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Advancing Automated Logistics: Operational Requirements, Costs and Benefits, and Safety Considerations in RORO Terminals

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Abstract

Many industries are reshaping with the help of Industry 4.0, including the logistics sector. RORO terminals worldwide are under-digitalized and under-digitized, leading to inefficient processes and bottlenecks. With the rapid development of AI and AV technology, this thesis aims to understand what operational requirements exist for the RORO terminal in Gothenburg, and what benefits can be gained from implementing those technologies.

To understand the operational requirements, a qualitative study has been conducted, including interviews with industry experts and researchers, providing a deeper understanding of the requirements and the benefits. The empirical findings from the interviews were then analyzed with the help of the theoretical framework.

The findings of this thesis highlighted multiple operational requirements that can halt the implementation of AVs in RORO terminals, including physical, digital, and technical infrastructure requirements. The dynamic environment of RORO terminals complicates the implementation and adoption of AVs. Some benefits can be gained from the implementation of AVs, such as efficiency gains, fewer errors, and increased productivity. Although there are requirements that can halt the implementation of AVs, certain processes can be automated, such as moving cassettes with an AV.

There is still a long way to go for the implementation of AVs in RORO terminals. Before it can be fully adopted, several issues need to be addressed. These include the lack of standardized ULDs (Unit load devices), such as trailers, which currently need manual work connecting air hoses and cables; these tasks are not yet feasible for AVs. Furthermore, AVs will struggle to adapt in dynamic environments, such as RORO terminals, due to the design of the area and the cargo being handled there. Physical and digital infrastructure also pose limitations, such as space limitation, and real-time connectivity. Resolving these issues is necessary to enable AVs to operate safely and efficiently. Once resolved, RORO terminals can gain many benefits, such as gains in efficiency, productivity, and fewer errors.

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Sincerely,
André Hjelm & Hussein Abucar
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Terminology & Abbreviations

ADS: Automated driving systems, it is found in level 3 of automation and onwards, and it are the system that performs the entire driving task.

Autonomous Vehicle (AV): A self-driving vehicle that can operate without human intervention with the help of AI, radars, and sensors.

Cassette: A steel platform with no wheels that is used to transport cargo.

Cost-benefit analysis: A Financial tool for measuring costs and benefits.

Digital twins: A digital model of a physical object or a system designed to accurately replicate the physical object or the system.

End-to-end process: Automation covering the whole operation from start to finish.

Freight truck: A heavy-duty truck whose purpose is to move goods and materials between locations.

IoT: A network of connected devices that communicate with one another and with the cloud through the support of technology.

ODD: Operational design domain, which is the specific operating conditions where autonomous driving is supposed to function.

Roll-on/Roll-off (RORO) terminal: a specialized terminal for maritime shipping designed for vehicles to roll on and off the vessel without modal change.

SAE: Society of automotive engineers.

Smart gate: a gate at the entrance of a terminal with sensors and cameras allowing vehicles to pass through without human intervention.

SMP: Small-medium size ports.

Total truck turnaround time (TTTT): Total time for a truck to enter the port>perform its tasks>exit.

1 Introduction

In this chapter, the background for this research will be outlined to examine the research in a committed way. Further, a problem description will be presented, and lastly, the Purpose and research questions will be outlined along with the report's scope.

1.1 Background

The history of autonomous vehicles dates to the 1920s when American companies paved the way for this technology. The company Houdina Radio Control, based in New York, took the first step in developing a radio-controlled car. The company installed transmitting antennas on a 1926 Chandler operated by another vehicle. This car transmitted radio frequencies to the radio-controlled car (receiving and using them) to direct its movements. This technological development laid the groundwork for the future of autonomous vehicles (Bimbraw, n.d.). Over the years, many advanced versions have been introduced, with General Motors participating in developing these autonomous vehicles (Bimbraw, n.d.).

Discussion about research and development of AVs has rapidly increased over the past two decades (Slowik & Sharpe, 2018). In recent years, new cars have advanced dramatically, including advanced technological features such as adaptive cruise control (ACC) and collision avoidance systems (Fagnant & Kockelman, 2015). The discussions have mainly focused on passenger vehicles, but stakeholders actively explore opportunities to implement these technologies also in the transportation industry. There is a general understanding that the advancements in AV technology have the potential to revolutionize transportation systems and address many of their challenges (Zemignani, 2023).

The advancements in AV technology are also being discussed in RORO terminals, where these environments have historically heavily relied on manual operations. The employees are required to use their driving skills and experience to precisely and accurately park the cargo. To perform these tasks, the operations require experienced employees with high attention and focus, leading to increased labor and operational costs. AVs have the potential to solve those challenges, but there are still issues regarding AVs operating in that environment. AVs' functionality is still limited, as they lack the adaptation needed for dynamic environments to make critical contextual decisions. Without these abilities, AVs struggle to detect objects in dynamic environments. AVs also face challenges in recognizing and correcting errors (Xu et al., 2025). Although AVs today are facing challenges operating in RORO environment, it can bring many benefits such as increased productivity that will potentially reduce the operating costs and increased efficiency (Park et al., 2023).

1.1.1 Ongoing challenges in the logistics industry

In the past thirty years, the transportation industry has been responsible for large amounts of greenhouse gas emissions, and initiatives and efforts have been taken to mitigate these emissions (Kopelias, 2020). According to the European Environmental Agency, road transportation accounts for the highest number of emissions in overall transportation, constituting approximately 73% of greenhouse gas emissions of all European transport in 2022 (EEA, 2024).

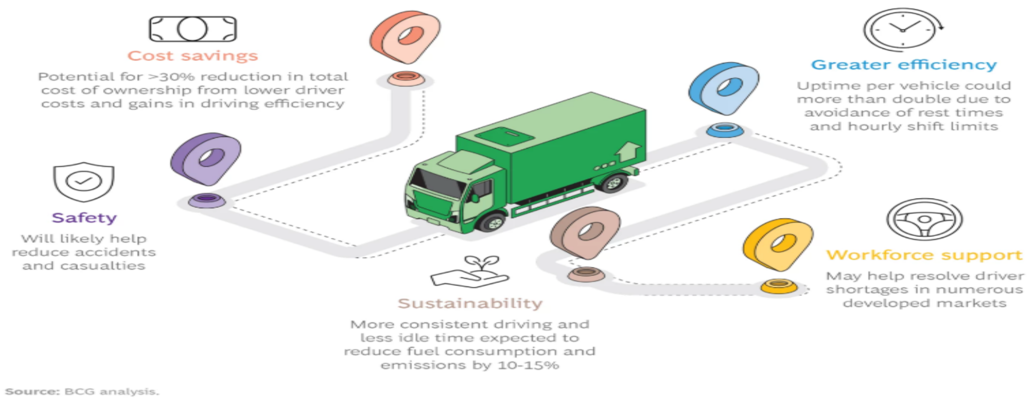
Current forecasts also suggest that the number of unfilled truck driver positions will increase to 745,000 due to the younger generation's uninterest in working in the industry and the older generation aging closer to retirement (Mckinsey, 2024). New autonomous technology may soon be the only option to combat these challenges.

AVs are currently being tested in various sectors as a solution to combat the lack of drivers and mitigate emissions. For example, Waymo is running a pilot test of driverless robotaxis in Phoenix (Waymo, 2024). AWARD is another current project showcasing the usability of autonomous vehicles in various real-world logistic operations such as hub-to-hub transportation, ports, and airports (AWARD, n.d.). The Award project, which includes a collaboration, shows what can be accomplished with cross-company partnerships. Lastly, Automotif is a project aimed at advancing automation in transportation systems. The goal of the project is to improve efficiency and sustainability throughout logistic operations with the help of several goals, for example, defining and standardizing technology and the use of simulations in different settings to validate the feasibility of AV's system (Automotif, n.d.). These cases showcase the rapid evolution of AV's use cases, but significant work lies ahead until we reach fully integrated driverless AVs.

1.1.2 Autonomous vehicles as a solution

BCG (2022) describes the solutions that AVs can provide to the transportation industry's current challenges. BCG (2022) includes five aspects that can provide benefits by adopting AVs. As these aspects are described in the figure below:

Figure 1: Potential benefits with AVs (BCG, 2022)



Cost savings and Greater efficiency

Engholm et al. (2020) argue that one potential key incentive for adopting new technologies in the transportation industry is the cost advantages they provide. The largest part of transportation costs is represented by the drivers' cost (Engholm et al., 2020). Adopting and developing AVs could also potentially reduce the Total Cost of Ownership (TCO) (Engholm, 2021). Adopting AVs could reduce the TCO by more than 30%. By adopting AV technology, the idle time of the trucks would decrease due to there being no driver rest and shift limits, which would increase efficiency and labor savings. Truck utilization would also increase by double, leading to increased productivity (BCG, 2022).

Safety

According to KPMG (2019), in 2016, 1.35 million people passed away due to fatal crashes on roads around the world, and nine out of ten crashes were caused by human error. Fagnant & Kockelman (2015) further describe that over 40% of fatal crashes in the US involve human errors such as a combination of distraction, alcohol, drugs, or fatigue. Adopting AVs could reduce the risk of human error, which would significantly reduce vehicle-related fatal crashes, assuming the AV has minimal malfunction and other factors remain constant. These factors include poor weather conditions or night-time driving (Fagnant & Kockelman, 2015; KPMG, 2019). However, AVs must be proven to have better safety than humans, since only a few fatal accidents might change the public perception of AVs. System malfunctions should also be as minimal as possible; an AV malfunctioning in a traffic-heavy highway, or causing traffic congestion, would also lead to the regulators and the public rejecting the idea of AVs (McKinsey, 2024).

Sustainability

Adopting AVs is expected to bring many benefits to the transportation industry, one of them being improved sustainability. According to Figure 1 from BCG (2022), AVs are expected to drive more consistently, leading to less idle time. This positively impacts the environment by minimizing fuel consumption and emissions by approximately 15%. Furthermore, AVs can drive zero emissions by using an electric battery; there is also the possibility of swapping the traditional powertrain technology of an internal-combustion engine (ICE) for a hydrogen ICE (McKinsey, 2024).

Fagnant & Kockelman (2015) also argue in their article "*Preparing a Nation for Autonomous Vehicles: Opportunities, Barriers and Policy Recommendations*" that advancements in autonomous vehicle technology have the potential to revolutionize transportation systems. This shows the potential impact on the transportation industry by, for example, increasing road capacity and safety, and lowering emissions.

Workforce support

As mentioned previously by BCG (2022) and McKinsey (2024), there are driver shortages in many places, and the situation looks severe in both the US and the EU. AVs have the potential to minimize the severity of the situation by replacing not only the close-to-retirement group but also the younger group who is not willing to work in those industries.

Despite the potential benefits AVs can bring to the logistics industry, many challenges have to be solved especially in RORO terminals, which will be further discussed in section 1.2.

1.2 Problem description: Why this research is important

The ongoing technological evolution of AVs is undoubtedly exciting. However, to reach seamless, integrated autonomous vehicle transportation, we must address the current challenges, such as a lack of legislation, infrastructure, standardization, and safety. Thus, the following sections will discuss and analyze these specific problems.

1.2.1 AV's Role in RORO-shipping

RORO shipping can be seen as a sustainable alternative to truck transportation. Maritime transport represents more than 90 % of global trade but only contributes to about 2.2% of emissions due to its capability to transport larger volumes than other transport methods (Woxenius et al., 2019). In that segment, RORO shipping allows for seamless intermodal transportation where vehicles can roll on and off the ships without on-off loading containers. The main differences between a RORO terminal and the more common container terminal are that RORO terminals have specialized ramps allowing trucks to drive on and off the vessels, compared to a container terminal, where the container is unloaded at the terminal and then moved onto the vessel with a crane. This means that before boarding the vessel, the trucks must go through the RORO terminal. This also leads to specific challenges, making RORO-terminals less standardized due to their nature of more goods in movement and the need to be able to handle different types of vehicles and cargo (Morales Fusco et al., 2010). These characteristics of the RORO terminal are some of the reasons why there is currently a lack of compatible infrastructure in the RORO terminal to handle the technological advancements of AVs. This is something essential and needs to be investigated further.

1.2.2 Stakeholders

Implementing AVs in the shipping industry could have many positive effects. According to a survey conducted by ETF (2018), showed that 42% of respondents thought AVs are a game changer for logistics. Kim et al. (2022) mentioned that stakeholders involved, such as shipping companies, ports, customers, etc., could reap significant benefits from using AVs. With the removal of human resources, the aspects of human error disappear, which is the number one cause of incidents. Kim et al. (2022) also bring up other potential benefits for vehicles, such as fuel savings, reduced emissions, and increased driving time. These are examples of drivers that show great potential in different forms. Even though these benefits could indicate that AVs are a valuable option, the complex structure of the many different stakeholders needed to make this a reality can be challenging. The involvement of stakeholders, such as vehicle manufacturers, shipping companies, and technology providers, will need to change their business structure to encompass the rapidly changing technological environment.

Collaboration is also a key factor since the investments from the different stakeholders need to be seamless and made in the same timeframe. Here, the role of the stakeholders, such as the terminal and logistic sites, is essential. To capitalize on the new technology and investment, the AV should be designed to operate without any human intervention during the whole process. Accordingly, all the stakeholders need to make this possible by upgrading their current technology and infrastructure.

According to Autor (2015), employees as stakeholders will face challenges due to the automation that AI, robotics, and digital technologies drive. Autor (2015) explains that workers with specialized skills and education have the opportunity to adapt to the benefits of automation, while workers with "ordinary" skills and no education will struggle as machines take over their positions. As companies automate their businesses to increase efficiency, many of their employees will risk losing their roles unless they upskill. This shift creates job insecurity, making proactive policies well needed; these can include retraining programs and job transition support (Autor, 2015).

1.2.3 Lack of digital infrastructure

With the introduction of this new automated transportation solution, new challenges arise. In the RORO terminal, improved and elevated infrastructure will be needed to handle this innovation and technology. In this instance, what operational requirements will be needed in the RORO terminal to implement an end-to-end solution? How should the cost-benefit trade-off be analyzed? What future challenges could halt the new processes?

Logistics demand has been growing over the years, and global trade is expanding even more, yet the majority of RORO terminals are still underdeveloped when it comes to digital infrastructure. The volumes that the terminals can handle are growing, and the complexities around the operations are getting complicated. Many of today's terminals do not have the necessary infrastructure and often rely on outdated systems (Nortal, 2024). The functionality of these systems may be good, but it is not perfect due to the inability to face many challenges arising from the growing demand. These issues include managing large volumes of vehicles, optimizing yard space, and finding optimal ways of using the available resources and capacity (Nortal, 2024).

Competitive pressure and changes in innovation and regulations are pushing ports to modernize their infrastructure, and the implementation of information systems has already begun (Haraldson et al., 2019). For AVs to operate effectively, terminals need to upgrade their infrastructure, which may include different sections of improvements such as an automated gate system, advanced traffic management, or cloud-based platforms to enable the interaction between the AVs and the logistics systems (Volvo Autonomous Solutions, 2022). If these necessary upgrades are not implemented, the terminals will face even more challenges in handling the complexity and scale which is required by autonomous technology, which can cause a restriction on AV's potential to improve logistics operations. However, ideally, these potential infrastructural upgrades will not only combat potential challenges but could also add benefits and efficiencies to the operation. Since it's not a question of whether automation will push the advancement of technology in the terminal, but when?

1.2.4 Current gaps in research

Current research on the development of AVs in RORO terminals is still insufficient. There have been studies on autonomous vehicles and automation in container terminals, but the complex nature of RORO terminals and their challenges have not been addressed to a great extent. There is a lack of research on what digital and physical infrastructural changes are needed to accommodate the implementation of AVs. Further, there is limited research and studies on the unique operational requirements specific to RORO terminals, such as the inability to stack containers. This has led to a lack of data and information needed to implement AV or automation in a good way. From a regulatory standpoint, only a few studies have investigated AV implementation's safety and regulatory aspects, such as labor replacement, work dynamics, and safety considerations.

