area, there are drop-off points for AGVs, to which the AGVs leave the pallets they have delivered from Logistics Centre. From these drop-off points, a human employee will take the pallet to its destination in STH. A third example of an indirect contact between AGVs and human employees is, when an AGV delivers an empty pallet from the STH to the Logistics Centre. In this situation, the pallet is transported to a workstation at which a human employee works.

In a situation, where the AGV picks up a pallet from the Logistics Centre and delivers it via the Hubway to the STH, two types of interaction take place: in the Logistics Centre, a human employee operating a manual forklift takes a pallet to the spot, where one of the AGVs will come and pick up the pallet, deliver it to the STH via the Hubway and leave the pallet at one of the drop-off locations in the STH. However, in addition to the shelves acting as direct interfaces between human employees and the AGVs, there are also pedestrians walking in the facility and this interaction is also vital to be considered.

Partly related to the safety aspect of the overall system, the shelves (interfaces between the human employees and the AGVs) to and from the AGVs will take the pallets, have to meet a certain set of criteria in their design and specifications: the height of the drop-off and pick-up locations cannot exceed the maximum height possible for the AGVs, the physical measures of the drop-off location must be suitable for the AGVs, and the shelves must be of such type that the AGVs can pick up and drop off the pallets at that specific storage bin. The route leading to the storage bin must also be suitable for the AGV in terms of space available and the route can have no obstacles.

All the people that the AGVs can meet, are authorized personnel either from Wärtsilä or from the companies operating in the internal logistics of the STH and Logistics Centre. The areas in which the AGVs operate, are closed private areas, thus not open for public. This reduces the risks of accidents, because it can be assumed that every person inside the facility has received training and instructions about moving and operating safely there. Another aspect closely related to this is, that the provider of the AGVs also organized a training for the employees operating in and with the system.

3.4.5 Possible benefits of the implementation of AGVs in the STH facility

The implementation of AGVs can have several benefits. As mentioned by Aguiar et al. (2019), they can increase traceability, because each transportation task is recorded into the system. In the STH-facility, each time a pallet is moved from one storage bin to another, a warehouse task is created, and the status of the warehouse task is updated in real-time. Therefore, in any problem situation, the movements of the material can be traced more easily in terms of storage bins it has been stored in, and the means by which and points of time when the material has been moved.

The implementation of AGVs also promotes sustainability, since they are commonly battery-powered instead of using fossil fuels. Additionally, they are operated in the most efficient manner possible, since they make no extra turns or stops, so the energy is only consumed to the movements that are needed. They also automatically go to the recharge station when the battery reaches a certain limit. However, when the threshold is reached, they will complete their ongoing task first. In the STH facility, where a large number of transportation tasks is carried out on a constant basis, efficiency of the operations can be beneficial also from an economic perspective.

Since the AGVs operate in the exact same way every time, their operations are highly predictable. The employees working in the STH's production areas will know, how much in advance they will have to order the pallets they need to get them when they need them. This is also beneficial in terms of future development of the system: when it is noticed, that something in the system should be changed or developed, these actions can be taken more easily when there is a proper understanding of the overall functionality of the system.

Related to flexibility, AGVs can operate at all times of the day. This means, that the employees working in the STH can place orders for pallets they need the following day, and during the night, the AGVs can deliver the requested pallets to the requested locations. With this, the employees in the production can immediately start their work in the morning without having to wait for deliveries of pallets. Therefore, these employees can use their working time more effectively and the waiting time is decreased. During the night, the AGVs can also transport empty pallets from production back to the Logistics Centre, releasing storage capacity from the storage bins in STH.

On a long term, the AGVs can also be cost-efficient: the only costs involved are costs related to the initial investment and the operating and maintenance costs. The operating costs consist mainly of the energy they consume, whereas the maintenance can take place regularly and/or when needed. This is in contrast with manual forklift drivers, who earn a salary (essentially a cost) and are not able to work 24/7 but require breaks, holidays and vacations. The only times when the AGVs are not operating are, when they are being recharged or are undergoing maintenance.

With AGVs, also safety can be improved. The AGVs always take the same routes to the same places, their sensors are operating constantly, their performance is always the same (whereas a human employee can be tired, for example, thus decreasing her/his level of performance) and they can be programmed to give any voice warning when approaching different locations, thus giving the employees an additional indication of the approaching AGV. This is especially important in a large and complex facility, such as the STH, where a large number of employees share the same environment with the AGVs: when there are no exceptions in how and where the pallets are being moved, it is easier for the employees to learn a safe way of moving in the facility.

Another benefit of the AGVs compared to the manual forklifts is the decreased risk of material damage: since the AGVs in the STH constantly monitor their environment, they detect any possible threat or risk of a crash and stop before the crash occurs. With the AGVs used in the STH, the forks for carrying the loads are located at the rear-end of the AGV, so that the AGV itself protects the loads carried by it in the unlikely cases when a crash takes place. This is in contrast with many of the manual forklifts, where the pallets are carried in front of the forklift and are at higher risk of being damaged in case of any crashes. The possible benefits of AGV implementation are summarized in Figure 7.

Figure 7: Possible benefits of AGV implementation

3.5 A revolutionary change carried out in an evolutional way

Since the commissioning of the Sustainable Technology Hub and Logistics Centre and decommissioning of the Delivery Centre Vaasa can be considered as massive changes in the operations of Wärtsilä, Change Management will play an important role in the success of the overall project. The changes include operating in a completely new facility, using new tools and systems. Also, the ways-of-working are new alongside the AGVs, that had never been used in Wärtsilä's premises in Finland. The scale of the changes will thus be significant and have an effect on a large number of employees working in Wärtsilä's Vaasa premises.

Throughout the project, there were numerous illustrations of change management but also some illustrations of change resistance visible. One concrete example of change management and reducing change resistance was offering the employees knowledge about the change, which was meant to increase the amount of information and decrease the amount of (possibly false) assumptions among the people directly and indirectly involved.

3.5.1 Change management in STH implementation project

Tamilarasu (2012) defines Change Management as: *"A structured approach to shifting/transitioning individuals, teams and organizations from current state to a desired future state"*. This indicates that the transfer from the original state to the future state is controlled and includes individual and/or larger groups of people. Therefore, because of the presence an involvement of people, there is uncertainty involved.

Tamilarasu (2012) points out the possible and common reluctancy towards change among people. People can have tendency to prefer the current state against change, which is the result of a large number of factors, including i.e., unawareness of the change project or its intended outcomes, lack of participation in the change process, uncertainty about the success of the change project or the lack of trust to the company's resources and capability to execute the change. Communications stand out before, during and after the change; when people do not have a proper knowledge and understanding about the change project, they appear to be more likely to resist it.

The attitude towards change can also be positive, however. Tamilarasu (2012) lists various situations, when people can see the change as something positive. The list includes scenarios such as when people expect to benefit personally from the change, feel that the change is a reasonable action to be taken in the current state, they were able to contribute to the change and in a situation where they have respect towards the person responsible for the change. Here, too, having enough knowledge about the change, the reasons behind it, the expected consequences, timelines, and people responsible will be crucial in terms of positive attitude of the employees towards the change. Therefore, communications overall are important when creating positive attitude about the change.

Rousseau and ten Have (2022) list actions with which an organization can better succeed when going through a change project. The list includes setting proper goals regarding the change, acting in a fair way in all circumstances, implementing the needed temporary structures to give the project the needed capacity, having proper feedback and redesign practices and loops in place, and finally, ensuring proper learning throughout and after the project. By utilizing these guidelines, the organization can not only increase the likelihood of success of the change project, but also ensure the changes implemented will be kept in place in the future. They can also help the organization to improve during the project by getting feedback and improvement ideas from the participants of the project. The list also highlights the fact, that change projects need proper resources to be implemented in the most effective way possible.

Rousseau and ten Have (2022) also give eight recommendations of actions that can be taken in the change project. These actions include gathering facts about the current situation and defining the problem, estimating the readiness of the organization to implement the change, developing possible solutions, establishing proper leadership in the organization, creating the vision of what the organization wants to be in the future state, utilizing the possibilities of social networks, utilizing the knowledge of the lower-level employees of the organization, and finally, ensuring the changed ways-of-working will be kept in place. These actions can first help the organization thoroughly understand the scale and need for the change, assess if the organization can carry out the change, how the organization will look like after the change and how to avoid sliding back to the old ways.

3.5.2 Change resistance anticipated and experienced in the AGV-project

In situations of change, resistance is one of the natural reactions of people involved in and affected by it. Tucker (2017) lists change resistance as one of the top issues when it comes to employee engagement and people challenges. Therefore, managers should include and let the employees know about the change. Tucker (2017) also mentions, that it can be an instinctive first reaction for people to resist a change. Tamilarasu (2012) shares the opinion and adds, that the managers and leaders can expect at least some level of change resistance to occur whenever implementing changes in a company. The level and appearance of the change is likely to vary among individual people.

In the current world, change can be considered to take place constantly, as technologies related to Industry 4.0 are utilized at an accelerating speed. According to Ouedraogo et.al. (2021), the ongoing change and the *fourth industrial revolution* will probably have an effect on every industry. They point out, that each person experiences the change differently and an important aspect appears to be the reason behind the change taking place. Also the frequency of changes in a company have an effect on the way employees experience change; employees working in a company with frequent changes are more likely to experience a larger amount of change fatigue, which can, through change cynicism, have a negative effect on the result of the change project.

Ouedraogo et.al. (2021) highlight, that employees experiencing change in the company they work for, are likely to feel more positive about the change, if they are explained the reasons for the change closely enough. They mention that the company should make the expected improvements and results clear to the employees. This way of thinking is called the *Logic of consequences*, which is likely to reduce change fatigue, thus increasing the likelihood of the success of the change. Therefore, it is valuable for the managers and change initiators to utilize this logic as much as possible.

Tucker (2017) encourages managers to prepare employees for a change and to be transparent about it. Managers should properly clarify the situation for the employees and answer to various basic questions about the change, such as “What needs to change and why?” and “When will the change take place and what are the requirements concerning the change?”. The purpose of the questions is to offer visibility for the people affected by the change and thus reduce the change resistance. It also helps the employees to gain more understanding of the change, which reduces the number of assumptions while increasing the amount of information and facts.

Employees affected by the change can be highly interested in how they will benefit from the change. A valuable act for managers to take is to include the employees in the change as early as possible. Tucker (2017) mentions that the change resistant employees might discover obstacles for the change, which in itself is of high value for the organization, because solving problems and removing obstacles proactively is more beneficial than afterwards fixing the problems.

Change resistance was also detected during the AGV implementation project in the STH-facility. The resistance towards the change was expected, because the change in the operations was significant. Most of the resistance and negative reactions by the employees was solved by direct and open communications between the project team and the employees themselves: when assumptions were replaced with facts, the attitude towards the change seemingly improved. The resistance changed into curiosity and ideas, that were extremely valuable for the project. The employees could at all times express their concerns towards the change and the project team had the responsibility to provide the answers.

3.6 Summary of the theoretical framework

This thesis and the research made during it is completely centred to the STH and Logistics Centre. The figure below illustrates the various topics discussed in this chapter.

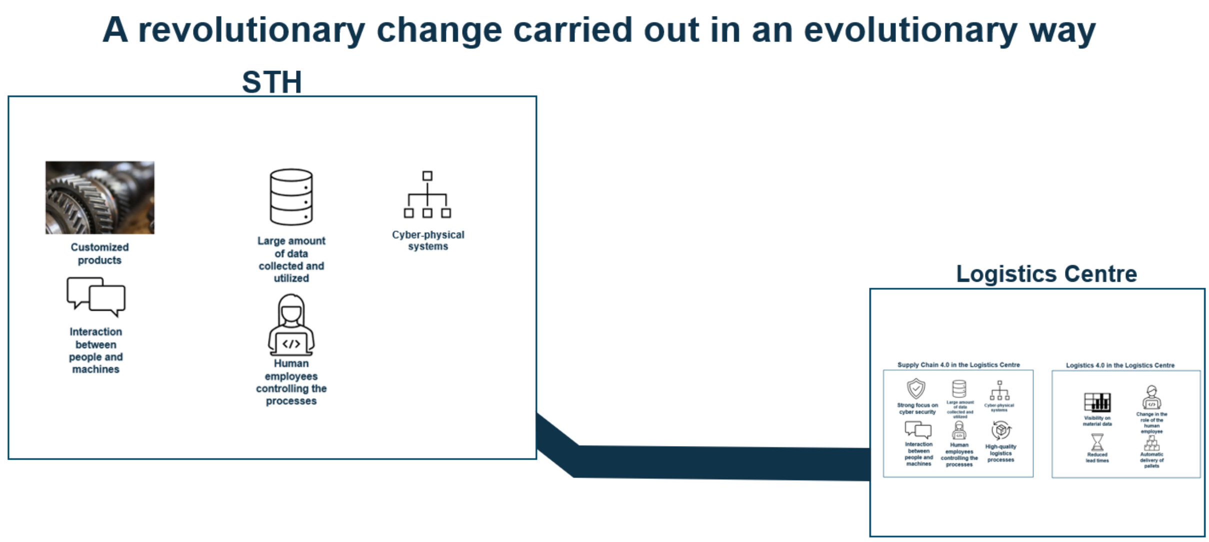

Figure 8: A revolutionary change carried out in an evolutionary way

4 Empirical study

In this chapter, the research methods, data collection process, data-analysis, and validity & reliability are discussed. The research onion, presented by Saunders et al. in 2007, was applied when determining the methodology utilized in this study. The research onion consists of six layers: philosophy, approach, strategy, choices, time horizon and finally, data collection & methods. In the context of this study, the research onion is described in Figure 9.

