AWARD
Scaling autonomous logistics

D9.7
Roadmap towards connected and automated heavy-duty vehicles for logistics operations

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List of acronyms

ADAS	Advanced Driver-Assistance Systems
AV	Autonomous Vehicle
CAHDVs	Connected and Automated Heavy-Duty Vehicles
CCAM	Cooperative, Connected and Automated Mobility
C-ITS	Cooperative Intelligent Transport Systems

DG Grow	Directorate-General for Growth
DG Move	Directorate-General for Mobility and Transport
EC	European Commission
EU	European Union
HDV	Heavy-Duty Vehicles
IRA	Infrastructure Investment and Jobs Act
ODD	Operational Design Domain
OEMs	Original Equipment Manufacturers
UNECE	United Nations Economic Commission for Europe
VRU	Vulnerable Road User

Glossary

Vision Canvas	A Vision Canvas is a collaborative tool used to define and capture an organization's future aspirations. It acts as a visual framework for brainstorming and outlining a desired future state, typically within a 2-5 years timeframe. The canvas typically includes sections for the Vision Statement, Bold Steps, Supporting Factors, Challenges, and Opportunities. By bringing these elements together on a single canvas, stakeholders can gain a shared understanding of the organization's goals and how to achieve them.

Executive Summary

This roadmap presents a comprehensive strategy for integrating connected and automated heavy-duty vehicles (CAHDVs) into the European Union's logistics sector. The vision, as outlined in Chapter 3, is a future where CAHDVs transform every facet of logistics, from warehouse automation to long-haul trucking on highways. Widespread adoption has the potential to significantly enhance efficiency, improve safety, and promote sustainability within the European logistics landscape.

In this deliverable, we explore various CAHDV applications across different logistics environments:

- **Ports:** Automated yard trucks can streamline operations within ports and terminals, expediting container handling and intermodal freight transfer.
- **Airports:** Automated baggage transport systems within airports can improve efficiency and reduce congestion in passenger terminals.
- **Hub-to-hub transportation:** Autonomous trucks can handle transportation improving efficiency and safety on high-volume routes.
- **Urban logistics:** Warehouses can leverage automated forklifts for optimized storage and retrieval.

Figure 1: Four Use Cases of AWARD

Embracing CAHDVs presents a multi-faceted opportunity for the EU. Widespread adoption promises to boost competitiveness through a more efficient and streamlined logistics sector, enhance safety with connected advanced driving systems, and promote sustainability through optimized routes and potential integration with electric vehicles.

To unlock the full potential of CAHDVs, this roadmap highlights key recommendations to facilitate their successful adoption, including:

- Scaling up with mass-scale pilots
- Establishing clear and harmonized EU-wide regulations for CAHDVs.
- Implementing a comprehensive communication strategy to raise public awareness and acceptance of AV technology.
- Developing dynamic and comprehensive CCAM standards.
- Investing in infrastructure development, such as digital infrastructure, smart traffic systems, and integrated charging stations, to support CAHDV deployment.
- Fostering collaboration among stakeholders, including industry, academia, and government, to accelerate innovation and knowledge sharing.

By prioritizing these recommendations, the EU can position itself as a global frontrunner in CAHDV development. Its leadership will unlock a future of economic growth, environmental improvements, and societal benefits for the European logistics sector. This roadmap serves as a comprehensive guide, equipping stakeholders with the knowledge and direction necessary to navigate the exciting journey towards a future powered by CAHDVs in European logistics.

1. Introduction

1.1. Aim of the project

AWARD aims at developing and enabling to deploy a safe autonomous transportation system in a wide range of real-life use cases in a variety of different scenarios. This encompasses the development of an autonomous driving system (ADS) capable of handling adverse weather conditions such as heavy rain, snowfall, fog. The ADS solution will be based on multiple sensor modalities to address 24/7 availability. The ADS will then be integrated into multiple vehicle types used at low speed, mostly in confined areas.

Finally, these vehicles are demonstrated in a variety of real-life use cases to validate their value in the application and identify any limitations. Logistics operations will be optimized thanks to a new fleet management system that will act as a control tower, gathering all information from subsystems (vehicles, road sensors, etc.) to coordinate the operations and protect vulnerable road users. This work should then enable commercial exploitation of the technology and policy recommendations for certifications processes.

1.2. Purpose and scope of the task

All project partners are a part of T9.4: Exploitation Roadmap of AWARD Project Results and IPR, which is led by ENIDE and runs from Month 1 to Month 36. There are two key parts to it:

- Exploitation Strategy: This duty entails developing and maintaining an exploitation strategy and plan that guarantees the answers to the project's problems will be viable in the long run. To efficiently use AWARD outputs and outcomes, innovation management is the main area of concentration.
- Exploitation Plans and Roadmap: This section creates recommendations for utilizing AWARD results, addressing topics such as locating exploitable outcomes, possible user groups, authorities, or investors, required steps, and intellectual property rights protection. Additionally, it keeps track of the project's IPR compliance.

As part of T9.4, we have developed this to facilitate the transition from the project's innovative solutions to widespread adoption in logistics operations. By outlining how to utilize AWARD's outputs, this roadmap directly contributes to the project's overall aim of commercialization. This exploitation strategy ensures AWARD project's advancements have a lasting impact within the logistics sector.

This deliverable also seeks to compile research from WP2 through WP8. In addition to making suggestions for additional study outside the purview of AWARD, this document will be directed at stakeholders and the mobility industry in Europe.

1.3. Aim of the deliverable

This roadmap for connected and automated heavy-duty vehicles (CAHDVs) in logistics operations constitutes a thorough framework to navigate the forthcoming transformation of the European logistics sector. It delineates a vision for widespread implementation of this

technology, investigates promising use cases, and presents recommendations to foster the widespread adoption of CAHDV technology.

According to the Grant Agreement: “the roadmap will recommend a viable timeline for an effective and timely implementation of the AWARD solutions, matching the consortium commitment to their widest diffusion with the previously identified stakeholder’s interests”.

In addition to the vision outlined in the Grant Agreement, this roadmap serves a multi-pronged approach. It identifies key challenges that need to be addressed for widespread CAHDV adoption. By outlining potential solutions and implementation strategies, the roadmap aims to bridge the gap between technological advancements and real-world implementation.

Furthermore, this deliverable leverages insights gleaned from discussions with a wide range of stakeholders across the CAHDV industry. By consolidating these diverse perspectives into a common vision, the roadmap aspires to unify stakeholders around a shared direction, fostering more collaborative efforts among industry players and policymakers. This collaborative approach will be instrumental in establishing best practices, developing safety standards, and ensuring a smooth transition towards a future powered by CAHDVs.

1.4. Intended audience

This is a public report, which means that in addition to internal use by consortium partners (as explained above in the context of this task and other work packages), external stakeholders can utilize the analysis presented in this report. This roadmap is therefore intended for a broad audience with a vested interest in the future of the European logistics sector. This includes:

Industry Stakeholders: This roadmap serves as a valuable resource for both internal consortium partners and external private companies. Consortium partners can leverage the roadmap's insights to further commercialize and exploit AWARD's research and development efforts for CAHDV technology. For private companies, including logistics providers, technology developers, and infrastructure operators, the roadmap offers valuable guidance for implementing CAHDVs and navigating the technological and operational hurdles towards successful integration. This roadmap equips them to make informed investment decisions and capitalize on the efficiency and productivity gains associated with CAHDV adoption.

Policymakers: This roadmap equips policymakers with the knowledge and insights necessary to develop effective regulatory frameworks that promote CAHDV adoption while prioritizing safety and efficiency. It informs policy decisions that can create a favorable environment for innovation and investment in CAHDV technology, ultimately benefiting European competitiveness in the global logistics landscape.

Researchers and Academics: This roadmap offers a comprehensive overview of the current state and future potential of CAHDVs, serving as a springboard for further research and development efforts in this critical domain. The roadmap's insights can inform grant proposals, research agendas, and academic discourse, fostering advancements in this rapidly evolving field.

Members of the General Public who are working on Mobility and Logistics: This roadmap provides a clear and concise overview of CAHDVs and their potential impact on the European

logistics sector. It empowers them to participate in public discussions and advocate for policies that promote sustainable and efficient transportation solutions.

1.5. Structure of the document

This introductory chapter sets the stage by providing an overview of the project's aim, scope, and purpose. It elucidates the specific objectives of this deliverable within the larger project framework.

Chapter 2 establishes the current state of the art for CAHDVs in logistics across various use cases, providing context for the future potential of this technology. Building on this foundation, Chapter 3 paints a long-term vision for the year 2040, defining the desired future state for CAHDV integration and outlining key steps to guide its achievement.

Chapter 4 delves into the practical applications of CAVs within the logistics sector. It categorizes these applications into short-term, mid-term, and long-term horizons, showcasing a phased approach to adoption that allows for a smooth transition.

Chapter 5 draws upon the insights from previous chapters to present a consolidated view. It provides specific recommendations for the EU to facilitate and accelerate the adoption of CAHDVs in logistics operations. These recommendations aim to unlock the potential for a more competitive and sustainable European logistics sector.

The concluding Chapter 6 emphasizes the roadmap's central message: the significant benefits that CAHDVs integration can bring to EU logistics. This chapter offers a glimpse into the future, highlighting the transformative potential of CAVs and the roadmap's role in paving the way for a more competitive and sustainable EU logistics landscape.

2. Connected and automated heavy-duty vehicles for logistics operations: state of the art

The aim of this chapter is to provide the reader with a general view of the current situation in ports, airports, hub-to-hub, and warehouses logistics. We focus on the state the of art of daily operations in order to understand how the processes are carried out, the level of automation and the use of connected and automated heavy-duty vehicles. In order to obtain this information, interviews were conducted with experts in the field, where participants described the day-to-day operations. Furthermore, desktop research helped to provide additional information.

This overview of the operations in each one of the AWARD's use cases will set the ground to understand our vision of the use of connected and automated heavy-duty vehicles in logistics operations for the upcoming years, which will be explained in Chapter 4.

Throughout this document, we will refer to the SAE levels of automation:

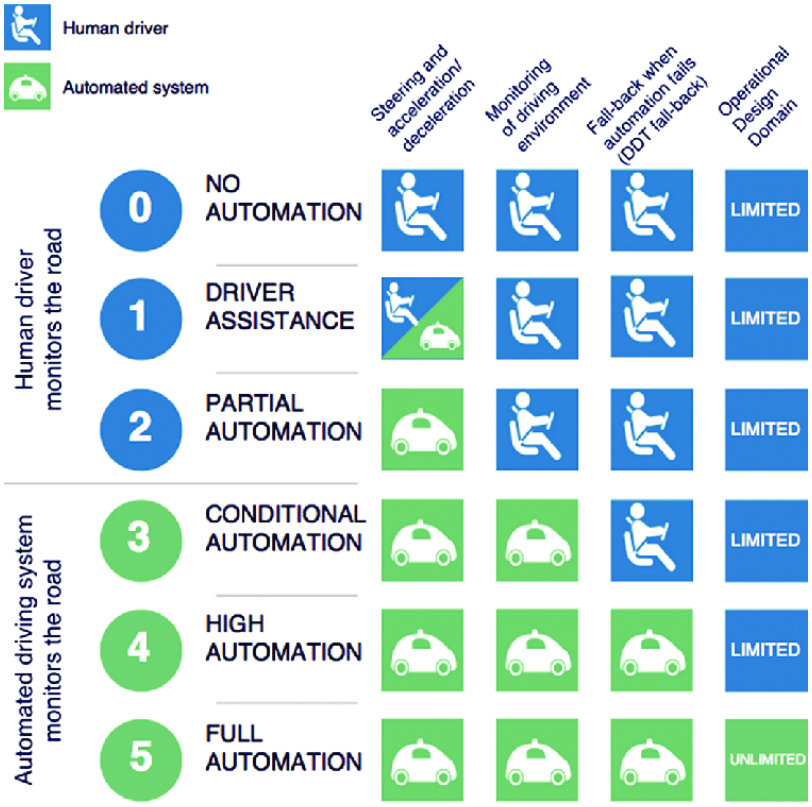

Figure 2: SAE Levels. [37]

2.1. Current trends in port automation

Enhancing port operations is a critical endeavor in the evolving landscape of global trade. This section delves into the present state of port automation, highlighting the intersection of

technological innovation and logistical demands that are transforming the dynamics of international cargo management.

2.1.1. Market overview

The global maritime transport sector, a crucial component of the logistics industry, is responsible for handling approximately 80% of the world's trade by volume and more than 70% by value [42]. In recent years, the adoption of AHDVs in port logistics has gained significant momentum, driven by the need for enhanced efficiency, reduced labor costs, and improved safety.

The global port automation market is projected to witness substantial growth, fueled by technological advancements and increasing investments in port infrastructure. As of 2023, the market size is estimated to be in the range of several billion dollars, with an expected annual growth rate of 10-15% over the next decade. This growth is underpinned by the rising demand for automated solutions to handle the escalating volume of maritime trade, which is forecasted to grow by over 2% annually from 2024 to 2028. [42]

Asia continues to lead in port efficiency, with several of the world's most advanced ports located in this region. In the 2023 Container Port Performance Index (CPPI) which is mainly derived from the time a vessel spends in port, 18 of the top 25 ports globally are located in Asia, including the highly automated Yangshan Port in China. [44]

In 2021, Europe boasted 1,200 ports, both major and minor, across various countries. Notably, the ports of Antwerp, Rotterdam, and Hamburg managed to collectively handle 12% of the world's cargo goods, making them the EU's top three ports in terms of gross weight of goods and container volume. Other significant ports include Bremerhaven in Germany, Algeciras, Valencia, and Barcelona in Spain, Piraeus in Greece, Felixstowe in the United Kingdom, and Le Havre in France, all of which manage substantial cargo volumes daily due to their strategic locations. However, in terms of automation at terminals, it was estimated in D8.5 that between 3% and 5% of the world's total container terminal capacity is automated, or around 10% of the world's ports [7]. For example, in the U.S., only four ports, including Los Angeles and Long Beach—which handle about 42% of all U.S. container trade with East Asia—currently boast automated terminals. The situation is similar in Europe, where major ports have implemented systems to automate certain operations. Yet, both globally and in Europe, the prevalence of fully automated terminals remains relatively low, although it is anticipated to increase in the coming years.

2.1.2. Current automation processes in ports

It is important to acknowledge the inherent variability in daily operations and levels of automation across ports. Factors such as port size, technological adoption rates, and budgetary constraints contribute to this diversity. Therefore, to provide a representative overview of container terminal processes, we focus on the most advanced ports.

The prevalence of automated operations in ports and terminals around the world is rising, which is evidence of how quickly technology is developing. These automated processes are mostly focused on fleet management, which is made easier by highly developed Terminal

Operating Systems (TOS). TOS have become a vital component of the contemporary port ecosystem because of their capacity to efficiently communicate messages between terminal operators and drivers while also allowing for scheduling and planning. This cutting-edge system is an essential part of almost every port's infrastructure because it not only controls and monitors activities but also tracks the movement of fleets and containers. Automation has boosted productivity, streamlined logistics, and general efficiency at ports and terminals; thus, TOS are common in most ports and container terminals.

In addition, the most advanced ports, like Rotterdam and Tianjin [10][12], have demonstrated significant improvements in operational efficiency and throughput capacity by integrating AHDVs in their operations. Containers are unloaded using automated ship-to-shore cranes, which rely on sensors and AI for precise handling. AVs then transport containers to the storage yard, where automated stacking cranes handle storage and retrieval. A Terminal Operating System (TOS), as explained above, manages all port operations, including real-time tracking and coordination with customs and security systems. Finally, for outbound transport, automated loading systems transfer containers onto trucks and trains. In the most advanced ports, automated systems can handle both loading and unloading processes simultaneously.

Key technologies that enhance port automation include AI, IoT, 5G, and digital twins, which increase efficiency, capacity, safety, and cost-effectiveness in port operations. Digital twins, in particular, represent the next major advancement and are a key innovation focus for both Rotterdam and Tianjin ports [10][12]. This technology creates a virtual replica of the port, allowing operators to monitor, simulate, and optimize port activities in real-time. Hardware also plays a critical role in yard automation. For instance, the port of Rotterdam employs around 80,000 transponders embedded in the ground to navigate its AVs efficiently [12].