In conclusion, there is a current lack of research, studies, and case studies regarding automation and digitalization in RORO terminals, especially for autonomous vehicles. Thus, this thesis aims to address these gaps by conducting a comprehensive analysis to contribute to advancing automation and digitalization in the logistics sector, leading to more cost-effective, efficient, and sustainable operations.

1.3 Research Question & Purpose: Central question(s) guiding the study.

As mentioned earlier, introducing AVs could be a game changer in the logistics sector due to the ongoing challenges with inefficient operations, emissions, and costs. However, due to the lack of tests in a real-world setting, there are still many challenges to address. For AVs to be able to operate in the RORO terminal, new guidelines, infrastructure, and investments need to be made; thus, the purpose of this thesis, conducted in a collaboration with DFDS and Gothenburg RORO terminal, is to investigate the operational requirements for autonomous transportation technology that are needed in RORO terminals, and the balance of costs and benefits. The goal is to find the main challenges and opportunities that come with automation, assess how realistic it is to achieve fully automated processes, and offer practical solutions, aligning with the purpose of this thesis.

1.3.1 Research Question

The main question formulated for this thesis is "How does autonomous transportation impact RORO-terminal operations, and how can this be addressed to enable a fully automated end-to-end process?"

This question can be divided further into three sub-questions that need to be explored to fully understand the impact of AVs on RORO terminals

- *What are the operational requirements for autonomous transportation technology in RORO terminals?*
- *How can the implementation of autonomous transportation benefit RORO terminals, and what are the main costs?*
- *What are the regulatory and safety considerations related to AV implementation in RORO terminals?*

1.3.2 Scope

The scope of this research mirrors the aim of the thesis, where the focus is on analyzing the operational requirements and potential benefits of accommodating autonomous transportation in RORO terminals. The study will specifically examine the necessary infrastructure, technology, and logistics adaptations for AV implementation. This study also aims to understand the efficiency, safety, and sustainability benefits AVs will bring to RORO operations. Due to the limited research on digitalized RORO terminals, this study aims to reduce the research gap by exploring the operational requirements and benefits of these terminals.

2 Theoretical Background

The theoretical background will thoroughly explain current theories, concepts, technology, and case studies relevant to this study. Lastly, a summary, including key takeaways, will be provided. This detailed overview will set the foundation for this thesis.

2.1 Technological foundations for autonomous vehicles in logistics

This section outlines the advancement of automation and digitalization in RORO terminals. These advancements include key concepts such as Industry 4.0, smart ports, and SAE levels. Along with key technological advancements such as V2X and 5G communications, these technologies and concepts set the foundation to successfully enable AV integration in RORO terminals.

2.1.1 Industry 4.0

Since the first industrialization, technology has evolved in different ways over time. The advancement of technology has revolutionized the world; the first revolution of technology, also called the first industrial revolution, was in the field of mechanization, the second industrial revolution was all about the intensive use of electricity, and the third industrial revolution showed the rampant spread of digitalization. As technology advances, factories are becoming more advanced by using the internet and smart machines to improve production, indicating an ongoing shift in industrial production (Lasi, 2014). The factories may work in a way where products can communicate with machines on how the products should be built, and this opens the opportunity that allows each product to be produced exactly as needed, one at a time, without losing pace, cost-effectiveness, and large batches. This major shift in industrial production was called Industry 4.0 (Lasi, 2014)

Lasi et al. (2014) explain two significant reasons for this change. The first is the need for change (Application pull). As the world changes and technology advances, companies and factories must advance at the same rate. The benefits stated by the authors of keeping up with global and technological advancements include faster innovation, custom products, more flexibility, faster decisions, and saving resources.

The other primary reason for the change is new technology (Technology push). New inventions are changing the daily life of our society, as well as how companies operate, for example, with smartphones and different apps. Some important technologies that can benefit the companies include:

- Automation and robotics: Automation and robots will do most of the work, minimizing the human workforce and making operations faster and easier. Some machines also have the potential to make their own decisions.
- Digitality and connectivity: Everything in the factory can be digital and connected, enabling machines to communicate with each other and solve problems. Digital simulations and Virtual reality (VR) also have the potential to help test ideas before production starts.
- Smarter and smaller devices: Computers used to be big, but nowadays, they can fit in tiny spaces, making it easier to add smart technologies where they are beneficial.

The transformative principles of Industry 4.0, which include different digital technologies such as automation and IoT integration, are not limited to manufacturing but extend to many other industries, including logistics and transportation. One area benefiting from the digital revolution of Industry 4.0 is the maritime sector, where ports are updating their infrastructure to become more automated and digitalized (Triska, 2022).

Industry 4.0's advancements, such as 5G, AI, big data, and cloud computing, have reshaped many industries and improved production processes. However, these technologies rely heavily on a stable electricity supply to function effectively (Jia, 2023).

2.1.2 Smart ports

Port terminals are currently enabling the effects of Industry 4.0, which includes improving infrastructure monitoring, port security control, energy consumption, and cargo handling operation productivity. Many international ports have already begun adopting certain aspects of Industry 4.0. These aspects include robotics, Artificial Intelligence (AI), the Internet of Things (IoT), Virtual Reality (VR), and sensing solutions, to mention a few. These adoptions are dominant in the bigger ports in the EU, such as Hamburg and Rotterdam. The adoption of Industry 4.0 in ports is also increasing globally, whereas the big ports in Asia and the US are starting to implement aspects of Industry 4.0 (Triska, 2022). Some frameworks have been discussed in academic literature and proposed during the last few years. The framework has been refined by Fundación Valenciaport and takes four levels of digital transformation in a smart port into account (Triska, 2022), as outlined below:

Internal digital transformation: The first level of digital transformation of ports consists of stakeholders involved in port activities collaborating to improve existing processes, with each stakeholder implementing and adopting internal digital transformation. In port operations, the level of digital maturity may vary between the different stakeholders. Some stakeholders may lag while others have higher digital maturity within their organization. This level aims to ensure that each entity can stay competitive through digital transformation and maximize the value of businesses by prioritizing investments in technology, information systems (IS), and internal quality systems, to mention a few. Even though these internal improvements are implemented, manual processes will still exist due to third parties working with the businesses. There will be a heavy reliance on inefficient methods, such as communicating with papers to communicate with third parties. At this level, the different stakeholders operate independently, and there is a lack of integration between them (Fundación Valenciaport, 2020).

Connected ports: This level of digital transformation aims to increase efficiency and reduce costs by replacing inefficient processes such as the ones mentioned above. Manual processes between businesses and third parties will be replaced with automated electronic processes. This level mainly focuses on the administration, which consists of different stakeholders, such as port authorities, and level two of the digital transformation enables better communication and data sharing between the various stakeholders (Fundación Valenciaport, 2020).

Connected port community: At level 3, the aim is to move to an advanced level of digital transformation, where ports move beyond just integrating their internal systems and start partnerships with different stakeholders to achieve a connected logistics hub. The primary focus at this level is the collaborative initiative across the entire port community, which ensures all involved stakeholders implement and adopt digital platforms such as Port Community Systems (PCS). The collaborative initiative aims to enable a seamless flow of information between the different port parties, reduce inefficiencies caused by the independent systems, and improve the coordination between maritime, road, and rail transportation. Further, quality systems and standardized operating procedures should be implemented to ensure consistency. By implementing and adopting PCS, ports can increase transparency, efficiency, and decision-making. This will benefit not only the individual stakeholders but the entire port ecosystem (Fundación Valenciaport, 2020).

Hyperconnected port: A port's highest digital transformation is at its fourth level, also called the leading level. At this level, stakeholders, people, and objects such as infrastructure, devices, vehicles, and sensors are interconnected. At this level, ports have not only digitized processes but also a virtualized environment, making the entire operation intelligent, automated, and interactive (Fundación Valenciaport, 2020).

To sum it up, collaborative digital transformation is important. Suppose individual stakeholders within the port are highly digitalized. In that case, the port itself is not considered to be a smart port unless the entire ecosystem is connected and functions as one integrated system. For this transformation to succeed, it relies on collaboration between the different stakeholders in the port. Without this collaboration, there is a risk that the digital transformation will fail (Fundación Valenciaport, 2020).

2.1.3 Industry 5.0

The Industrial Revolution has evolved since its beginning, which has led to many transformative advancements in different subsystems of society. The previous Industrial Revolutions introduced many positive developments in society, but lacked certain concepts such as sustainability, reduction of carbon emissions, and human centricity that benefit humans and the environment. With the introduction of Industry 5.0, the aim is to focus on increasing sustainable development for all humans by achieving social goals that go beyond growth and employment. Industry 5.0 can be achieved by placing humans and their well-being as the main focus of manufacturing systems. The growth of Industry 5.0 came from the issues between social needs and manufacturing (Leng, 2022).

Industry 5.0, in contrast to 4.0, reintroduces humans in the production process, focusing on resilience, trusted autonomy, and sustainability. Industry 5.0 also introduces “Cobots” (collaborative robots), meaning machines and humans working together. Robots can adapt and understand human intentions, such as observing humans and picking up their techniques, which ensures a safer and more efficient working environment. Integrating humans and robots can increase human capabilities rather than replace them, fostering a more harmonious relationship between machines and the human workforce (Leng, 2022).

2.1.4 Industry 5.0 and smart ports

As mentioned, Industry 5.0 has a holistic vision supporting hyper-connectivity between social, technological, and economic aspects. While Industry 4.0 aims at the technological-driven industrial shift by adopting and implementing advanced digital technologies to increase the efficiency of processes and profitability, Industry 5.0 focuses more on human involvement and creativity. One key feature of Industry 5.0 that is mainly used is digital twin technology. Digital twin technology makes collaboration between humans easier. Digital twin technology has an important role where it increases the encouragement of human involvement in creativity and decision-making. Digital twin technology is an advanced and widely used concept across different industries and is gaining more attention as an innovative solution in the maritime industry (Zhou, 2024).

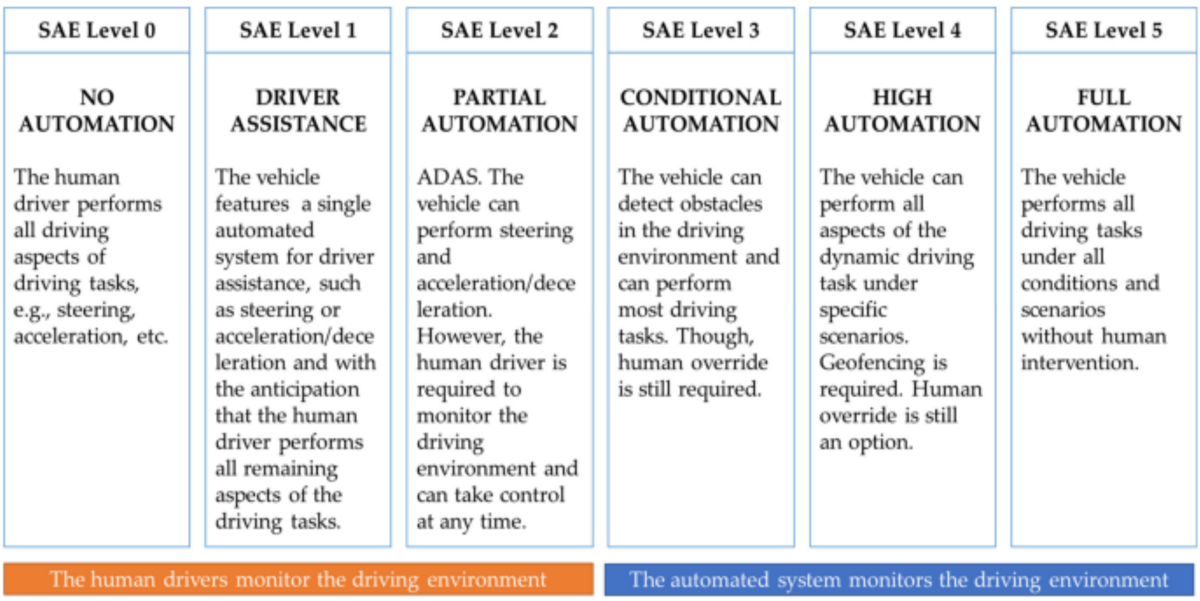
In recent years, the new technological and industrial revolutions have led to increased challenges in the maritime industry. To cope with the arising challenges, the industry needs innovative solutions to tackle the challenges in areas such as port operations and decarbonization initiatives. The industry aims to increase operational efficiency, sustainability, and safety by integrating advanced technology with Digital twins, such as IoT and digital technologies. Integration brings new opportunities and resilience to the maritime industry through innovative practices from the Digital Twins' exclusive emulation and simulation capabilities (Zhou, 2024). The advancement of technology is being done in parallel, both at ports and also for the external and internal vehicles entering, operating, and exiting the ports.

2.1.5 Autonomous Vehicle Technology

SAE International (2021) has released a document defining the different levels of vehicular automation. To fully understand the definitions of the automation levels, some concepts provided by SAE must be explained, in particular DDT, ODD, and ADS (SAE, 2021). Starting with DDT (Dynamic Driving Task), which are the task of driving the vehicle, and the tactical and operational functions that are needed to operate a vehicle in traffic. The other concept is ODD (Operational design domain), which is the specific operating conditions where autonomous driving is supposed to function; the conditions include restrictions on certain factors that must be present, such as time of the day, environment, such as rain or sun, and roadway characteristics. Lastly, ADS (Automated driving systems). ADS is found in level 3 of automation and onwards, and it is the system that performs the entire driving task (ISO, 2020).

Now that the concepts are explained, SAE's (2021) definitions of vehicular automation can be presented. There are six automation levels, which range from level 0 to level 5. As illustrated in Figure 2, starting at level 0, there is no driving automation, which means that the entire DDT is performed by a person. At level 1, there is some kind of driving assistance where the ADS handles an ODD-specific part of the DDT. The execution of the specific ODD part is called lateral or longitudinal, which means either turning or accelerating/decelerating. At this level, both processes cannot be executed simultaneously. Level 2 is similar to Level 1. The difference between these two levels is that the system can perform both longitudinal and lateral driving simultaneously. At level 3, conditional driving automation, ADS can handle a wider ODD-specific part of DDT, but with the expectation that a person will be ready to respond when ADS requests it. Level 4, which is high-driving automation, explains that the ADS can now handle the entire DDT in a specific ODD without human intervention, but if the ADS exits the ODD, a human must take over. Lastly, level 5, which is full driving automation, is not ODD-specific since it does not have a condition not to function. At this level, the ADS is expected to handle the entire DDT as well as a skilled driver (SAE, 2021).

Figure 2: Sensor and sensor fusion technology in autonomous vehicles (Yeong et al., 2021)



2.1.6 5G Mobile Communication

Mobile communication plays a significant role in our modern society. Today, billions of people connect online through phones and computers. In the logistics industry, current ambitions are shifting toward connectivity for machines and systems, thus creating the Internet of Things (Gerhard et al., 2016). The fifth generation (5G) of mobile communications will enable new innovations and solutions that were previously unattainable due to 4G's lack of compatible capabilities.

5G benefits include the following characteristics:

*Ultra reliable and low latency (URLLC***)**: This aims to deliver 0.5 MS latency, ensuring instant data delivery and enabling a new era of real-time data sharing. For automation, safety, and traffic control, ultra-low latency will be a requirement to ensure efficient and safe operations.

*Massive machine-type communication(mMTC)***:** 5G allows many devices to interact with each other using a wireless network. This supports Communication between a much larger number of machines, systems, humans, and robots than previously.

*Reliability***:** 5G will provide more reliable connectivity, reducing connectivity loss in harsh environments. For crucial operations, this will help ensure fewer interruptions and ensure the process operates efficiently (Skold et al., 2021).

The benefits presented can be seen as an enabler for new autonomous technology. For autonomous vehicles to be able to operate within an RORO terminal, real-time data sharing and vehicle-to-everything (V2X) communication will be crucial. The autonomous vehicle will need real-time information to be able to enable vehicle-to-everything communication, which can be achieved with advanced 5G functionalities (Garcia et al., 2021). 5G will also enable the required communication between several devices and systems, simultaneously creating an overhead system allowing real-time changes and adjustments of current tasks and operations.