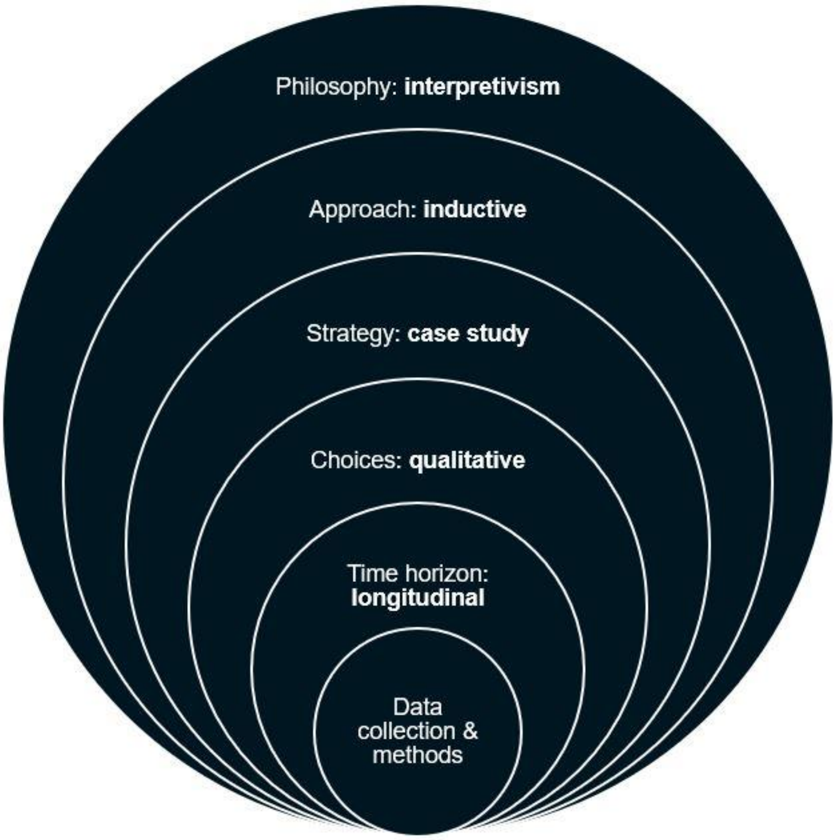

Figure 9: Research onion of this study. After Saunders et al. (2009, p.108).

Interpretivism was selected as the philosophy behind this study. According to Ritala (2003), in interpretivism, the researcher is typically part of the research process. In this case study, I held a duplicate role: at the same time, I was a member of the project team with defined responsibilities, but also doing my master's thesis about the project. Therefore, my approach was subjective and large amount of the data was collected by observing the events in the project. However, a theoretical framework was established to deepen the understanding of the topic and possible benefits of the project.

The approach in this study was inductive. This decision was made because of the qualitative data: since the research was made on only one implementation project, the qualitative nature of the data was inevitable. As Ritala (2003) points out, the benefits of the inductive approach include the possibility to gain a deep understanding of the topic, which was one of the core purposes of this study: to understand this particular implementation project as thoroughly as possible. There were also no presumptions or hypotheses to be tested, but I decided to start from "an empty table" so, that my own possible pre-assumptions would not limit my data collection. This, however, forced me to carefully consider, what kind of data would be valuable and relevant to collect during the research, and how to do it in an ethical manner.

Because of the nature of the topic (individual implementation project in a new facility), having case study as the main research strategy was an obvious choice: the iterative nature of action research made that strategy not feasible; the purpose was to produce deep knowledge about one specific case and not consider any trends or changes, meaning that grounded theory was not considered optimal. However, the study had ethnographical aspects to it: the cooperation between the human employees and the AGVs was one of the focus areas of the study, and methods typical for ethnographical research were utilized, such as observing and interviews.

Due to this thesis being a case study considering only one facility, it was decided, that the study would be a qualitative one, with an inductive approach. Thus, my focus in terms of the data was more on its quality than quantity, since with just one facility and a limited number of employees involved, having a large amount of data would not have served the purpose and not been possible to collect. This supports the core purpose behind this thesis: to produce knowledge about one case rather than make generalizations.

The data used in this study was collected throughout the study, starting from October 2021 and ending in September 2022. The end time was selected due to the implementation phase of the AGVs coming to a conclusion at that time. The data was collected by observing the project, participating the project as an active member, interviewing the participants, and by gaining theoretical knowledge of the topic by studying the topic from various websites, research articles and books. There were also countless unofficial discussions during coffee and lunch breaks, as well as while working, which broadened my understanding of the overall topic and were an invaluable source of information.

4.1 Implementation of the AGV system in the STH-facility

The core purpose of the AGV-system in the STH-facility is to deliver pallets containing materials from the Logistics Centre to the STH, and return empty pallets from the STH to the Logistics Centre. The empty pallets are not listed or processed in the EWM system, thus the orders for the AGVs to pick them up cannot be given in a similar way with the loaded pallets. A separate interface was created, with which the empty pallets could be transported back to the Logistics Centre to be reutilized. The interface was created using a software commonly used in Wärtsilä’s logistics operations.

Four different perspectives were selected to the case study -part of the study. The selection of the perspectives was based on the expected mid- and long-term benefits for Wärtsilä and the overall smoothness of material flows, and my own interests. The perspectives include implementation, uninterruptedness, responsibilities in problem situations, and finally, lessons learned after the project. The data for each of the listed items was collected and processed during the thesis-writing process.

The success in the implementation phase of the AGV system has an important role in starting the operations with the new tools and ways-of-working. This phase can be compared to building the foundations to a skyscraper: without proper foundations, problems are more likely to occur in later stages, and the later the problems occur, the more difficult they are to be solved and the more serious their consequences can become. With a successful implementation, a smooth start for the operations can be achieved and the amount of unexpected situations and problems can be minimized. Therefore, the negative effects on productivity and value creation can be minimized.

Minimizing the amount and effects of interruptions in the operations of the system effects the overall system stability. Interruptions in the AGV system can have direct and/or indirect effects also on other processes, such as production and the usage of the available pick up and drop off points of pallets. Problems in the AGV system can cause congestion in some places and lack of resources in others, which can be seen disrupting the operations of the entire facility, in the worst case.

In case of errors and malfunctions in the AGV system, clear processes must be in place for efficient and effective problem solving. This raises the need for a proper understanding and definition of responsibilities in all situations that might pose a threat for the operation of the system. Various tools along with defined and documented methods and ways-of-working are to be utilized to minimize the effects of the possible problem situations and to increase the speed at which the problems are solved. As one of the respondents in one interview mentioned, the responsibilities must be clear to everyone.

There are multiple individual aspects concerning the success of AGV system implementation. Hrušecká et al. (2019) highlight organizational issues as the most important ones when it comes to achieving the expected level of performance in the system. This can be concerned surprising, since it is not directly related to features like the layout of the system, the usability and user-friendliness of the system or the specifications of the devices.

When considering the success of an implementation project, a clear way of measuring and defining the level at which the project can be considered a success, must be defined. Hrušecká et al. (2019) divide the Critical Success Factors (CSFs) into three categories: Technological, Organizational and Safety. However, the success of the implementation project can fully be determined only after the implementation project has been finished. Therefore, the actual measurement of the success of the project is left outside this thesis.

According to Liu et al. (2017) there are three types of conflicts, all of which can be avoided with *intelligent scheduling*: *intersection conflict*, *catching up with conflict* and *facing conflict*. In *intersection conflict*, two AGVs are approaching an intersection and will be at the intersection at the same time when only one vehicle can occupy the intersection at a certain time. This risk in the STH-facility has been eliminated by having the AGVs communicate with each other, and a priority sequence is in place to determine, which AGV gives way to the other(s). Several of these situations were intentionally created in the test sessions to first ensure the prioritization sequence works as planned, and secondly, to ensure the employees understand this sequence.

Catching up with conflict occurs, when two AGVs are running one after another and the one driving in front has a lower speed than the one behind it, causing the AGV driving behind to catch up the one in the front. This risk has been eliminated in the STH-facility by having all the AGVs programmed to operate only at certain speeds at certain areas. Therefore, the distances between the AGVs in same areas will always be kept the same and the risk of such a conflict minimized. However, if an AGV malfunctions, causing its speed to decrease, this kind of a conflict can occur.

In *facing conflict*, two AGVs are driving towards each other on a single lane path and without stopping on time, they could crash, if the safety scanners failed at the same time. In the STH facility, *facing conflicts* are avoided with the two-lane routes and having the AGVs move at certain exact speeds in certain areas. Additionally, only six AGVs are operating in the relatively large facility, decreasing the risk of two AGVs being in a same intersection at the same time. In the current state, there is only one place in the facility, where the AGVs use the same lane to travel to both directions, and without a malfunction in the operating system or the software in the AGV, this kind of error will not occur. It will, however, possibly cause waiting times, if two or more AGVs get a task to this same location.

Since the capacity of the pathways in the STH is limited, there can be situations where other actors in the facility occupy the pathway of the AGV so, that the AGVs are temporarily unable to utilize those pathways. These situations include, for example, when heavy items must be transported by lifting from one place to another and the route of the movement crosses the pathway used by the AGVs. These heavy objects refer to any large components handled in the facility, but those components and processes will not be described in detail in this thesis. In these situations, the safety scanners of the AGVs will be utilized: the pathway of the AGVs is blocked with traffic cones, which the AGVs' safety scanners will detect, causing the AGVs to stop. One possible conflict situation was noticed during the early phases of testing: a man lift was being operated in one of the routes of the AGV and the AGV had to be stopped until the lift was driven away from the route. This situation highlights, how valuable it is to communicate all the repair and construction activities among all the parties operating in the facility.

Since the AGVs use radio communications in their operations, a radio system was mandatory to be included in the AGV system. For this, a permit for a radio system was applied from the national authority, Traficom. In the application, the purpose of the radio system and the network were identified, along with the direction (one-way or two-way) of the communications. Also, information concerning the base stations of the radio system were described, including the transmitting power and frequency, the industrial type of the transmit antenna, channel width, and transmitting and receiving frequencies.

Since the AGVs will be a part of the daily operations of the STH-facility, and the system will directly or indirectly be in contact with multiple business units, inter-department cooperation will be a highly important point to consider in the implementation project of AGVs, as pointed out by Lazanyi (2017). All the departments that will directly or indirectly be in contact with the AGVs must be informed their role in the process and the expectations towards them. In the STH-facility, there are multiple business units and worker groups with which the AGVs are in contact in its normal operations: first, the AGVs act as tools for the Material Management -organization, which will use them to deliver a significant percentage of the materials going from Logistics Centre to STH. The manual forklift drivers will use the same paths and corridors as the AGVs, and people working in the production will see them regularly. Also, during the implementation, support was requested from the Health, Safety and Environment -business unit, when an instruction was made for the STH workers.

During the implementation project, a possible safety issue was noticed concerning the returning process of the empty pallets from the STH to the Logistics Centre. In the STH, pick-up locations for empty pallets are defined to the EWM. From these pick-up locations, the AGVs will pick up the emptied pallets back to the Logistics Centre. The problems occur, when a pallet of wrong type has been left to the pick-up location and, since the AGVs do not have sensors to identify the pallet type, the AGV picks up a wrong type of pallet. If the pallet is an oversized one, the person safety scanners no longer work properly, thus causing the risk of the AGVs hitting people in the facility. This issue was brought up in an unofficial discussion, supporting my original assumption of their importance.

Another risk involved in the issue concerning wrong types of pallets is, that when an AGV mistakenly transports an oversized pallet and takes it to a shelf made for the right-size pallets, the AGV could crash either into the shelf or to the pallets in the shelf, possibly causing the pallets in the shelf to fall down. This would pose risks for the AGV, materials in the pallets and, most importantly, to the people working in the facility. Therefore, the risk had to be considered a significant one and the likelihood of it happening was evident. However, in this kind of situation, is the justification of why the wrong-size pallet is at the wrong place; the AGV will only pick up pallets from where it is instructed to, so it purely relies on the orders it gets.

To mitigate the risks related to the AGV picking up and carrying a wrong-size pallet was minimized by several means. One part in which the issue was considered, was to have the AGV operate in the Logistics Centre only in the storage bins that can take only the right-sized pallets. Another aspect was that a decision was made to install guidance rails to each storage bin that the AGVs operate in. This would eliminate the risk of two possible issues: first, a pallet too large is physically impossible to be put to these storage bins and second, the pallet will always be in the exactly right location. Despite being a simple, purely mechanical solution, it is a usable and cost-efficient solution, while also avoiding the need for sensors and wirings, for example. It is notable, that the root cause of this kind of issue is the human factor: a human employee might mistakenly put a wrong type of pallet to a wrong type of storage bin, without even noticing the mistake.

Outside the risks caused for human employees, when pallets crash or fall to the ground, it can cause significant damages to the materials stored in the pallets. Damaged materials can have serious consequences to the production flow of the facility; if a material cannot be used, new, replacing materials will possibly have to be ordered, which can cause delays in the production (caused by manufacturing and delivery times of that specific material) and unnecessary monetary losses. If the AGVs get damaged, too, it will have its own set of consequences in terms of not being able to utilize that AGV, thus increasing the delivery times inside the facility. The severity of such issues was emphasized at the time of writing: the global lack of components would extend the delivery times and possibly increase the price of components.