2.2. Current trends in airport automation

This section delves into the world of airport automation, where cutting-edge technologies are transforming airline logistics. We explore the current state of automation in airports worldwide and examine the challenges and opportunities of automation in aviation, from the complexities of implementing autonomous solutions to the innovative projects underway at some airports.

To understand current approaches and the disruptive potential of autonomous vehicles, we focus on two key areas: luggage transfer and turnaround operations (preparing planes for their next flight). As we navigate this complex ecosystem, we explore the pros and cons of airport automation, providing a comprehensive analysis of its impact on operational efficiency, cost-effectiveness, and the passenger experience.

2.2.1. Market overview

The airport automation market is projected to experience significant growth in the coming years, with estimates suggesting a CAGR of around 6%. In 2023, the market size was valued between USD 6 and 7 billion, and this figure is expected to surpass USD 10 billion by 2032. This expansion is fueled by several factors, most notably the rise in passenger traffic and the

need to reduce labor costs. The Asia-Pacific region, in particular, is anticipated to be a key driver of this market growth.[19][25][31]

Within the airport automation market, operations are segmented across terminal-side, landside, and airside functions. Notably, landside operations, encompassing potential use cases for AHDVs, represent a significant market share of around 43%. This segment presents an exciting opportunity for the deployment of automated vehicles for various tasks, including passenger and baggage transportation between terminals, as well as cargo and maintenance equipment movement. [19]

2.2.2. Current automation processes in airports

While there are over 41,700 airports worldwide [4], with the US leading the pack at 13,000, only a small fraction currently uses autonomous solutions. The level of automation and technology varies significantly across airports, and complete automation of all airport operations is still a long way off. Security checks, air traffic control, and customer service continue to primarily rely on human expertise. Hence, most airports still depend heavily on manual labor for their day-to-day operations. Our analysis focuses on luggage transfer and turnaround operations to understand current practices and how autonomous vehicles might transform them.

An airport turnaround involves several procedures to efficiently manage luggage handling, arrivals, and departures. When a plane lands, baggage handlers unload luggage onto trolleys. These trolleys are then manually transported by truck to a designated unloading area, where the luggage is transferred to the baggage carousel for passenger pick-up. Empty trolleys are then stored after unloading. The turnaround process thus also involves transporting empty trolleys for loading and subsequent departure.

This process can be automated, and a prime example of it happens in Changi Airport, which is spearheading airport automation technologies. To address manpower shortages and enhance baggage handling efficiency, Changi Airport in Singapore is collaborating with Aurrigo to trial a fleet of autonomous electric baggage vehicles. This initiative marked the world's first deployment of autonomous vehicles for underwing baggage loading and unloading at aircraft stands. The AutoDolly tugs navigate using Aurrigo's Auto-Connect software platform, which allows for scheduling, monitoring, and communication between the vehicles. These electric vehicles boast several innovative features, including a sideways drive system for maneuvering in tight spaces, 360-degree turning capabilities, and robotic arms for precise Unit Load Devices[1] (ULDs) handling. [51]

The initial trials successfully demonstrated the vehicles' ability to operate autonomously on airside roads, within the baggage handling area, and to perform automated loading and unloading in various weather conditions. Now, the airport focuses on testing communication between a fleet of AutoDolly tugs to streamline the turnaround process for wide-body aircraft. This innovative technology holds promise for improving baggage handling efficiency,

[1] ULDs are essentially containers used to transport baggage, cargo, or mail on aircraft.

reducing reliance on manpower, and contributing to a more sustainable future for airports. [51]

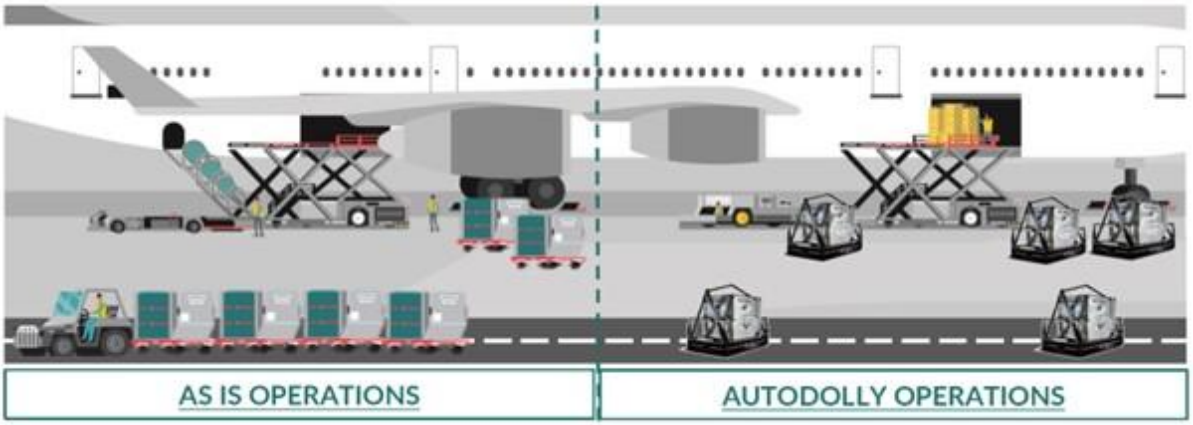

Figure 3: Auto-Dolly Operational Advantage [33]

Figure 3 displays how the automated tugs eliminate the need for human intervention, while increasing versatility by allowing each ULD to move independently.

In Europe, several airports have also began to use some type of autonomous vehicle and fleet management system. Gatwick Airport has partnered with Oxbotica to trial a fleet of self-driving pods for staff shuttle services between terminals. This technology offers Gatwick the potential to significantly reduce reliance on its current fleet of 300 airside vehicles, which are stationary for most of the day [30]. In the meantime, they have also partnered with Aurrigo to trial self-driving baggage carriers. The AVs utilize a digital map of the airport to navigate airside and transport luggage from terminals directly to aircraft. It is expected that the integration of this technology will reduce baggage handling staff needs by 90%. This could alleviate staffing pressures and streamline baggage operations, improving turnaround times and reducing the frustration of lost or delayed luggage for passengers [50]. Similar experiments are underway at Schiphol Airport in the Netherlands, Charles de Gaulle Airport in France, Heathrow Airport in the UK, and Frankfurt Airport in Germany.

Another innovative solution is provided by Yeti Move, which offers an automated snow removal service. Utilizing cloud-based software and artificial intelligence, Yeti's system coordinates a network of snow vehicles, including plows, sweepers, and blowers, ensuring efficient and optimized snow removal across runways [21]. Trial deployments, which began in 2018 in Norway at Fagernes Airport and in 2020 [30] in Sweden's ten largest airports managed by Swedavia [16], have demonstrated the effectiveness of this technology, significantly reducing clearing times and improving consistency and efficiency in snow removal. This technology reduces delays and disruptions for air traffic, requires fewer personnel, and optimizes vehicle usage, leading to cost savings and a lower environmental footprint.

Overall, while significant advancements have been made in the deployment of autonomous vehicles in airport logistics, several challenges remain. Vehicle technology limitations, such as the need for higher reliability, flexibility, and consistency, are significant hurdles to broader

airport automation. Autonomous vehicles must achieve a level of performance that ensures smooth and safe operations under all conditions.

AWARD project aims to contribute to this by developing the EZTow, the industry's first driverless, electric tow tractor, specifically engineered to enable autonomous material handling in both indoor and outdoor logistics environments. By addressing these challenges, the AWARD project and other similar initiatives are paving the way for a more automated and efficient future in airport logistics, where autonomous vehicles will play a crucial role in transforming freight and baggage handling processes.

2.3. Current trends in hub-to-hub automation

This section examines warehouse and hub-to-hub automation in European logistics, drawing on research from the European Association of Storage and Logistics and the Transport Intelligence. The sector's importance for supply chain efficiency cannot be understated, with more than 50,000 warehouses in Europe. Our analysis explores the current state of warehouse operations, highlighting the extensive use of manual labor and pinpointing areas where automation is already making inroads. While acknowledging the technological, financial, and logistical challenges of this transformative journey, we delve into the future of warehouse hub-to-hub automation, exploring the potential for creating a more automated, efficient, and cost-effective warehousing sector.

2.3.1. Market overview

The global truck market is experiencing significant growth, driven by the ever-increasing demand for freight transportation. While light commercial vehicles currently dominate the overall truck population, heavy-duty freight trucks (HFTs) are the workhorses of the industry, responsible for a staggering 65% of freight movement. This reliance on HFTs is expected to continue, with projections indicating the number of these heavyweights will reach 64 million by 2050. In the meantime, light commercial vehicles (LCVs) are expected to increase to around 220 million vehicles. The overall truck market itself is mirroring this growth trend, with a market size exceeding $2.6 trillion in 2023 and projections for continued expansion to $3.7 trillion by 2032, reflecting a CAGR of 4.0% [18]. This surge highlights the crucial role the hub-to-hub logistics industry plays in the global economy. [43]

2.3.2. Current automation processes in hub-to-hub logistics

In order to understand current practices, we conducted an analysis of the state of art of hub-to-hub operations of major European logistics companies.

Our analysis identified three key operations related to warehouse and hub-to-hub operations: truck travel between hubs, trucks moving trailers/swap bodies on the yard, and loading/unloading goods from the building in/out the trailers (see 2.5.2). We evaluated the potential benefits of automating each process to determine the most suitable starting point.

Operations between logistical hubs are currently carried out solely through manual labor, besides few ongoing trials. The trucks used in these operations are manually driven and

mostly diesel-powered. Drivers operate the trucks, loading and unloading cargo at each facility along the route. Automating this aspect is not a short-term priority for many hubs due to the short distances involved and the lack of regulation, as well as the lack of supplier offering autonomous driving solution to drive on public roads.

In terms of moving trailers/swap bodies on the yard, most of the important logistic centers and factories have their own yard trucks to move trailers from different position on the site. The typical process for trailer movement involves several steps. First, an external long-haul truck driver drops off a trailer at an “arrival” parking area. A site terminal truck then picks up the trailer and parks it in a designated parking space. When the consumption point is ready to receive the trailer, the site terminal truck moves it to the appropriate gate. Throughout its journey on the site, a trailer may be moved multiple times between parking spaces and site gates. Finally, the trailer is taken to the departure parking area to be collected by another long-haul external truck driver. Given the inherent dangers of yard operations, logistics sites are keen to minimize the presence of external truck drivers in the complex yard maneuvering areas to enhance safety and avoid potential accidents.

In the AWARD project, we worked on a case where a factory delivered their finished good to a subcontracted warehouse at few hundred meters away. Those flows can be found in huge number of factory/logistic sites, especially around airports, ports or around major industrial sites but this latest operation is seen as the hardest one to automate since it requires to drive on public roads

Despite the current limitations on widespread adoption, pioneering companies are already implementing L4 trucks in hub-to-hub operations, demonstrating the feasibility of AHDVs for these applications. In China, Inceptio Technology has achieved a significant milestone in 2024 with its L4 autonomous trucks, surpassing 100 million kilometers of safe commercial operation. This translates to benefits like reduced driver costs (40-50% for express delivery companies) and improved fuel efficiency. [29]

Other companies like Volvo and Aurora have also successfully developed L4 trucks capable of doing long-haul transportation. So far, Aurora trucks have driven more than 2.4 million kilometers on public roads, including during night and through bad weather, thanks to a powerful LiDAR which allows the truck to “see” more than 400 meters down the road [46]. However, their operations are far from being profitable. The company lost a staggering $1.7 billion in 2022 and Aurora remains unproven to be commercially viable. Nevertheless, it did not prevented it from going public in 2021, and successfully raising 2 billion [8]. Ongoing projects like ATLAS-L4 in Europe target these challenges, aiming to have a concept ready for automated truck operation on motorways by 2025, paving the way for production [27].

Platooning also presents significant potential benefits for the hub-to-hub logistics. This technology uses connected and autonomous systems to enable trucks to travel close together, minimizing air drag and fuel consumption [23]. In 2019, MAN successfully tested truck platooning in Germany in partnership with DB Schenker and Fresenius University. Two linked trucks covered 35,000 kilometers achieving a 3-4% fuel reduction with potential for increased road space efficiency and fewer lane changes, improving overall safety [23].

More recently, the ENSEMBLE project has focused on multi-brand truck platooning technology. Concluded in 2022, the project successfully demonstrated the viability and potential benefits of platooning through real-world testing and discussions with key stakeholders [13].

As technology advances, regulations adapt, and commercial viability improves, L4 trucks hold significant promise for transforming the efficiency and sustainability of hub-to-hub operations.

2.4. Current trends in forklift automation

Logistics automation is rapidly evolving, driven by factors such as digital transformation and the growing emphasis on efficiency, and warehouses are no exception. Europe's logistics sector relies heavily on warehousing, with over 53,000 facilities. These warehouses include both public facilities operated by third-party logistics providers and private warehouses managed by individual companies. The European Association of Storage and Logistics estimates a total storage capacity exceeding 7.5 billion square meters, with an average utilization rate of around 80%. Additionally, Transport Intelligence reports over 28,000 logistics service companies operating in Europe. Many of these businesses have their own distribution facilities and warehouses, while others rely on outsourced logistics firms.

Our analysis focuses on forklifts, which are essential for streamlining material handling in warehouses. The vehicles are at the forefront of the automative transformation, offering a cost-effective solution for lifting and transporting heavy loads [48].

2.4.1. Market overview

The global forklift market is experiencing significant growth, driven by the rise of e-commerce, online retailing, and the increasing emphasis on warehouse automation. Valued at USD 81 billion in 2023, the market is projected to grow at a compound annual growth rate (CAGR) of 6.5%, reaching USD 144.5 billion by 2032 [48]. This expansion is largely fueled by the need for more efficient material handling solutions to keep up with the rapid pace of modern logistics [48].

In terms of sales volume, approximately 1.49 million forklifts were sold worldwide in 2019, with 43.3% of these sales occurring in Asia [35]. China, as the largest producer and seller, accounted for 74.9% of these sales, highlighting its dominant position in the market [35]. By 2023, the Asia Pacific region further strengthened its hold on the global forklift market, capturing around 50% of the market share. Rapid industrialization, particularly in China and India, continues to propel the demand for forklifts in warehouses and production facilities [48]. Notably, the counterbalance segment accounted for approximately 60% of the market share in 2023, underlining the widespread preference for this type of forklift in various industrial applications [48].

Within the broader forklift market, the segment for autonomous forklifts is also expanding rapidly. Valued at USD 5.3 billion in 2023, this segment is expected to grow at a CAGR of 12%, reaching USD 14.6 billion by 2032 [49]. The advancements in navigation technology, coupled

with growing labor shortages and the rising demand for warehouse automation, are primary drivers of this growth [49].

Europe (EU) demonstrates steady growth in the autonomous forklift market, with an estimated value of USD 1.28 billion in 2023 [5][15][9]. Projected expansion between 2023 and 2029 is expected to propel the market to a value of USD 2.6 billion by 2032, reflecting a notable CAGR exceeding 9% [5][15][9]. European countries, including France, Germany, the UK, and the Netherlands, witness significant strides in the adoption of autonomous forklifts [49][49]. Responding to supply chain disruptions, these nations embrace automation to facilitate swift and efficient order fulfillment, driving the demand for advanced distribution infrastructure.

Similar trends are also observed and expected in the US [41], the Middle Eastern & African (MEA) region [49][49], as well as the Asia Pacific region, which emerges as the fastest-growing market for autonomous forklifts, commanding a significant share of over 40% in 2023 [49].

2.4.2. Current automation processes in warehouses

In warehouses, different types of automated vehicles handle internal transportation, but their guidance methods differ. Earlier versions, dating back to the 1960s, follow pre-programmed paths guided by magnetic strips or lasers. These function similarly to trains, stopping for obstacles and excelling at repetitive tasks with heavy loads. In contrast, more recent vehicles have become popular within the last decade. Equipped with advanced sensors and software, they can navigate dynamically and adapt to changing warehouse layouts. This flexibility makes them particularly suitable for the constant flow of e-commerce fulfilment. [26]

The growing demand for automation in warehouses and logistics centers is significantly driving the adoption of autonomous forklifts. These forklifts operate continuously without the need for breaks, supervision, or the risk of human error. With the current labor shortages faced by the logistics industry, autonomous forklifts present a valuable solution by reducing the reliance on human operators for repetitive tasks. Utilizing precise sensors and programming, these forklifts minimize errors in picking, placing, and delivering goods, thereby reducing product damage, enhancing inventory management, and lowering insurance costs [49][49]. While the concept of autonomous forklifts isn't entirely new—companies like BALYO went public in 2017 with innovations dating back to 2004—their implementation is becoming increasingly critical in modern logistics [3][48][2].