2.1.7 Vehicle-to-everything (V2X)

V2X is a type of wireless omnidirectional communication system between the vehicle and all of its surroundings (Wang et al., 2019). V2X technology uses sensors and detectors to collect real-time data on the road infrastructure, other vehicles, and pedestrians (Naeem et al., 2024).

The required traffic information is then exchanged with the vehicle, where the AV's AI algorithm adapts to unexpected situations. Wang et al. (2022) mentioned that V2X can be seen as the umbrella term for vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I), vehicle-to-cloud (V2N/V2C), and vehicle-to-pedestrian (V2P). This means that requirements for a functional V2X system need to include omnidirectional communication with all these simultaneously.

V2X will be important for safe and efficient autonomous vehicle operations at RORO terminals. RORO terminals have constant flows in different directions, with heavy-duty trucks and machines operating in the area with little capacity. For autonomous vehicles to operate safely and efficiently, V2X technology must provide real-time updates about the current environment to enable the vehicle to make the best decision, even in difficult situations. The AV also needs to be able to receive information from the terminal planners through real-time connection between the vehicle and the port management system (Sonia et al., 2024). It is a two-way communication where the AV sends information regarding the current location, status, and alarms, whilst the port management system needs to send information regarding the routing and location planned by the port operators.

2.1.8 Previous Research: RORO terminal automation

According to Min Hokey (2022), the advancement of innovation during the fourth industrial revolution has led to increased pressure on terminals to create and advance smart operation systems. Park et al. (2023) and Yun et al. (2022) add to this and mention that in RORO ports, there is still a need for manual labor to drive the vehicles within the terminal and the inability to stack vehicles on top of each other. Compared to bulk and container terminals, where automated cranes can be utilized to stack and move containers, this type of automation cannot be done for RORO operations. Yun et al. (2022) bring up that the human resource factor is the current main solution to increase productivity in RORO terminals, which leads to longer working hours and overtime. Fatigue leads to human errors, and the solution of employing more workers is not economically sustainable.

Many terminals are also using outdated Terminal Operating Systems (TOS) that cannot be flexible and the integration that is needed to meet modern challenges, leading to bottlenecks and operational inefficiencies (Nortal, 2024). The adoption of smart port technologies, which integrate advanced digital tools to address certain challenges met in the terminal, including safety, efficiency, and sustainability. According to Lasi et al. (2014), the push towards smart port technologies can be aligned with a description of Industry 4.0, where the focus is on cyber-physical integrations. The integration includes real-time data and automated decision-making to increase operational efficiency. Integrating technological tools in RORO terminals can be a potential step towards achieving the autonomous and self-regulating system envisioned by Industry 4.0.

A potential solution to the major pressure in RORO-ports is through the characteristics of AVs and their ability to utilize unmanned communication with their surroundings and local systems (Park et al., 2022). An automated loading system within a RORO terminal can be created if an infrastructure between the terminal and the ship is developed, which could solve the issue with insufficient human resources. Park et al. (2022) conducted simulations of an automated loading system in the terminal and found that it could lead to a reduction of emissions, operational costs, and a reduction of over 45% for loading time onto the vessel. A reduction of over 90 % of operational costs could also be achieved over 15 years, according to the simulations. However, according to Park et al. (2022), there is a lack of knowledge regarding what infrastructural upgrades would be needed for an automated loading system to function. Infrastructural changes, such as 5G, Location awareness, and dedicated lanes, etc., were not analyzed; thus, the AVs moving the cargo onto the vessel could face unpredictable challenges in a real-life setting.

A similar study, by Jacobsson and Lantz (2024), conducted a hypothesis test on what effect the automated gate system had on Total Truck Turnaround Time (TTTT) in the container terminal of Gothenburg. The result showed a decrease of 7% in TTTT. Jacobsson (2024) believes it's important to use a broader view where his research on TTTT also looked into other effects. For example, the smart gates also led to decreased administrative work previously conducted manually by truck drivers. This source provides valuable insight into the focus on the broader view over the terminal. It gives a deeper understanding of other potential benefits that could potentially be eliminated if the focus is too narrow on only one operation. This hypothesis test was conducted in a container terminal and not a RORO terminal, and as mentioned above, RORO terminals are less standardized; thus, these results may not be applicable in RORO terminals.

To sum it up, these studies showcase the great potential that automation and digitalization could have on the RORO terminal. By implementing advanced digital systems and AVs, RORO terminals could potentially improve efficiency, reduce costs, and become more sustainable. However, it is important to consider the infrastructural requirements and challenges specific to RORO terminals, as the study by Jacobsson focused on container terminals, and Parks et al. (2022) did not include the operational requirements for real-life implementation. For that reason, the potential benefits of automation and digitalization are logical, but the current challenges in RORO terminals need to be understood as well for a successful implementation.

2.2 Human and social factors in autonomous logistics

This subsection of the theoretical framework will focus more on the human aspect. examining how the introduction of Autonomous vehicles will impact workers and their insight into the technology.

2.2.1 Labor replacement

As mentioned earlier in this thesis, autonomous vehicles can bring several benefits for both industries and our society; however, the introduction of Autonomous vehicles could also lead to labor market disruptions. Nikitas et al. (2021) conducted an online survey with over 700 responses, and some main takeaways revealed that the participants believe that governments are not prepared for the transformation AVs will force upon workplaces. Historically, new technology has generated more jobs, but in the short term, it can lead to areas of industries with high unemployment (Parker et al., 2018).

The high-risk category of being replaced by autonomous vehicles is repetitive jobs often related to blue-collar work, such as motor vehicle operators with limited transferable skills to other jobs (Nikitas et al., 2021). Reskilling and awareness should be made by the stakeholders involved, giving people an opportunity to find other or new job opportunities.

2.2.2 Public acceptance & Regulations

When AVs start entering our highways and places of work, people will need to be able to trust that the vehicle will operate safely. According to David et al. (2020), people's initial trust and trust after interacting with an autonomous vehicle are significantly different. Public Trust is prone to increase if the AV operates without low risk. However, that built-up trust can quickly be erased once an autonomous vehicle accident occurs. This skepticism could quickly lead to a lack of trust among workers. For example, an AV Uber killed a pedestrian because it failed to recognize the pedestrian as a human (Ajenaghughrure et al., 2020). This incident underscores the importance of vigorous safety measures and transparent communication to maintain the trust built up.

According to Sun (2025), there are major discussions about who should be held responsible for AV crashes should it be the human, the AV, or the manufacturer? Sun (2025) explains that some think that the human who operates the AV should take responsibility if an accident occurs based on the responsibility of them supervising the machine, while others tend to blame the AVs. According to Sun (2025), they analyzed over 90,000 social media posts from different Chinese platforms using AI-powered text analysis. The researchers found that the majority of people tend to blame AV systems more than human drivers, even when both may share the responsibility, and the "blame gap" could shape future laws and regulations to develop around AVs (Sun, 2025).

2.2.3 Gaps in regulations

KPMG's (2019) report takes a broad, global perspective, analyzing the transformative potential of AVs and ranking countries based on their readiness for AV adoption. It assesses various factors such as "Policy & Legislation" and "Technology & Innovation," providing a comparative view of how different nations approach AV regulation. Sweden's preparedness is discussed in this context, highlighting strengths and improvement areas. Compared to Sweden, the United States demonstrates a more market-driven approach, where individual states can set their own AV regulations. This decentralized framework allows for rapid innovation and competition, particularly in states like California, which encourages strong technological advancements, but the lack of a unified federal policy creates inconsistencies. On the other hand, the European Union focuses more on harmonized regulations across member states, which ensures legal certainty, but sometimes it may slow down implementation.

Hansson (2020) takes a more academic approach where the author critiques the fragmented regulatory landscape, focusing more on the need for a standard regulation framework that can keep pace with technological advancements, aiming more at Sweden and Norway. Hansson (2020) discusses, for example, the present outdated regulations, such as the international laws that are designed for human drivers, which make no allowance for autonomous driving. This leads to inflexibility in meeting the changing landscape of society.

2.2.4 Safety

According to Araujo et al. (2019), one of the main technical challenges and concerns in our society related to AVs is how they handle unique safety-critical situations. Autonomous vehicles will operate with 100 % accuracy if everything works normally; however, when handling rare safety-critical events, the AVs lack the decision-making skills that a human driver would have (Araujo et al., 2019). According to Feng & Liu (2024), AVs have a difficult time handling rare events because the occurrence probability is low, thus leading to a lack of data and information on rare events, making it difficult to deep-learn the AVs with machine learning since the data for rare events often becomes hidden by normal data.

There are also some regulatory and legislative challenges existing regarding AVs globally. Out of the 10 leading countries regarding infrastructure readiness, 6 of these countries, Sweden being one of them, are not part of the top 10 of the legislative environments, which shows that there is still room for improvement regarding AV regulations and legislation (KPMG, 2019). Regulating and legislating AVs seems problematic due to the traditional laws of how a vehicle is maneuvered. Traditional laws put the responsibility of maneuvering the vehicle on a person, but the advancement of AV technology conflicts with the regulations due to transferring the responsibility from the person to the vehicle (Hansson, 2020).

2.3 Summary theoretical background

To sum up this chapter, the theoretical background explores AV implementation in RORO terminals through technological advancements such as Industry 4.0 and 5.0, which focus on automation and human-machine collaboration. Other advancements include smart port technologies such as 5G, V2X, and the SAE automation levels. This chapter also addresses challenges specific to the RORO terminal, such as human factors, which include labor replacement and safety, and the regulatory gaps that currently exist, focusing on the specific infrastructure and technologies that are needed for successful AV implementation. The theoretical background will therefore serve as a foundation for the analysis of the empirical findings.

3 Methodology

In this chapter, the methodology of the research is presented. Firstly, the research approach, design, and process will be discussed; thereafter, data collection and analysis will be described, and lastly, research quality and limitations will be discussed.

3.1 Research approach

The research approach was chosen after investigating potential methods for collecting data that would align with answering the research questions. Here, the main paradigm and the reason for choosing qualitative methods for this thesis will be explained.

3.1.1 Paradigms

According to Collis & Hussey (2014), a research paradigm is a philosophical framework that guides researchers on how scientific research should be conducted. There are three research paradigms, and for this thesis, the interpretivism paradigm was chosen. Interpretivism is an approach where the aim is to gain interpretive understanding by using different qualitative methods that focus on translating and describing, in other words, coming to an understanding of social complexities. (Collis & Hussey, 2014). An interpretivism approach was chosen for this thesis because of the interviews the authors will have with different individuals. The authors believe that this choice of research paradigm will help understand the complexity of the RORO terminals and seek to understand the requirements, challenges, and costs and benefits that can occur. The authors also believe that it will lead to a more holistic point of view and is considered best suited for answering the research question.

3.1.2 Qualitative methods

Qualitative research can be defined as a non-numerical gathering of participants' experiences, perceptions, and behavior (Cleland, 2017). It is usually preferred when research questions include how or why and help answer questions that are not quantified. Qualitative research methods have not been used as much as quantitative methods throughout the history of logistics due to their tendency to analyze the process more than the variables involved; however, in the last two decades, qualitative methods such as interviews and case studies have gained ground (Halldorsson & Aastrup, 2003).

Bryman & Bell (2019) explain that a qualitative method takes an interpretive and naturalistic approach, meaning that in an interpretivist approach, researchers focus on understanding the subjective meanings people attach to their interactions, actions, and environments. In other words, the researchers seek to explore how and why people perceive the world in a certain way. Meanwhile, with the naturalistic approach, data collection happens in real-world settings instead of controlled environments, meaning that researchers put themselves in the participants´ natural context to be able to capture attitudes, authentic behaviors, and meanings (Bryman & Bell, 2019).

3.2 Research design

For this thesis, a case study was chosen as the primary method of gathering empirical data. According to Yin (2018), a case study is a valuable tool for connecting the research question to a real-world setting, allowing for a more in-depth analysis of how theories and practice are interconnected. Due to a lack of previous research, an exploratory case study will be conducted to provide new insight into the subject of autonomous vehicles' impact on logistics. The authors of this thesis believe that a case study will provide a real-world understanding of how RORO terminal operations work in practice, which also sets the foundation for the interview questions that were chosen. Gothenburg RORO terminal was chosen as the main case study because this thesis is done in collaboration with DFDS, and Gothenburg RORO terminal is an operational unit operating in DFDS business.

According to Bryman & Bell (2011), based on the subject studied, there are four different types of case studies. For this thesis, a single location was chosen. The advantage of a single-location case study is the reduction of scope, limiting the empirical findings to one location. A potential disadvantage is that the empirical data found may not be applicable in other locations. To mitigate this, interviews will be conducted with people from different industries to get a broader insight and to be able to help with the analysis and discussion subsections. Yin (2018) mentions that fieldwork consisting of short interviews with a variety of participants can be a helpful tool to answer research questions.

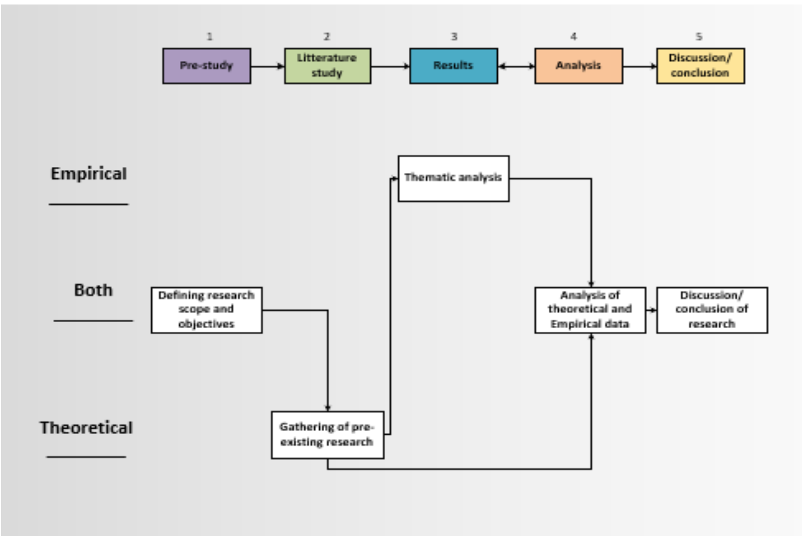
3.3 Literature Review

The secondary data collected for this research consists of reports and academic articles, to mention a few. A systematic analysis of different previously written sources was conducted to collect the necessary data. Different platforms to access the sources, including the university library, its website, and various academic platforms, such as Scopus. In addition to these sources, we also reviewed different statements from the case company and its partners. According to Flowerdew (1997), the benefit of using secondary data is that it provides a deeper context for the case study. Using secondary data has allowed us to obtain a deeper understanding of automation and digitalization. The secondary data collected was used in the theoretical background, which, together with the results, aimed at answering the research questions for this thesis

3.4 Research process

The process of writing this thesis can be divided into five main phases. Firstly, a pre-study was conducted where the research scope was defined and the objectives for the thesis were set. Secondly, a comprehensive literature study was conducted, and relevant sources were collected and analyzed. Thirdly, a case study was conducted, gathering empirical data through observations and interviews. Following that, the analysis and discussion were carried out. Lastly, the conclusions were drawn. These last two phases overlapped, and some parts were written simultaneously. The figure below shows the process through a timeline, which also includes whether the phase was empirical, theoretical, or both.

Figure 3: Research process (Authors)



3.5 Data collection

This subsection explains the data collection process. The data obtained includes both primary and secondary data. The primary data consists primarily of interviews and observations conducted as part of the case study. In contrast, the secondary data consists of reports and academic articles on the topic of automation and terminals.