Another risk recognized in the facility was, that human employees would accidentally get in the routes of the AGVs, causing unnecessary stops. The probability of an AGV hitting a human employee is minimal due to the safety scanners of the AGVs. However, the unnecessary stops would cause the delivery times to be extended, thus causing avoidable delays. This risk was considered and solved by installing floor markings, indicating all the areas on which human employees would be allowed to walk in the facility, and where materials and vehicles, for example, could be left safely. This is a simple, yet an effective solution. From my own subjective perspective, the situation visibly improved after the floor markings had been installed and a less amount of materials were in the wrong places.

4.1.1 Preparations of the Commissioning-phase of the system

The actual operations of the implementation of the AGVs at the site began, when two Solving employees at the lead of the project arrived to visit the STH facility. From Wärtsilä, employees from Production and Assembly were present, along with myself, at the time working in the Material Management -organization of the company. The purpose of the visit was to get an overall image of the situation at the site, so that the physical preparations for the implementation of the system could start. During the visit, both STH and Logistics Centre were still under construction, so one of the most common discussion topics were the places of the mirrors used in the laser-guided AGVs' navigation system, since there was a possibility that some of the existing pillars and structures would be covered later, which would block the visibility of the reflectors.

There were multiple benefits to the actual visit: it was the first time me and the Solving employees met face-to-face, despite having been working in the same project for a long period of time. In the COVID-19 era, most meetings and visits had taken place via virtual collaborating tools, such as Teams or Zoom, and mostly the participants had kept their cameras off, so they had only known each other by voice and possible profile pictures. As Lazarova et al. (2023) put it, the amount of Working from Home (WFH) has increased massively during the pandemic, and that was the case in this project as well: a large percentage of the meetings took place in Teams and the information exchange was largely carried out using virtual tools. Even though Lazarova et al. (2023) mention, that the global travel restrictions have largely been removed, it can be suspected, that with the COVID-19 pandemic, virtual tools available are now being utilized more instead of spending time travelling to physical meetings and site visits.

One week after, three employees from Solving arrived at the site to start the actual preparations for the implementation of the system. During the visit, the employees marked places for the mirrors used by the AGVs in their navigation, went through the layout and started the installation process for the "brain" of the AGV system, i.e., the different cabinets containing the AGV PC and the logical devices required. At all times, the AGVs must detect a minimum of three reflectors to maintain position information. The navigation system calculates the angles and speeds involved, so it can be on some level compared to an inertia-based navigation system commonly seen in modern airplanes. It also has similarities to the widely-known GNSS-system, since in those kinds of systems the receiver must constantly detect a certain number of satellites to maintain a reliable position information.

During the installations, one issue was discovered: the AGV PC was originally planned to be located in the Logistics Centre and all the network-related infrastructure was prepared for that. However, it was noticed that the maximum length of the cable connecting the AGV PC and one of the antennas was 10 meters, which is clearly exceeded in the situation where the AGV PC is located in the Logistics Centre and that particular antenna in the middle of the Hubway. A solution was suggested: the AGV PC would be moved to the middle of the Hubway, but that option was considered impossible to implement, since the Hubway is due to safety reasons a prohibited area from pedestrians, once the facility is completely operative and therefore, nobody would be able to access that PC without causing disruptions to the AGV and manual forklift traffic in the Hubway. This situation required the installation of one additional component to the Hubway to ensure a constant, stable connection between the systems and the AGVs. After all the work and installations carried out during the week, the next step was to have the AGVs arrive at the site.

Safety also had a crucial role in the preparations of the implementation phase: the Occupational Safety Cards of the Solving employees were inspected upon arrival, and they received a safety training issued by Wärtsilä. This training also included a test, which the external employees had to pass, to be allowed to work at the site. Additionally, the employees were given a verbal briefing about operating safely in the facility, and they had a phone number to call in case of any questions or things that needed clarifying.

To ensure a constant connectivity of the AGVs' navigation system, an employee from a separate company visited the facility to measure all the reflectors installed by solving employees the week before. The purpose of the visit was to ensure, that in all situations the AGVs would maintain their position information when moving around the facility. Losing the position information would require actions from human employees, which would cause unnecessary delays, possibly affecting the production functions of the facility.

4.1.2 Factory Acceptance Test (FAT) of the first AGV

During the same week when the measurements took place in the facility, the Factory Acceptance Test (FAT) of the first AGV to be implemented to the STH-facility took place. A group of employees from Wärtsilä and the company operating in the internal logistics in the Logistics Centre, participated the FAT and the core purpose was to witness, whether the first AGV worked the intended way. The Wärtsilä team consisted of two management-level employees and myself, who at the time worked as a Thesis Worker for the company.

During the FAT, numerous different scenarios concerning the functionality of the first AGV were tested, with high focus on the safety of the devices. The scenarios included having an object on floor level in front of a moving AGV, an object coming from a 90 degree angle compared to the path of the AGV, an object crossing the path of the AGV at a close range, having a lifted object on the pathway of the AGV, driving the AGV at a full speed, picking up a heavy (approximately 1300 kg) pallet from a floor location, taking a heavy (1300 kg) pallet to a certain storage bin and repeating the test to see the accuracy, and removing a pallet from a storage bin. Thus, a high focus of the FAT was on safety-related issues, and especially on the types of issues, that might occur in the STH-facility. Therefore, a maximum effort was paid on gaining the best possible value already from the FAT.

During the FAT, a possible safety hazard was discovered: in a situation, where the intended unload-storage bin is already occupied, the loaded AGV would not be able to detect that the storage bin is already occupied and simply pushes the pallet into the already occupied bin. This might cause the pallet already in the storage bin to be pushed down from the bin, causing a severe safety risk: the pallet might drop on people or equipment. It immediately became apparent, that a solution would have to be found before the AGVs would start operating to storage bins having that risk.

The FAT offered the project team an opportunity to witness the functions of the AGVs themselves, which offered a better visibility on the movement, scales and functions of the devices. Without the physical visit, some of the issues noticed during the FAT might had been left unnoticed and in the worst case, not be noticed until the devices were in use in the STH-facility. Another benefit of the actual visit compared to a visit executed with a virtual tool such as Teams or Zoom was, that the participants were free to observe the testing from anywhere they considered best. With virtual tools, the perspective of the camera is significantly more restricted and does not allow as high-level observation as in this situation.

Since the Solving employees participating the FAT had been working on the project for a long period of time, the possibilities for employees participating the FAT to ask questions were excellent. I subjectively consider that the threshold to ask questions face-to-face is lower than in a situation, where one has to block the entire Teams call for a question. The questions asked from the Solving employees considered safety, usability, manual operation of the AGVs and their technical features. The interaction during the event was constant and direct, which decreased the threshold to ask any questions or point out any concerns.

4.1.3 Commissioning-phase of the system

The commissioning-phase of the implementation began with the arrival of the first AGV. The supplier of the AGVs reported the estimated arrival date and time well before the estimated arrival time, which helped the employees at the site to be prepared for the arrival. The AGV had been transported from the Solving’s factory and the original plan was to have the AGV unloaded in the Logistics Centre, but that was considered not possible due to various reasons, so a decision was made to have the AGV unloaded in the STH.

After the truck arrived at the STH, it drove inside the facility, where the unloading of the AGV could be carried out safely, according to the supplier’s instructions and with minimized risk of causing any damage or risk to people, the AGV or the surrounding infrastructure. The unloading was done by people authorized to operate the heavy cranes in the STH facility. The AGV was located to a place where it would not be in the way of anyone and would not affect the normal operations of the facility.

The arrival of the first AGV was communicated to the people most closely working on the project, and some of them also witnessed the arrival and unloading. During this, I got asked multiple questions about the AGV, its operations and functions. The observations I made during this situation were completely in line with what an employee from another company using the same supplier’s AGVs said in a previous interview: people are interested in anything new arriving at the factory and being utilized there. From communications perspective, I considered this highly beneficial, because the spread of facts rather than assumptions is a positive phenomenon and can decrease the amount of false information about the topic. The informal discussions are also important in terms of team dynamics, which are beneficial in a complex project, like which had not been carried out before in the same context.

During the commissioning phase, it was agreed that the core project team would have a brief, 30-minute meeting each day throughout the commissioning. The purpose of these meetings was to act as status checks: what had been done that day, what would be done the next day and were there any existing or potential obstacles, issues, or threats to the original commissioning plan. One such issue was found at a relatively early stage of the commissioning: since the STH at that time was in construction phase, some of the pallets delivered there from the Logistics Centre had to be left to temporary locations, some of which were blocking the routes used by the AGV.

During the commissioning phase of the AGV-system, I wanted to find out the concrete consequences of a situation, when an AGV malfunctions and the tasks allocated to AGVs will have to be taken care of with manual forklifts. Therefore, I decided to ask one of the people working in a supervisory position in the logistics about the topic as follows (translated from Finnish): *"What happens from your perspective, if one of the AGVs gets inoperable and the same tasks will have to be taken care of with manual forklifts without pre-warning?"*

In their answer, the first point mentioned by the interviewee was that it is important to get the information via the system so, that they could allocate resources to take care of the tasks. Secondly, the person mentioned that they would have to move the needed resources from other tasks to take care of the transportation tasks, which would cause deficiencies in other tasks. Per se, they do not allocate resources to be in reserve. They would also have to prioritize the tasks, and something might be left undone while the AGV is inoperable, and the malfunction situation exists, or they have gotten additional resources to work.

Allocating the available resources clearly stood out in the interviewee's answers. An important point given by the interviewee was, that there is not enough forklift capacity to take care of the entire workload of both AGVs and manual forklifts, so prioritization would have to done during those events. This can cause negative effects to other work tasks. From the interviewee's answers it can be seen, how interrelated and interconnected various tasks in the overall process really are: the malfunction of one part of the process inevitably affects many others.

4.1.4 Communications between the AGVs, AGV scanners and the EWM

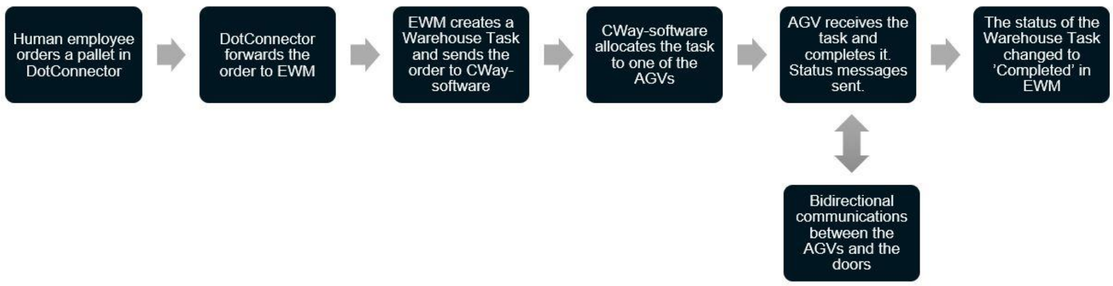

Figure 10: Communications between different actors in the AGV-system when transporting a loaded pallet from the Logistics Centre to STH

Figure 10 gives a simplified representation of the communications taking place between human employee, different systems and individual AGVs in the STH-facility. Data and communication play key roles in modern warehouse management systems in the contexts of Industry 4.0 and Logistics 4.0. Since the communications are constant and the volume of the materials being transported in the facility is high, the amount of data being transmitted in the system is also high. As Swinkelhaus & Grosse (2020) mention, Big Data is one of the enablers of optimizing and forecasting the behaviour of a system. This is also the reality in the AGV system discussed in this thesis and it can be stated, that from reliability and usability perspective, communications are of essence.

In the AGV system, the communications between the AGVs, their scanners and the EWM take place in the form of telegram messages. These telegram messages are essentially data packages containing information about the source storage bin and destination bin. Each message has its own individual number, which separates it from any other telegram message sent in the system and eliminates the possibility for the messages to get mixed up with each other.

There are multiple individual purposes for the use of the telegram messages in the overall AGV system. First, they enable the monitoring of the system status. Since the system is highly automated, the monitoring and alert-sending enables quick and efficient actions in situations of any anomalies. This relates to one of the goals defined to this thesis: the uninterruptedness of the overall system. From this perspective, it is relevant also from the EWM perspective to have actual, up-to-date data about the status of the AGV system because in situations where the AGV capacity has decreased, the manual forklifts will have to carry out those transportation tasks.

Secondly, the communications between the AGV software and the EWM enable human employees to give commands for the AGVs to deliver pallets from the Logistics Centre to the STH's different drop-off locations. At the time of writing, the production process of an engine was divided into different phases. When an engine reaches certain p hases, next phases are released for picking, during which the materials belonging to those phases are picked from the warehouse and transported to various locations in the production area.

Third, the communications allow the system also to return filled pallets from the STH to the Logistics Centre. This situation can occur, for example, when a component going to an engine is assembled, but it cannot yet be installed to the engine itself and it is decided to temporarily store it in the Logistics Centre rather than in the storage bins of the STH. Since the storage space in many locations of the STH is limited, this feature helps space utilization and supports the pull-mindset in the facility, in which Production determines, when materials are needed, and Material Management acts accordingly.