Autonomous forklifts could particularly improve the process of loading/unloading goods in/out the trailers. This process currently requires effective implementation of expensive conveyor/belt systems inside the trailers and inside the warehouse. Those automatic trailer loading/unloading systems have been deployed in relatively low numbers due to their high cost, lack of flexibility, and space usage. By using automated forklift solution, those disadvantages are reduced. Once the truck docks at the warehouse, automated forklifts can take over, handling goods from or to anywhere in the building without additional infrastructure, saving then space, infrastructure cost, and keeping operation flexibility to use any gate for any purpose.

In conclusion, forklift automation is no longer a trend, it’s a necessity. Automated forklift manufacturers, like Vecna Robotics, continue to attract significant investment, demonstrating

the attractiveness of this technology [22]. Recently, in April 2024, retail leader Walmart initiated a rollout of 19 autonomous forklifts across four of its distribution centers, marking a strategic move to automate warehouse loading operations. The decision for this deployment followed a successful 16-month proof of concept at one of its facilities, demonstrating the viability and benefits of automated solutions [6]. As technology advances, businesses must embrace these innovations to stay competitive, improve efficiency, and contribute to a sustainable future. The next big step in this industry is to make automated forklifts able to operate outdoors as well. A challenge that has been successfully tackled within AWARD.

3. Vision of connected and automated heavy-duty vehicles for logistics operations

3.1. Methodology

Understanding the transformative impact of digitalization and automation on future mobility and logistics is crucial for AWARD. To develop a comprehensive vision for this future, EasyMile and Enide facilitated a series of 3 workshops with various project partners. These workshops brought together diverse perspectives on the future of connected and automated heavy-duty vehicles (CAHDVs) in the logistics sector. By engaging a range of stakeholders, the project aimed to capture a holistic view of the different visions for the market of AVs in logistics.

The workshops employed a structured approach to vision building. A central tool used was the "5 Bold Steps Vision Canvas" (Figure 4) of David Sibbet [11]. This facilitated collaborative brainstorming to co-design a vision for a future-oriented company in the logistics sector, alongside the 5 bold steps needed to achieve it.

The canvas guided participants through defining essential themes, exploring how those themes would manifest in real-world applications, identifying both supporting factors and potential challenges, and outlining a roadmap with "5 bold steps" for realizing the vision. This process not only helped define the desired future state but also fostered a shared understanding of the opportunities and obstacles along the way.

Hence, this vision canvas helps to derive design criteria for business model(s) and strategy. The vision statement answers the question, “Where do we want to go?” by trying to articulate what the aspiration of the company is so that a framework for strategic planning can be established.

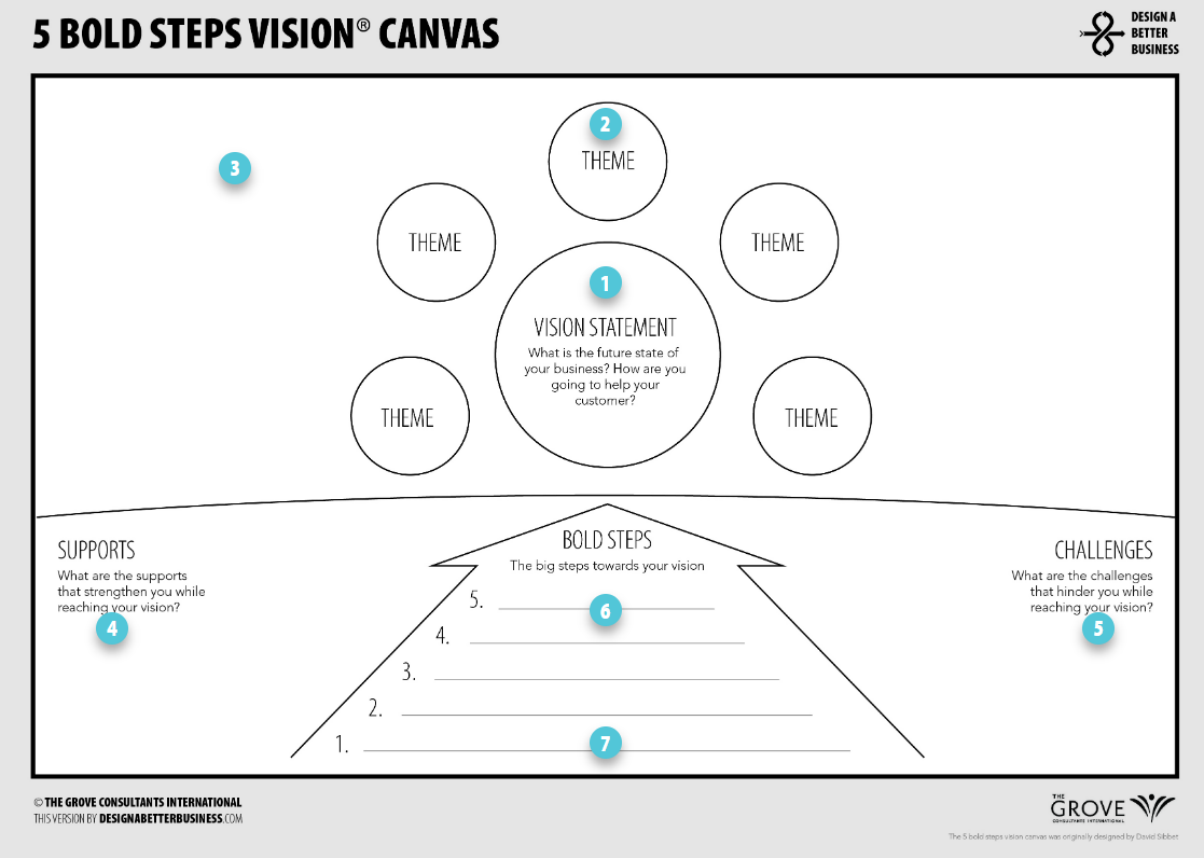

Figure 4: Five Bold Steps Vision Canvas [11]

The canvas is filled out in a particular order:

1. Vision statement: What is the future state of our company? How are we going to help our customers?
2. Essential themes: What are the essential themes supporting our vision? Describe them in 1 or 2 single words.
3. How it shows up: How will the themes show up in our company? How will they make the vision themes concrete and how will they inspire others?
4. Supports: What are the supports that enable us to reach our future?
5. Challenges: What are the challenges that hinder us from reaching our future?
6. 5 bold steps: what are the 5 bold steps to take in order to achieve your vision?
7. Key values: What are the crucial values that form the foundation for your vision and steps? How can we align those values?

During the workshops, participants actively shared their ideas, insights, and expectations related to CAHDVs. Their diverse perspectives enriched the vision by reflecting the broad spectrum of challenges and opportunities within the logistics sector.

Figure 5 provides an example of a workshop's outcomes from the metro retro board used during this session.

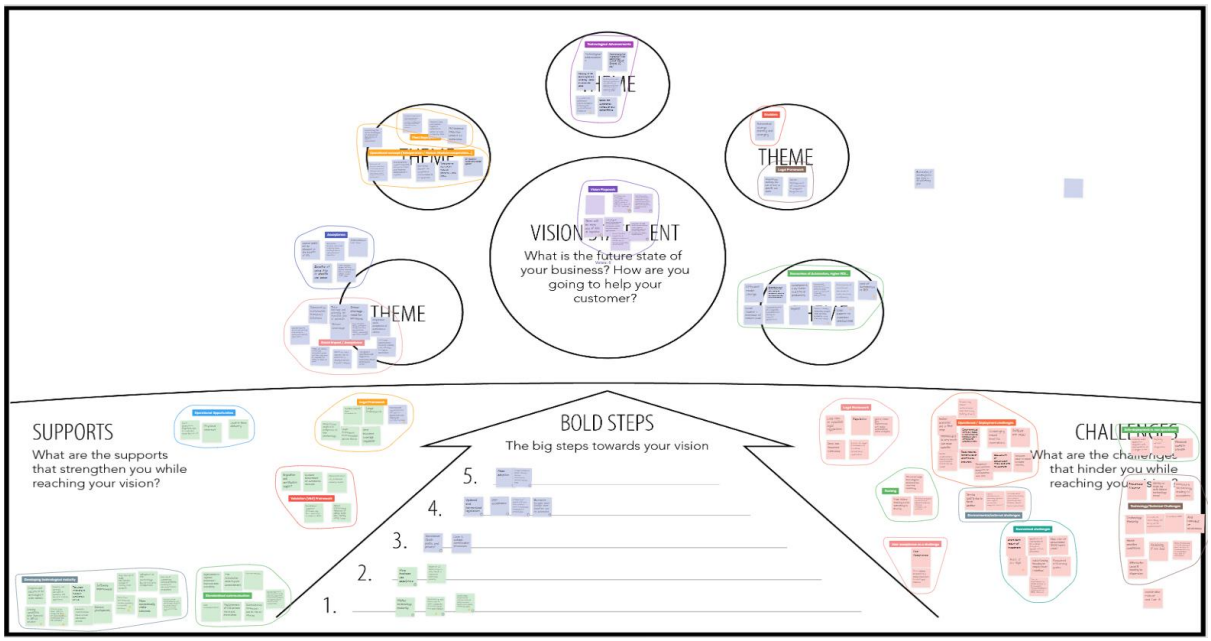

Figure 5: Metro Retro Results of the Workshop

3.2. General Vision for AVs in Logistic

3.2.1. Vision Statement

Starting with the vision: "What is the future state of your business? How are you going to help your customer?" Participants had the opportunity to express their view on the future of autonomous vehicles in logistics operations. Here is the resulting vision statement for AVs:

Transforming logistics with safe, efficient, and autonomous vehicles to achieve the EU's ambitious climate goals.

3.2.2. Key Themes

Participants categorized their vision on the future of AVs in logistics by different themes: legal framework, technological advancements, fleet deployment, operational concept, public and stakeholders' acceptance, and economics of automation.

Table 1: Key Themes

Economics of Automation
A central theme for achieving widespread adoption is a compelling economic case for AVs. Removing the need for a safety driver is crucial, as it significantly improves the business case for end-users. Achieving at least cost parity with current logistics operations will be a key target. A comprehensive analysis of automation costs versus return on investment (ROI) will be essential. Ultimately, automation is expected to drive significant efficiency gains within logistics operations, solidifying the economic viability of AVs and broader automation within the sector.

Legal framework
A critical theme for enabling the vision of autonomous vehicles (AVs) in logistics is the legal framework. This framework will prioritize the development of regulations specifically designed for AV use cases within the logistics sector. The Management of Electronic Transport Regulations (METR) will play a crucial role alongside these regulations, establishing clear guidelines for data management and communication protocols. This comprehensive approach will ensure the safe and reliable operation of AVs in logistics, paving the way for their contribution to achieving the EU's ambitious climate goals outlined in the Fit for 55 package.
Technological Advancements
Another key theme driving the vision is technological advancements. This theme emphasizes the development of high-performance, precise localization technology for both goods and passenger transportation within the logistics sector. Advancements in existing technologies like LiDAR, radar, cameras (LWIR/multispectral), and communication infrastructure (5G) will be crucial. These combined advancements will unlock the full potential of autonomous vehicles in logistics, ensuring safe and reliable operations.
Fleet management software
A central theme for realizing the vision is strategic fleet management. This theme envisions the implementation of software enabling the supervision of multiple autonomous vehicles by a single person. It will play a key role, ensuring communication with customers and supplier IT systems, enabling safe and efficient exception handling, monitoring system performance, as well as realizing optimization over the fleet usage and each vehicle missions, while anticipating charging time to handle peak charge.
Operational concept
Another crucial theme is the operational concept, meaning how the vehicle is utilized. Who is in charge when an exception appears? Does the flow can be stopped if environment become out of the validated nominal Operational Design Domain. Does the autonomous vehicle have degraded mode and what are their impact. It may emphasizes human-machine collaboration. Humans can act as critical backups, taking over control (teleoperation) when the vehicle encounters situations exceeding its operational design domain (ODD).
Public and Stakeholders' Acceptance
Public acceptance is a critical theme for successful AV integration within logistics. Educational initiatives will play a key role in informing the public about the benefits of AVs. Furthermore, automation presents a strategic solution to address labor shortages caused by Europe's aging population. Early adoption by industry players, particularly within confined outdoor areas with mixed traffic, will serve as real-world demonstrations, fostering business use cases and wider acceptance. This focus on public education, coupled with the growing demand for sustainable solutions, driver shortages, and the automation of repetitive tasks, will pave the way for broader adoption of AVs in the logistics sector.

3.2.3. Bold Steps

Figure 6: Bold Steps General Vision for AVs in Logistic

3.2.4. Opportunities & Challenges

This section explores the transformative potential of Automated Vehicles (AVs) in logistics. By leveraging advanced technologies and data-driven approaches, AVs offer significant opportunities to increase efficiency and productivity across the entire logistics chain. This includes extending operational hours, optimizing routes in real-time, and reducing reliance on human labor. These advancements can contribute to faster delivery times, improved resource allocation, and a more sustainable logistics industry. While AVs hold immense promise for the future of logistics, there are significant challenges that need to be addressed before widespread adoption can be achieved. This section explores these challenges, encompassing concerns related to public acceptance, technical limitations, infrastructure gaps, and the evolving regulatory landscape. Overcoming these hurdles will be crucial to unlock the full potential of AVs and transform the logistics industry.

OPPORTUNITIES	CHALLENGES
1. 24/7 Operations: Autonomous vehicles can operate continuously, extending operational hours beyond traditional shift limitations and potentially increasing overall logistics throughput. This can be particularly beneficial for time-sensitive deliveries or handling perishable goods. Furthermore, 24/7 operation paves the way for significant traffic congestion reduction on roads. This is further complemented by the potential of optimized routing and platooning technologies to contribute to even greater efficiency. **2. All-Weather Operation**: Guarantees year-round operation regardless of weather conditions. **3. Reduced Reliance on Human Labor:** AVs can address the growing labor shortages in the logistics industry, automating tasks like long-haul transportation or repetitive warehouse operations. This allows human workers to focus on higher-value activities like inventory management or customer service. **4. Real-Time Optimization and Control:** By integrating with existing management systems, AVs can leverage real-time data on traffic patterns, weather conditions,and vehicle performance, to dynamically optimize routes, improving driving patterns. This real-time monitoring ensures efficient movement of passengers and cargo which further enhances overall resource allocation and operational efficiency. It also provides greater visibility into the supply chain, enabling proactive logistics management. **5. Flexible and Scalable Operations:** AV fleets can be easily scaled up or down depending on demand, offering greater flexibility for logistics companies during peak seasons or unexpected changes in volume. **6. Improved Fuel Efficiency:** Route optimization and optimized driving (acceleration and deccelration for instance) can contribute to environmental sustainability by reducing fuel consumption. This could lead to significant reductions in emissions and a more sustainable logistics industry. **7. Enhanced Safety Through Advanced Sensor Technology:** By eliminating human error and utilizing reliable, high-performance sensors like cameras, radar, and LiDAR, AVs have the potential to significantly reduce accidents in logistics operations. These advanced sensors enable accurate perception of surroundings and safe navigation decisions, even in complex environments with varying weather conditions. This improved safety benefits not only workers but also protects cargo and reduces insurance costs.	**1. Public and Stakeholders Acceptance:** Overcoming public anxieties about the safety of autonomous vehicles and addressing job displacement concerns, while navigating potential negative impacts, are crucial for widespread adoption. **2. High Initial Investment Costs:** The high upfront costs associated with acquiring and deploying AV technology, along with the necessary supporting infrastructure (charging stations, communication networks), can be a significant barrier, especially for smaller companies. **3. Unclear Legal Frameworks and Restrictive Regulations:** The legal frameworks governing AV operation are still evolving, and potentially restrictive regulations could hinder the adoption of this technology. **4. Technical Limitations:** Current sensor technology can be limited in adverse weather conditions such as heavy rain, fog, or snow. Advancements in sensor performance and weather-resilient designs are needed for reliable all-weather operation and achieving a level of reliability that matches that of human drivers. **5. Integration with Existing Infrastructure and Systems:** Integrating AVs with both physical infrastructure (roads, traffic signals) and logistics management systems (warehouses) can be complex and require significant modifications or upgrades. This may involve building new infrastructure like charging stations and high-speed internet networks, as well as adapting existing warehouse infrastructure and logistics management systems to seamlessly interact with AV technology. **6. Unproven Technology:** Thorough testing and safety validation are crucial to demonstrate the maturity of AV technology. This is essential to build trust in the reliability of AVs operating in real-world conditions. **7. Cybersecurity Threats:** The increasing reliance on digital systems in AVs necessitates robust cybersecurity measures to protect against potential hacking attempts that could disrupt operations or compromise cargo security.