3.5.1 Interviews

According to Bryman & Bell (2019), interviews are the most used method in the qualitative research approach because of their flexibility. Qualitative interviews tend to be less structured than quantitative ones since the qualitative approach aims to understand the participants´ perspectives and thoughts instead of seeking standardized, quantifiable responses. The interview respondents for this research have been sampled using three principles: purposive sampling, theoretical sampling, and snowball sampling. Starting with purposive sampling, the interview respondents were intentionally selected based on their relevant knowledge of the subject.

The research questions guide determined which respondents were deemed relevant for this research. Carefully selecting respondents provides a relevant and diverse understanding of the research topic. Secondly, the concept of theoretical sampling is a purpose-driven sampling method used in grounded theory research. In this research, we gathered data about concepts and categories that combine both into a theory. This means that data collection and analysis happened simultaneously, and we did not decide on all respondents in advance. Instead, we analyzed the data as it was collected and adjusted the sampling decision based on the findings. This concept is used to create a deeper understanding of the current gap in research. Lastly, the idea of snowball sampling was used to recruit other respondents with the help of the already obtained participants. For example, we began with a small number of interview respondents and, with their help, recruited more respondents with relevant knowledge of the subject.

The sample of respondents is from different categories, from both the case company and other relevant fields. The respondents from the case company and the terminal consist of individuals who have roles such as programmers, project managers, and RORO terminal staff. The non-case company respondents are individuals who are relevant to the research, focusing on different roles such as regulators, AI and digitalization specialists, and logisticians.

The qualitative interview method has taken a semi-structured approach. Bryman & Bell (2019) explain that interviews can be prepared in a manner where the interviewer has a list of questions that need to cover specific topics, also called an interview guide. Using a semi-structured approach, the interviewer has flexibility and the freedom to divert from the interview guide to ask follow-up questions. The interviews have been recorded after receiving consent from the respondents and have been complemented with the notes.

Table 1: Interview respondents

interviewee type	**Respondent ID**	**Role/Title**	**interview date**	**Interview Length**
Industry expert	IE1	PhD/Research manager	2025-03-13	30 min
Industry expert	IE2	PhD/Advisor digital development	2025-03-14	30 min
industry expert	IE3	PhD/Senior strategic advisor	2025-03-14	30 min
Industry expert	IE4	Sakkunnig ISM	2025-03-28	*
Terminal management	TM1	Digital development manager	2025-03-20	60 min
Terminal management	TM2	Infrastructure manager	2025-03-21	30 min
Terminal management	TM3	Operation business care	2025-04-03	35 min
Case company	CC1	Product owner TOS	2025-03-28	30 min
Case company	CC2	Head of transformation	2025-04-01	30 min

3.5.2 Observation at the terminal

Observation is a method for collecting data in an artificial or natural setting to observe individuals´ behaviors and actions. There are two types of observation methods: non-participant observation and participant observation. With participant observation, researchers are fully involved in observing the participants or phenomena being researched. This observation type focuses on gathering a detailed understanding of participants or phenomena (Collis & Hussey, 2021).

The observation type used in this research has been participant observation, where we have observed different processes and areas in the RORO terminal to gain a deeper understanding of the requirements and how they will benefit the terminal. Due to the single location case study, the observation was only done in the Gothenburg RORO terminal.

3.6 Data analysis

Since this thesis has used a qualitative method to collect data, the approach chosen was an interview study that was analyzed together with the help of the theoretical background in the analysis chapter. Further, the observations at the RORO terminal helped understand the current operations, which helped when creating the interview guides.

3.6.1 Qualitative Data Analysis

Firstly, the method chosen for analysis of the qualitative data collected through the interviews is thematic analysis. Thematic analysis is used to identify, analyze, and report patterns in data collected (Braun & Clarke, 2006). Braun & Clarke (2006) mentioned that the thematic analysis should be conducted in six phases.

Phase 1 is "*Familiarization*", here all interviews (verbal data) were transcribed using the Microsoft Teams transcription tool, and then the transcripts were read through thoroughly. Phase 2 is "*Initial coding*", which means that a list of interesting ideas and topics was made, consisting of key phrases, relevant keywords, and insights related to AVs and RORO terminals, resulting in initial codes. Phase 3 is "*Developing draft of themes.*" Here, the codes created in phase 2 are added to broader themes using a mind map to visualize the relationship between different codes. Phase 4 is "*Review current themes.*" The themes were analyzed and refined to ensure correct usage of the data collected. The 5th phase is "*Defining the themes.*" The main themes are now defined with supporting comments from the respondents. And the 6th and last phase is "*Analyzing the result";* the thematic analysis was structured to show the connection between the qualitative findings and the research objectives of this thesis. This method established a structured and well-documented presentation of the qualitative findings.

3.7 Research quality

In this sub-section, two concepts, reliability and replicability, will be explained. These two concepts were prioritized to increase the overall quality of the research by using a consistent and transparent approach.

3.7.1 Reliability and Replicability

According to Collis & Hussey (2021), research quality can be characterized as reaching detailed and in-depth data, as the quality that is provided to the research could influence the results. Reliability can be considered an essential aspect of research quality. It refers to the consistency and dependability of findings over time. According to Bryman & Bell (2019), research is considered reliable if the outcome can be repeated and remains stable under the same conditions.

According to Bryman & Bell (2019), for research to be replicated, the methodology must be detailed for other researchers. By clearly outlining the methodology, other researchers will have the ability to follow the same procedures as the methodological process has been described in detail. The absence of a detailed methodology leads to reducing the credibility of the research. However, efforts were made by the authors to achieve high replicability, but due to the nature of qualitative studies, some variation may still occur if the study were replicated by other researchers.

3.7.2 Validity

Another important criterion for research is validity. Validity can be further divided into four categories: measurement validity, internal validity, external validity, and ecological validity (Bryman & Bell, 2019). In this research, the focus will mainly be on external validity due to its impact on the generalization and reliability of the findings.

3.7.2.1 External validity

According to Bryman & Bell (2019), external validity refers to the generalizability of results beyond the specific research setting. Since this research is based on a single-location case study, which is the Gothenburg RORO terminal, there might be a risk that the results of this research may not apply to other terminals with different infrastructure or operational challenges. However, the authors of this study have taken several strategies to increase external validity; these include comparing gathered data with industry reports. Reports on AV adoption in other transport sectors confirm that some aspects align with wider trends in automation and logistics.

Interviewing people from different backgrounds, experiences, and regions provides a deeper understanding beyond the Gothenburg RORO terminal. Exploring regulatory frameworks across various regions showed how different legal environments influence AV adoption.

While the focus is on the local operations of the Gothenburg RORO terminal, the authors wish to contribute to a broader understanding of how AVs impact RORO terminals at a systematic level. And by incorporating these elements, the authors are aiming to offer an understanding to Gothenburg RORO terminal but also other RORO terminals considering adopting AV technology.

3.7.3 Research ethics

According to Collis & Hussey (2014), research ethics can be defined as the manner in which the research has been conducted and how the results have been reported. The authors of this thesis have informed the respondents about the purpose of the thesis, and also gave the respondents the possibility of voluntary participation, in the form of cancelling or the opportunity to withdraw from the interview at any given moment. The interviewees also had the possibility of anonymity and confidentiality. With anonymity, meaning that the respondents will not be named in the research if the respondent wished that, and with confidentiality, meaning that the information provided from the respondent cannot be traceable back to the respondent.

3.8 Research limitations

According to Collis & Hussey (2022), a limitation describes a weakness in the research such as a lack of available data or time constraints. Despite the rigorous planning made by the authors, there are still certain weaknesses in the research. Firstly, due to confidentiality restrictions from the case company, some important aspects regarding AVs could not be included. This led to more emphasis on qualitative data collection and industry benchmarking to reduce the gaps. Secondly, due to the classified status of protection objects for the terminals in Gothenburg, technical data, including drawings, pictures, and GPS information, could not be utilized.

Lastly, time constraint was a challenge for the authors. The time for gathering empirical data was approximately 7 weeks, which led to constraints in the scope of the research. The interview respondents were limited to 9, which could affect the reliability of the research due to the lower number of interview respondents. If the research had been repeated, the results may have varied. A higher number of interview respondents generally increases reliability by reducing the random variations and biases. The time constraint also led to the main focus of the empirical research being conducted in Sweden, however, insight from international industry experts was collected through interviews.

These limitations presented challenges, and alternative sources of information and methodological changes were utilized to maintain the thesis validity and relevance. However, the readers should be aware of these limitations when reading the findings.

3.9 Usage of AI

AI applications have been utilized in different ways for this thesis, but the authors have been careful not to copy or use text written by AI. AI such as ChatGPT and Copilot have been used as a ball plank when developing new ideas or structure for the thesis. An example of a prompt is “Hi, what do you think of our structure in the analysis chapter, and does it align with our main goal?” or “Is the flow and wording academically good in our result chapter?”. This has helped us to get quick tips on what can be improved in a certain section, brainstorming, or what potential subjects could be interesting to add.

4 Results

In this chapter, the results from the interview study will be presented. The results will be divided into three main sections consisting of "***Operational requirements***", "***Cost and benefits***", and "***Human factor & regulations***". Every main section will have sub-sections where the respondents' main takeaways will be presented.

4.1 Operational requirements

In this section, the most important aspects of the operational requirement regarding AVs in the RORO terminals will be presented, where the section is divided into different themes of requirements

4.1.1 RORO terminals compared to container terminals

A recurring theme throughout the interviews was the comparison between RORO and container terminals. Containers are standardized in size, making the implementation of automated processes easier than in RORO terminals, where goods come in all forms and sizes (IE1, IE2, IE3, TM1, TM2, TM3, CC1, and CC2). The market size of the container business is according to a Digital development manager at the RORO terminal (TM1) significantly larger than the RORO business in transport logistics. This leads to a lack of incentives for tech providers to focus on automation solutions within RORO terminals. The lack of standardization in different RORO terminals is summarized by respondent TM1 as *"There aren't so many systems, I think it's because either you build it yourself or the market isn't big enough."*. Since there is low competition from automation solutions providers, it slows down the integration of automation, leading to often under-digitalized terminals.

Further, the lack of standardization also has a great impact on what operational requirements will be needed before implementing an AV. Respondent TM2 mentioned that in the container terminal, there is a forward flow where trucks drive and offload containers and then place them in the correct location with forklifts. In RORO terminals, however, the terminal trailer handling shunting needs to drive and reverse when offloading a trailer into the correct location. *"At least now, the autonomous terminal tractor can't reverse,"* explained by respondent TM2. Similar thoughts are brought up by respondents IE1, IE2, and CC1 that a difficult aspect is the placement of cameras on terminal tractors, since the trailer behind could interrupt the vision and could lead to mistakes during the reversing of the trailer.

In summary, lack of standardization, lack of automated solution providers, and technical challenges highlight some of the challenges specific to RORO terminals.

4.1.2 Digital Infrastructure

For automation in RORO terminals to succeed, a strong digital infrastructure is needed. As the respondent IE1 explained, *"Automated driving is highly dependent on digitalization. Without that, it will not work at all because it's so important with the correct sensors."* Whereas CC1 mentioned that *"Infrastructure is key if we want to fully automate everything,"* This shows that there is a need for an integrated sensor network and other digital elements that many RORO terminals are currently lacking. Respondents CC1, CC2, TM3, and IE3 mention technologies that can help to increase efficiency in the terminal operations. And one of the most important aspects of the need for digital infrastructure is location awareness, which improves operational efficiency in the ports.

Respondent CC1 mentions, *"Location awareness is one of the most valuable things[...] knowing where units are optimizes vessel loading."* This real-time tracking technology helps the terminal to know where the cargo is located, but also where to park the cargo to enable more coordinated and efficient vessel loading. CC1 further explains that when a unit comes into the terminal, an efficient way to coordinate and find the best possible location for the cargo is to use algorithms and previous data of what they know. Respondent CC2 and TM3 also argue about the need for location awareness technology and being able to detect the correct containers. CC2 and TM3 explain that cargo numbers are hard to detect even if they are in the front or the back of the cargo, but camera technology that uses AI might help with the detection issues. TM3 strengthens the statement by explaining the importance of matching the right cargo with the right booking, and by using AI to handle previous data, consisting of, for example, previous cargo and customer behavior, they can more accurately know when the cargo is coming in and where it can be dropped.

Respondent IE3 further pushes the need for location awareness and the port's ability to conduct experiments regarding that technology. Respondent IE3 states *"port is a very a restricted area[...] makes it very suitable to experiment[...] from my point of view, what it requires is* *very, very high degree of situational awareness"*. For AVs to be able to operate safely within the terminal premises, a constant real-time data exchange between AVs and the terminal staff is necessary. But for that kind of real-time monitoring to be working more efficiently, there will be a need for better networks. Respondent CC2 explains, *"You could use a dedicated Wi-Fi network[...] 5G might work better[...] You need to be able to connect to the trailer with a proper guidance system."*. This strengthens the importance of strong and high-speed networks. Standard networks can be utilized in those processes, but to efficiently support the real-time tracking, a faster and more reliable network is necessary to allow precise coordination between the AVs and the monitoring staff.

Respondent TM3 explains the need for real-time visibility throughout the operations: *"We need a faster and more accurate way of knowing when the cargo arrives[...] to have it just free flow going through the gate."*. TM3 further explains that the cutoff time for the cargo is shorter in RORO terminals, customers can therefore deliver cargo one hour before the cutoff time, which makes it hard for the terminal to plan the loading capacity. With real-time visibility, the process of gate-in and cargo location, for example, will be simplified, reducing delays and bottlenecks, which optimizes cargo movements more efficiently.

When the right systems are implemented in RORO terminals, the benefits are undeniable. According to the respondent IE2, *"The more digital you make something, the easier it will be to increase efficiency and productivity."* Though this sounds easy, RORO terminals are facing the challenge as mentioned in the previous section, such as a lack of demand and technical providers, which leads to technology providers not being motivated enough to develop specialized solutions, and without those solutions, RORO terminals struggle to modernize.
Although there are challenges faced by RORO terminals, progress will likely happen step by step. Rotterdam has set an example, as stated by the respondent IE1, *"You can look at Rotterdam, which has already installed autonomous driving vehicles, and I believe that this is a very good point."* But for every RORO terminal to succeed in its transition, they will need to find their own approach.

4.1.3 Physical infrastructure

Related to the physical infrastructure, some of the respondents (TM1 and TM2) stated some key challenges in introducing AVs in RORO terminals. The firm and rule-based nature of AVs clashes with the rational decision-making of humans. Humans can find solutions to uncertainty and adapt to different situations, while AVs might struggle with unstructured environments, making their adaptability to the RORO terminal environment hard. The main issue is that AVs lack the reasoning ability that allows humans to handle uncertain situations. A human driver might, by instinct, adjust their path when an unexpected obstacle is in the way, those can be windmills or other types of cargo that are stored in RORO terminals. The main challenge with AVs is that they rely only on pre-programmed algorithms and sensor data. As respondent TM1 puts it, *"I think the challenge here is, of course, as it always will be, the interaction between machine and human or autonomous vehicles*.", which shows that AVs cannot easily adapt to irregular behaviors such as informal traffic flows and changing terminal environments.

The challenges become clearer in respondent TM2's observation that *"There's always new business flows that could come into the terminal[...] You must do a special solution for traffic flows and changing terminal environment."*. Human workers naturally adjust to changing layouts, uneven loads, and temporary obstacles. While AVs, which are designed for continuity, can misunderstand changes, halt operations when uncertain, or require manual assistance when faced with these kinds of situations. For example, a human driver might see an obstacle on the normal route and steer around or find another route, whereas an AV, which lacks contextual awareness, might stop and cause operational halts, bottlenecks, or, in the worst case, fail to detect the obstacle, which leads to safety risks. TM2 and IE2 explain that early AV deployment should focus on simple, repetitive tasks that are the most feasible for initial automation. These tasks can be simple, fixed-point shunting as stated by respondent TM2: *"It's possible at first to do shunting between A and B on the actual terminal."*. Starting with these controlled operations helps the RORO terminal to build confidence in technology while avoiding challenges that are mentioned earlier, such as AVs making too complex decisions. Over time, the information that is gained from early deployment can guide the RORO terminal to small expansions of AV integration into more changing environments.