4.1.5 User Training

From the usability and end-user perspective, a key part of a successful implementation is getting a proper training for the system. Since the technology had never been utilized in Wärtsilä premises in Finland before, training was considered an essential part of the implementation project. Focus points when designing the trainings were i.e., the following: Who will participate the trainings? When will the trainings be organized and how long will they take? What will be included in the trainings? These focus points would define the overall image of the trainings.

The trainings were divided into two parts according to the focus groups, which were named "operators" and "maintenance personnel". Both groups' preliminary training program included "general system presentation”, “manual operation of AGV" and "general safety training". Additionally, the operators' training included "graphical operator's interface", "releasing emergency stop" and "auto-insert", whereas the maintenance personnel’s training included "mechanical service" and "electrical maintenance, sensors, adjustments, Operation Panel".

The purpose of the training was to prepare the employees to work in and with the system. This purpose included two perspectives of this study: safety and usability. It is considered vital, that the employees know how to operate safely in an environment, where also vehicles without human drivers operate regularly. It also enabled them to share the information with their colleagues.

The duration of the trainings was planned to be four consecutive days, 8 hours each, during normal working time between 8-16 Finnish Time. The training was planned to take place face-to-face, which could increase interactivity and decrease the threshold to ask questions. It would also offer the possibility for the participants to see the actual AGVs and their operating environment in real-life.

The first part of the training was the Operator training. The training was divided into classroom-studying and hands-on training. In the classroom-studying, the users who had different roles in the overall AGV system and who were from Wärtsilä and the company operating in the internal logistics in the Logistics Centre, got teaching about basics of the AGV and its functionalities, components such as lights, both navigation and safety scanners, and the AGV manual. During the training, the participants also had opportunities to ask questions.

In the Operator training, there was also a hands-on part, which took place physically at the shop floor with one of the AGVs. During that training, the instructor introduced the participants to the components and parts of the AGV in practice, such as scanners for both navigation and safety, the lights, the forks, the safety switches (such as the emergency and soft stop buttons), the AGV PC and its CWay-software, removing an AGV from the system, and driving an AGV manually. The training offered the participants also the opportunity to witness the movement of the AGV.

The maintenance training offered the participants a basic technical understanding of the AGVs. During the training, the instructor briefed the participants through the different components of the AGV and where, for example, the circuit breakers, different sensors (such as height and speed), are located. Additionally, the participants had an opportunity to manually drive an AGV, since it was considered one of the basic tasks that the trained employees would have to be able to do.

Maintenance training and the possible issues that were identified are directly linked to responsibilities in problem situations. It should be noted, that employees from multiple companies operate directly or indirectly with the AGV system: the two companies operating in the internal logistics of STH and Logistics Centre, alongside Wärtsilä employees.

Therefore, the clear responsibilities and clearly defined processes are highly valuable and enhance the speed and effectiveness in problem solving. To start defining these processes, I sent an email to the Project Engineer of Solving, asking about what types of and which kinds of error and failure situations should the people involved be prepared for.

Once the possible issues were identified, it was time to define process charts on each identified situation with ”swimming lanes” indicating the responsible party/person for certain phases in the process. This, however, should be seen as a continuous process: whenever a new issue is discovered, the problem-solving process including clearly allocated responsibilities should be defined. A common location of such documents and processes was agreed, and accesses organized.

Since the AGVs would operate in the STH, where also human employees work continuously, it was decided to organize a training for them, too. The contents of this training were discussed with two different target audiences: the forklift drivers and assembly workers. Both groups received a basic-level training of the functionalities of the AGVs and especially their safety devices. The training was organized by Solving, and during the classroom training, the participants had the opportunity to address any concerns and ask any questions they had.

Since not only the so-called key users would operate in the same environment with the AGVs, also two separate trainings were organized for companies working in the internal logistics of the Logistics Centre and the STH. The training group here were the forklift drivers, who would place pallets to shelves (also called storage bins) from which the AGVs would pick them up and deliver them to Logistics Centre. Another scenario is that in some areas, the AGVs deliver a pallet to a shelf and a human employee will deliver it to the final storage bin. The training of the manual forklift drivers included basic-level theoretical training and visual observation of the operations of the AGVs. *Basic-level* in this context means knowing the various components of the AGVs and how to operate safely in the same environment.

A training session was also organized for the people working as assembly workers and team leaders in the STH assembly area. The focus here was on the safety and safe operations with the AGVs. During the training, the workers also brought out concerns about possible issues, which the AGVs might come across. These included hanging objects, which the navigation scanners of the AGVs might not be able to observe, thus being a clear safety concern. Since I was also mostly present in these trainings, it offered me valuable information about the possible threats that the operations might come across. The finding highlights, how valuable it is to involve a wide-enough participation in the project: different employees can view same things completely different, which can be beneficial from the perspective of the project's success. Also, the value of leaving time for free discussion in the training stands out. My own conclusion of these observations is, that the more there is room for expressing concerns and asking questions, the more there is information instead of assumptions, and the less there is change resistance towards the new tools and ways-of-working.

4.1.6 Testing-phase of the AGV implementation

After the needed employees had been trained, the implementation project moved to test-phase. During the test-phase, the different areas in which the AGV would operate, were tested in terms of how well the AGV could manoeuvre there, do all the systems work properly (for example, would the doors open when approached by an AGV and be closed when they were past the doors, and whether the messages between the AGV, the CWay-software and the EWM be transported correctly), and were there any unexpected issues. This was also a way for the project team to ensure that the AGVs would not lose the connection at any point.

The tests were carried out by using actual pallets containing materials going to production, but also empty pallets. The first two areas to be tested were Common Labs and MTAC. The tests were initiated, when there was a pallet ready to be transported from the After Picking Buffer to a storage bin in the STH. During the first tests, people from all needed companies were present to ensure the result of each test phase. The team had a constant, real-time connection, and the person following the test at the site would report each movement and action taken by the AGV.

Numerous benefits were achieved by the testing. First, the participants could witness first-hand how the AGV operates, how fast it moves in the different areas of the facility, how the loading and unloading happen, and how its collision avoidance systems work does. Because of the real-time communications within the team, if there was a message expected to be sent to a system, such as EWM, the result of that test phase could be confirmed immediately. This made the tests more valid and reliable, since the results were immediately visible. Finally, the employees working in the STH-facility who were not part of the project team, could witness and observe, how the AGV operates, thus giving them better understanding about the topic. Observing also offered them a possibility to see, how close objects, such as pallets and forklifts, could be without causing the AGVs to slow down or stop completely. Besides that, it gave the employees an opportunity for interaction. The overall reactions of the employees were curious and excited, some of them even asking for possibilities to come see the testing.

Several tests were done for each area where the AGVs operate, and after each test, the results were recorded and reported to the project team, but also to the STH management. This was to give the management a realistic situational awareness of the implementation project and the possible issues the team had faced or were still facing. It also gave the management an opportunity to ask questions or express any concerns regarding the topic, highlighting the value of communications not only within the project team, but also within the entire STH community.

4.2 Data collection process

In this chapter I will describe, how the data for the study was collected. The data collection process began by deciding, what kind of data would produce the most valuable information and knowledge from the perspective of myself and the company for which this thesis was written. The data collection process was guided by the research question and the objectives determined by the company, but I was not limited from doing research from other relevant subtopics of the field as well.

As the research made for this thesis is qualitative rather than quantitative, having small numbers of answers was expected. However, I had been working with some of the interviewees for a significant amount of time, so there was an existing mutual trust between the interviewer and the interviewees. Therefore, I have no reason to believe, that the interviewees would have intentionally given any false information or tried to hide or unnecessarily highlight anything in the interviews.

Having the research done for this thesis rather qualitative than quantitative, had a major effect on the data collection process. I had to understand from the very beginning, that it would be impossible to get a large number of answers to the interviews or collect information about trends of the behaviour, reliability and volumes of transport carried out by the AGVs. The low amount of data is one of the limitations of this study.

4.2.1 The Sustainable Technology Hub and the Logistics Centre

The data for this study was collected in the Sustainable Technology Hub (STH) -facility operated by Wärtsilä, in Vaskiluoto, Vaasa. According to the company (Wärtsilä, 2021c), the total investment to the facility is approximately 200 million euros, of which the company's part is 80 million euros targeted to the modern test- and production technology of the facility.

The company describes the facility as a *"Factory of the Future"* (Wärtsilä, 2021c) and mentions, that flexible manufacturing systems, additive manufacturing and robotics will have an important role in the facility. AGVs are directly related to two of the three previously mentioned concepts, since AGVs are essentially robots that are involved in enabling flexible manufacturing.

According to Wärtsilä (2020), one part of the Sustainable Technology Hub -facility will be the Logistics Centre, where a major part of all the logistics operations of the facility will take place. According to the company (2021c), all the deliveries of Wärtsilä are coordinated at the Logistics Centre. Approximately 50 people will work in the facility and the number consists of both white- and blue-collar workers.

The facility's total area is 14,500 square meters and according to Wärtsilä (2021f) there will be room for 21 600 pallets at the height up to 17 meters and 15 000 storage places for smaller boxes at the height of 18 meters. The processing of the smaller boxes is handled with a highly automated mini-load-system, which is not included in the scope of this study, since it is a separate system from the AGV-system.

The Logistics Centre and the STH are physically connected by the Hubway, which is essentially a corridor in which the AGVs and manual forklifts travel. To ensure the smooth and continuous operations of the AGVs, a radio transmitter and antenna were installed to the Hubway. This ensures that the AGVs will at no point lose contact with the network and can receive tasks constantly when operating in the facility. The Hubway itself is restricted from pedestrians and is only used by manual forklifts and AGVs, which increases the overall safety of the employees working in the logistics operations of the facility, since the space in the Hubway is limited, and the pedestrians, who are more vulnerable in crash situations than manual forklifts (in which the drivers, each of whom is trained, are protected by the structures of the forklift and are wearing seatbelts at all times, for example) and AGVs, which have high kinetic energy due to their heavy weight and relatively high speed.

4.2.2 Interviews

One of the most important data collection methods in this study were the interviews. Altogether five interviews were carried out. The purpose of the interviews was to get insights from professionals from different organizational levels in different organizations, with tasks directly or indirectly related to the AGV-system and -project. The roles of the interviewees are illustrated in Figure 10.

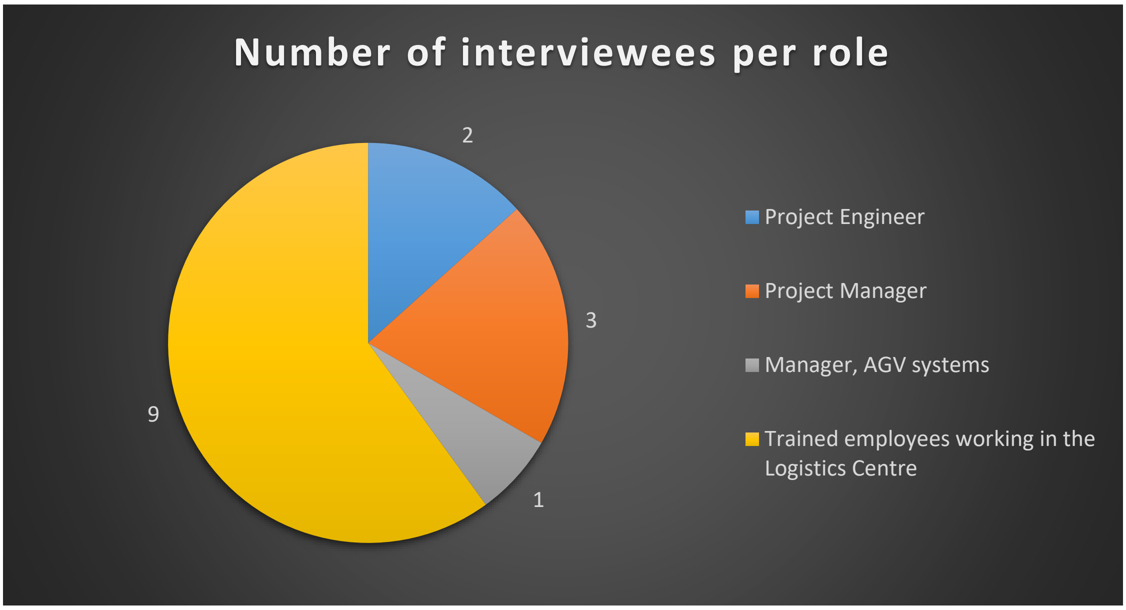

Figure 11: Number of interviewees per role

In Figure 10, it is visible, that most of the interviewees were the trained employees from Wärtsilä & the company operating in the internal logistics in the Logistics Centre, who would have AGV-related tasks in their work during the commissioning phase but also after the Go-Live. Therefore, their insights were considered valuable. Also, the insights from the employees working most closely in implementing the system, the project engineers, were of importance and enabled a more holistic understanding of the successful implementation of the AGV-system. Project management worked closely together throughout the project. The group consisted of experienced, high-skilled employees. All the interviews were carried out between March 2022 and June 2022. Timeline of the interviews is presented in Figure 11. The high-level contents of the interviews are also illustrated there.