Figure 7: Opportunities and Challenges General Vision Avs in Logistic

3.3. Vision for AVs in Ports

3.3.1. Vision Statement

Leveraging expertise from DFDS, a leading player in ferry operations and short sea shipping, this section explores the vision for the future of connected and automated heavy-duty vehicles in ports. Here is the vision statement outlining their perspective:

Autonomous vehicles seamlessly transport cargo across port terminals, eliminating the need for manual drivers.

This vision reflects the priorities and needs identified by key stakeholders directly involved in ports operations. In contrast to the general vision for the industry, a more targeted group of experts was consulted here to ensure deep understanding of the specific challenges and opportunities within the port environment.

3.3.2. Key Themes

Table 2: Key Themes for AVs in Ports

Automated Planning and Fleet Management
Powered by AI, crucial for optimizing traffic patterns and resource allocation, eliminating the inefficiencies of manual scheduling.
Overcoming Challenges
Solutions needed to replicate the intuitive decision-making currently done by human operators in complex outdoor environments.
Remote Supervision
Plays a vital role, focusing on digitalizing port infrastructure to provide the real-time data and communication channels necessary for effective AV control.
Cost Savings and ROI
Achieving savings through a strong return on investment hinges on maximizing operational efficiency.
Success Measurement
Evaluated by factors such as reduced congestion, faster turnaround times, and optimized workforce utilization—all made possible by the seamless integration of AVs into port operations.

3.3.3. Bold Steps

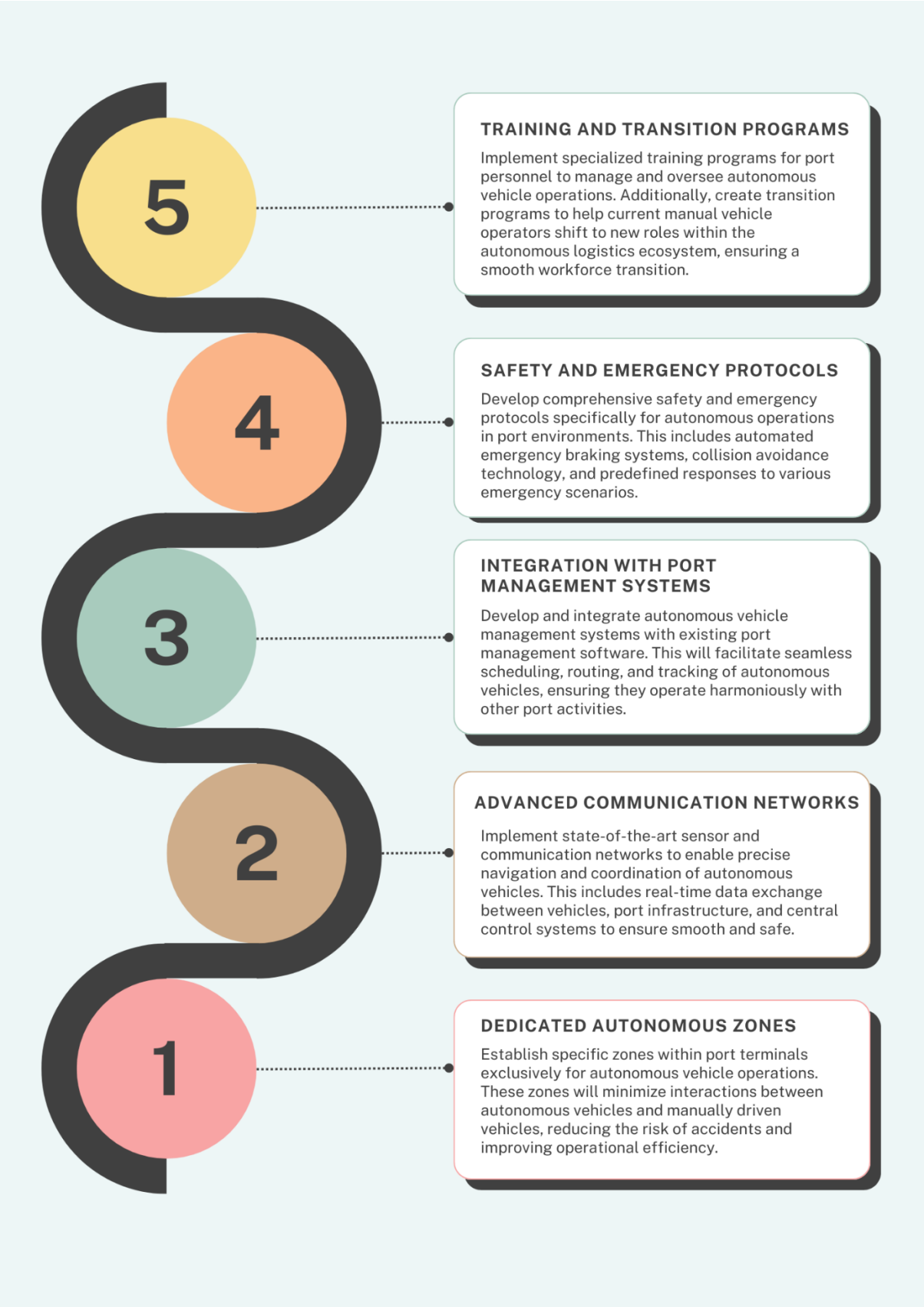

Figure 8: Bold Steps for AVs in Ports

3.3.4. Opportunities & Challenges

While autonomous vehicles (AVs) promise widespread benefits across the logistics landscape, their deployment in ports unlocks a distinct set of advantages. This section dives deeper into the specific opportunities that AV technology presents for port operations, going beyond the broader applications of logistics automation. Here, we'll explore how AVs can be tailored to address the unique challenges and workflows of port environments, maximizing efficiency and transforming cargo handling capabilities. Beyond the general challenges of AV technology, ports introduce a complex environment demanding robust solutions. Here, we delve into the specific obstacles facing AVs in port operations. These challenges go beyond the broader concerns of logistics automation, requiring tailored strategies for sensor technology, operational integration, and safety protocols to ensure the successful integration of AVs within the intricate world of port logistics.

OPPORTUNITIES	CHALLENGES
1. Automated Yard Operations: AVs can manage container yards, autonomously stacking, retrieving, and transporting containers between storage locations and loading zones, increasing efficiency and reducing reliance on human drivers. **2. Berth Automation**: Autonomous vehicles can be used to precisely maneuver trailers between container ships and designated loading areas on the dock, streamlining the loading and unloading process. **3. Gate Automation:** AVs can handle gate access and security checks for incoming and outgoing trucks, reducing congestion and wait times at port entrances and exits. **4. Inter-Terminal Shuttles:** AVs can be employed for shuttling containers between different terminals within a port complex, offering a more efficient and reliable alternative to traditional shuttle trucks. **5. Dangerous Goods Handling:** AVs can be specifically designed for handling hazardous materials within port environments, minimizing human exposure to potential risks. **6. Integration with Port Management Systems:** AVs can be integrated with existing port management systems, allowing for real-time tracking, route optimization, and data-driven decision-making to further enhance efficiency.	**1. Saltwater Corrosion:** Port environments are exposed to constant saltwater spray, which can accelerate corrosion of sensors and other electronic components on AVs. Special materials and protective measures will be needed to ensure long-term functionality. **2. Docking and Maneuvering Challenges**: AVs need to handle precise maneuvering and docking procedures alongside large container ships and other vessels. This requires robust sensor fusion capabilities for accurate object detection and distance estimation in close quarters. **3. Integration with Terminal Operating Systems (TOS):** Seamless integration with existing TOS is crucial for AVs to receive real-time cargo data, optimize routes based on loading/unloading schedules, and maintain efficient workflow within the port terminal. **4. Night-time Operations and Limited Visibility:** Many port operations extend into nighttime hours. AVs need advanced vision systems with robust performance in low-light conditions to navigate safely and efficiently during these periods. **5. Unpredictable Cargo and Debris:** Ports often handle a variety of cargo types, some with irregular shapes or potential for spillage. AVs need object recognition capabilities to adapt to these variations and navigate around unexpected debris or obstacles.

Figure 9: Opportunities and Challenges for AVs in Ports

3.4. Vision for AVs in Airports

3.4.1. Vision Statement

Leveraging expertise from Avinor, which operates most of the civil airports in Norway, and SAS, specializing in sustainable aviation technologies, this section explores the vision for the future of connected and automated heavy-duty vehicles within airports. Here is the vision statement outlining their perspective:

> ***Autonomous ground support equipment facilitates seamless transport of goods in both indoor and outdoor airport environments.***

This vision reflects the priorities and needs identified by key stakeholders directly involved in airports operations. In contrast to the general vision for the industry, a more targeted group of experts was consulted here to ensure deep understanding of the specific challenges and opportunities within the airport ecosystem.

3.4.2. Key Themes

Table 3: Key Themes for AVs in Airports

Airport Outdoor Autonomy
The vision of seamless airport operations extends beyond the terminal walls. Outdoor autonomy plays a crucial role in this equation, encompassing two key areas. Focusing on freight transport first allows for gradual integration and familiarization with the technology. As confidence builds and regulations adapt, the potential for autonomous passenger aircraft movement can be explored further. Autonomous aircraft tug can then revolutionize aircraft movement to the runway. These automated vehicles will eliminate the need for traditional pushback procedures, reducing reliance on jet fuel and minimizing emissions. This not only contributes to a more sustainable airport environment but also streamlines operational efficiency. However, achieving widespread acceptance for autonomous aircraft movement to runway requires a phased approach This multi-pronged approach, combining autonomous tugs for freight and a long-term vision for passenger aircraft, unlocks the full potential of airport autonomy in optimizing operations and reducing environmental impact.
Efficient Cargo Handling
The vision of seamless airport operations extends beyond cargo movement, encompassing the passenger experience as well. Efficient cargo handling plays a key role, and here, a suite of autonomous solutions can revolutionize the passenger journey. Imagine autonomous buses equipped with premium security check features, whisking passengers and their luggage directly to designated checkpoints. This eliminates the need for separate luggage drop-off and reduces congestion. Furthermore, the concept of autonomous luggage service could extend efficiency beyond the airport. Passengers could schedule luggage pick-up directly from their homes, with autonomous vehicles ensuring secure and trackable transport to the airport. At the airport, automated loading and unloading stations would seamlessly integrate with baggage handling systems, further streamlining the process. These autonomous solutions not only enhance passenger convenience and reduce wait times, but also free up personnel to focus on higher-value customer service interactions. By implementing a network of interconnected autonomous technologies, airports can

significantly improve efficiency and create a more stress-free travel experience for passengers.
Remote supervision
Unlocking the full potential of remote supervision for airport operations hinges on a collaborative effort. Government funding can play a crucial role in supporting research and development of robust remote monitoring technologies. This, coupled with the establishment of clear regulations governing safe and reliable autonomous operations, will foster a supportive environment for innovation and adoption. This public-private partnership approach is essential for ensuring successful implementation of remote supervision and achieving the vision of seamless airport operations.

3.4.3. Bold Steps

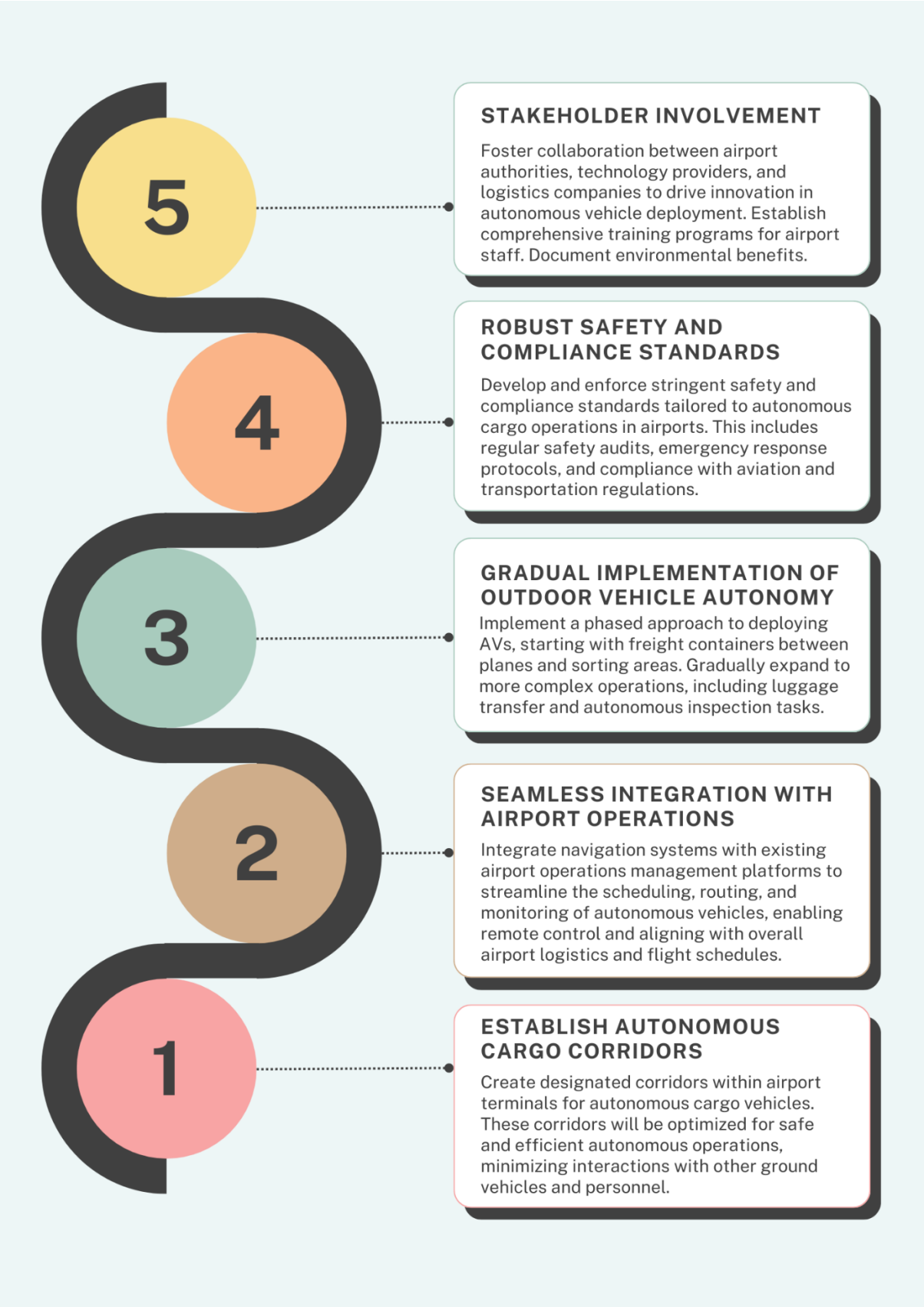

Figure 10: Bold Steps for AVs in Airports

3.4.4. Opportunities & Challenges

AV technology offers significant benefits for airport operations. However, airports present a unique environment with specific challenges and workflows. This section delves deeper into the distinct opportunities that AVs can unlock for airports, going beyond the general advantages of logistics automation. Here, we will explore how AVs can be tailored to address the specific needs of airport operations, enhancing efficiency, safety, and the overall passenger experience. While automated vehicles (AVs) hold immense promise for revolutionizing airport operations, successfully integrating them within this complex ecosystem presents a unique set of challenges. Beyond the general hurdles faced by AVs in logistics, airports introduce a demanding environment with diverse traffic patterns, restricted airspace considerations, and the critical need for seamless operation. This section delves deeper into the specific obstacles that AVs need to overcome in airport settings. These challenges go beyond the broader concerns of logistics automation and require tailored solutions to ensure the safe, efficient, and reliable integration of AVs within the intricate world of airport operations.