Another infrastructural challenge that can be found in the RORO terminals, or terminals in general, is electricity availability. Respondent CC2 explains that one challenge that is sometimes overlooked is the charging infrastructure. Respondent CC2 states: *"Something people don't usually think about is the charging infrastructure and where the electricity is available."*. Since AVs are usually electric, they need to have an efficient charging infrastructure to function 24/7. CC2 also states: *"Because electricity availability in the Netherlands at least is not good[...] And these AVs are usually electric. I don't think anywhere* *in the Netherlands there's enough kind of capacity to accommodate that"*. In this example, CC2 argues that it will be infrastructurally challenging to implement and adopt AVs in the Netherlands since there is not enough electricity to charge the AVs, and if they can implement and adopt AVs, it will be costly, which is not beneficial for the terminal. However, this lack of electricity varies from country to country, where CC2 mentions as an example that in France, there is enough electricity.

4.1.4 Technical requirements

Before implementing AVs, many challenges have to be faced and solved, for example, the electricity issue in several parts of the EU. But the current main challenge is to be able to connect the AVs to different types of cargoes, especially trailers, which are the main cargo type that is handled in the EU, as stated by respondent TM3: *"The operators in Europe, it means that 80% of our cargo is semi-trailers."*. Respondents TM1, CC1, CC2, and TM3 explain that there are challenges when an AV connects to the semi-trailers, consisting of the hose, electric cables, and winding up leg issues. All four respondents agree that semi-trailers will be harder to automate, and it is one of the main challenges people tend to overlook. Respondent CC2 explains *"You need to attach to the trailer as well. Because usually a trailer is on its break when it's not connected to air and electric hose. You need to connect it to the air to take the break off. "*. And CC1 explains: *"You have to wind landing legs back down without a person physically doing that"*. Respondent CC2 emphasizes the fact that technology today is not advanced enough to make a robot connect the hose and the electric cables to a non-standardized cargo type, and this is based on the fact that these types of cargo do not have them in one position but differ from cargo to cargo. CC2 also explains that even if that challenge is resolved, it won't be cheap to make it, which makes it even less attractive for terminals today to implement these technologies.

Beyond these challenges, TM3 explains that other cargoes in RORO terminals are standardized; these include cassettes and other standardized cargoes that make up about 20% of the total cargo that is handled in the terminal. These types of cargoes do not need any type of connection to an air hose or electric cables, which makes them easier to automate. TM3 explains it in this way*: "But the problem is still these connections to the air hoses. But we do have carriers, like cassettes and other cargoes, that are standardized, and no connection is needed."*. Instead of connecting these types of cargoes to an AV with air hoses and electric cables, there are huge tractors today with a hydraulic wagon that goes under the cassettes, for example, and lifts them to deliver them to the needed place.

4.2 Potential costs and benefits of introducing an AV in a RORO terminal

In this section of the results, the direct and indirect costs and benefits associated with introducing an AV will be presented. This will not only showcase the direct costs and benefits but also explore different perspectives highlighted by the respondents.

4.2.1 Costs

The majority of the respondents (IE1, IE2, IE3, TM1, TM2, TM3, CC1, and CC2) all believe that the most impactful cost will be the upfront investment in buying the autonomous vehicle. Respondent IE1 mentions: *"the cost side is that you need to have the implementation cost to install, and you have to purchase the new vehicle[...] So, I believe that it is a huge, fixed cost at the beginning."* TM1 adds further to this discussion: "It's probable that the AV will be incredibly expensive and will probably work half as good as a human driver to begin with." This highlights the substantial upfront cost of buying the AV; however, indirect or hidden costs also need attention. The product owner TOS respondent CC1 brings up the importance of upgrading infrastructure as key to enabling automation, but it also comes with a cost. The different systems, such as integrating 5G and system-to-system communication, etc., will be expensive. Respondent CC2 adds to this in the statement: *"I don't see a big hurdle to a proper TOS system[...] apart from, of course, money"*. This shows indirect costs related to digital infrastructure. However, TM2 also mentions physical infrastructure, such as buying traffic lights for safety reasons.

These upgrades will be expensive; thus, several of the respondents (IE1, IE2, IE3, and TM1) bring up the importance of conducting a cost-benefit analysis and looking into long-term ROI and efficiency gains to decide if AVs are a valuable option or not. CC1 summarizes it as: *"Proving the value, that's the most important thing for us, and when we expect the ROI."*

4.2.2 Benefits of implementing an AV

In contrast to the cost of implementing an AV, the biggest benefit, according to several respondents (IE1, IE2, IE3, TM2, and TM3), is the reduced labor costs. Respondent TM3 brings up that the biggest cost in terminals is labor cost*." An AV could operate 24/7 and doesn't need rest or break"* as explained by IE1, thus leading to a long-term reduction in costs. TM1 follows up on the time aspect of AVs and explains similarly to how TM3 explains in section 4.1.4:

"So, I think it will be hard to have AVs for trailers, but we handle containers as well. We put them on different carriers called cassettes[…] So I mean an autonomous cassette vehicle could be used to transport lift units from the lifting area to the key area or vice versa, depending on if it's import or export[…] I think that would be one of the easier things to do, and that could be a 24/7 operation provided that the AV can recharge somehow, that could work in a good way.".

Another major benefit that AVs could bring to the RORO terminal is improved efficiency and the reduction of human mistakes. CC1 and TM3 mention that the biggest problem in RORO terminals is human mistakes caused by external drivers. Respondent CC1 explains: *"The driver is trying to optimize their way of working on the terminal"*. CC1 continues with an example*:*

"The drivers are advised to drop off a trailer close to the vessel for loading, but the trailer they are bringing out of the terminal is on the other side. Thus, they drop off the first trailer next to the one they are picking up to save time and fuel, leading to huge logistic problems for the terminal operators.".

Respondent CC2 explains that having a designated area for trailers from external trucks, which could then be driven to the correct location by an AV, could increase the accuracy of trailer location before loading the vessels and reduce the number of vehicles on the terminal. This will not only benefit the loading of vessels but also the planning and scheduling for terminal planners, since the trailers can be placed in rows instead of a fishbone structure, according to TM3. However, CC2 also mentions that this will be difficult and explains

"You can have an handover area where you would for instance have all the truck drives delivery units where then an automated vehicle takes it away, puts it somewhere close to the vessel and then you ideally have that automated vehicle also take an import[...] but you have to make sure you have large enough space and enough automated vehicles so you can keep that in circulation[...] so it is possible, but whether it's feasible and cost effective, I don't know".

And as TM1 mentioned, he believes that AVs used for trailer movement is very difficult, and AV for movement of cassettes is a better starting point when introducing AVs

4.3 Human factors & regulations

This last section will focus on the human and safety aspects. What safety precautions need to be taken before implementing an AV in the RORO terminal to ensure a safe work environment? Further, how does AV affect work safety?

4.3.1 Safety concerns

A critical decision that needs to be made, according to respondents IE1 and CC2, is whether the terminals can have a fenced-off area where the AVs can operate.

Respondent IE1 reinforces this issue, arguing that: *"The first step is if you want to introduce autonomous vehicle driving within the terminal, you should try to get rid of all the humans working within the same area to reduce the safety issues"* This shows the current state of AVs, where they are less adaptable than humans in uncertain settings. Humans rely on instinct, experience, and social cues to navigate the complexities surrounding the RORO terminal, according to TM2 and CC2, while AVs operate within rigid boundaries, making them inappropriate for shared spaces without taking the necessary steps to ensure high safety, as explained by TM1. Respondent TM1 also states*: "Do we need to fence off areas for AVs, or can they coexist with humans?"*. There is already a lack of space, and to fence off an entire area may not be feasible according to TM1, TM2, and EI3. This could indicate that a shared space between AVs and human-driven vehicles may be the only option due to space utilization. This puts further pressure on AV technology to work with 100 % accuracy with V2X technology, sensors, and cameras to reduce the risk of incidents. As mentioned in the section on digital infrastructure, automated driving is highly dependent on digitalization.

Regarding the liability and accountability, whether accidents involving AVs were to happen in the terminal seems unclear compared to when speaking about automating ships. Respondent IE4, who works with different maritime safety aspects, explains that the liability and accountability regarding the automation of ships is the "million-dollar question". But some solutions are discussed within that area. For example, IE4 mentions questions regarding the algorithms in the Automated Navigation System (ANS) and how a flag state should address the functionality of these different solutions that come to the market when they are used on a ship that is approved. One proposal is to use test facilities that can "type-approve" different ANS in the same simulation environment, respondent IE4 explains.

Regarding AVs in the terminal, the situation might look a little more complicated. TM1 states that they are regulated by 20 or so government agencies today, depending on where you are operating within the terminal and what you are doing. TM1 also explains that many parties are interested in that area, which makes it even more complicated. If an accident happens within the terminal, who will bear the responsibility? Will it be the software provider, AV manufacturer, or the terminal operator? It's crucial to decide this before the implementation of AVs.

4.3.2 Regulations

When it comes to implementing AVs, certain rules and regulations need to be met, with a more specific focus on labor and workforce. IE2 explains AV technology as a disruptive force, as with any other new technology introduced. Respondent IE2 also explains that when doing these kinds of technological implementations, the terminal must consider making it right from the very beginning. IE2 continues and explains: *"During a disruption, not everyone is happy. I have no answer other than it's very delicate. And as a manager in a system where you have a high degree of automation potential, you need to make sure that you do it right."*. This indicates the importance of detailed analysis before implementation, so everything goes as planned.

Other respondents explain that automation will not replace humans for a while, and since it is a very sensitive topic for the terminal employees, some parties are blocking those kinds of innovations. Respondent IE2 explains it this way*: "It's a sensitive issue, and you have unions blocking, especially in the USA."*. Even if the terminals could implement and adopt AVs, they must consider the rules and regulations regarding the workforce and labor, since they cannot get rid of the workers, they need to meet that challenge in a more diplomatic way, where all parties are satisfied with the outcome. Respondent IE3 also explains that since there are rules and regulations regarding labor dynamics, it complicates AV adoption, since unions and trade unions are blocking those disruptions.

However, there might be solutions where a balance between innovation and workforce stability can be achieved. Respondent CC2 explains that layoffs are not feasible due to regulations and union agreements, but the retirements and the re-positioning that will occur during a period of 10-20 years might ease the transition. "Many employees will probably retire during the 10-20-year period, and other employees will find other occupations". Even though this phase-out period includes dual costs, which consist of investing in AVs and labor costs, it also opens up opportunities for the terminal to retrain and provide other positions for the employees, which are better suited for technological progress without compromising the employees' work safety

4.3.3 Labor replacement

The deployment of AVs in RORO terminal operations will have the ability to reshape the traditional labor dynamics, which will spark important discussions around job displacement, workforce restructuring, or maybe the role of internal training to provide smoother transitioning. Automation and digitalization will inevitably replace some roles within terminal operations, especially the roles that require manual or repetitive tasks. Most respondents explain that it might be beneficial to retain some of the employees through internal restructuring and retraining rather than a major layoff of the employees.

One key theme that is shared among several respondents (IE1, IE2, TM1, TM2, and CC1) is that automation and digitalization does not lead to mass unemployment, but a slight shift in job responsibilities. There will be certain positions that will be affected by automation and digitalization, for example, internal drivers.

Another important aspect mentioned by respondent TM1 is that, instead of reducing the workforce, reallocating these resources to another place within the terminal to meet the new operational needs. *"It might just be a question of restructuring the way our manning situation works[...] maybe we need to hire even more people in the long run."*. This argues that the assumption of automation and digitalization leads to job losses, instead it can be perceived as an opportunity to shift certain employees into higher value position or maybe needing more employees within the same area to help the AVs operate. Respondent TM2 explained similar things, stating*:" You could adapt to a dispatcher role for surveillance and telling the operations what to do."*, which suggests that the repositioned workers can take roles such as dispatcher or other surveillance roles, where they can use their operational experience in new ways.

For the shift to be successful, it will depend on the worker's attitude toward getting back to school and getting the necessary education. Respondent IE1 explains that experienced workers, for example, drivers, have knowledge that can be considered valuable, which can enhance the automated systems if they receive the right training/education. If they can bring their knowledge into the new system, the system can be much more efficient.

However, this will depend on the workers' willingness to get retrained and re-educated, and that is something that is not guaranteed due to that resistance being common, especially among workers who fear losing their jobs. Respondent IE1 states:

"If they think smart, the term operator, maybe they can use the knowledge of the drivers when they develop the system and also monitor the system later on. The drivers can maybe help with that, but they need more advanced education compared to what the drivers have today for sure".

Many of the respondents saw benefits of workers getting retrained/educated, which can be seen as a proactive way to help reduce job displacement issues.

4.4 Summary of results

To summarize the result chapter, the interview data gathered and used for the thematic analysis highlights the complex nature of RORO terminals and the many different aspects that need to be taken into consideration before implementing AVs.

The operational requirements are vast and all need to be taken into consideration to avoid inefficiency, costs, and incidents. This includes identifying and deciding on potential digital and physical upgrades needed, such as 5G, location awareness, system-to-system communication, and whether you should use a fenced-off area or not etc.

The costs and benefits of AVs are decisive as to whether implementation is worth it or not. The upfront cost of purchasing the AV and indirect costs, such as upgrading systems and infrastructure, will be expensive; thus, the benefits, such as reduced labor costs, more efficiency, and reduced human errors, need to outweigh these initial costs.

Safety and regulations are important factors due to the many workers and vehicles operating in RORO terminals. Ensuring that the AV can operate safely within the same space as humans is a key factor that needs to be planned from the start. Compliance with regulations is another important aspect, and retraining, relocation, and new jobs created need to be decided on if an AV is set to replace a current job in the terminal. However, as mentioned earlier, several potential solutions are creating an environment where workers and machines can work together.

5 Analysis

In this chapter, the results of the interview study will be analyzed through the lens of the theoretical background to be able to answer the research questions outlined in this thesis. The operational requirements, cost, and benefits, and regulatory and safety considerations related to introducing AVs in RORO terminals will be analyzed. The findings from the interview will, together with the theoretical background, provide the readers with the current challenges and opportunities related to digitalization and automation in RORO terminals.

5.1 What are the operational requirements for autonomous transportation technology in RORO terminals?

Understanding the operational requirements, such as digital and physical infrastructure, is key to enabling the successful implementation of AVs, as stated by industry expert CC1. Thus, in this subsection, the main operational requirements will be brought up and analyzed and shown through a requirements framework.

5.1.1 Digital infrastructure

The fourth industrial revolution has led to new advancements in technological solutions, for example, automation and IoT. One sector that could benefit from the technological push of Industry 4.0 is the maritime sector (Triska, 2022). As explained by the industry expert IE1, automated driving is highly dependent on digitalization to be able to operate efficiently and safely. Therefore, upgrading systems, network, and sensors at the terminal must be considered so that the AV can operate correctly. Another industry expert, IE3, mentions that a very high degree of situational awareness will be needed. For this to work, real-time data exchange or V2X communication between the AVs and terminal staff should be fully operational. As pointed out by Nortal (2024), today, many terminals are using outdated terminal operating systems (TOS) that cannot integrate new technology. Upgrading these systems will be necessary to allow V2X communication. V2X, which utilizes omnidirectional real-time data communication from the AV with all of its surroundings through the usage of sensors and cameras (Naeem et al., 2024).

Allowing this V2X technology to work in real-time is a crucial safety aspect where the AV's AI algorithm can use the data to adapt to uncertain situations. Terminal management TM1, TM2, and industry expert IE3 push on the fact that a shared space between AVs and humans may be the only option, thus highlighting the importance of a fully working V2X communication system from a safety and efficiency perspective.