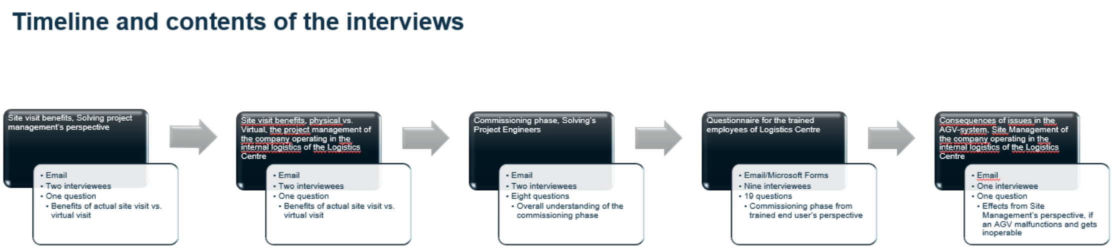

Figure 12: Timeline and contents of the interviews

Interview for Solving project management: site visit benefits

As per my own experiences, face-to-face meetings and interaction allow more spontaneous questions and the usage of small gestures, such as nods and facial expressions. To gain more knowledge about the benefits of physical site visits compared to a virtual visit, I decided to interview Solving's project management via email. Two employees received the question: *"What kind of benefits did the visit to the STH at the beginning of last week have from your perspective, if one compares that visit to a situation, where the visit would have had to be completed only via a virtual platform, such as Teams or Zoom?”*

The answer pointed out that: *"Those digital platforms do not give a "3D real image" of the factory buildings and the machines and fittings installed to them"* and added: *"Exactly the AGV system is installed to a "very broad area in the facility""*, pointing out that: *""Nothing beats" the amount of information in the situation where "one walks through the route, making observations""*.

Interview for the project management of the company operating in the internal logistics in the Logistics Centre: site visit benefits

During the same day that the Factory Acceptance Test (FAT) of the first AGV took place, the project team from the company operating in the internal logistics of the Logistics Centre, had the opportunity to visit the STH facility. For some of the project team, it was the first actual visit to the site and until that, all the interaction, cooperation, planning and preparations had taken place via virtual platforms. As the benefits of the physical visits to the site is of interest in this study, I asked the project manager to give his opinion on *"What kind of benefits was there with the actual, physical visit to the facility, compared to a situation where the same visit was made using a virtual tool, such as Teams or Zoom?"*.

The answers given by the project manager highlighted the value of getting the right impressions of dimensions. This is related to the second point mentioned by him, pointing out that a physical visit helps understanding the actual reality at the facility: where there is a limited amount of space available for the AGV, where the AGVs share the same environment with human employees and where there are corners, for example, that have to be considered. Overall, he mentioned, that *"the human eye works better than a camera"* and pointed out, that all these things can also be re-checked from security perspective.

Related to the limited space and possible corners, the project manager from the company operating in the internal logistics of the Logistics Centre, mentioned, that disturbing elements can be more easily noticed, when being physically present at the facility. By the disturbing elements, he referred to small areas, spaces used by operation and possible installed components. All of these will inevitably have a direct or an indirect effect on the operability of the AGV. Overall, he mentioned, that recognizing the reality and circumstances at the facility is important for the commissioning. This also includes the loads that the AGVs have to be able to carry. During the visit, the group spent also time observing the loads currently carried by manual forklifts. The participants of the visit pointed out possible issues and problems with the loads, which would have been significantly more complex by using only virtual tools.

A highly interesting aspect mentioned by the project manager and closely related to the human-perspective of the entire project was, that *"It is helpful and useful for cooperation to establish personal contact with the team"*. Reyers et al. (2021) agree by pointing out the importance of the relationships between teammates. In the enterprise and industrial world, the group dynamics and relationships in teams can be significant assets effecting the performance of the team.

Reyers et al. (2021) add, that a common understanding of the overall situation and goals amongst the team members is important. This supports the answer given by the project manager working in the company operating in the internal logistics of the Logistics Centre, who highlighted the establishment of personal contact with the team. Strong group dynamics in the project team can help the team to understand the same things in the same way, which supports the common understanding of the team's goals in the project.

Despite proper planning and preparation, reality in some situations in project context may differ from the plans. This is also something the project manager working in the company operating in the internal logistics of the Logistics Centre, mentioned in his answers, pointing out that difference in the context of *"loads, target positions, process at production line"*. One of his comments was, that: *"It's different to see it in reality instead of virtual"*. Based on this, it can be understood that one can get more information of the same environment by actually making observations in the facility.

Interview for Solving’s project engineers: Commissioning phase

To gain knowledge about a successful commissioning from the AGV supplier's perspective, I sent questions to two of the AGV supplier's Project Engineers working on the commissioning of the AGV-system at the STH facility. The questions were sent during the commissioning phase to get as actual information as possible and to try to minimize the possibility of forgetting smaller events. Four questions were asked:

1. What do you see as the most important prerequisites for a successful commissioning and implementation of an AGV system?

2. What kinds of obstacles/challenges have you come across during this commissioning phase?

a) How were they solved?

b) Did the companies regularly operating in this facility (STH, Hub-way and Logistics Centre) provide you enough and right kind of assistance/resources when solving these issues?

3. What aspects have made the commissioning phase more successful?

a) What could be improved?

4. What do you consider as the most likely reasons to cause interruptions in the system?

a) How could one prepare for these interruptions to minimize their effects?

One of the Project Engineers answered the questions. The answer *("A clear view from both the customer and supplier of what needs to be completed before the commissioning starts, and what the biggest obstacles are"*) to the first question pointed out the importance of clear definitions and understanding of what must be done before the project moves to the commissioning phase.

The second question I asked, considered the possible obstacles and challenges thus far during the commissioning phase. Notable here is, that the commissioning phase was still ongoing, when I asked and the interviewee replied to the questions. According to the interviewee, there had not been any uncommon issues and the ones that occurred, were for example, situations where the AGV could not fit into load stations. The interviewee added that the obstacles have been discussed with the necessary participants, and the solution has been figured out together. Once again, communications seem to have a crucial role. However, the communications apparently have to be well planned and the need of an actual meeting has to be carefully considered, because they can take time from a large number of people.

The third question was about finding the factors and aspects that can make the commissioning more successful. The interviewee's answer pointed out active discussion about the progress of the commissioning by saying, that with active communication, issues rose up quickly, but on the other hand, planning and meetings took a lot of time. He added that the company makes their own commissioning plan and thus the planning meetings with their customers for the coming days are unnecessary. These answers support the importance of mutual understanding of other companies' goals regarding the project.

The fourth and final question was about predicting issues in the future - also after the Go-Live of the system. In addition to bringing out the possible issues, the interviewee suggested solutions to solve these issues already in advance, which was extremely valuable from the project's perspective. The interviewee mentioned objects in the AGVs' routes as one possible issue, which could be solved by proper training for the employees working in the same environments as the AGVs. Also, the possible new structures built to the areas where the AGVs operate, can block the reflectors used by the AGVs for navigation. A possible solution to this would be to consider the AGV system whenever construction takes place in the facility and possibly contacting the AGV supplier to move the existing reflectors.

Interview for the employees expected to work with the AGVs in the STH-facility

I decided to interview the employees of Wärtsilä and the company operating in the internal logistics of the Logistics Centre, who had participated the training organized by the AGV manufacturer. Overall, approximately 50 people work in the Logistics Centre on a wide range of tasks. With the research question and targets in mind, I decided to focus on the employees, who had received the training from the AGV-supplier and would therefore on one hand be expected to have AGV-related responsibilities in their work, but on the other, have a broader set of skills and understanding than the employees without the training. Therefore, I expected them to have valuable insights and knowledge about the topic, which would be valuable for the project and for the study. I expected the AGV-trained group of employees to also have better abilities to imagine possible problem situations, detection of which was considered important for the uninterruptedness of the AGV-system.

The interview was carried out using an email message containing a link to the interview form. The form was created using Microsoft Forms and the questions are presented in Appendix 1. The opinions and insights from the end users were considered valuable, since they would be the people working in the same environment with the AGVs and it could give them the possibility to be heard, which is beneficial for both the end-users and the project team, because, as per my personal assumptions, the end users might have ideas and thoughts that the me and the project team would not necessarily have come across.

Ten employees, including myself, participated the training organized by the AGV supplier. The link to the interview questions was sent to the remaining nine employees. The interviewees were given 20 days to answer the questions. Six days before the time window to answer the questions was closed, I sent a reminder email to the recipients of the original email to increase the number of answers, and thus, to get more reliable and versatile data and knowledge. By the end of the time period to answer the questions closed, three out of nine interviewees had given their answers, giving an answer rate of 1/3. The questions were asked in Finnish, and I translated the answers into English for the representation of the results.

Despite only three employees responded to the interview, some of the remaining six employees contributed in unofficial, informal situations, such as coffee breaks and short discussions while working on other tasks. The answers given by them supported the answers given by the respondents, by pointing out similar aspects and concerns regarding the successes and failures in the project, along with unplanned stops in the AGV operations. These discussions sometimes took place on the Logistics Centre floor and the employees could directly show their points in practice, which made their arguments even more credible and concrete.

The group of respondents consisted of three employees. Their work role, experience in material management, frequency of AGV-related tasks in their work, and their experience thus far in the project has been presented in Table 2.

Role	Years in Material Management	Frequency of AGV-related tasks	Time thus far in the AGV-project
Storage key user	25 years	Almost daily	One year
All tasks related to material management	10 months	Daily	Six months
Key user in EWM, inventory & automation	21 years	A few times a week	Six months

Table 2: Respondents' role, years in Material Management, Frequency of AGV-related tasks, and Time thus far in the AGV-project.

The data in Table 2 supports my expectation of having selected the right group of interviewees: people, who regularly work on AGV-related tasks. I also wanted to interview employees with varying level of experience, which happened with one respondent having less than one year of experience in material management -related tasks. Two interviewees described themselves as *key users* indicating that they would later be supporting their colleagues in their tasks.

When asked, what had gone well in the project thus far and why, the respondents' answers varied: one told, that nothing had gone well, whereas one praised the cooperation with Solving. According to one respondent *"things have been planned and considered* *the possible challenges, that might be come up with"* and added that *"AGV-user training has been given to several (employees)"*. The next question was an opposite to the previous one: the interviewees were asked, what had not gone well and why. All the interviewees' answers pointed out the same thing: the implementation had taken too long.

Related to the previous questions, the interviewees were asked to describe in their own words, what could have been done differently. One of the interviewees did not answer the question, but the two other interviewees pointed out simulation of the implementation and better preparation for the implementation, such as by having the floor markings done in advance. It can be understood from the answers, that proactive actions benefit the implementation.

The next question was about how well the interviewees know their tasks, once the system is in operational use. The results are illustrated in Figure 9.

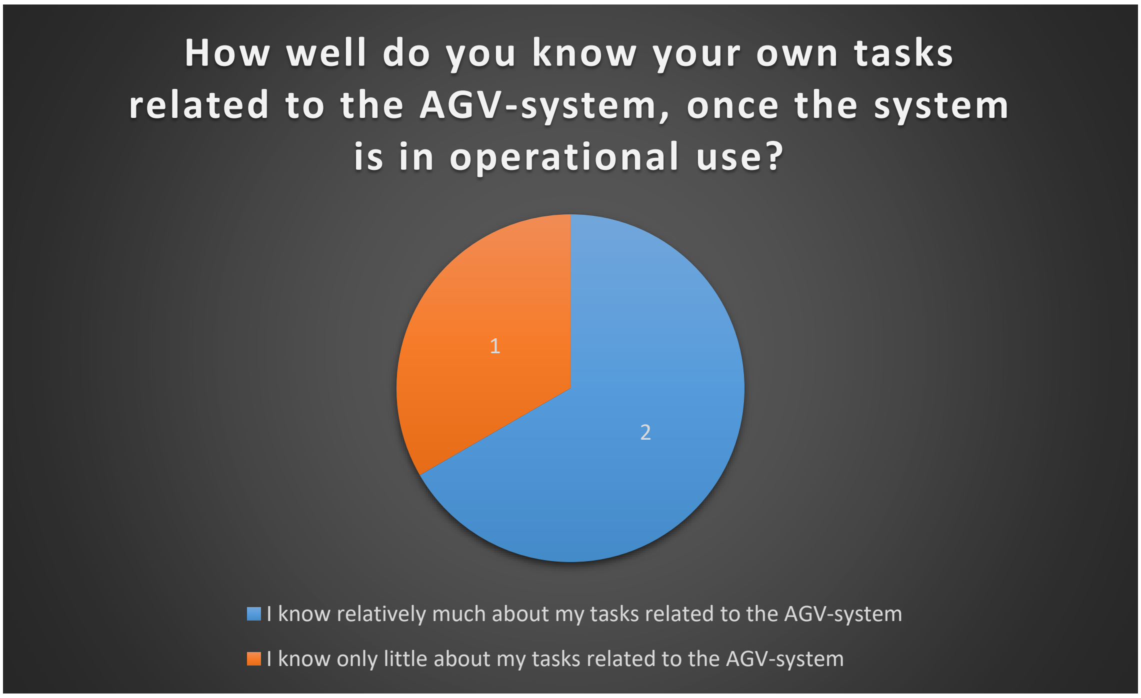

Figure 13: How well do you know your own tasks related to the AGV-system, once the system is in operational use?

Since there were five options ranging from *"I do not know my tasks related to the AGV-system at all"* to *"I completely know my tasks related to the AGV-system"*, the result shows, that the interviewees have at least a little understanding of their tasks in the system. None of the respondents indicated having either no understanding or complete understanding of their tasks in the system.

One of the focus areas of this thesis was decided to be the problem-solving process. Therefore, I decided to ask the users about their understanding of the topic. The question and the results are illustrated in Figure 14.