OPPORTUNITIES	CHALLENGES
1. Streamlined Ground Handling with Precision Docking and Maneuvering: AVs can automate baggage and cargo movement between terminals, gates, and aircraft, while precisely maneuvering around obstacles and optimizing space utilization. This not only reduces wait times but also minimizes the risk of ground collisions, improving overall efficiency and safety in ground handling operations. **2. Enhanced Passenger Experience:** AVs can provide on-demand or scheduled passenger shuttles between terminals, parking areas, and gates, offering a convenient and time-saving alternative for passengers with limited mobility, families with young children, or those with bulky luggage. This, along with shorter wait times for baggage claim and boarding, contributes to a more efficient and stress-free travel experience. **3. Enhanced Perimeter Security and Intrusion Detection:** AVs equipped with sensors and cameras can continuously monitor and patrol airport perimeters, deterring potential threats, and providing real-time situational awareness for security personnel.	**1. Diverse Traffic Mix:** Airports are highly complex environments with diverse traffic patterns. Unlike most roadways, they present a complex mix of vehicle types with varying speeds and priorities. AVs will need to safely navigate alongside aircraft, passenger cars, service vehicles (refuellers, baggage trucks, catering trucks), and potentially even emergency response vehicles. **2. Restricted Airspace and Ground Maneuvering**: AVs operating on airport grounds will need to be aware of restricted airspace and adhere to specific protocols to avoid any interference with aircraft taking off or landing. This requires precise positioning and awareness of both ground and air traffic. **3. Maintenance and Downtime Management:** AV breakdowns or malfunctions in a critical airport environment can cause significant disruptions. Strategies for rapid identification, isolation, and repair of faulty AVs will be crucial to minimize downtime and maintain operational efficiency.

Figure 11: Opportunities and Challenges for AVs in Airports

3.5. Vision for AVs in Hub-to-Hub

3.5.1. Vision Statement

Leveraging expertise from DB Schenker, a leading global logistics provider, DigiTrans, a specialist in autonomous vehicles tests & validation, and BRP-Rotax, an expert in the development and production of powertrains, this section explores the vision for the future of connected and automated heavy-duty vehicles in hub-to-hub operations. Here is the vision statement outlining their perspective:

> ***Seamless and fully automated freight transportation between hubs to increase operational efficiency and safety while reducing costs.***

This vision reflects the priorities and needs identified by key stakeholders directly involved in hub-to-hub operations. In contrast to the general vision for the industry, a more targeted group of experts was consulted here to ensure deep understanding of the complexities of hub-to-hub logistics.

3.5.2. Key Themes

Table 4: Key Themes for AVs in Hub-to-Hub

Safety Enhancement
Safety enhancement is seen as integral to the vision for automated freight transportation between hubs. Through advanced vehicle connectivity, Autonomous vehicles dynamically adjust driving behavior to respond to the environment, reducing the risk of accidents while optimizing efficiency. Robust regulations for mixed road use and addressing concerns to ensure safe integration needs to be in place. Innovative solutions targeting blind spots, especially with trailers, enhance visibility and awareness. By prioritizing the separation of the driver from the vehicle, we aim to minimize human error and elevate safety standards in the industry.
Operational Efficiency
Operational efficiency lies at the heart of the vision for automated freight transportation between hubs. Firstly, implementing an Automated Fleet Scheduling System streamlines logistics, optimizing routes and vehicle utilization. Automated loading and unloading processes minimize turnaround times, while automated charging at terminals ensures fleet readiness. Improved job planning and dispatch mechanisms enhance resource allocation and scheduling precision. Moreover, redefining the safety driver's role to focus on system oversight enhances operational reliability. Lastly, by minimizing cargo moving waiting times, throughput and resource utilization can be maximized, thereby realizing the full potential of automated freight transportation network.
Long-Distance Transportation
Efficient long-distance transportation within automated freight networks demands meticulous planning and infrastructure preparedness. Critical strategies entail the deployment of automated charging stations along routes to maintain fleet uptime and streamline operations. Gate access control systems play a pivotal role in goods identification and loading dock assignment at distribution hubs, ensuring seamless

processes. Furthermore, ensuring infrastructure readiness, encompassing road conditions and supportive technologies, is imperative for the effective functioning of long-haul automated freight transportation systems. By prioritizing these strategies, robust frameworks can be established for efficient and reliable long-distance freight transportation in automated networks.

Cost Reduction Strategies

Effective cost reduction strategies are integral to optimizing automated freight transportation systems. Implementing automated charging stations reduces downtime and associated costs, enhancing operational efficiency. Improved job planning and dispatch mechanisms streamline resource allocation, minimizing wastage and improving overall efficiency. Considering the role of automation in potentially replacing human operators, careful assessment is crucial to balance cost reduction with workforce considerations. Automated maintenance diagnostics enable proactive maintenance, reducing repair costs and preventing costly breakdowns. Additionally, separating the driver from the vehicle and minimizing cargo waiting times further contribute to cost reduction efforts by enhancing efficiency and throughput.

3.5.3. Bold Steps

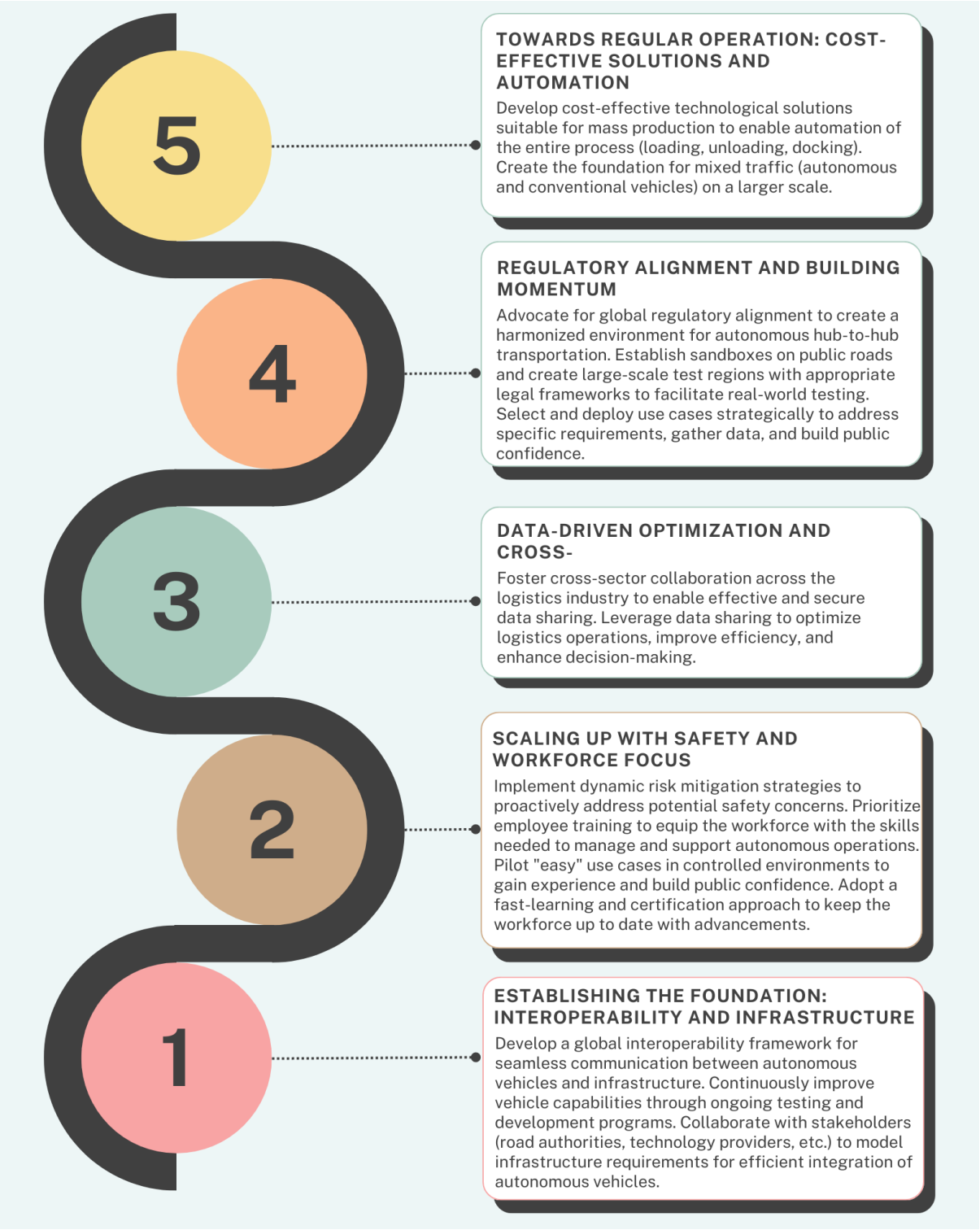

Figure 12: Bold Steps for AVs in Hub-to-Hub

3.5.4. Opportunities & Challenges

Many opportunities arise for H2H use cases. The vast majority are also applicable to different use cases and to AVs in logistics as a whole. Therefore, they are mentioned in the first point

of this section. In order to avoid unnecessary repetitions, only those specific to the Hub-to-Hub use case are shown below. While the Hub-to-Hub (H2H) use case presents unique advantages, many of the challenges associated with autonomous vehicles in logistics also apply here. To avoid redundancy, this section will primarily address the hurdles specific to H2H operations, building upon the broader challenges.

OPPORTUNITIES	CHALLENGES
1. Hub-Specific Legislation and Acceptance: Clear legal frameworks tailored for hub operations. **2. Automated Loading/Unloading:** Streamlines freight handling within hubs. **3. Sandbox Testing at Hubs:** Provides controlled environments for testing within hub environments.	**1. High Costs for First Adopters:** Hubs investing in initial automation technology may face a significant financial burden before widespread adoption reduces costs. **2. Partly Non-Automated Process Steps**: Challenges arise when integrating autonomous vehicles with existing, non-automated processes like loading/unloading within hubs. This can disrupt workflow and limit efficiency gains. **3. Data Protection Regulation (Camera Operation):** Hub-to-Hub automation relies on cameras within controlled environments. Balancing data privacy regulations with the need for operational data collection is crucial. **4. Dealing with Mixed Traffic Complexity (within Hubs)**: Managing interactions between autonomous vehicles and human-operated equipment within a hub environment adds complexity and requires careful planning

Figure 13: Opportunities and Challenges for AVs in Hub-to-Hub

3.6. Vision for AVs in Forklift

3.6.1. Vision Statement

Leveraging expertise from Palfinger, a leading manufacturer of innovative lifting solutions, and AIT, Austria's largest research and technology organization, this section explores the vision for the future of connected and automated heavy-duty vehicles in forklift operations. Here is the vision statement outlining their perspective:

> ***Fully automated loading of pallets indoors and outdoors, even without an existing logistics infrastructure.***

This vision reflects the priorities and needs identified by key stakeholders directly involved in forklift operations. In contrast to the general vision for the industry, a more targeted group of experts was consulted here to ensure deep understanding of the specific challenges and opportunities that are associated with forklift operations.

3.6.2. Key Themes

Table 5: Ket Themes for AVs in Forklift

Efficient intralogistics workflows
Within warehouses and distribution centers, seamless material handling is paramount. This theme emphasizes the optimization of intralogistics workflows through the strategic deployment of autonomous forklifts. Automated solutions can address repetitive tasks like pallet movement and stock retrieval, streamlining processes and maximizing throughput. Integrating these autonomous forklifts with existing Warehouse Management Systems (WMS) can further enhance efficiency by enabling real-time tracking and inventory management. This focus on automation within confined spaces allows human personnel to dedicate their time to higher-value activities such as order picking and quality control.
Enhanced Safety and Precision Material Handling
This theme merges the critical aspects of safety and precision in dense warehouse environments. Autonomous forklifts equipped with advanced sensors and perception capabilities can not only maintain safe distances from obstacles and personnel but also handle fragile or heavy objects with exceptional dexterity. This combined functionality minimizes the risk of collisions and product damage, fostering a safer and more efficient work environment within warehouses and distribution centers. Furthermore, real-time data from these sensors can be used to identify potential hazards and alert personnel proactively.
Integration with Collaborative Robots (Cobots)
The future of intralogistics lies in seamless collaboration between humans and machines. This theme emphasizes the potential for integrating autonomous forklifts with cobots to achieve a new level of operational efficiency. Cobots can be programmed to perform tasks like picking and packing individual items, while autonomous forklifts handle heavier loads and bulk material movement. This human-machine collaboration leverages the strengths of both, maximizing productivity and optimizing workflows within warehouses and distribution centers.
Scalability and Adaptability
Warehouse layouts and operational needs can vary significantly. This theme underscores the importance of scalable and adaptable autonomous forklift solutions. Modular systems with customizable payload capacities and functionalities can be tailored to specific warehouse requirements. Furthermore, the ability to integrate seamlessly with existing infrastructure and expand functionality through additional modules ensures future-proof investment in automation solutions for evolving intralogistics needs.

3.6.3. Bold Steps

Figure 14: Bold Steps for AVs in Forklift

3.6.4. Opportunities & Challenges

While there are many potential benefits for autonomous vehicles in logistics overall, forklift automation offers unique advantages specific to warehouse operations. To avoid

redundancy, this section will focus solely on the opportunities that are most relevant to automating forklift operations within warehouses, as opposed to broader logistics applications. While autonomous vehicles in logistics face a wide range of challenges, automating forklifts within warehouses presents distinct hurdles. To avoid repetition, this section will focus primarily on the obstacles specific to forklift automation, acknowledging that some broader challenges from general AV technology also apply.

OPPORTUNITIES	CHALLENGES
1. Flexible Automation: Forklift automation can be implemented in a more modular way compared to autonomous vehicles, allowing for a gradual increase in automation levels within warehouses. **2. Technology Transfer to Various Forklift Types Possible:** Forklift automation solutions may be adaptable to different forklift types used within warehouses, maximizing the potential impact. **3. Standardization of Cargo:** Increased adoption of forklift automation might incentivize standardization of cargo within warehouses to optimize automated processes.	**1. All-round View for Remote Operation:** Control that might be more challenging than for open-road AVs. **2. Surface Conditions of the Ground - Interaction Close to the Ground:** Forklifts operate close to the ground and on various surfaces (warehouse floors, loading docks) which can be more sensitive to sensor performance compared to typical AV road environments. **3. Detection of Concealed and Stacked Loads:** Forklift automation needs to reliably detect and navigate around partially hidden or stacked loads, a challenge not as prominent for most AVs. **4. Acceptance by the Workforce/Sabotage**: Warehouse staff may have concerns about job security or resist automation, potentially leading to intentional disruption. **5. Admission Procedure and Regulatory Aspects:** There might be specific regulatory hurdles or approval processes for operating autonomous forklifts within warehouses, beyond those for general AVs. **6. Efficiency – Frequent Manual Intervention Necessary:** Certain warehouse tasks may require frequent human intervention for handling delicate items or unexpected situations, impacting overall automation efficiency. **7. Lack of Required Flexibility:** Forklift automation solutions might not yet offer the same level of flexibility as human operators in adapting to unexpected situations or variations in warehouse layouts. **8. Limited Traffic Space:** Autonomous navigation within tight warehouse spaces or with limited maneuverability can be more challenging compared to AVs on open roads. **9. Mix of Different Load Carriers**: Handling a variety of pallet sizes and non-standardized cargo within warehouses can pose challenges for automated forklift systems. **10. Few Technology Providers:** The pool of companies offering reliable and well-developed forklift automation solutions might be smaller compared to the broader AV technology landscape.

Figure 15: Opportunities and Challenges for AVs in Forklift

4. Applications of connected and automated heavy-duty vehicles for logistics

This chapter outlines the anticipated applications of Autonomous Heavy-Duty Vehicles (AHDVs) in logistics from 2024 to 2040. We will provide a detailed look at the expected progress in automation technologies, supported by real-world examples and a clear delineation of the technology levels involved. This structured approach ensures an achievable path toward the widespread adoption of AHDVs in the European logistics sector.