For real-time data sharing to work, another digital infrastructure upgrade is needed, upgrading the network connection. CC2 believes that you need to choose how you should send signals to the AVs, either by a dedicated network for the AVs or a 5G system that may be easier to maintain. 5G capabilities allow for real-time data sharing due to low latency, allow machines to interact with each other through the wireless network, and offer better reliability in harsh weather conditions (Skold et al., 2022; Garcia et al., 2021). 5G will also enable the required communication between several devices and systems, simultaneously creating an overhead system allowing real-time changes and adjustments of current tasks and operations
In conclusion, this will allow the AV to operate with real-time data sharing, leading to more efficient and safe work, allowing it to communicate potential obstacles to terminal staff and handle uncertain situations.

Lastly, respondents from the case company, the industry, and terminal management (CC1, CC2, IE3, and TM3) believe location awareness is a key requirement not only for AV operations but overall, in the terminal. Location awareness is, according to CC1, a total visibility of where every trailer is in the terminal. TM3 mentioned that integrating cameras with AI technology could help identify the cargo numbers. For an AV to be able to locate the correct cargo and move it to the new location, a location awareness system in the terminal will be needed. This could help reduce human mistakes of misplacement of goods and reduce the loading time of vessels. These advancements can be summarized as a push towards reaching the fourth level of port digital transformation, with interconnection between humans, vehicles, and sensors making the entire operation intelligent and automated (Fundación Valenciaport, 2020).

In conclusion, there is a long way there, but according to an industry expert (IE1) and Triska (2022), the push from Industry 4.0 is being adopted by bigger ports across the world, such as Rotterdam and Hamburg. When the larger ports become more digitalized and automated, it pushes SMP to advance their digitalized operations as well to stay competitive.

5.1.2 Physical infrastructure

As Jia (2023) explain, digital advancements, such as AI and 5G, are majorly dependent on a stable electricity supply. The European energy crisis has shown many countries how fragile the reliance on electricity can be when supply lags demand. This is also explained by a respondent from the case company (CC2), who pointed out the challenges with charging infrastructure for AVs, stating that in countries like the Netherlands, there is a limited electricity capacity that creates challenges, while in France, with more electricity capacity, have better conditions for the charging infrastructure for AVs. The variation of electricity capacity between different countries shows how dependent the success of AV adoption is on the local electricity infrastructure, supporting the finding that other alternative methods of harvesting energy or complementing the existing infrastructure with alternative sources of energy.

Further, another important physical requirement is the choice of operation for the AV. Respondents from the industry, and terminal management (IE2 and TM3) explain that early AV implementation should focus on simple, repetitive tasks to verify the feasibility and make the implementation smoother. The tasks include fixed-point shunting to put the AVs in predictable operations. TM2 explains the importance of starting with straightforward processes as mentioned before. This approach should be taken to build confidence with the implementation and learn more about how the AVs behave in those environments, it also minimizes the complexity of decisions the AVs require them to take in dynamic environments. The implementation of simple, repetitive tasks will also open the possibilities for the terminal to reduce the manual intervention, and gradual learning curve and expansion. This can be compared with Jacobsson and Lantz's (2024) hypothesis test, which showed that automated systems as smart gates, reduce manual labor, such as administrative work, that was previously handled by truck drivers. Although Jacobssons and Lantz's (2024) study focused on the container terminal, the concept of simplifying initial automation spread to the RORO terminal. DFDS, in collaboration with Volvo Autonomous Solutions, created a smart gate using a cloud-based system to manage vehicle entry and routing without human intervention.

The challenge of space limitation in RORO terminals is important to discuss. Respondent CC2 explained the idea of creating a designated area for trailers delivered by external trucks and organizing the trailers in rows instead of a fishbone system. As explained by respondent TM3, the terminal could improve efficiency in trailer location accuracy and vessel loading processes.

This perspective shows the need for systematic space management to overcome infrastructural challenges, in this instance, space limitation.

However, as CC2 explains, the implementation of such a system depends heavily on the space and the available resources, which include enough AVs that can be kept in circulation for continuous operation. Therefore, the feasibility of this approach can be dependent on space availability, the number of AVs, and how they function in these environments.

5.1.3 Technical infrastructure

Comparing RORO terminals with container terminals, there is a major difference. As Yun et al. (2022) mention, in RORO ports, manual-driven vehicles and the inability to stack containers on top of each other lead to technical challenges for automation specific to RORO terminals. According to respondent TM3, 80% of cargo is in semi-trailers, at least in the Gothenburg RORO terminal, but it may vary from port to port. To be able to move trailers with an AV, several technical requirements need to be met. Several respondents such as terminal management and case company (TM1, CC1, CC2, and TM3) bring up challenges such as connecting and disconnecting with the air hose and winding down the landing leg to put the trailer in the correct position. CC1 mentions that today's machines cannot handle this since there are no standardized semi-trailers where the hose and electricity cables are in the same position. If an AV were implemented at the terminal for moving trailers, the AV would only reach SAE level 3 or 4. L3 or L4 AVs would need a human to connect and disconnect the trailers from the AV since the ADS will exit the specific operating conditions where autonomous driving is supposed to function (ISO, 2020).

This would lead to major inefficiency problems. Thus, AV for moving trailers is not a valuable option currently. However, as CC2 mentioned, the trailers are not standardized, and the hose and cable connections are located in different places. If these trailers became standardized across Europe, then the AV providers could more easily solve the problem of connecting and disconnecting the AV to the trailer. This also means that there needs to be a major replacement for trailers, and investing in new ones. For this to be possible, there needs to be an incentive for it, such as a proven AV record across terminals of reducing costs and increasing efficiency, or it is a potentially more sustainable option. This could be done, but it will probably take many years until it is seen as a real alternative.

Due to these technical challenges, Respondent TM3 argues that the movement of cassettes is easier from a technical requirement perspective. The cassettes are generally used for the shunting of containers that are put on the standardized cassettes. Al Hurani (2023) mentions that standardized UL would simplify automation, reduce costs, and optimize material handling. Due to this standardization, the AV can be equipped with the correct tools to be able to move the cassettes without human intervention, thus leading to SAE level 5 of automation, where the AV's ADS is expected to handle the entire DDT (SAE, 2021).
To sum up, the main technical requirements for AVs are standardization. Movement of standardized cargo would mean that the AV providers can create specific tools on the AV necessary to be able to operate in fully automated L5 for certain operations.

In summary, all the requirements brought up will be needed for successful implementation, and as mentioned during pilot testing with a repetitive task, additional requirements will probably be found. The table below summarizes the key requirements

Table 2: Operational requirements

Requirements	Purpose	Category	Description
5G	Real-time data sharing allowing better AV communication	Digital Infrastructure	Connectivity
Location Awareness System	Enables accurate location of cargo across the terminal	Digital Infrastructure	Cargo tracking
V2X Communication	Omni-directional communication between AV and operators, allowing better decision making	Digital Infrastructure	AV/systems/personnel communication
Electricity/Charging	Technologies such as AI, 5G, and AVs are dependent on enough electricity	Physical infrastructure	Energy supply
Repetitive Tasks	For safer implementation, start with simple repetitive tasks before advancing to more complex operations	Physical infrastructure	Simple operations
Space limitation	Optimal is fenced off area for AV operations but	Physical infrastructure	Choose operational area

	depends on the size of the RORO terminal		
AV-capability	For standardized cargoes such as cassettes, AV can reach SAE level 5	Technical Infrastructure	standardized cargo
Need for more standardized cargo	For non-standardized cargo such as trailers can currently only reach SAE level 3 or 4	Technical Infrastructure	non standardized cargo

5.2 How can the implementation of autonomous transportation benefit RORO terminals and what are the main costs?

In this section, the major costs and benefits of AV implementation will be analyzed. A cost and benefits framework will then be presented to make it easier for the readers to understand the costs and benefits of an AV implementation.

5.2.1 Benefits

The potential of Automation and digitalization in RORO terminals is massive. The advancement of Industry 4.0 has led to increased pressure on terminals to advance smart operation systems and automation (Min Hokey, 2022). Park et al. (2022) believes that AVs characteristics of unmanned communication with its surroundings have the potential to solve the increased pressure.

The majority of the respondents believe that the biggest benefit an AV can bring is a reduction of labor costs. If electricity charging is available, the AV can operate 24/7 and won't make errors due to fatigue or tiredness explained by IE1. This would lead to a potential reduction of labor, which is the biggest cost in RORO terminals, as mentioned by industry expert IE. This reduction of labor cost is very positive, as it leads to opportunities to redistribute money to, for example, new investments and pure profit. But as mentioned by respondent CC2, labor laws could prevent direct layoffs of employees. This could, in some way, reduce the benefits of reduced labor costs. However, these workers could be retrained to, for example, move from shunting to loading of vessels, leading to shorter lead times for off and onloading of cargo, leading to better operational efficiency. Another solution is to reduce the number of consultants working in the terminal, thus reducing labor costs and aligning with labor regulations.

Another way AV could benefit the terminal is through the reduction of operational costs. Park et al. (2022), who conducted simulations of a connected automated vehicle system for on/off loading of a vessel, saw a predicted 90 % reduction of operational costs and a 45% reduction of loading time over 15 years. These simulations did not consider infrastructural requirements; thus, the result may only show the potential benefits in a perfect working environment and SAE level 5 fully automated. However, the main operational cost savings from Park et al. (2022) simulations could be related to the importance of V2X communication and location awareness mentioned by respondents CC1 and TM3. If the AV could operate fully, being able to communicate with its surroundings and have a fully integrated location awareness system, the AV could potentially be able to operate more efficiently than the current process, leading to reduced human errors, more accurate placement of trailers, and improved safety. Thus, the simulations conducted by Park et al. (2022) could be similarly done, but with the inclusion of operational requirements such as location awareness and V2X technology to more easily show the benefits of AVs and get a more accurate outcome of reduction of operational costs and improved efficiency.

5.2.2 Costs

As mentioned by the majority of respondents, the biggest cost will be the upfront cost of purchasing the AV. There is no exact number; the cost varies depending on what company you buy the AV from and for what type of operation it should be used. As mentioned by the terminal management TM1 that the AV will be incredibly expensive, and the implementation cost will be quite high because of the vehicle itself and the technology in it

This is a substantial cost, especially since AVs' efficiency becomes clearer, as Park et al. (2022) mention, with more than one AV, due to AVs' potential of working in cooperation.

Other direct costs to take into account are the cost of upgrading digital and physical infrastructure, such as location awareness systems, 5G, changes of lanes, etc. The requirements for AV implementation in RORO terminals brought up in subsection 4.2.1 will be expensive, however, a long-term investment plan can be made to spread out the costs over time.

As Jacobsson and Lantz (2024) mentioned, their implementation of smart gates in the container terminal led to reduced total truck turnaround time and time for handling the administrative process. Further, the digital development advisor (IE2) pushes on the fact that the more digital you make something, the easier it will be to increase efficiency and productivity. Thus, a direction that could be taken in the RORO terminal is to first invest in digital infrastructure, such as a location awareness system and 5 G.

Skold et al. (2021) explain that these upgrades will not only be necessary for implementing the AVs but could also benefit the terminals without an AV. The location awareness system would help increase visibility over the terminal, making sure all trailers and containers are in the correct location, leading to more efficient loading of vessels. Further upgrading the network to 5G would increase real-time data sharing and updates as well as massive machine-type communication, allowing more workers, devices, and machines to interact seamlessly. In conclusion, these upgrades will not only be necessary for an AV implementation but will also lead to a more digitalized and automated terminal that aligns with the smart port evolution of advancing terminals and to become interconnected with the terminal (Fundación Valenciaport, 2020). In the future, this could allow for advanced internal AVs and an interconnected environment, allowing external Autonomous trucks to interact and operate on the terminal and with the systems available.

Framework costs and benefits

This framework will contain the main costs and benefits, providing a clearer view for the readers. Costs for implementing an AV in the RORO terminal will be named cost and number(CX). Quantifiable benefits are named benefit and number (BX), and unquantifiable benefits are named unquantifiable and number (UX).

Table 3: Costs of AV implementation

NON-RECURRING COSTS	
Buying the AV	**C1**
Upgrading the digital infrastructure (V2X system, Location awareness system, 5G, TOS system)	**C2**
Upgrading physical infrastructure (Traffic lights, charging stations, readjustment of lanes)	**C3**
RECURRING COSTS	
Maintenance and repair of AV	**C4**
Staff training/retraining	**C5**
Software updates for AV	**C6**
Insurance for AV	**C7**
Charging cost (Electricity)	**C8**

Table 4: Benefits of AV implementation

QUANTIFIABLE BENEFITS	
Reduction of labor costs	**B1**
Increased operational efficiency and reduced errors(loading/unloading, Movement of Cargo)	**B2**
Reduced Energy consumption (Through optimized driving)	**B3**
Reduction of CO2 emissions (AV driven on electricity)	**B4**
Potential Safety improvements (Safer working environment)	**B5**
UNQUANTIFIABLE BENEFITS	
Improved reputation (Trailblazing technology in RORO terminals)	**U1**
Safety (Safer working environment)	**U2**
Scalability (Reduced load/offload time = More vessels per Week)	**U3**
Potential to push further digitalization and automation in RORO terminals	**U4**

5.3 What are the regulatory and safety considerations related to AV implementation in RORO terminals?

In this last sub-section, regulations and safety will be in focus, analyzing what is needed and why, since implementing an AV will lead to big changes in operations, and safety and regulations need to be understood to be able to operate safely as well as align with current and future regulations.

5.3.1 Safety

There are two main challenges explained in chapter 2.2.3 regarding AVs and the safety aspect, being situational awareness and trust. Araujo (2019) mentions that AVs can operate with high accuracy under normal conditions but face challenges when unpredictable situations occur due to lack of insufficient data on these kinds of situations. This statement is also backed by Feng & Liu (2024). These statements by the researchers also align with the answers from the respondents, TM1 and TM2, where AVs can have challenges adapting to unstructured environments in RORO terminals, which compares with humans who rely on instinct and past experiences to navigate through these situations and environments. While AVs must depend on pre-programmed algorithms and data, making them less flexible in dynamic situations and environments.

This can be connected to the second challenge, which is trust. As explained by David et al. (2020), the trust in AVs can grow if they can operate safely, but one accident, such as the Uber fatality accident explained by Lamas et al. (2020), can shatter that built-up confidence and the trust that has been growing. Therefore, this raises the question of whether humans and AVs can coexist and work together in the same environment, which is also emphasized by respondent TM1, whether they will fence off some of the RORO terminal area or will they be able to coexist with humans. These challenges show that there are difficulties in handling the balance between safety and practicality of the coexistence between humans and AVs, especially in space-limited RORO terminals.

The transition to Industry 5.0 may offer potential solutions that can address these challenges, since Industry 4.0 focused on automation and efficiency, often at the expense of human-centric considerations, whereas Industry 5.0 focuses more on human and machine collaboration (Leng, 2022). The concept of Cobots, which is machines that learn and adapt to human behavior, can be seen as a solution or model for AV implementation in RORO terminals. Instead of replacing humans, and when fenced-off areas are not feasible due to space limitations, AVs could be designed in such a way that humans and machines can complement each other.

However, the current limitations of AVs programming based on data and algorithms, there is a lack of contextual awareness, and the dependency on a perfect digital infrastructure leads to more challenges. Respondent TM2 explains that RORO terminals are dynamic environments where business flows and environments change very often, and human adaptability is still more advanced in those situations, which suggests that AV implementation may need advanced communication systems such as V2X and advancement in AV system programming.

5.3.2 Regulations

Regulations play an important role when implementing AVs in RORO terminals. Research shows the societal tendency to blame AV systems more than human drivers in accidents, even when the responsibility is shared. The "Blame gap" that exists suggests that the design of the liability framework could be more challenging, the liability aspect could be dependent on different scenarios, where different factors may play a role in the liability. A potential source of inspiration can be taken from the maritime industry, even though the liability question is still unsolved where respondent IE4 explains it as "the million-dollar question", there is a potential plan on how to resolve the liability questions, where they have a standardized testing and type-approval process for Automated Navigation Systems (ANS).