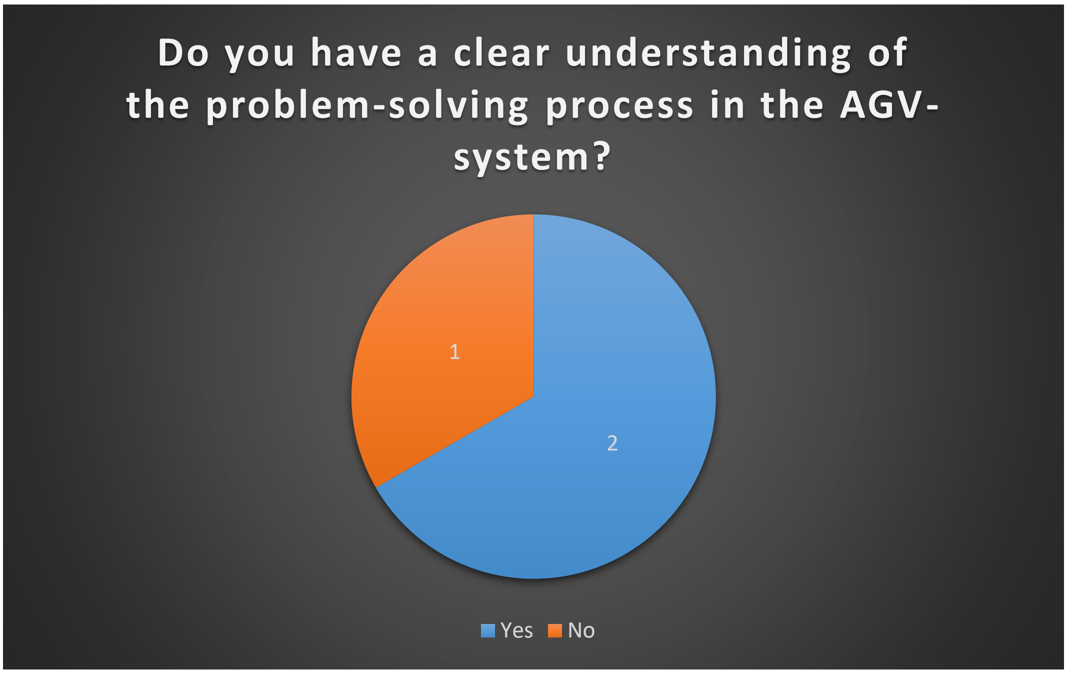

Figure 14: Do you have a clear understanding of the problem-solving process in the AGV-system?

This question had only two answer options: *"Yes"* and *"No"*. Two of the respondents reported to have a clear understanding, whereas one of the respondents told not having a clear understanding of the problem-solving process. A follow-up question was asked about which things needed clarification and the interviewee responded, that they do not have an exact knowledge of the behaviour of the EWM-tasks in a situation where an AGV does not recognize a barcode, for example. However, all the respondents answered "Yes", when asked, if they knew their point of contact, if they were to face a problem that they were unable to solve themselves. This indicates, that even though the employees might not have an answer to each possible scenario, they know, where to reach to get the answer.

Related to usability, I asked the interviewees to describe in their own words the easiest and most usable way for them to get information about the AGV-system, including problem situations. Two of the interviewees pointed out that they would gain information from practice, whereas one interviewee wished for an info session to be organized. Since I was actively working in the project, I decided about organizing the requested info session once the system had been implemented. This is a clear example of how valuable the requests and thoughts from the users are for the project management, and how valuable the interaction between project management and the end users is: the project management wants to know, what the end users want to know.

As uninterruptedness was also selected as one of the areas of interest in the thesis, I asked the users' opinion on what would in their opinion cause the most amount of problem situations in the AGV-system. Two of the interviewees pointed out physical objects, such as pallets or materials, being left on the AGVs' routes, whereas one respondent mentioned that: *"In the production side, pallets will probably be left in storage bins that according to the system should be empty and thus, the AGV is unable to leave the pallet to the right storage bin"*. All the risks listed by the interviewees are related to the human-factor constantly present in the system: a human employee can possibly leave a pallet to the route of the AGV or mistakenly place a pallet to a wrong storage bin. The answer to this question was in line with the following question, in which I asked the interviewees about what they see as the most likely factors causing unplanned stops for the AGVs. Each interviewee pointed out pallets left on the AGVs' routes.

Next, the interviewees were asked, what they had learnt throughout the project. Two of the interviewees mentioned the overall operations of the AGVs and one pointed out the importance of planning and responsibilities, when several companies were working together. These answers were also in line with the next question: *"Which of the things learnt during this project do you believe will help you in your future work and projects?"*. One interviewee mentioned the manual driving of the AGVs and returning them back to the system, another pointed out the general knowhow and experience of how to work with this kind of devices and the third mentioned scheduling and sharing of responsibilities.

All the interviewees answered that too much information had not been given on any topics, and that they were unable to specify any things that they wished still to learn through the project, two of them mentioning as a reason that the AGVs were not in use at the time of the interview.

Finally, I offered the interviewees an opportunity to freely bring up any thoughts about the AGV-system. One of the interviewees gave an answer, highlighting that: *"Everyone has a lot to learn from this project, how to work in the future in similar projects, so that things would go better. One thing would be, how to predict better instead of just reacting once the situation comes up"*. In their answer, the interviewee refers to continuous development and acting in a proactive manner.

4.2.3 Observing as an active member of the project team

As I was a member of the project team, observing became one of the most crucial data collection methods. Since I often was the contact person between different companies, participating the weekly and in the commissioning phase daily meetings, I was able to also observe the daily life in the project. Therefore, I could capture and document what I observed during the project. This was beneficial in multiple ways: first, it gave me an understanding of how the overall project proceeded. Secondly, it enabled me to reflect, which practices used in the project were beneficial and which were not. Also, the possible causes of unplanned stops were easy to see and understand this way. Overall, by observing, it was possible to gain a holistic understanding of the entire implementation process.

During the training, for example, the participants brought out a wide variety of opinions, insights and concerns from their perspective, which proved to be beneficial from the project's perspective: the participants could point out issues and even possible safety concerns that the project team might not had come across. Therefore, it enabled the project team to document the identified threats and proactively eliminate them. The same information and experiences would have been significantly more difficult to get otherwise. This indicates, how important it is to bring the employees working in the area, involved in the project as early as possible, and to recognize their expertise and knowledge as contributors to the project.

The commissioning and testing -phases offered excellent possibilities for observing the implementation. In the commissioning-phase, the early on-site work took place, starting from the arrival of the first AGV to the moment, where the project team was ready to start the actual testing of the operations. Being involved in the daily work of the commissioning phase was an invaluable method for collecting information and I subjectively consider, that observing and active documenting in this phase not only deepened my professional skills but also brought a significant amount of value to the study. The experienced value of on-site observing is also in line with the comments from the interviewees.

While observation proved to be a successful choice as one of the data collection methods, it also increased the amount of interaction between the project team and the employees working in the STH-facility: very often, employees would come and witness the testing, asking questions and making comments about the AGVs. This helped them to get used to an environment, where AGVs are present, but also to get first-hand information and facts about the AGVs and their functionalities. The benefits were mutual, and once this was noticed by the project team, conscious efforts were paid to increase the interaction.

Observing also offered the possibility to document the errors faced during the commissioning and testing. These errors and failures were properly documented along with their solution processes. When combined, they created the answer to two of the targets of this study: uninterruptedness and responsibilities in problem situations: when each problem along with their solutions were documented, the project team and users got a constantly-developing documentation of the situations faced. Thus, some of the issues could be solved proactively, increasing uninterruptedness, while the others act as direct instructions on how to solve the possible issues along with the responsibilities directly identified.

4.2.4 Summary of the data collection process

The data collection phase started with collecting the theoretical knowledge of the topic and related topics, such as the AGV, *Industry 4.0* and *Logistics 4.0*. Theoretical framework and understanding of the theoretical side of the AGV implementation broadened and deepened the possibilities for other data collection methods: understanding the technical functionality of the navigation method, for example, enabled to better understand its functions in the observation phase. Also, understanding the changing role of a human employee in *Industry 4.0* helped understanding, what the role change from a forklift driver into system supervisor or key user actually meant. Theory was combined with practice.

Interviews and questionnaires intended to collect first-hand insights from the employees working in various companies and various roles in the implementation project. The intention was to interview as broad audience as reasonably possible from the research question’s and targets' perspective. Therefore, the roles of the interviewees ranged from the trained end users to the project management and the AGV supplier. The insights given by different employee groups on one hand differed at times significantly, but often also complemented each other.

After the interviews it could be concluded, that executing the interviews with the interviewees' language as much as possible, seemed to be a successful choice, allowing the interviewees to focus on their answers rather than translating their thoughts into different languages. However, that required me to have a sufficient skill level in that particular language. It also proved to be successful to keep the interviews as brief as possible. This, on the other hand, forced me to carefully consider, what kind of questions would produce the most valuable answers. Thus, planning of the interviews stood out, and close attention should also be paid to the timing of the interviews so, that the number of available interviewees is maximized, and a minimum number of employees would be on vacation, for example. Increasing the number of interviewees increases the amount of data collected, which can have positive effects on the reliability of the study.

Related to the interviews, the informal discussions throughout the implementation project proved to be highly beneficial. These discussions took place during lunch and coffee breaks, but also during the trainings. It seemed, that in a relaxed, open atmosphere, people are more willing to express their opinions and concerns and ask questions. However, one must consider, that during breaks, the discussion is seldom structured, and the topics might vary constantly. The ethics of the researcher also rise to a big role, since I had to constantly be sure, what is appropriate to include to the study and what is better to leave outside.

Informal discussions also took place, while data was collected by observing. Often, the employees of the STH would ask questions about the AGVs, its functionalities and schedules of when the AGVs would operate in certain areas of the facility. It should be noted, that observation took place throughout the project, since I was a member of the project team from October 2021. By active participation and own interest towards the topic, I could focus on the aspects directly related to the research question and targets while observing. Therefore, the most value-creating data could be collected while observing the progress in the project. By witnessing the different events myself, the risk of second-hand information was minimized. However, a deeper understanding of the topic could have been gained by participating some of the events only as an observer rather than having the duplicate role of observer and project team member. This way, more holistic view could have been taken when observing.

4.3 Data Analysis

In this chapter, I will analyse and summarize the data collected during the study. Due to the nature of the study, qualitative data analysis had to be carried out with the purpose of gaining the maximum value from the data. The data was collected in the STH-facility, including the Logistics Centre, starting in October 2021 and ending in September 2022.

The decision to analyse the data as qualitative originates from the methods and type of data collected. Most of the data collected during the study was non-numeric. To analyse the data collected, an inductive approach was taken, meaning that no predefined hypotheses were set. Instead, I decided to collect the relevant data and make my judgments based on that. This decision was taken due to the uniqueness of the project and that I did not want to restrict the data collection unnecessarily by having any pre-assumptions in a situation, where the amount of data collected was already limited.

In the interview carried out for the trained employees using the form, the respondents underlined the human factor as a probable cause for unplanned stops of the AGVs. From a descriptive perspective, they seem to expect materials being in the wrong places in the beginning. This indicates, that since the ways-of-working are new, the employees have not necessarily gotten used to how important it is to only leave items to where they are supposed to be left. From a diagnostic perspective, the respondents seem to understand the human-factor in the system. None of the respondents pointed out any mechanical or system failures, for example, indicating that the users are likely to trust the technology.

T he trained employees expressed to mostly understand their tasks when the system is in full operational use, or at least know their point of contact, if an unfamiliar error occurs. However, based on their answers, additional training will be needed especially for problem situations. One of the respondents mentioned a very specific topic in which additional training is needed. This indicates, that since the system has been in operational use and extensive testing has been carried out, the understanding of the system has increased, leading to more detailed questions being asked. From the uninterruptedness-perspective, it shows the interest of the trained employees towards the topic. Since the operations at the time of writing were in early stages and the understanding and knowledge of the operations is expected to continuously increase, the project team can expect similar and more detailed questions to be brought up as the journey continues.

All the criticism towards the implementation project from the trained employees was about the extensive time it took to implement the system. This was also supported by the comments received from various parties in informal discussions: the most common topic of questions was about when the system would be in use. However, an interesting finding was made when analysing the interview data: despite the respondents criticised the lengthy implementation time, they pointed out that the preparedness for the implementation could have been better, and simulations could have been made for it, for example. They also pointed out concrete reasons, why the full-scale operations would not have been possible. This shows, that despite the respondents criticise the time it took to implement the system, they seem to understand the reasons for it, and even suggest improvements.

The trained employees interviewed during the study praised the cooperation with Solving. This supports my own views: the cooperation throughout the project was smooth and mutual understanding of various topics was gained easily. As an interesting note, however, one of the respondents also mentioned, that planning of different things was one of the successes in the project, and that the project team had considered different things, that might come across. A connection to this can be seen in the question concerning the things learnt throughout the project: planning and clearly allocating the responsibilities stood up. From a diagnostic perspective, the employees seem to understand the importance of cooperation and preparing for various situations to be ready to act without delays. This relates to almost every topic of this research: how the implementation can be carried out with minimum number of issues, how to operate the system in a manner, that a minimum number of delays occur, and what are the responsibilities in problem situations. Also, organizing the trainings to a wide audience received positive feedback from one of the respondents, meaning that also the trained employees want the system to work without interruptions, and want to have the skills to support it.