Developing a comprehensive roadmap for AHDVs in logistics operations is a challenging task. The rapid pace of technological advancement, coupled with varying degrees of regulatory and market readiness across different regions, adds layers of complexity. Furthermore, companies publicly disclose only a few details of their R&D&I efforts to maintain their competitive edge. It is therefore difficult to assess the pace at which they can achieve their targeted use cases. Nevertheless, we are committed to providing a robust and realistic timeline for the integration of AHDVs in the European logistics sector, recognizing both the opportunities and the obstacles ahead.

Currently, the state of AHDVs in logistics is varied. As of 2024, the first practical cases of automated vehicles in airports are facilitating the transportation of cargo and passengers within airport premises. Concurrently, some port terminals already operate with full automation, and autonomous forklifts have been operating indoors for many years. However, these vehicles are not yet equipped to handle harsh weather conditions, highlighting the contribution of the AWARD project. A more comprehensive analysis of the state-of-the-art autonomous trucking projects in Europe can be found in Figure 16.

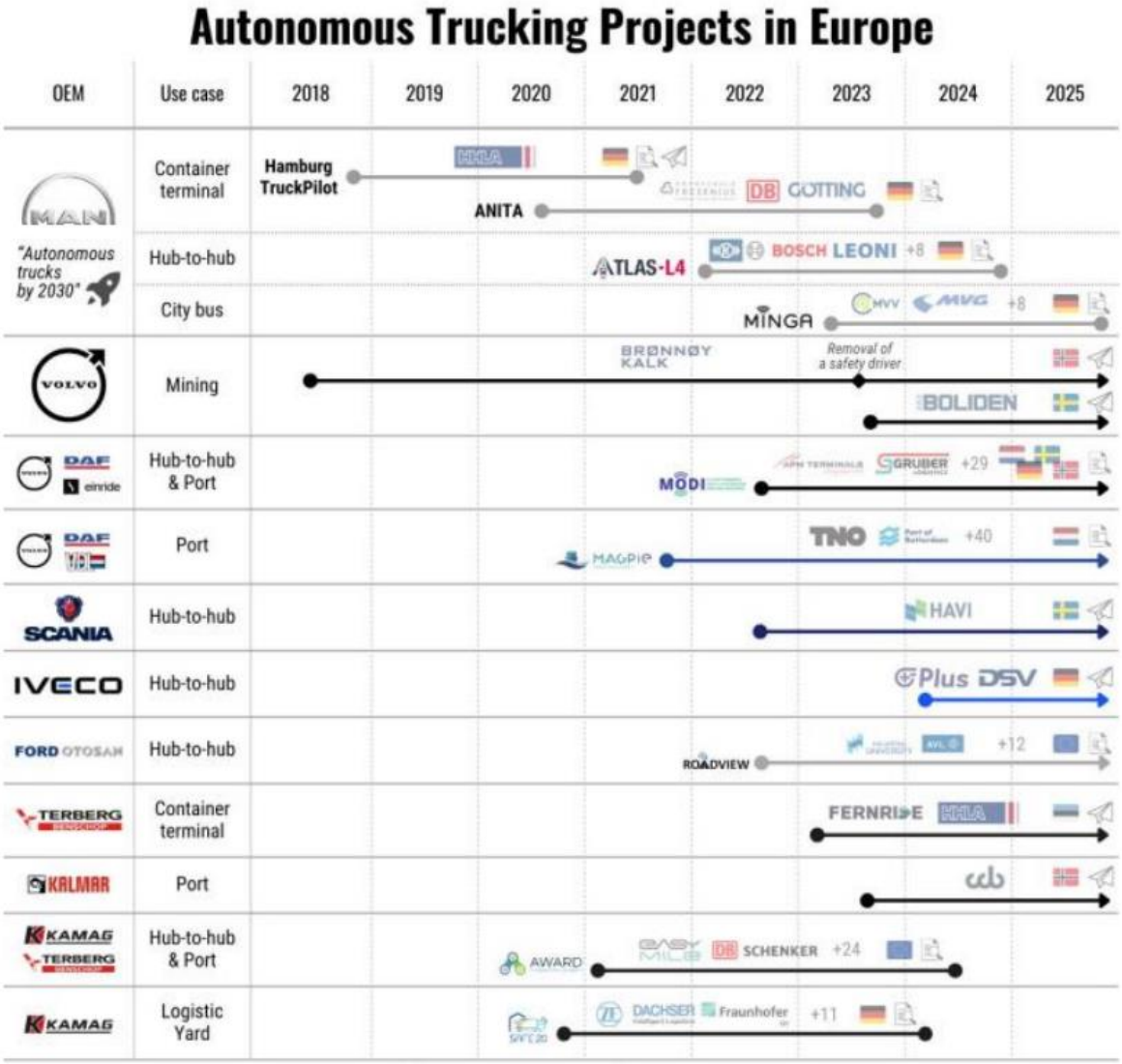

Figure 16: State-of-the-Art Tracking Projects in Europe [39]

Figure 17 illustrates the complexity of several use cases relative to their addressable market, underscoring the significant investments required for more advanced applications. More complex use cases may enter the market sooner than simpler ones, as they attract significantly more investment. Hence, companies have the potential to develop these innovations much faster than those working on simpler applications.

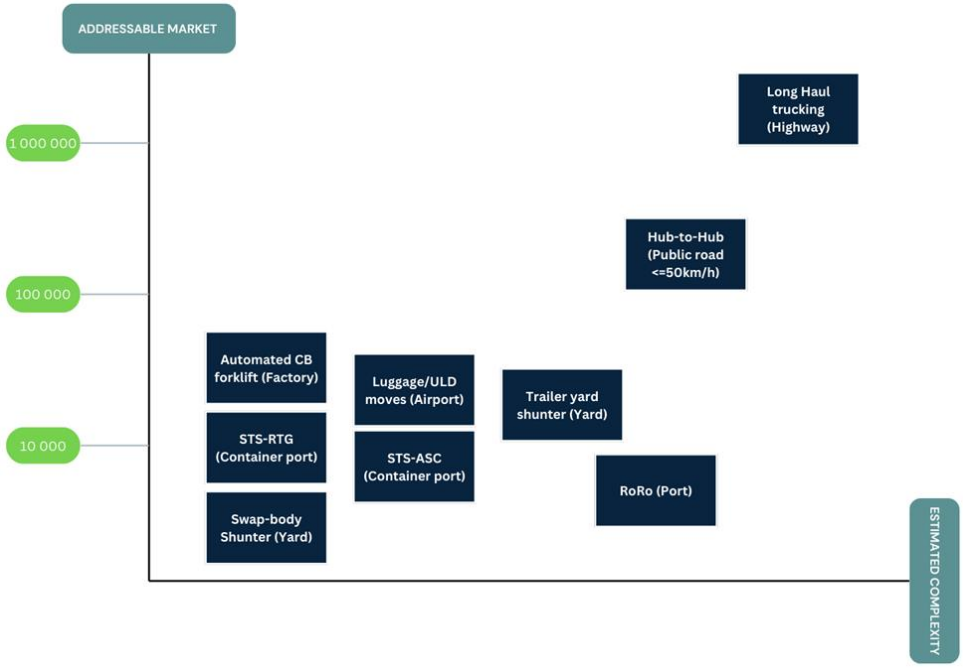

Figure 17: Estimated Complexity vs. Addressable Market by Use Case

The landscape of yard truck automation is being significantly shaped by a number of innovative startups that have emerged in recent years. These companies are pioneering advancements in autonomous technology, focusing on enhancing efficiency and safety within various logistical environments such as distribution yards, container terminals, warehouses, seaports, and intermodal terminals. Founded between 2002 and 2019, these startups span multiple countries, including the US, Germany, China, France, the UK, and Switzerland, each bringing unique technological solutions to the table (Figure 18).

- **United States:** Outrider is revolutionizing distribution yard operations, while Phantom Auto is enhancing intermodal terminal logistics. ISEE is transforming warehouse logistics with autonomous solutions designed to optimize inventory management and material handling.
- **Germany:** FERNRIDE is making significant strides in automating container terminals, partnering with major players like HHLA.
- **United Kingdom:** StreetDrone is automating container terminals, collaborating with QT Terminals, and AIDrivers is improving efficiency in seaports.
- **China:** Westwell, collaborating with Hutchison Ports, is focused on container terminal automation, aiming to streamline operations and reduce labor costs.
- **France:** EasyMile is enhancing efficiency and safety of cargo handling in port logistics.
- **Switzerland:** Embotech is implementing technologies that enhance the efficiency and safety of cargo handling in port logistics.

These startups are not only enhancing operational efficiency but also fostering collaborations with key customers, including Georgia-Pacific, Hutchison Ports, Lineage, and ConGlobal. By integrating cutting-edge AI and sensor technologies, these companies are setting new standards in yard truck automation, paving the way for a more efficient, safer, and cost-effective future in logistics.

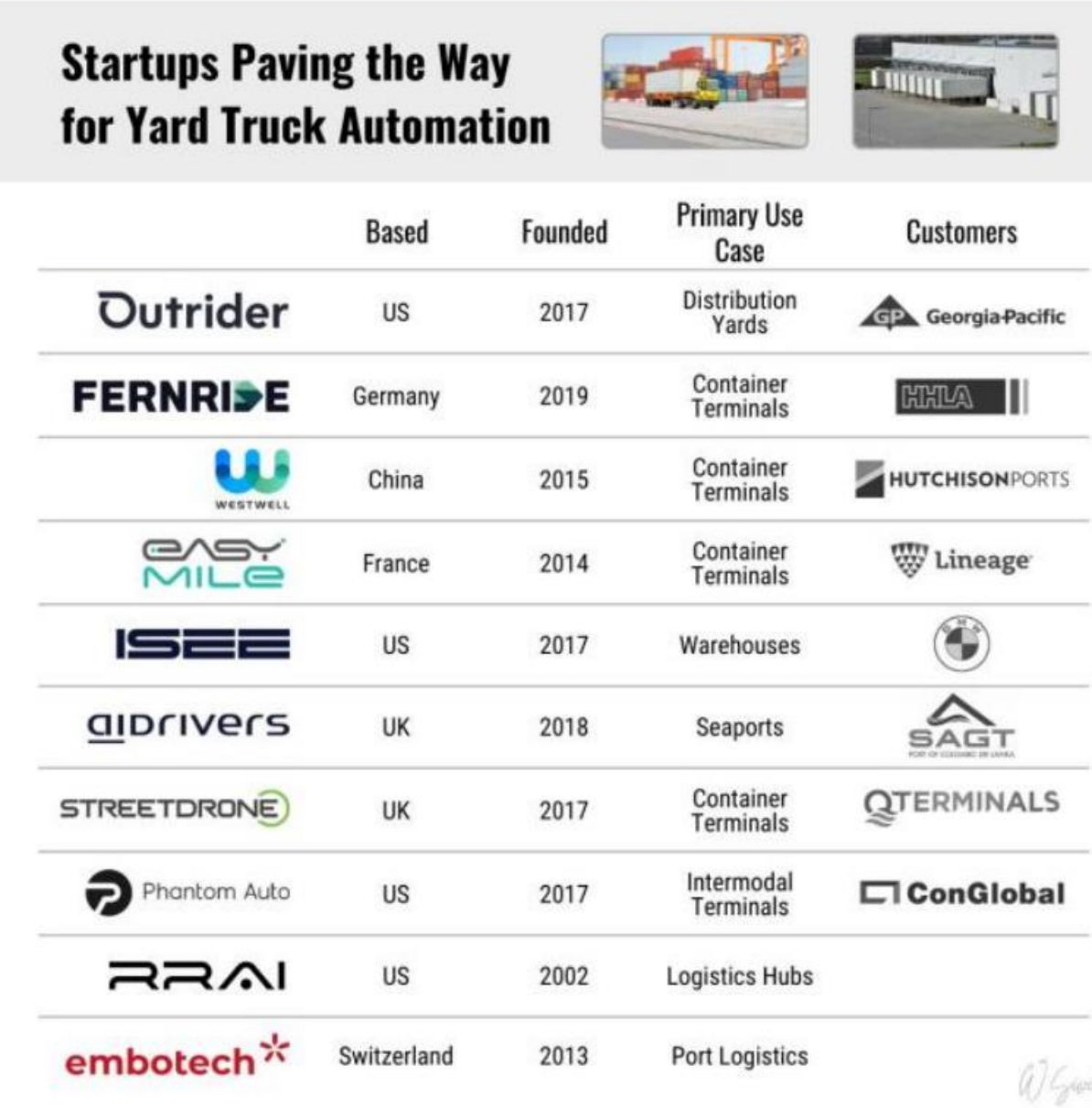

Figure 18: Startups Paving the Way in Yard Truck Automation [40]

This diverse group of innovators is collectively driving forward the capabilities of yard truck automation, demonstrating the vast potential of autonomous technologies in transforming the logistics industry. Their efforts are crucial in meeting the increasing demand for efficient and reliable logistics solutions across various sectors.

4.1. Phased Roadmap for AHDV Integration

The timeline for the adoption of AHDVs (Figure 19) is divided into four phases based on the complexity of scenario-use cases and commercial viability:

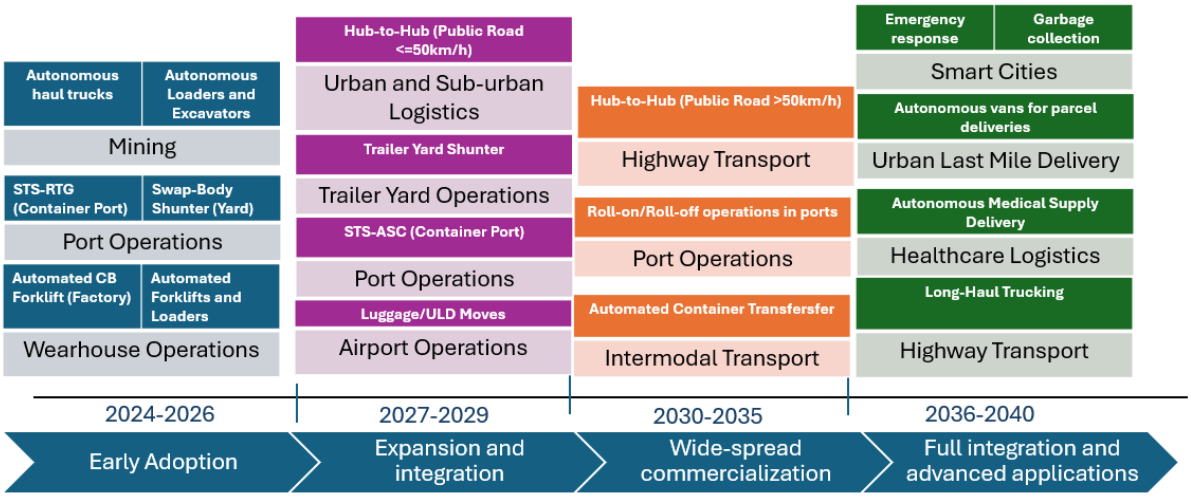

Figure 19: Phased Roadmap of the Adoption of Autonomous Heavy-Duty Vehicles in Logistics (2024-2040)

4.1.1. Initial Integration (2024-2026)

In the short term, within the next three years, ADHVs will be integrated into simpler use cases with high impact. This integration is limited to controlled environments such as ports, warehouses, and factories. The following use cases are expected to occur first due to their low complexity and proven high commercial viability, which provide immediate efficiency gains in logistics processes.

Key Use Cases

1. **Autonomous Haul Trucks and Loaders/Excavators in Mining:**
    a. **Description:** Deployment of autonomous haul trucks and loaders/excavators in mining operations.
    b. **Rationale:** As mining environments are often remote and controlled, they present ideal characteristics for an early integration of autonomous vehicles in logistics operations. Companies like Rio Tinto and Caterpillar have already implemented autonomous haul trucks in their operations, which significantly improved productivity and safety. These investments from pioneer companies are further justified by high labor costs and the challenging working conditions of this activity. Significant efficiency gains and cost reductions are thus foreseen.
2. **STS-RTG (Container Port) and Swap-Body Shunter (Yard):**
    a. **Description:** Automation of Ship-to-Shore (STS) Rubber-Tired Gantry (RTG) cranes in container ports and swap-body shunters in yard operations.
    b. **Rationale:** Logistics operations in ports involve a set of repetitive and well-defined tasks conducive to automation. As the relatively controlled environment of these use cases facilitate an early adoption of ADHVs, several ports, including Rotterdam and Singapore, have been pioneers in implementing

automated STS cranes and yard shunters. This resulted in increased throughput and reduced operational costs. Furthermore, the high volume of container movements, combined with the need for speed and precision, enhance the commercial viability of these applications.