In contrast, TM1 states that the terminal operations involve many different stakeholders depending on where one is operating in the terminal, making the liability question even more fragmented. Unlike the maritime industry, where they have test facilities that could standardize ANS approvals, RORO terminal AVs lack that type of clear liability framework. This uncertainty is criticized by Hansson (2020), the outdated regulations designed for human drivers fail to address AV-specific challenges. The current lack of harmonized and legal framework that currently exist with AVs will lead to terminal operators facing confusion about what is permissible legally and what not. Supporting the need for a proactive regulatory adjustment before implementing AVs in RORO terminals.

The global regulatory framework differs from country to country. KPMG (2019) explains how regulatory readiness varies between different countries. The U.S. adopts a market-driven, state-by-state approach, which encourages innovation but creates inconsistencies. Compared to the EU, where a prioritization on harmonized regulations is preferred, which ensures legal stability but potentially slows down adoption and innovations. Sweden, for example, might have advanced policy and technology, but it still struggles with inflexible laws, as Hanssons (2020) explains.

The human factor in the regulatory landscape is still a major barrier to AV adoption. IE2 explains automation as a "disruptive force", which needs careful handling to avoid workforce backlash. The sensitivity of this issue is brought up by IE2, that during a disruption, not everyone is happy, and you need to make sure that you do it right from the beginning. Unions, especially in the U.S., resist automation, which is based on the fear of job losses. This also aligns with Hansson's (2020) argument that the regulations must evolve with technology.
However, CC2 has a potential solution, which is the natural attrition that will occur. This will reduce the issue of forced layoffs while allowing workforce shifts. Although it involves dual costs, it presents an opportunity for retraining and role transitions, which aligns innovation with workforce stability.

Table 5: Regulations

Regulatory Area	Challenges	Recommended Solution	Potential Result of Solution
Liability	Unclear responsibility/Liability when accidents occur with AVs	Design a liability framework differentiating the liability roles of the manufacturer, operators, and software	Clearly who is accountable reduces the disputes and increases the trust of stakeholders
Harmonization	Different regulation depending on country to country	Encourage a more harmonized regional/global AV regulation and standards	Greater scalability and Clearer frameworks
Proactive/Adaptive Regulatory Mechanism	The development of AVs outpaced the outdated regulatory frameworks.	design a more adaptive and flexible regulatory framework for AVs	Promotes innovation while still having

			oversight of technology

5.3.3 Labor replacement

The introduction of autonomous vehicles in RORO terminals presents benefits such as efficiency and innovation, and challenges such as labor market disruptions. Previous research also explains the challenges arising with AVs, focusing on the government's unpreparedness for workplace transformations (Nikitas et al., 2021) and the short-term unemployment risks in industries reliant on repetitive, low transferability positions (Parker et al., 2018). These challenges are especially relevant in RORO terminals, where manual labor is still important for operations (Parker et al., 2018). However, the results from the respondents show a different picture, where automation will not necessarily lead to mass layoffs, but rather a restructuring of roles, depending on workforce adaptability, and terminals taking proactive retraining initiatives.

Nikitas et al. (2021) explain that AV adoption could majorly affect blue-collar workers in repetitive roles, such as vehicle operators, where their skills may not be easily transferable to other sectors. This aligns with the respondents' perspective that certain positions, such as internal drivers, will be impacted. However, as theory explains automation as a threat to employment, the industry experts interviewed argue against that assumption, explaining that automation will primarily lead to a shift in responsibilities instead of major layoffs.

This can be explained by terminal management TM1 and TM2, where workers who are displaced can transition into a higher-value position, such as dispatcher or surveillance operators, using their operational knowledge and expertise in a new way. This reflects the industry 5.0 principle of integrating human creativity with technology (Zhou, 2024), where digital twin technology and hyper connectivity increase human decision making instead of replacing them. The idea of internal restructuring, where workers are repositioned instead of laid off, comes as a counterpoint to the theory of major job losses related to automation. Industry 5.0 provides an important perspective for understanding the respondents' point of view. Digital twin technology, as explained by Zhou (2024), has the possibility of improving the roles of the workers rather than erasing them, which can be compared with the respondent

TM2 suggestion that the workers could be repositioned into other roles, such as system-monitoring.

The push from the terminals for smart operations (Min Hokey, 2022) and the resilience through digitalization support the idea that AV adoption in RORO terminals may not necessarily lead to a reduction of labor demand but instead reposition the roles.

One recurring theme in both the literature and the empirical findings is the importance of retraining. While Parker et al. (2018) and Nikitas et al. (2021) explain the risks of technological unemployment, the respondents explain retraining as a strategy to reduce these risks. Respondent IE1 explains that experienced employees possess valuable operational knowledge that could improve the automated systems. This aligns with Industry 5.0’s focus on human and machine collaboration, where workers evolve with the technology instead of being sidelined by it (Zhou, 2024). The success of this transition is, however, dependent on the worker's willingness to adapt. As IE1 explains, resistance is a major barrier, especially among workers who fear job insecurity.

To sum up this chapter, the implementation of AVs in RORO terminals faces challenges such as regulatory, safety, and labor issues. The safety aspects revolve around situational awareness, trust, and human and machine coexistence, which requires advanced systems such as V2X and adaptable programming. Regulatory frameworks are still inconsistent globally, with liability challenges and workforce resistance leading to innovation barriers. However, Industry 5.0 offers a solution through human-machine collaboration, retraining, and role restructuring, shifting roles instead of eliminating them. And lastly, proactive regulatory adjustment and workforce adaptation are important for successful AV implementation.

6 Discussion

The purpose of this thesis is to understand what the operational requirements for autonomous transportation technologies are, the balance of costs and benefits, and what safety and regulatory considerations that will be needed in RORO terminals, thus providing further insight into the possibilities and challenges of creating a more automated and digitalized RORO terminal through AV implementation. This chapter will provide the readers with the key findings and information regarding the research process, such as limitations with the research design and what potential consequences this could have. Further, this section will be summarized along with both practical and research implications, showcasing the importance of this thesis. Lastly, future research, which the authors believe will be both necessary and interesting for further advancement of AVs, will be presented

6.1 Summary of key findings

The main question asked in this thesis is "How does autonomous transportation impact RORO-terminal operations, and how can this be addressed to enable a fully automated end-to-end process?". The result and analysis indicate that in RORO terminals, there is higher complexity when looking into AV implementation compared to container terminals. However, it is possible and can bring benefits, leading to more efficient operations. Three main aspects need to be understood before implementation. First, operational requirements include all the requirements so that the AV can operate efficiently and safely. Second, all the costs and potential benefits need to be analyzed to be able to see the long-term feasibility of an AV implementation. Lastly, safety and regulatory considerations need to be addressed. This includes everything from how to prevent accidents, labor safety, training of personnel, and new legislation, etc. These topics have been comprehensively addressed throughout this thesis and could provide a foundation for future implementation of AV in RORO terminals, which could lead to a fully automated end-to-end process.

6.2 Interpreting the results

The result from this thesis shows that there is a clear pattern between digital infrastructure and how feasible AVs are in RORO terminals. Technologies such as real-time tracking and 5G connectivity were something that was explained as a necessity for the digital infrastructure. Beyond the digital infrastructure, there are physical and operational challenges, such as reversing the trailers and handling the different types of cargoes, which can be seen as a technical obstacle that the current AVs are not able to handle.

For these challenges to be met, there has to be more focus on the RORO terminal from a tech provider point of view. The results show that there is limited attention from tech providers due to less standardization compared to container terminals, but also due to the market size. This leads to drawbacks in the RORO industry, holding back innovation in that area.
The thesis also found benefits of automation, one of which stood out was how location awareness not only improves AV navigation/location, but also cargo planning and vessel loading, which adds more value than was initially assumed.

The initial expectation of the thesis was that automation, or specifically AVs, could be feasible across most of the RORO terminal operations. However, the results show that full automation or using AVs across the operations is not currently feasible due to the existing challenges. However, certain areas or processes show potential for automation, such as the internal movement of the cassettes. Although full automation may not be achievable today, it is still a possibility for the future, especially if the infrastructure and challenges with AV technology continue to evolve.

6.3 Practical implications

The results from this thesis have great value for RORO terminals and other stakeholders working in that area and with AV technologies. One key aspect to consider is that implementing AVs in those dynamic environments is not just about introducing new vehicles, but requires much research and investment based on how the terminal is designed, managed, and its digital maturity. This thesis shows the operational requirements that have to be met when implementing AVs in RORO terminals, such as reliable digital infrastructure, real-time location tracking, and how complex the non-standardized cargoes are. Thus, this thesis can support terminal operators, technology providers, and regulators who are exploring the possibilities of AV technology in RORO terminals. For example, for RORO terminals, this thesis provides an understanding of the operational and digital infrastructure requirements that potentially need to be implemented for AVs to function efficiently and safely. The understandings which are based on the empirical findings from the interviews, combined with the existing theories, can support the evaluation what their current capabilities are, identify important challenges, and prioritize important infrastructural investments such as digital infrastructure. Regarding technology providers and AV manufacturers, this thesis supports them with specific current challenges, such as reversing, cargo handling, and the dynamic terminal environment that can potentially impact the design and the system of the AV. Regulators might also find value in this thesis based on the discussion around safety, labor replacement, and the need for updated regulations that can keep up with the advancement of AVs and general technology. To summarize it, this thesis can act as a benchmark and support those who are looking for a better understanding of how the implementation of AVs in dynamic environments might look like.

6.4 Research implications and contributions

As mentioned in the previous chapters, there is a gap in the research regarding AVs in the RORO terminal environment. The academic focus has been on container terminals, which are more standardized than RORO terminals. Even though there are many challenges in RORO terminals, this thesis aims to fill the existing gap in the research by focusing on how AVs can be implemented and utilized in RORO terminals. The challenge with implementing AVs in RORO terminals is based on the dynamic environment RORO terminals have, they are usually less standardized and digitalized. Based on that, there are not many theories that can support or fit automation in RORO terminals. But by investigating what is required, both from a technical and an operational point of view, this thesis helps to widen the understanding of an area that has not been deeply studied and also provides new understandings that could help future research and development in the area.

The findings of this thesis can also be connected to widely known ideas deriving from research on smart ports and Industry 4.0 (Triska, 2022). Such as the importance of digital infrastructure, but add more depth to the research by adding the human factors, for example, how people react to automation, job displacement, and the need for updated regulations. These aspects can sometimes be overlooked, and by combining interviews and theory, this thesis aims to provide something new and interesting to the knowledge on automation in logistics, potentially promoting more research focused on making automation work in those dynamic environments that have not been studied yet.

6.5 Limitations

The two main limitations acknowledged during the research process are the small number of interviews for the thematic analysis and a lack of quantitative data for conducting a cost-benefit analysis.

The data collected for the thematic analysis consisted of a total of nine interviews. This is a relatively small number, where many interviewees reside in Sweden. The generalizability of the result could thus be limited. The reason for the small number of interviews was the time constraint that made it difficult to conduct more interviews within the set deadline. However, to combat the potential biases and lack of diverse answers due to the number of interviews, the interviewees were selected from several different sectors, such as PhD researchers, terminal management, case company employees, and consultants. This diverse set of people from different sectors with different knowledge and experience was chosen to get a broad set of perspectives to understand the full picture of AVs, RORO terminals, and current challenges. This diversity of perspectives helped answer the research questions efficiently.

Lastly, as mentioned by several respondents, it will be important to conduct a cost-benefit analysis. The CBA will provide objective data comparing the costs and benefits gained by implementing an AV. In RORO terminals, this will be extremely important since the benefits of an investment need to outweigh the costs over a certain period. A CBA was not utilized in this thesis due to a lack of usable data as well as time constraints. However, in subsection 5.1, some of the more important costs and benefits gathered through the interview, as well as previous research, were showcased in a framework to highlight the potential impact of an AV.

6.6 Future research

The main insight from this thesis consists of several elements relevant for an AV implementation in a RORO terminal, aimed at increasing the current research on RORO terminals, which is currently lacking. There is still a lot of interesting and important research that can be done on the subject. Firstly, a thorough cost-benefit analysis should be performed to be able to gain valuable knowledge if the benefits outweigh the cost and whether an investment in an AV for RORO terminal operations is worth it or not. A recommendation from the authors is to benchmark AV implementations in container terminals, such as in Rotterdam, which already have AVs. The knowledge gained at the Container terminal could then be used for the CBA in the RORO terminal.

Furthermore, the authors believe it would be very interesting to see a pilot test of AVs in RORO terminals. As mentioned by several respondents, simple automated repetitive tasks should be tried first to be able to identify challenges. Thus, we believe a progressive pilot test first conducting very simple tasks, such as moving from point A to B without any cargo to just see if the AV can handle the instructions and then continue with more complex tasks. This would potentially lead to new operational requirements and safety concerns being found, since with a machine, some things that seem very simple for a human can be very difficult for an AV. Thus, new requirements needed can be noticed once it is operating in real life, such as whether the AV can reach SAE level 5 or not.

Lastly, future research including aspects from the rapid technological advancement of industry 4.0, the simulations of a CAV system for loading in RORO terminals conducted by Park et al. (2023) were well conducted and brought new insight into the effect of connected autonomous vehicles in RORO terminals. It would be interesting to see similar simulations being done, including operational requirements and safety considerations, to be able to get more accurate results. This research would allow for a more thorough analysis of the expected outcome before investing in an AV. Similarly, with the rapid advancement of AI in recent years, it would be interesting to see how the evolution of AI could lead to more advanced AVs and if they will be able to handle complex situations with the help of AI technology.

7 Conclusion

The purpose of this thesis was to understand and investigate how autonomous transportation impacts RORO-terminal operations, and how this can be addressed to enable a fully automated end-to-end process. As technology continues to develop and evolve, this thesis aims to minimize the research gap that currently exists in that area by focusing on the less automated and standardized RORO terminal environment.

To be able to answer the research questions, the results were analyzed through the lens of the theoretical background. By connecting the perspectives of the respondents with the different concepts mentioned in the theoretical background, the analysis provided a deeper understanding of how feasible the implementation of AVs in RORO terminals is and what potential challenges exist. Based on the result and analysis, the research questions could then be answered,

First, *what are the operational requirements for autonomous transportation technology in RORO terminals?* Several operational requirements were found necessary for successful AV implementation. Understanding what type of digital infrastructure needs to be upgraded or implemented will be crucial. The most important upgrades needed are the location awareness system to accurately identify the location of cargo. 5G is needed for real-time data updates, which is important for instruction of AV operations, and in unstandardized RORO terminals, this can change rapidly. V2X communication system, both for the AV and terminal operators, needs to work fluently. Fluent communication between AV and workers will lead to a safer working environment and more efficient operations. Thus, it is important to understand how system-to-system communication should be handled to get to an interconnected system where internal and external actors could communicate both with the AV and workers. The physical infrastructure, compared to digital infrastructure, is more terminal-specific and not as generalizable since RORO terminals have different layouts. What needs to be decided is whether to have a fenced-off area or not, as well as choosing a repetitive task, such as the movement of cargo from point A to B, at least for the initial implementation. Specific technical requirements will be dependent on what task the AV performs. The findings conclude that the movement of cassettes is a good starting point, and future improvements of AVs' capabilities could allow for the movement of trailers, which would be more profitable.

The second research question addresses: How *can the implementation of autonomous transportation benefit RORO terminals, and what are the main costs?* The biggest cost will be the upfront cost of buying the AV, as well as infrastructural upgrades derived from the operational requirements. On the benefit side, the main benefits are reduced labor costs since the AV can operate 24/7. Due to the reduction of human errors, the accuracy of cargo location could be improved, which is currently a big challenge in RORO terminals, as well as improved safety if the AV operates correctly. Since no cost-benefit analysis was included in this thesis, this needs to be performed to evaluate the investment. The framework in sub-section 5.2 could be utilized to see what costs and benefits should be included in the CBA.

The last research question is "*What are the regulatory and safety considerations related to AV implementation in RORO terminals?*" The regulations need to be updated to keep pace with the evolving AV technology. Currently, there exists a "blame gap", and based on the previous theories regarding AV regulations, the majority focuses on a human driver. There needs to be an updated version focusing on AVs and the accountability of different parties, such as the operator and manufacturer, for example.