Finally, according to the trained employees, the things they had leant throughout the project included, how important it is to properly plan such projects, and to allocate responsibilities properly. This is something I fully agree with: there is a saying: *"If **somebody** should do it, nobody will do it"*, meaning that there always has to be a clear responsible defined, when a task is assigned for a team. The respondents mentioned too, that they had learnt about the functions of the AGV, which is beneficial in ensuring smooth operations after Go-Live: if a malfunction is detected, the employees are more likely to understand the symptoms and correct ways-of-working to solve the issues. These exact same things they expect to benefit them in their future projects. Therefore, they understand that the things learnt in this implementation project can also be helpful for them in the future.

From the implementation perspective, it seems that physical site visits are more beneficial for the companies involved, both customer and supplier. I asked from both the supplier and customer companies about the benefits, and both pointed out, that getting the right impressions of the dimensions in the facility is easier during an actual site visit. According to one of the interviewees, during actual visits it is also possible to detect possible threats in terms of security, and how the people and AGVs will cooperate in small areas. Human-factor stands out, which is in line with my own understanding: despite thorough planning, human behaviour cannot yet be accurately modelled and countless factors effect on it. The human factor was also brought up in the responses of the trained employees, indicating how important it is in terms of both implementation and safe operations. Also planning was highlighted in both this interview and the interview for the trained employees: the trained employees highlighted planning, whereas project management pointed out the concern, whether something differs from what had been planned. Thus, the same concern can have different views when moving between employee groups.

The answers received from the project engineer working on the commissioning supported the responses received in the previous interviews. In the answers, the project engineer brought up the possibility of AGVs not fitting into load stations, relating directly to the dimensions, which was also highlighted in the answers by project management. This respondent mentioned the communications, too, but added, that despite the benefits of active communications, meetings and planning can take time from the actual work. From this it can be understood, that even though active communications are beneficial for the project, the communications should be planned to ensure it always serves the purpose. When it came to the possible causes of interruptions, this interviewee's answers were in line with the trained employees': objects in the routes were one possibility concerned by this employee, but also new structures being built, covering the reflectors used for navigation. The latter point occurred after the commissioning: a wall was built, creating a dead space for the navigation, creating a need for new reflector installation.

The findings of the data analysis are presented in Figure 15. In the figure, the different factors effecting the successful implementation (time until Go-Live) and uninterruptedness (time after Go-Live) have been listed. It is evident from the factors, that despite the highly-automated system, the human-factor is either directly or indirectly present in all of the factors, and that the role of the human employee is changing in the *Industry 4.0*:

previously, it was the human employee, who would operate the manual forklift in carrying pallets, but now the AGVs carry the pallets and the human employee acts as a coordinator and problem-solver. The findings also relate to another target of this study: responsibilities in problem situations must be clear to avoid spending time on finding the right party to solve the issue, causing increases in the lead-time of troubleshooting.

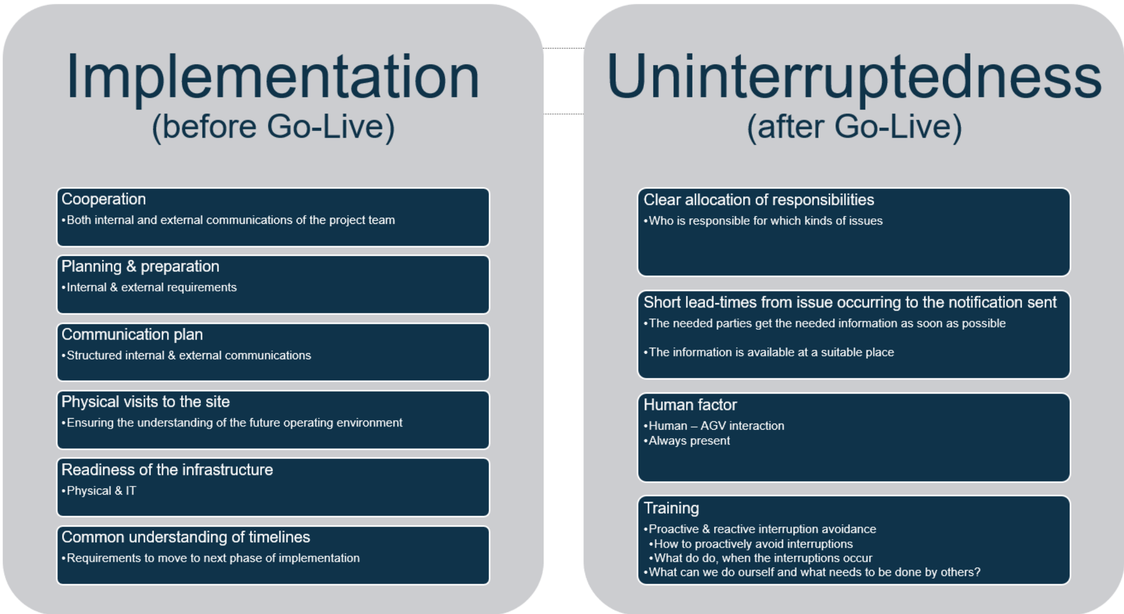

Figure 15: Data analysis findings concerning relevant aspects both before and after the Go-Live of the AGV-system, including factors related to the uninterruptedness of the system

4.4 Validity & reliability of the study

In this chapter, I will discuss the validity and reliability of the study. I anticipated the reliability of the research to be high since I had at the beginning of the research process been working in the same business unit for years and personally know many of the interviewees. Therefore, I had no reason to expect them to tell anything but the truth and their actual opinion.

Subjectively, I consider the validity of the study relatively high. I gave a significant effort to focusing only on the research question and objectives, which gave the direction and perspective for the interviews carried out and the questions asked. I also did my best to maintain that perspective when making observations during the project.

The most significant roadblocks expected during the research were to find case studies of similar nature to this study: an AGV system that would be implemented in a completely new facility, where also new tools and systems would be utilized; thus, the AGV system would be only one of the new systems rather than the only new system established in the facility. Despite it being a decreasing factor to the reliability, it can be considered highlighting the contribution of this study to the scientific community.

Another roadblock was related to the high workload of the participants of the project at the time when the study was carried out. I anticipated, that due to the high workload, the employees would possibly not have enough time to participate the interviews or answer the questions I sent. To my knowledge, any similar research had not been carried out previously in that business unit, so preconceptions towards the interviews were expected. However, I did encourage and remind the employees to answer the interview questions, and that there would be no right or wrong answers: the answers would be the interviewees' subjective opinions and that was exactly what I was looking for. It was also clear for me right from the beginning, that I would never reveal the names of the interviewees to anyone under any circumstances.

To increase the validity of this thesis, I should have interviewed employees also from business units outside the Material Management. This would have broadened my perspective and deepened my understanding about the usability of the AGV system from a broader audience's perspective. Collecting data from other business units regarding the implementation-phase would have also given me a more comprehensive and holistic understanding of the implementation from the perspective of people not directly involved.

I did also have my own subjective opinions and answers to the interviews carried out and questions asked. These were supported by the answers given in the interviews, which I find as supporting my assumptions being correct, since the interviewees had also made similar observations during the project as I had.

There are limiting factors regarding the reliability of this case study: only one facility and implementation project was studied. In this facility, only a relatively small number of employees were involved in the AGV project. Only a part of these employees responded to the interviews, which further limits the reliability of the study.

4.4.1 Constructing validity

There were no reasons for me to do anything but my best to ensure the validity of this study. A large number of different sources of information was utilized with the intention to gain as holistic understanding of the topic as possible. During the interviews and questions asked, I included people from all levels of the project organization with the same intent. This also supported me in the desire to get as many sources of evidence as possible.

4.4.2 Internal validity

Since the environment and events taking place in the facility could not be perfectly controlled, i.e., the facility could not be considered as a laboratory, the internal validity is questionable. Another limiting factor for the internal validity of the study was the low response rate of the interview carried out for the trained employees. The response rate of only 1/3 was lower than expected.

An increasing factor to the internal validity of the study was, that no names were collected during the interview. I am the only person with the access to the answers. Neither is their employer’s name revealed in this study, protecting their anonymity.

4.4.3 External validity

Case study was selected as the research method of this study because of the unique nature of this implementation project: implementation of a facility such as the STH can be considered a rare occasion and there is a limited amount of existing research about an AGV-system being implemented simultaneously with the facility itself. Because of the uniqueness, the replication possibilities of this study remain limited, decreasing the external validity.

A factor increasing the external validity was to include employees from various organizational levels and companies in the scope of interviews and questions. The level of experience and tasks varied significantly, thus it was possible for me to study, if there were connections between experience and the answers given.

4.4.4 Reliability

This subchapter discusses the reliability of the study carried out for this thesis. The replication possibilities are limited due to the circumstances and context. This also relates to the data collection, which took place during the implementation project, when the various events took place, and I was able to actively observe and participate the events. As time passes, the risk of people remembering certain events in a different manner increases.

In the future, a similar study can be repeated, if an industrial facility is established and implemented, and it is decided, that an AGV system will be in place in the facility. The specific industry in which the facility operates or will operate, is of minor relevance; material volumes and the sizes of the components transported, and the complexity of the facility layout will rise to a more relevant role. The findings of this study are fundamental in nature, which enables future research to investigate, whether similar findings occur in other implementation projects.

The methods used, and the questions in the interviews can be replicated due to them not being strictly tied to the environment or physical context. This increases the reliability and repeatability of the study. Getting a relatively larger number of responses to the interviews would have increased the reliability further and would possibly reveal further aspects that were not brought up in the answers given by the interviewees. Along with interviews, the information and data used in this study was collected by reading numerous scientific references including articles and books, but also websites. During the case study process, I considered the physical observing and participation in the project to be the most beneficial and viable way of collecting information.

4.5 Monitoring the success of the implementation project

Once the AGV system has been implemented, monitoring the continuous, day-to-day operations of the system stands out. For this, Key Performance Indicators (KPI) should be implemented and followed regularly to be able to react to any anomalies. Hrušecká et al. (2019) point out, that the KPIs can be divided into three individual categories: *delivery in time*, *delivery in full* and *costs of material handling*. The costs of material handling are not considered in this thesis, because that would require a longer monitoring period.

Monitoring the overall functions of the AGV-system remotely was made possible for the AGV-supplier. Lazarova et al. (2023) mention the possibilities offered by digitization and one concrete example of such a possibility was, that the company installing the AGV system could remotely connect to the AGV PC, thus being able to check for any anomalies in the system. This reduced the need for physical visits to the site, thus reducing travelling time and costs. It also reduced the lead-time for getting expert assistance, in which I consider Solving succeeded extremely well throughout the implementation project.

5 Lessons learned throughout the project

The Lessons learned -phase is an integral part of both the project and this thesis. During this phase, an objective look is taken into the overall project to understand, what was learned, what went well and why, and what should have been done differently and why. The core purpose is to create knowledge to be used in the possible future projects to avoid the "reinventing the wheel" -effect.

Various lessons were learned throughout the project. Here it is important to point out, that I got involved with the project at the beginning of October 2021 at which point my knowledge of the AGVs overall was zero: I had no previous experience or knowledge about AGVs. Therefore, my learning curve was also relatively steep throughout the project and at the end of the test-phase, I had reached the skills to track down the possible issues to the root cause -level.

First, during the project it became evident, how important part communications play overall in such a project. From my personal perspective and subjective opinion, without proper communications, the project would have faced severe difficulties and even financial losses. As Lazarova et al. (2023) mention, the COVID-19 pandemic has increased the amount of remote work. This can have consequences also in terms of communication: when people spend less time working in the same physical area, the likelihood of spontaneous communications is decreased. Also, the number of informal discussions during breaks has decreased. Several valuable concerns and ideas from employees from various levels of the different organizations appeared during unofficial discussions, in a relaxed and informal atmosphere. Therefore, even under pressure and within tight time constraints, enough time should be left for informal discussions.

Another notable aspect was, that during the project, there were numerous companies involved. At the time of the implementation, several different companies were working on various different areas and tasks in the facility, being varyingly related to each other: for example, one company was responsible for completing the cabling for a computer installed by a second company, used by two more companies. Another example is, that one company implemented the AGV system, for which a second company measured the exact locations of the reflectors, and the AGV system itself was used by two completely separate companies. This highlights the mutual understanding of timelines and responsibilities. At all times, different instances should understand same things in the same way.

Since the project took place during the pandemic, the first meetings of the project took place only in Teams. Only in the later stage were physical visits possible and as a student studying on a university-level during the pandemic and having experienced the joys of remote studying, this topic got my interest. Therefore, I asked the participants about the benefits of the physical visits to the site compared to the situation in which same visits would have been carried out using virtual tools. Despite I expected the physical visits being highly beneficial, the results and answers exceeded my expectations. Therefore, despite the flexibility offered by remote working, the benefits of on-site visits and physical presence are significant.

Partly related to communications and the overall implementation, there was a requested change in the first area to be implemented at a relatively short notice. This, however, was not considered possible, since the implementation date was approaching quickly and in the project team it was concluded, that such a change could not be carried out properly within the time restraints available. A very essential action to be taken by the project team was to communicate the negative news for the requestor and properly explain and clarify, why the change would not be possible. Despite the project team having to be flexible and open for suggestions, it is beneficial for them to have a constant knowledge and understanding, what can be done and what not, and if a change must be carried out, what will it require.