3. **Automated CB Forklift (Factory) and Automated Forklifts and Loaders:**
    a. **Description:** Integration of automated counterbalance (CB) forklifts and other automated forklifts and loaders in factory settings.
    b. **Rationale:** The stable and predictable environment of factories and warehouses also presents an ideal opportunity to deploy automated vehicles in logistic operations. Automated forklifts and loaders can greatly improve efficiency and reduce labor costs, while minimizing human error. Thus, automated handling equipment provides an attractive solution commercially. Companies like Amazon and Ocado have successfully deployed these solutions in their warehouses, achieving significant efficiency gains in their logistics operations.

4.1.2. Expansion and Optimization (2027-2029)

The second phase of the roadmap, which extends from 2027 to 2029, will witness the integration of AHDVs into more complex use cases. The following applications focus on semi-controlled environments such as public roads and urban and suburban logistics, as well as integrated port and yard operations. Their increased complexity and commercial viability motivated our decision to include them in this timeframe. In the meantime, technological advancements and regulatory developments will support their inception.

Key Use Cases

1. **Hub-to-Hub (Public Road <= 50km/h):**
    a. **Description:** Autonomous AHDVs operating between logistics hubs on public roads with speed limits up to 50km/h.
    b. **Rationale:** For this use case, the need to cope with public road traffic introduces a moderate level of complexity. However, the controlled routes between hubs make it feasible. The high commercial viability and significant efficiency gains are driving investments, while pilot programs by companies like Volvo and Scania have demonstrated the potential of hub-to-hub autonomous logistics.
2. **Trailer Yard Shunter Operations:**
    a. **Description:** Automation of trailer yard shunting operations in logistics yards.
    b. **Rationale:** Yard shunting operations involve more dynamic interactions than factories or warehouses, while remaining within controlled environments. This higher complexity is balanced by significant commercial benefits, namely labor costs reduction and higher operational efficiency. Some examples of

autonomous yard truck implementation include Outrider and FERNRIDE startups.

3. **STS-ASC (Container Port):**
    a. **Description:** Automation of Ship-to-Shore (STS) Automated Stacking Cranes (ASC) in container ports.
    b. **Rationale:** This use case requires precise coordination between the automated stacking cranes and other automated systems, as well as with human operators. Therefore, integrating these cranes into port operations is more complex. Nevertheless, the commercial viability of this application is strong, driven by the need for efficient container handling and storage solutions. Furthermore, such technology has already been implemented in the Port of Rotterdam and the Port of Singapore, showcasing the effectiveness of the ASCs.
4. **Luggage/ULD Moves (Airport):**
    a. **Description:** Automation of luggage and Unit Load Device (ULD) movements within airport environments.
    b. **Rationale:** Integrating AVs in airports presents a higher degree of complexity due to the need to coordinate with flight schedules and passenger movements. However, similarly to previous applications, airports settings are controlled environments, and the high potential for efficiency gains make this use case commercially attractive. Few pilot projects like at Schiphol and Changi airports have demonstrated the effectiveness of autonomous luggage handling systems, paving the way for a greater adoption of this technology in the coming years.

4.1.3. Autonomous Network Deployment (2030-2035):

In the mid-term, the industry will target the wide-spread commercialization of AHDVs in high-complexity and high-impact use cases. This phase focuses on the integration of AHDVs into various transport and logistics operations.

Key Use Cases

1. **Hub-to-Hub (Public Road > 50km/h):**
    a. **Description:** Autonomous AHDVs operating between logistics hubs on public roads with speed limits above 50km/h.
    b. **Rationale:** Despite the high level of complexity introduced by the interaction with fast-moving public road traffic, the demand for efficient long-distance logistics solutions and drivers' shortage makes the commercial viability of this use case substantial. Companies like Daimler and Waymo are already piloting autonomous long-haul trucks, demonstrating the potential for large-scale adoption.

2. **Roll-on/Roll-off Operations in Ports:**
    a. **Description:** Automation of roll-on/roll-off (RoRo) operations in ports.
    b. **Rationale:** RoRo are complex operations as they require very accurate maneuvering of vehicles and cargo onto ships. There are few pilot projects, but ports like Zeebrugge and Antwerp are already exploring autonomous RoRo solutions to enhance efficiency and throughput. The controlled environment of port and high volume of RoRo operations justifies the commercial viability of this use case.
3. **Automated Container Transfer:**
    a. **Description:** Automation of container transfer operations within ports and intermodal terminals.
    b. **Rationale:** The transfer of containers between different modes of transport, namely ships, trucks, and trains, necessitates a high level of coordination, making this a complex use case. This difficulty though, is balanced by substantial commercial gains driven by the need for efficient intermodal logistics. In addition, the successful completion of pilot projects at the ports of Los Angeles and Shanghai illustrates the potential of automated container transfer systems.

4.1.4. Full Autonomy and Integration (2036-2040):

The fourth and last phase of this roadmap, which spans from 2036 to 2040, focuses on the long-term applications. It targets the full integration of AHDVs into the most complex and advanced use cases, encompassing smart cities, urban logistics, healthcare logistics, and long-haul transportation.

maximizing their commercial and operational impact

Key Use Cases

1. **Emergency Response and Garbage Collection in Smart Cities:**
    a. **Description:** Deployment of autonomous vehicles for emergency response and garbage collection within smart cities.
    b. **Rationale:** These use cases are very complex as they require AVs to be able to accommodate the dynamic and unpredictable character of the urban environment. However, some pilot projects deploying AVs for emergency response and waste management have already been conducted in Dubai and Singapore, showing promising results. The significant efficiency gains and critical nature of these services strengthen the commercial viability of these applications.
2. **Autonomous Vans for Parcel Deliveries in Urban Last Mile Delivery:**
    a. **Description:** Use of autonomous vans for parcel deliveries within urban areas, focusing on last-mile delivery.

b. **Rationale:** Urban last-mile delivery is highly complex due to dense traffic and the need for precise navigation. The commercial attractiveness of this use case lies in the substantial cost savings and efficiency improvements it can bring to a growing e-commerce sector. Companies like Amazon and FedEx are already testing autonomous delivery vans, highlighting the potential for large-scale implementation.

3. **Autonomous Medical Supply Delivery in Healthcare Logistics:**
    a. **Description:** Automation of medical supply delivery within healthcare logistics networks.
    b. **Rationale:** The critical stakes in the medical field leave no room for error. Hence, the complexity of this use case is further increased by the need to ensure timely and reliable deliveries in critical situations. On the other hand, the potential to improve the efficiency and reliability of healthcare logistics through automation enhances the commercial attractiveness of this application. Pilot projects, like the autonomous delivery of medical supplies by Zipline in Rwanda and the US, showcase the benefits of this use case.
4. **Long-Haul Trucking in Highway Transport:**
    a. **Description:** Autonomous long-haul trucking on highways, expanding beyond initial pilot phases to full-scale operations.
    b. **Rationale:** The complexity of this use case lies in the extended travel distances and varying road conditions on which AVs must drive. Nevertheless, there are already companies like TuSimple and Embark that are making rapid progress in this area, demonstrating the feasibility and advantages of autonomous long-haul trucking. The commercial benefits include significant reductions in transportation costs and efficiency improvements.

5. Consolidation and Recommendation for the European Union

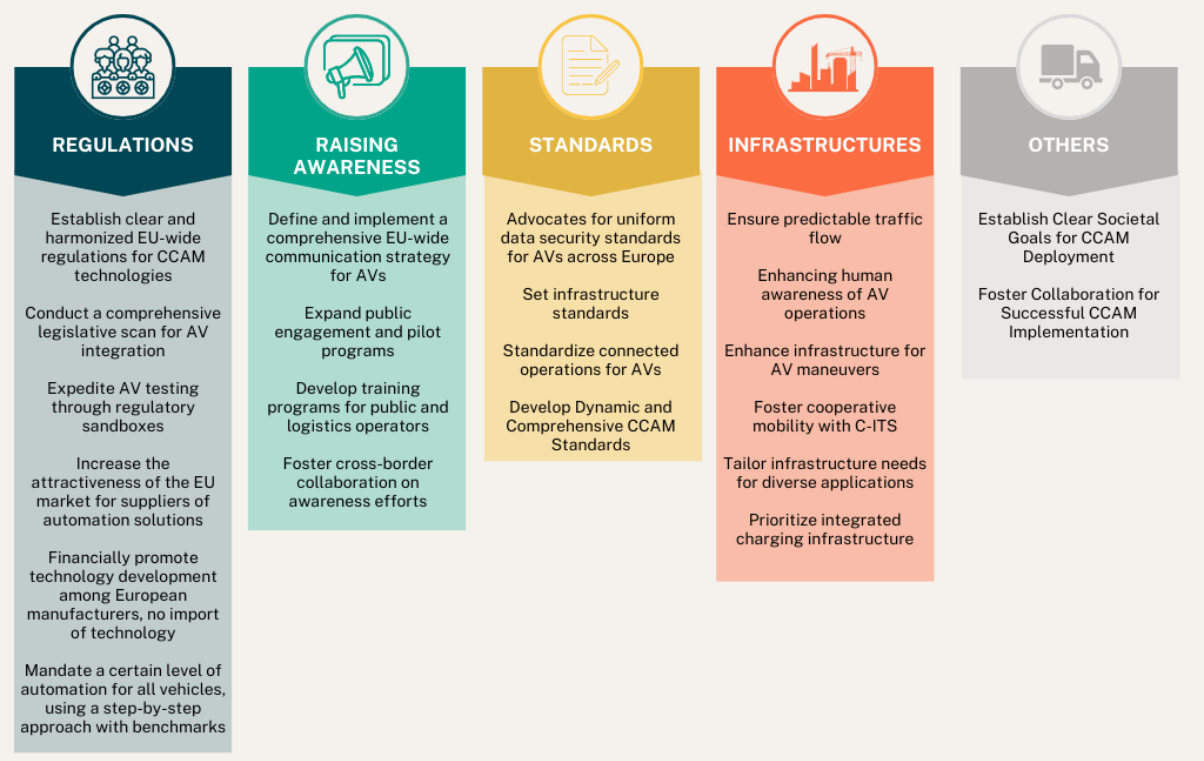

Figure 20: The five areas of focus

This chapter addresses key topics crucial for transforming the logistics sector. The five areas of focus, namely **Regulations**, **Raising Awareness**, **Standards**, **Infrastructures**, and **Others**, present valuable insights and recommendations from project partners that are necessary for a seamless integration of AVs in the European market. These themes were identified as the most challenging aspects that companies face when deploying autonomous vehicles. Each of them highlights several challenges that currently hinders AV development in Europe and makes suggestions on what the European Commission (EC) could do in order to enable the adoption of AVs in logistics and increase the attractiveness of the European Union (EU) market for suppliers of automation solutions.

For a comprehensive overview of current research projects, policies, and instruments related to Connected and Automated Mobility (CCAM) within the EU, along with member state initiatives, we highly recommend consulting Chapter 5 of the Connected, Cooperative and Automated Mobility Roadmap [14].

The information provided in the following chapter results from workshops and discussion involving various actors of the AVs landscape in Europe, such as experts, manufacturers, and logistics operators, who are part of AWARD consortium.

5.1. Regulations

Establish clear and harmonized EU-wide regulations for CCAM technologies

The successful and widespread deployment of CCAM necessitates a clear and harmonized legal framework across the EU. This framework should address various aspects to ensure safety, competition, and responsible innovation, encompassing the following key areas:

Harmonized legal framework: Create a consistent legal framework that governs cross-border testing to avoid regulatory fragmentation across member states (conformity principle).

Competition and data ownership: Implement stricter anti-monopoly laws aligned with the EU competition rules, including data ownership. For instance, to prevent OEMs from establishing monopoly or oligopoly positions in areas like mapping services, customers could utilize mapping data from a different provider than the vehicle manufacturer. This will foster a competitive landscape and ensure open access to essential data for innovation.

Tele-operation regulations: Develop clear regulations governing tele-operation of AVs, outlining the responsibilities and qualifications required for remote operators.

New driver licensing framework: Establish a legal basis for a "new driver's license" or redefine licensing requirements considering potential scenarios like tele-operation.

Clarifying responsibilities: Clearly define liability and responsibility for CCAM operation within the legal framework. This includes addressing the potential overlap between international law (UNECE) and European law (DG Grow, DG Move).

Centralized validation and certification: Create Europe-wide efforts for validation and certification of CCAM technologies. Moving the responsibility for placing CCAM vehicles on the market from individual member states to the EU level will ensure consistent standards and a more streamlined process (potentially requiring a new dedicated authority).

Conduct a comprehensive legislative scan for AV integration

The EC should conduct a comprehensive review of all its existing transport and logistics regulations to assess their compatibility with AV technology (e.g. Vienna Convention, role of the driver, etc.). Rapid advancements in AV technology have in many cases outpaced current regulations. This review would therefore identify potential hurdles and opportunities for adapting existing regulations to integrate AVs (e.g., review and update Implementing Regulation 1426). By proactively addressing regulatory gaps, the EC can create a more streamlined and innovation-friendly environment for the adoption of AVs. Overall, this tackles the challenge of making regulations more dynamic with technological developments.

Expedite AV testing through regulatory sandboxes

The EC should establish a framework for regulatory sandboxes across Europe, involving scientific and industry stakeholders to determine whether operation is possible within the desired restrictions.

This approach is crucial for Europe to remain competitive as level 4 automation is currently not authorized in most areas which is slowing progress. Regulatory sandboxes would address this issue by creating designated areas where companies could pilot AVs under specific conditions by facilitating a risk-managed approach to testing and development. This would allow for crucial data collection on AV performance and safety in real-world scenarios. An EU framework would therefore be of great benefit as engaging negotiation processes with local administrations can be time consuming.

In the meantime, regulatory sandboxes could act as a catalyst for attracting investment by creating a clear pathway for testing and deployment. Allowing companies to sell some units to then test them on public roads would foster significant progress in AV's deployment while allowing for evidence-based regulation.

Increase the attractiveness of the EU market for suppliers of automation solutions

So far, some member states have taken measures but there is no European-wide funding dedicated to AVs, and the Horizon fund is not sufficient to compete with the like of US and China. That was one of the complaints brought by companies about competing with the Infrastructure Investment and Jobs Act (IRA). Companies are actually leaving Europe for the US for they are getting federal funding there. Hence, there is a need for more funding and investment from the Commission for projects related to AVs in logistics, including for cross-border testing, in order to remain competitive.

Financially promote technology development among European manufacturers, no import of technology

More financial means supporting the development of AV technologies by European manufacturers are necessary to reduce Europe's reliance on imported technologies and foster a robust domestic AV industry.

Manufacturers/operators should be liable for damages and any accidents

Advocates for a well-defined legal framework that assigns liability to manufacturers or operators in case of accidents involving autonomous vehicles. This clarity is essential for ensuring accountability, deterring negligence, and protecting victims in the event of an accident.

Mandate a certain level of automation for all vehicles, using a step-by-step approach with benchmarks

This guideline proposes a gradual introduction of mandatory automation features in all new vehicles. This would be implemented in a step-by-step approach with clearly defined benchmarks, similar to the EU Green Deal model. The progressive rollout would improve road safety through advanced driver assistance systems (ADAS) and prepare the industry for the future widespread adoption of AVs.

5.2. Raising awareness

Define and implement a comprehensive EU-wide communication strategy for AVs

A clear and coordinated communication strategy across the EU is essential to raise public awareness of AVs and CCAM technologies. This strategy should address key concerns.

First, it should delve into how automation will change transportation and its broader societal implications. Transparent and honest information is critical. While acknowledging potential risks like accidents, the strategy should also highlight long-term benefits such as improvements in road safety and logistics efficiency. We also advise communicating more strongly about AVs' sustainability advantages.