Concluding this thesis, enabling autonomous transportation can lead to great things. Currently, many RORO terminals are probably not prepared for AV implementation due to the lack of solid research and understanding of requirements, costs, and regulations. Thus, this thesis has aimed to reduce this research gap and build further knowledge that could lead to future implementation of AVs across RORO terminals, and if you look through a long-term perspective, AVs could bring many advantages to the terminal, such as improved operational efficiency, safety, and sustainability. The advancements of digitalization and automation could also lead to a more interconnected environment, including terminal operators, suppliers, customers, 3PL, etc., leading to more streamlined and efficient supply chains. And to mention a quote from this study, "The more digital you make something, the easier it will be to increase efficiency and productivity".

Reference list

Ajenaghughrure, I. B., da Costa Sousa, S. C., & Lamas, D. (2020). Risk and Trust in artificial intelligence technologies: A case study of Autonomous Vehicles. *2020 13th International Conference on Human System Interaction (HSI)*, *2020*, 118–123. https://doi.org/10.1109/HSI49210.2020.9142686

Automotif. (n.d.). Driving innovation through automation for an integrated and seamless multimodal transport. https://automotif-project.eu/

Autor, D. H. (2015). Why Are There Still So Many Jobs? The History and Future of Workplace Automation. The Journal of Economic Perspectives, 29(3), 3–30.

AWARD. (2020). All Weather Autonomous Real Logistics Operations and Demonstrations. https://award-h2020.eu/

BCG. (2022). Mapping future of autonomous trucking: https://www.bcg.com/publications/2022/mapping-the-future-of-autonomous-trucks

Bell, E., Bryman, A., Harley, A., & Harley, Bill. (2019). Business research methods (Fifth edition). Oxford University Press.

Bryman, A., & Bell, E. (2011). Business research methods (3. ed.). Oxford University Press.

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology*, *3*(2), 77–101. https://doi.org/10.1191/1478088706qp063oa

Cleland, J. A. (2017). The qualitative orientation in medical education research. *Korean Journal of Medical Education*, *29*(2), 61–71. https://doi.org/10.3946/kjme.2017.53

Collis, J., & Hussey, R. (2014). *Business research a practical guide for undergraduate & postgraduate students* (Fourth edition.). Palgrave Macmillan.

Skold, J., Parkvall, S., & Dahlman, E. (2021). *5G NR - The Next Generation Wireless Access Technology (2nd Edition)* (2nd ed.). Elsevier. https://doi.org/10.1016/C20170013472

Engholm, A., Kristoffersson, I., & Pernestal, A. (2021). Impacts of large-scale driverless truck adoption on the freight transport system. *Transportation Research Part A: Policy and Practice,153*,161–175. https://www.sciencedirect.com/science/article/pii/S0965856421002627

Engholm, A., Pernestål, A., & Kristoffersson, I. (2020). Cost analysis of driverless truck operations. *Transportation Research Record,* *2674*(8), 165–174. https://journals.sagepub.com/doi/10.1177/0361198120930228

European Environment Agency. (2024). Greenhouse gas emissions from transport. European Environment Agency. https://www.eea.europa.eu/en/analysis/indicators/greenhouse-gas-emissions-from-transport

Fagnant, D. J., & Kockelman, K. (2015). Preparing a nation for autonomous vehicles: opportunities, barriers and policy recommendations. Transportation Research Part a Policy and Practice, 77, 167–181. https://doi.org/10.1016/j.tra.2015.04.003

Flowerdew, R., Martin, D. M., Flowerdew, R., & Martin, D. (1997). Methods in Human Geography: A guide for students doing a research project (2nd ed., pp. xxiii–xxiii). Routledge. https://doi.org/10.4324/9781315837277

Fundación Valenciaport. (2020). *Smart ports manual: Strategy and roadmap.* Inter-American Development Bank. https://publications.iadb.org/en/publications/english/viewer/Smart-Ports-Manual-Strategy-and-Roadmap.pdf

Garcia, M. H. C., Molina-Galan, A., Boban, M., Gozalvez, J., Coll-Perales, B., Sahin, T., & Kousaridas, A. (2021). A Tutorial on 5G NR V2X Communications. *IEEE Communications Surveys and Tutorials*, *23*(3), 1972–2026. https://doi.org/10.1109/COMST.2021.3057017

Halldórsson, Á., & Aastrup, J. (2003). Quality criteria for qualitative inquiries in logistics. European Journal of Operational Research, 144(2), 321–332. https://doi.org/10.1016/S0377-2217(02)00397-1

Parker, J., Arrowsmith, J., Halteh, J., Zorn, T. E., & Bentley, T. (2018). The impact of technology on employment: a research agenda for New Zealand and beyond. *Labour & Industry (Brisbane, Qld.)*, *28*(3), 203–216. https://doi.org/10.1080/10301763.2018.1519774

Haraldson, S., Lind, M., Karlsson, M., Bach, A., Woxenius, J., & Gonzalez-Aregall, M. (2019). Digitalisation and automation in small and medium-sized Swedish ports (SMPs). Lighthouse. https://lighthouse.nu/images/pdf/FS9_2019-Digitalisation-and-automation-in-small-and-medium-sized-Swedish-ports.pdf

Hansson, L. (2020). Regulatory governance in emerging technologies: The case of autonomous vehicles in Sweden and Norway. Technological Forecasting and Social Change, 160, 120238. https://www.sciencedirect.com/science/article/pii/S0739885920301657

International Organization for Standardization (ISO). (2020). *ISO/TR 4804: Road vehicles — Safety and cybersecurity for automated driving systems — Design, verification and validation.* ISO. https://www.iso.org/obp/ui/en/#iso:std:iso:tr:4804:ed-1:v1:en:term:3.14

Jia, S., Guo, N., & Liu, Y. (2023). Electricity shortage and corporate digital transformation: Evidence from China's listed firms. *Finance Research Letters*, *57*, 104260. https://doi.org/10.1016/j.frl.2023.104260

Keshav, Bimbraw, (N.D.). Autonomous cars: Past, present and future a review of the developments in the last century, the present scenario and the expected future of autonomous vehicle technology. https://ieeexplore.ieee.org/document/7350466.

Kopelias, P., Demiridi, E., Vogiatzis, K., Skabardonis, A., & Zafiropoulou, V. (2020). Connected & autonomous vehicles – Environmental impacts – A review. Science of The Total Environment, 712, 135237. https://doi.org/10.1016/j.scitotenv.2019.135237

KPMG. (2019). 2019 autonomous vehicles readiness index: Assessing countries' preparedness for autonomous vehicles. KPMG International.

https://assets.kpmg.com/content/dam/kpmg/xx/pdf/2019/02/2019-autonomous-vehicles-readiness-index.pdf

Lantz, B., & Jacobsson, S. (2024). Evaluation of the implementation of automated gate services in a seaport freight terminal. *World Review of Intermodal Transportation Research*, *12*(1), 25–43. https://doi.org/10.1504/WRITR.2024.10065894

Lasi, H., Kemper, H.-G., Fettke, P., Feld, T., & Hoffmann, M. (2014). Industry 4.0. Business & Information Systems Engineering, 6(4), 239–242. https://doi.org/10.1007/s12599-014-0334-4

Leng, J., Sha, W., Wang, B., Zheng, P., Zhuang, C., Liu, Q., Wuest, T., Mourtzis, D., & Wang, L. (2022). Industry 5.0: Prospect and retrospect. Journal of Manufacturing Systems, 64, 169–188. https://www.sciencedirect.com/science/article/pii/S0278612522001662

Liu, H. X., & Feng, S. (2024). Curse of rarity for autonomous vehicles. *Nature Communications*, *15*(1), 4808–5. https://doi.org/10.1038/s41467-024-49194-0

McKinsey & Company. (2024). Will autonomy usher in the future of truck freight transportation? McKinsey & Company: https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/will-autonomy-usher-in-the-future-of-truck-freight-transportation

Morales-Fusco, P., Saurí, S., & Spuch, B. (2010). Quality indicators and capacity calculation for RoRo terminals. *Transportation Planning and Technology*, *33*(8), 695–717. https://doi.org/10.1080/03081060.2010.527179

Naeem, A. B., Soomro, A. M., Saim, H. M., & Malik, H. (2024). Smart road management system for prioritized autonomous vehicles under vehicle-to-everything (V2X) communication. *Multimedia Tools and Applications*, *83*(14), 41637–41654. https://doi.org/10.1007/s11042-023-16950-1

Nikitas, A., Vitel, A.-E., & Cotet, C. (2021). Autonomous vehicles and employment: An urban futures revolution or catastrophe? *Cities*, *114*, 103203. https://doi.org/10.1016/j.cities.2021.103203

Nortal. (2024). Smart ports: What about RoRo terminal digitalization? https://nortal.com/insights/smart-ports-what-about-roro-terminal-digitalization/

Park, S., Yun, S., & Kim, S. (2023). Autonomous Vehicle-Loading System Simulation and Cost Model Analysis of Roll-On, Roll-Off Port Operations. *Journal of Marine Science and Engineering*, *11*(8), 1507. https://doi.org/10.3390/jmse11081507

SAE International. (2021). *J3016_202104: Taxonomy and definitions for terms related to driving automation systems for on-road motor vehicles.* SAE International. https://www.sae.org/standards/content/j3016_202104/

Slowik, P., & Sharpe, B. (2018). Automation in the long haul: Challenges and opportunities of autonomous heavy-duty trucking in the United States. International Council on Clean Transportation (ICCT). https://theicct.org/wp-content/uploads/2021/06/Automation_long-haul_WorkingPaper-06_20180328.pdf

Sun, H., Chen, Y., & Zhang, Y. (2025). Who is to blame for AV crashes? Public perceptions of blame attribution using text mining based on social media. *Computers in Human Behavior*, *168*, 108627. https://doi.org/10.1016/j.chb.2025.108627

Triska, Y., Frazzon, E. M., Silva, V. M. D., & Heilig, L. (2024). Smart port terminals: conceptual framework, maturity modeling and research agenda. Maritime Policy and Management, 51(2), 259–282. https://doi.org/10.1080/03088839.2022.2116752

Volvo Autonomous Solutions. (2022). More than autonomous trucks: Building the ecosystem for autonomous transport solutions in ports and logistics centers. Volvo Autonomous Solutions. https://www.volvoautonomoussolutions.com/en-en/news/press-releases/2022/feb/more-than-autonomous-trucks-building-the-ecosystem-for-autonomous-transport-solutions-in-ports-and-logistics-centers.html

Wang, J., Shao, Y., Ge, Y., & Yu, R. (2019). A survey of vehicle to everything (V2X) testing. *Sensors (Basel, Switzerland)*, *19*(2), 334. https://doi.org/10.3390/s19020334

Waymo. (2024). From surface streets to freeways, safely expanding our rider-only testing. https://waymo.com/blog/2024/01/from-surface-streets-to-freeways-safely-expanding-our-rider-only-testing

Woxenius, J., Raza, Z., & Christodoulou, A. (2019). The Integration of RoRo Shipping in Sustainable Intermodal Transport Chains: The Case of a North European RoRo Service. *Sustainability*, *11*(8), 2422. https://doi.org/10.3390/su11082422

Xu, Y., Bao, R., Zhang, L., Wang, J., & Wang, S. (2025). Embodied intelligence in RO/RO logistic terminal: autonomous intelligent transportation robot architecture. *Science China. Information Sciences*, *68*(5). https://doi.org/10.1007/s11432-024-4395-7

Yeong, D. J., Velasco-Hernandez, G., Barry, J., & Walsh, J. (2021). Sensor and sensor fusion technology in autonomous vehicles: A review. Sensors (Basel, Switzerland), 21(6), 1–37. https://doi.org/10.3390/s21062140

Zemignani, F. (2023). The Slow Revolution of Autonomous Vehicles: The Fragile Art of Coexistence. *European Business Law Review*, *34*(Issue 1), 145–156. https://doi.org/10.54648/EULR2023012

Zhou, F., Yu, K., Xie, W., Lyu, J., Zheng, Z., & Zhou, S. (2024). Digital Twin-Enabled Smart Maritime Logistics Management in the Context of Industry 5.0. *IEEE Access*, *12*, 10920–10931. https://doi.org/10.1109/ACCESS.2024.3354838

Appendix A

1 interview guide industry experts

Interview questions

- Since you know, we will write this thesis about the impact of AVs on RORO terminals. Before we start, could you please describe your background and experience, and current occupation?

Operational requirements/technological advancement

Broader perspective

- In many places of the world, RORO terminals are often under-digitalized and automated. What do you think are the key factors halting RORO terminals' adoption of digitalization and automation?
- Do you believe that the technological push from industry 4.0 and 5.0 could push roro terminals automation. And what technology do you think will have the most impact?

Av and technical questions

- If autonomous vehicles were introduced at the terminal, what operational requirements or digital infrastructural upgrades do you believe will be necessary and why? Such as smart gates, 5 G, or system-to-system communication.
- How important is the collaboration between different stakeholders in determining the success rate of implementing autonomous vehicles, and what could be the biggest
- Are there any challenges often overlooked when looking into autonomous vehicles or automation in general in terminals?

- **Safety concerns**
- What safety concerns should be addressed when introducing AVs?

Cost/benefits

- What do you think the biggest benefits of introducing an autonomous vehicle could bring to the terminal
- If we look at a broader perspective, do you think the introduction of autonomous vehicles and the required digital and physical upgrades lead to additional operational benefits, such as automating other processes or less manual work?

2 interview guides for terminal management and the case company

Current State & Challenges of Digitalization

- In many places of the world, RORO terminals are often under-digitalized and automated. What do you think are the key factors halting RORO terminals' adoption of digitalization and automation?
- How is technology currently integrated into terminal operations?

Potential use cases and operational requirements

- If we look at Gothenburg RORO terminal, could you describe a process where autonomous vehicles has the potential to be used for?
- What will be the main operational requirements before implementation?
- What types of infrastructural upgrades would be needed such as 5g, better systems etc

AV interaction with existing workflow & safety concerns

- How would an AV interact with existing work operations? And do you see any risk here with AV and humans working in the same space.
- What safety concerns should be addressed when introducing AVs?

Financial considerations & benefits

- What will be the biggest costs with implementing an AV?
- Who should finance the infrastructural upgrades & the maintenance of the AV? Would it be a collaborative investment?
- What potential benefit do you see the AV bring to the terminal?

Workforce impact

- "How do you think AV implementation would affect the workforce? Would existing employees need to be retrained or let go, and if so, in what areas?"
- "How would you measure the success of AVs in the terminal? What KPIs (Key Performance Indicators) would be most important?"

Appendix B

Equipment & Technology supporting AVs

Equipment/Technology type	Description of equipment	How to apply
ULD (Unit Load Device)	Unit Load (UL) is a type of unit that all firms use to handle and transfer their products, but the (UL) comes in different types based on the industry, there are for example, containers, cassettes and pallets. However, (UL) has issues consisting of lacking standardization that creates inefficiencies in automated systems-	As the logistics industry moves from manual to machine-drive, the lack of standardization in UL designs complicates operations. A standardized UL would simplify automation, reduce costs, and optimize the material handling process.
Radar	Radar sensors use electromagnetic waves in the area and receive the reflecting wave from the objects and uses the doppler property to determine distance and velocity of the object. Radars used to detect objects are superior when it comes to operating in various weather conditions and low lighting.	Radar can assist AVs with operating in RORO terminals dynamic environment, supporting AVs with detection of objects and tracking with Radars 360 range of detection.
Lidar	Uses similar technology as Radar but instead of using electromagnet waves, Lidar	Certain technologies from Lidars can be used in AV systems, for example the

	uses laser to scan the environment and creates a detailed 3D digital map of the environment, Lidar is beneficial to use in structured environments.	technology of creating a detailed 3D digital map of the environment, which can be beneficial for AVs to operate in the dynamic environment of RORO terminals.