The number of participants also stood up during the project: with too few people, too much information can be behind one person and with too many people, the information might be shattered, and the people can understand same things in different ways, creating confusion and unbalance of information. Everyone in the project team must also have a relevant role to on one hand ensure the benefits to the project team, but on the other, to eliminate the risk of wasting anyone's working time. Therefore, the weekly meetings had a crucial role in maintaining a common understanding and ensuring that all the people involved had a sufficient amount of information to succeed in their tasks and responsibilities.

Since the project took place during the global pandemic, one of the more concrete issues was the global lack of components. The prediction of the arrival dates of various components appeared to be difficult and the delivery dates changed even on a short notice, causing the project team to be forced to take rapid actions and make changes on extremely short notice. Therefore, having a clear understanding of the possible threats towards the project proved to be crucial. This way, the project team could alleviate and prepare for these risks, thus decreasing their possible effects. Proactivity overall was found to be extremely beneficial.

6 Summary and conclusions

In this chapter, I will summarize the findings of the study including the contents and findings. Also, a number of future research possibilities are suggested. In this thesis, I have researched the implementation of an AGV system in the STH-facility. The uniqueness of the project comes from the AGV system being implemented simultaneously to the facility itself. The study had four topics:

i) Implementation of the AGV-system
ii) Uninterruptedness in the operations of the AGV-system
iii) Clarifying the responsibilities in problem situations
iv) Collecting the lessons learned throughout the project

To produce knowledge of the topics defined for the study, the following research question was established:

"How can Automated Guided Vehicles be implemented and utilized in an ever-changing corporate landscape?"

The study started by introducing the basic concepts related to the implementation of the AGV-system in the STH-facility. In Chapter 1, the background, the research gap, and the objectives of the research were introduced. Also, the definitions for the concepts under the context, along with the research design and structure were discussed. In Chapter 2, an introduction of the case company was given, and the framework of the study was introduced from the start of Wärtsilä's operations to the implementation of the STH-facility. Also, the current operating environment as well as the future of logistics management in the context of the STH and AGVs were introduced.

Chapter 3 contained the literature review carried out for this study, including all the relevant concepts. The findings in the literature review were connected to the STH-facility and the AGV implementation project in the facility. These included concepts such as

Cyber-Physical systems existing in the facility, safety as the centre of operations, and *Industry 4.0* along with its sub concepts *Supply Chain 4.0* and *Logistics 4.0*.

Chapter 4 contained the empirical study, including data collection process, interviews carried out, analysing and debriefing the interviews, and the overall progressing in the AGV implementation project. Then, data analysis was carried out and the validity and reliability were assessed, and the possibilities of repeating this type of study discussed. Finally, in Chapter 5, the lessons learned in the project were discussed to collect data about the best practices for such projects as studied in this research.

With this study, more knowledge has been produced about which factors influence a successful implementation project of an AGV system. Both the direct and indirect roles of the human employees and the interaction between human employees and the AGVs have been recognized and identified. Also, the overall functionality of the STH-facility has been described. The factors of a successful AGV implementation are illustrated in Figure 16.

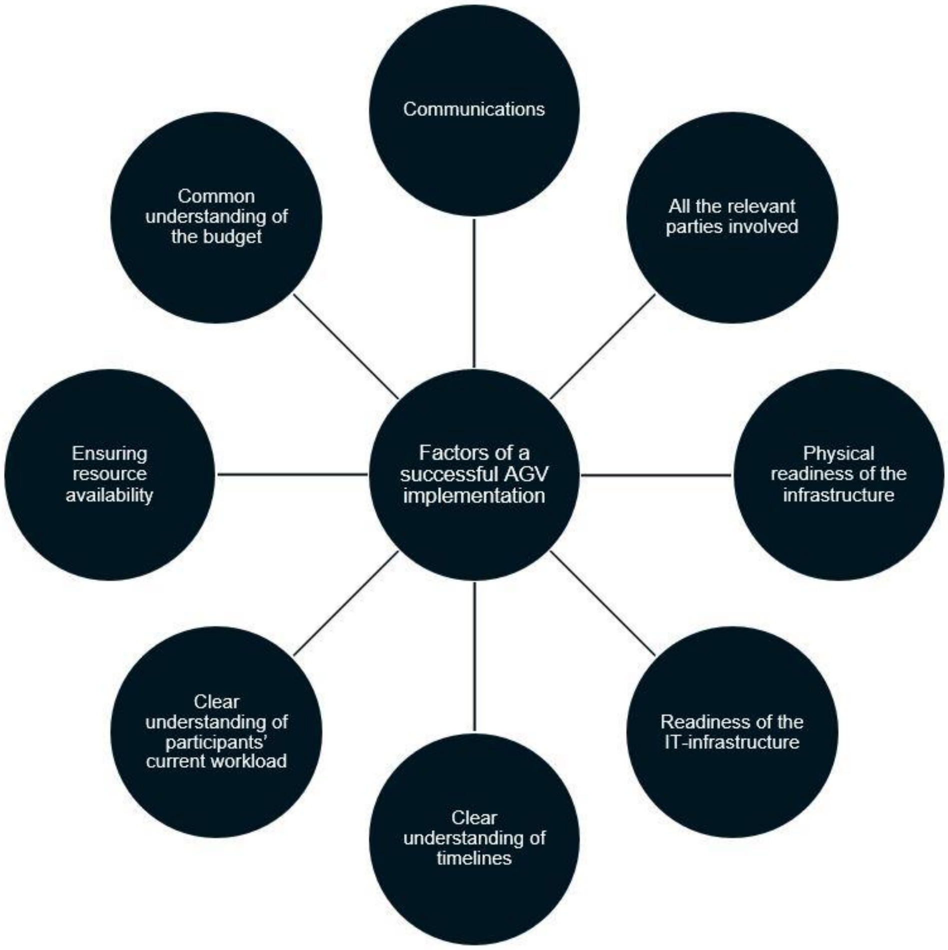

Figure 16: Factors of a successful AGV implementation

Eight factors effect implementing an AGV-system: communications, having all the needed parties involved, ensuring the physical readiness of the infrastructure, ensuring the readiness of the IT-infrastructure, establishing and maintaining a clear understanding of the timelines, establishing and maintaining a clear understanding of tasks on peoples' tables (their workload), constantly ensuring the availability of proper resources, and maintaining a common understanding of the budget.

Communications form the basis of the everyday life in the project. When the employees working in the project are located in different cities and even different countries, it is vital to maintain proper communications to ensure each project participant has the same understanding of the project at all times. This enables the stable progress of the project and misunderstandings can be avoided.

Communications is also related to the second aspect of a successful AGV implementation: ensuring all the needed parties are involved. At the beginning of the project, it is recommended to recognize all the parties that might be affected by the AGVs and bring them involved. Therefore, different perspectives can be considered, and the project team can more easily understand the needs of the people working in the production, and likewise. Even though it might expand the project team and make it heavier, it can benefit the final result in terms of all the possible factors being considered. This reaches from the requirements of the infrastructure to the requirements of the material volumes transported with the AGVs.

Once the team has been established, common timelines should be discussed and agreed on. This is to ensure with all parties, that the planned timeline is realistic and possible to execute. This relates to how interlinked different steps in the project can be: without the reflectors of the navigation system being installed, it is impossible for the AGVs to move independently in the facility, or without the key users being properly trained, it is impossible to start the test-phase, where problems are likely to occur. Here, also the possible affecting factors should be considered and predicted as much as possible.

Having the timelines agreed on, the resources should be allocated to various tasks. In the STH implementation project, this relates to people having numerous different tasks on their desks at the same time, and the tasks might need different amounts of time, for example. Therefore, an understanding should be reached about the workloads caused by different tasks to ensure, that the time needed is actually available. This might also help the project team to recognize, if any resources are missing and react to the situation on time.

To start the implementation and the actual operations with the AGVs, readiness in terms of both the physical infrastructure and the IT-infrastructure should be ensured. This way, the time spent on the project can be used more effectively: rather than having to wait for a shelf to be installed and only then starting the test phase, the project team should be informed in advance about the schedule of the infrastructure being ready, thus enabling them to operate more efficiently and with shorter waiting times.

This study has contributed to the existing research concerning AGV implementation by describing and carefully studying one AGV implementation project, and by collecting aspects having positive effects on the implementation project. The study has also provided examples of the emerging *Supply Chain 4.0* and *Logistics 4.0* -concepts that as research fields were relatively new at the time of writing. In this study, also the effects on the nature of labour and skills required in the *Industry 4.0* have been discussed.

6.1 Future research

This study offers multiple future research opportunities. One example is to study the operating costs of the system, which were left out of the scope of this thesis. The operating costs are directly related to the economic viability of the AGV-system and consist of a large number of factors, such as optimal route planning, time spent at idle (i.e., without transport tasks), maintenance, and time when the AGV is driven manually by a human employee. The use of the AGVs also causes the parts and components of the AGV to wear, which can also be considered as one of the operating costs alongside the electricity they consume.

Path planning itself offers a potential topic for future research. That research could be about the relationship between the operating costs of the AGV system and the optimal path planning. As pointed out in this thesis, the optimal route from place A to place B is not necessarily always the shortest and whenever an AGV moves, costs are inevitably created.

This thesis was written in the planning, implementation and test -phases of the AGV-project. Therefore, the amount of knowledge gained during this thesis writing process about the potential improvement and optimization of the system was limited. A possible research area in this sense would be, how the system could be optimized.

In the subject of this thesis, I directly referred to the ever-changing operating environment that companies increasingly face in their operations. This offers one highly viable future research topic: how much and what kinds of resources and effort will it require to make certain types of changes to the overall AGV system. In that study, one could consider the possible change requirements in the IT- or physical infrastructure, the routing of the AGVs, or the need to transport different types of materials.

Another potential future research topic originated from this study would be to research, how the implementation of the AGV system effected the flow of materials in the STH in terms of throughput times, predictability and number of damaged pallets and materials. Here, one could try to find data about the situation before June 2022 and after that. Also, the trends after June 2022 (the implementation time of the AGVs) could be researched to possibly notice, if any learning or optimization had taken place after the implementation.

Since this research was only one case study, a possible future research topic would be to try to make generalizations about successful AGV implementation projects, their key success endorsers and key things to avoid. For this, a large-scale literature review or multiple case studies could be carried out, with the intention of finding similarities or differences along with their root causes. That type of research could benefit both the scientific and industrial community.

Also, the possibilities of combining the AGV-technology with other illustrations of *Industry 4.0*, such as *computer vision* and *artificial intelligence* and *machine learning*, should be studied further. By combining such concepts with the AGVs, the versatility, independency and safety of AGV-systems could be developed further. For example, in the STH-facility, automated decision making could independently give alerts to the parties responsible, if an obstacle is detected on the route of the AGVs'. Computer vision would enhance detecting and identifying such objects along with human employees. From the collected data, the most typical places of such issues could be detected, and the root causes to be found easier. Therefore, the decision-makers could focus on solving the issues rather than finding them.

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Appendices

Appendix 1. Introduction and questions in Interview 1

The first Interview carried out for this thesis was done in Finnish, by email. I gave the participants background and purpose of the interview. The background and the questions are presented in this appendix.

Hello,

I'm currently working on my Master's Thesis to Vaasa University. The subject of my thesis is "Implementation and Usability of Automated Guided Vehicles: A Case Study of Wärtsilä Smart Technology Hub and Logistics Centre".

This interview is intended to find out the aspects related to the implementation of the AGV-system especially from the end-user point of view. There are no right or wrong answers to this interview and I ask, that you answer the questions based completely on your own feelings and experiences.

The answers received from this interview are also intended to utilize in the development of the usability and smoothness of the system, so every answer is extremely valuable also from the perspective of future development.

Please ask these questions as soon as possible – by 30.7. I will use the data collected in the answers in my Master's Thesis without mentioning any names of the interviewees. It takes approximately 10-15 minutes to answer the interview.

Additional information:
Olli Karvonen
olli.karvonen@wartsila.com
+358 40 7039612

Background questions

In the interview, the acronym AGV refers to term Automated Guided Vehicle, which freely translated into Finnish means automaattitrukki.

1. How long have you been involved in the AGV-project
2. How often do you face things related to the AGV-ensemble in your work?
3. How long have you been working in Material Management?
4. Describe your current tasks on general level.

Implementation

5. What has gone well in the project and why? Describe in your own words.
6. What has not gone well in the project and why? Describe in your own words.
7. What could have been done differently? Describe in your own words.
8. How well do you know your own tasks in the AGV-system, when the system is in operative use?
    a. I do not know at all my tasks related to the AGV-system
    b. I know only little about my tasks related to the AGV-system
    c. I do not know little or much about my tasks related to the AGV-system
    d. I know quite much about my tasks related to the AGV-system
    e. I completely know my tasks related to the AGV-system

Responsibilities in problem situations

9. Do you have a clear understanding of the problem solving process in the AGV-system?
    a. Yes
    b. No
10. If you answered “No” to the previous question, what things need clarification and/or additional information?
11. If you face a problem in the AGV-system, which you cannot solve, do you know, who to contact?
    a. I do know

    b. I do not know

12. What would be the easiest and most usable way of getting information about the AGV-system, including problem situations. Describe in your own words.
13. What do you see as the most likely things causing problem situations in the AGV-system?
14. What do you see as the most likely things, that cause unplanned AGV-stops?

Lessons learned

15. Describe the things you have learnt during this project.
16. What things that you have learnt during this project do you believe will help you in your future tasks and projects?
17. Has there been too much flow of information about some topic?
18. What do you still wish to learn in the framework of this project?
19. Free speech. In this field, you can bring up any thoughts related to the AGV-system in this field.