Furthermore, the strategy should establish clear and consistent terminology for AVs that is easily understood by the public, while acknowledging varying levels of technology literacy among different users.

Finally, it is important to craft a compelling narrative that resonates with both the public and logistics operators, outlining the positive impacts of AV adoption. This is a task that should be coordinated on a high level and then scaled down so that individual entities can have a clear picture of what kind of narrative the EU strikes to convey.

By spearheading a comprehensive communication strategy that allows individual entities to adapt it, the EC can overcome public fear and skepticism. This will promote social acceptance and pave the way for successful AV integration across Europe.

Expand public engagement and pilot programs

A crucial step to continue to raise awareness of AVs and CCAM technologies is to implement AV pilot programs in more regions across Europe. These programs can provide the public with firsthand exposure to the technology and its potential benefits. Effective communication about these ongoing pilot programs is also essential. By clearly explaining progress, addressing concerns, and fostering transparency, the public can stay informed and engaged.

Furthermore, actively engaging citizens in discussions about AVs is vital. This allows for gathering public feedback, addressing anxieties, and building trust in the technology. A well-informed and engaged public is more likely to embrace AV integration.

Bringing together diverse stakeholders, including industry, policymakers, and citizen groups, will allows for a comprehensive understanding of needs, technology readiness, and potential use cases. By incorporating the perspectives of various stakeholders, effective communication strategies can be developed to raise awareness and promote AV adoption.

Develop training programs for public and logistics operators

This guideline highlights the necessity of developing training programs to prepare both drivers and logistics operators for the introduction of AVs. Each group of stakeholders must be addressed differently and specifically.

Training the public: As AVs become more prevalent, the general public needs to understand how to interact with them safely on the road. This might involve incorporating information about AV behavior and capabilities into new driver education programs. Additionally, public awareness campaigns can educate pedestrians and cyclists on how to share the road safely with AVs. By providing drivers with the necessary knowledge, this guideline aims to reduce the risk of accidents due to misunderstandings between humans and AVs and reduce their aversion to AVs' deployment.

Training logistics operators: The transition to AVs requires adjustments for logistics companies. The training should focus on operational standards to equip logistics personnel with the skills and knowledge to manage AV fleets effectively. This could involve training on new operational procedures, data management practices specific to AVs, and potential maintenance needs of these technologies.

Foster cross-border collaboration on awareness efforts

A unified approach to raising awareness is essential. By working together, EU member states can share best practices, develop harmonized messaging, and avoid confusion among the public. This collaboration could involve joint communication campaigns for instance. By fostering a collaborative environment, the EU can achieve a more unified and effective approach to raising awareness of AVs throughout the EU.

5.3. Standardization

Advocates for uniform data security standards for AVs across Europe

The EC needs to address cybersecurity and privacy concerns specific to AVs, particularly within the logistics sector. In terms of cybersecurity, while the EU's risk-based approach outlined in the AI Act is a strong foundation, it might require some adaptation for AVs. The current focus on generative AI needs to be broadened to increase the consideration given to the everyday operational risks associated with AI-powered logistics and AVs.

In terms of privacy, we acknowledge the challenges of regulating data privacy in the context of AVs. While a centralized entity overseeing AVs might be beneficial, striking a balance between data sharing requirements and protecting business confidentiality is crucial. Regulations should not force companies to reveal data that could jeopardize their competitive edge.

Overall, creating a robust framework that addresses data standardization issues specific to AVs will strengthen cybersecurity and foster trust in the technology.

Set infrastructure standards

To ensure a safe and seamless integration of AVs in mobility, several areas require standardization. Here we focus on two key aspects:

Physical infrastructure: Standardizing physical infrastructure elements like road markings, road signs, and traffic light communication protocols is crucial to ensure easy recognition by AV sensors. This harmonization will ensure clear and consistent communication between the road environment and AVs across different regions, improving safety and operational efficiency.

Charging infrastructure: Establishing standardized charging infrastructure for AVs is essential for seamless charging across Europe. This includes plug types, communication protocols, and potentially even power delivery specifications.

By implementing these standards, this guideline aims to create a more uniform and interoperable environment for AVs throughout Europe.

Standardize connected operations for AVs

Seamless communication and operation are crucial for AVs. Standardizing gateways will enable AVs systems to exchange data efficiently with each other, infrastructure, and connected devices, facilitating functionalities like real-time traffic updates and cooperative maneuvers. Additionally, standardization is essential for secure remote control of AVs. This includes protocols for secure communication channels, human-machine interfaces, and data security measures. By implementing these standards, the EU can create a more robust and interoperable environment for AVs across Europe.

Develop Dynamic and Comprehensive CCAM Standards

The EU should actively promote the development of dynamic and comprehensive CCAM standards that address the following key aspects:

Continuous refinement: Establish a framework for the continuous review and refinement of CCAM standards. This will ensure that standards remain relevant and accommodate evolving technologies and emerging use cases.

Uniform reporting: Develop standardized reporting mechanisms for CCAM operation. This will allow for the collection of comparable data across Europe, facilitating the evaluation of CCAM's impact, including potential rebound effects.

Safety requirements: Establish clear and comprehensive safety requirements for the use of automated vehicles. These requirements should address both technical specifications and operational procedures, ensuring the safe integration of AVs into the transportation ecosystem.

Scenario databases: Create standardized scenario catalogues and databases to be used for type approval and registration of CCAM vehicles. This will ensure a consistent and rigorous testing process across Europe, promoting safety and interoperability.

5.4. Infrastructure

Ensure predictable traffic flow: speed limit enforcement and digital infrastructure

The successful integration of AVs in logistics hinges on predictable traffic flow, especially in mixed environments with human-driven vehicles. In such cases, ensuring consistent adherence to speed limits is crucial. This can be achieved by deploying speed cameras at strategic placement along routes frequented by AVs. However, while speed limit enforcement is important, a broader approach to infrastructure digitalization is necessary due to the unpredictability of human behaviors. Therefore, equipping roadways with a denser network of sensors and cameras that provide real-time data on traffic flow, incidents, and potential hazards would allow AVs to adjust their behavior accordingly and further enhance safety and efficiency.

Enhancing human awareness of AV operations

While information exchange between AVs and infrastructure is crucial, there is also a need to enhance human awareness of AV activity on the road. This could be achieved by leveraging existing technologies like turn signals and brake lights or by exploring new ones that utilize data from AV sensors to provide real-time information that is readily perceivable by human drivers.

Enhance infrastructure for AV maneuvers

Equipping key intersections with smart traffic lights can significantly improve traffic flow and safety for both AVs and human-driven vehicles. These intelligent systems can be particularly beneficial for AVs, which can leverage the data to optimize route planning and intersection navigation. For example, smart traffic lights can improve the efficiency and safety of complex maneuvers like unprotected left turns.

These smart traffic lights should be strategically deployed at locations of greatest interest to logistics companies and AV operators. This targeted approach will ensure the technology benefits the segment most likely to utilize AVs.

Foster cooperative mobility with C-ITS

The successful integration of AVs in logistics relies heavily on the benefits of Cooperative Intelligent Transport Systems (C-ITS). This technology facilitates real-time information exchange between vehicles, infrastructure, and pedestrians. By implementing C-ITS, the EU

can significantly enhance safety, efficiency, and streamline operations for AVs in the logistics sector.

To achieve these benefits, the EC should prioritize two key actions. Firstly, promoting investment in C-ITS infrastructure along key logistics routes across Europe is crucial. Secondly, advocating for the development and adoption of standardized C-ITS protocols will ensure seamless information exchange and maximize the technology's potential.

Tailor infrastructure needs for diverse applications

It is important to consider the tradeoff between local requirements and generalization. The EU should advocate for a strategic approach to infrastructure development that considers the diversity of CCAM applications across various environments.

The minimum physical and digital infrastructure necessary for the different use cases in which CCAM is to be deployed should be defined separately. For instance, the minimum requirements for operating AV shuttles in a dense urban environment will naturally differ from those needed for autonomous agricultural equipment in a rural area. Moreover, encouraging infrastructure development that adapts to the specific needs of each environment (urban, suburban, and rural) is vital. Urban areas might prioritize high-density sensor networks for real-time data exchange, while rural areas might focus on strategically placed communication towers to ensure connectivity.

Prioritize integrated charging infrastructure

The successful integration of CCAM presents an opportunity to promote sustainable practices in the logistics sector. A key aspect of this is ensuring seamless integration with electric vehicle (EV) technology. The EC should take a holistic approach to CCAM infrastructure development, prioritizing sector coupling. This means strategically planning and integrating charging infrastructure for electric CCAM vehicles alongside the broader CCAM infrastructure rollout from the outset. This strategic placement of charging stations can optimize route planning for electric CCAMs, minimizing downtime and maximizing operational efficiency.

This forward-thinking approach will ensure CCAM not only revolutionizes logistics but also contributes to a more sustainable transportation future for Europe.

5.5. Others

Establish Clear Societal Goals for CCAM Deployment

The EU should take a leadership role in establishing clear societal goals for the successful deployment of CCAM, as well as their priority. We do not want to be in a situation where we implement technology for the sake of implementing technology. It needs to be based on solving a problem, addressing clear societal needs, including environmental sustainability.

Further research into the environmental impact of AVs, focusing on identifying emission-intensive areas within different automated applications, can inform targeted development efforts.

Foster Collaboration for Successful CCAM Implementation

The EU should play a key role in promoting cross-sector collaboration among key stakeholders to address challenges that cut across multiples domains. Building on the success of existing knowledge exchange platforms [14], the EU should further strengthen these efforts by promoting broader participation from the logistics sector, with a particular focus on facilitating cross-border collaboration to increase the exchange of best practices and lessons learned on CCAM project implementation across Europe. Finally, implementing incentive programs that encourage cooperation between technology companies will accelerate innovation and development of CCAM technologies. By actively fostering this collaborative environment, the EC can ensure that the expertise of various stakeholders is leveraged effectively.

6. Conclusions

This comprehensive roadmap has charted a course for the successful integration of CAHDVs into the European Union's logistics sector. As envisioned in Chapter 3, CAHDVs have the transformative potential to revolutionize every aspect of logistics, from last-mile delivery to long-haul transportation. Widespread adoption of CAHDVs promises to enhance efficiency, improve safety, and promote sustainability within the European logistics landscape.

This roadmap serves as a critical guide for all stakeholders – policymakers, industry leaders, researchers, and the public – as they navigate the exciting journey towards a future powered by CAHDVs. By outlining key focus areas and highlighting potential challenges, this roadmap equips stakeholders with the knowledge and direction necessary to overcome hurdles and unlock the full potential of this transformative technology.

Key Takeaways and a Call to Action

Across the roadmap's chapters, several key themes emerge as essential for successful CAHDV integration:

- Raise awareness of AVs and CCAM technologies: Implement AV mass scale pilot programs in more regions across Europe.
- **Harmonized Regulations and Funding:** A clear and consistent legal framework across the EU, coupled with robust funding initiatives, is paramount. This will foster a competitive European AV industry and ensure safe and responsible deployment of CAHDVs.
- **Public Awareness and Stakeholder Collaboration:** Addressing public concerns and building trust are crucial. Effective communication strategies, public engagement programs, and training initiatives are necessary to prepare all stakeholders for the

transition. Open and collaborative partnerships between industry, academia, and government will accelerate innovation and ensure successful implementation.

- **Standardization and Infrastructure Development:** Robust data security protocols and standardized infrastructure specifications are essential for seamless and safe AV operations. Investments in digital infrastructure, smart traffic systems, and integrated charging stations will pave the way for widespread CAHDV adoption.

By prioritizing these key focus areas, the EU can position itself as a global leader in CAHDV development and deployment. This leadership will not only unlock economic benefits but will also contribute to a more sustainable and efficient transportation ecosystem. The potential for improved safety, reduced emissions, and a revitalized logistics sector is significant.

Looking Forward: Embracing the Future of Logistics

The roadmap serves as a springboard for exciting possibilities. As the EU embraces CAHDVs, we can anticipate a future where:

- **Logistics operations are significantly more efficient:** Automated routing, optimized schedules, and streamlined processes will dramatically improve delivery times and reduce costs.
- **Safety on the roads is considerably enhanced:** Advanced driving systems and a connected infrastructure will minimize human error and lead to a significant decrease in road accidents.
- **Sustainability becomes a cornerstone of the logistics sector:** Reduced fuel consumption, optimized routes, and integration with electric vehicle technology will contribute to a cleaner and more environmentally friendly transportation system.

The successful integration of CAHDVs presents a unique opportunity for the EU to reshape its logistics landscape, unlocking economic growth, environmental improvements, and societal benefits. By harnessing the collective knowledge and collaborative spirit outlined in this roadmap, the EU can pave the way for a future where CAHDVs revolutionize the way goods move across Europe.

References

[1] abbmarine, Hutchison Ports Stockholm – Automating for the future [Video file], *no location*, June 2022

[2] Ardiyok, S., & Articles, A., The legal framework for autonomous vehicles in the European Union, *no location*, February 2020.

[3] Balyo, Balyo: about us, *no location*, May 2024

[4] Baniulis, M., & Welsch, S., How many airports are there in the world?, *no location*, February 2024.

[5] BlueWeave Consulting, Europe Autonomous Forklift Market Size, Share & Trend 2029, *no location*, November 2023

[6] Borrás, J., Walmart is putting AI-powered electric forklifts to work [video], *no location*, April 2024

[7] Buzinkay, M., The limits of container port automation, *no location*, February 2023.

[8] CNBC, How Aurora got Self-Driving trucks on the road [Video file], *no location*, August 2023

[9] Credence Research, Europe Autonomous Forklift Market, *no location*, May 2024

[10] Cyrus Janssen, How China built the world's first FULLY automated 5G port [Video file], *no location*, February 2023

[11] DesignABetterBusiness.Tools, 5 Bold Steps Vision® Canvas, *no location*, April 2024.

[12] Discovery UK, How do 80,000 "Lipsticks" help the largest port in Europe run on automation? | Richard Hammond's Big [Video file], *no location*, June 2020

[13] ENSEMBLE, ENSEMBLE final event, *no location*, March 2022

[14] ERTRAC, Connected, Cooperative, and Automated Mobility (CCAM) Roadmap for Europe, *Brussels*, July 2022

[15] ERTRAC, Long-Duty Freight Transport Roadmap 2019, *Brussels*, July 2019

[16] European Commission, No more stranded passengers at airports in the winter thanks to self-driving snow clearing vehicles, *no location*, March 2021

[17] European Parliament, Connected and Automated Driving: An Overview, *Brussels*, 2016

[18] Fortune Business Insights, Freight Trucking Market Size, Share & Industry Analysis, By Truck Type (Refrigerated Truck, Tanker, Dry Van, and Flatbed), By End User (Automobiles, Machinery, Apparels & Footwears, Pharmaceutical Products, Retail, Electronics, Petrochemicals, Agriculture, Building Materials, and Others), and Regional Forecast, 2024-2032, *no location*, May 2024

[19] Global Market Insights, Airport Automation Market - By System (Data Storage, Automation & Control, Data Acquisition & Communication, Software & Solutions), By Level of Automation, By Technology, By Application, By End User & Forecast, 2024 – 2032, *no location*, February 2024

[20] Grand View Research, Forklift Market Size, Share & Trends Analysis Report, 2030, *no location*, 2024

[21] Halden, J. E., Yeti Move keeps the runways clear of snow with AI and machine learning, *no location*, April 2024

[22] Heater, B., Vecna gets $65M to replace forklifts with robots, *no location*, January 2022

[23] Higgs, R., FEATURE: MAN achieves real-world platooning trial success, *no location*, June 2019

[24] Internal document Enide, T.7.2 Regulatory, Market analysis Avs, *Barcelona*, 2022.

[25] Introspective Market Research, Airport Automation Market-Global Share Analysis (2024–2032), *no location*, May 2024

[26] inVia Robotics, AMR vs AGV Robotic Solutions in Warehouse Automation [Video], *no location*, May 2023

[27] Jentzsch, G., ATLAS-L4 funding project: self-driving from hub to hub, *no location*, June 2022

[28] KPMG China, Special Report on Autonomous Driving, *China*, June 2022

[29] Logistics Business, Milestone for Autonomous Heavy-Duty Truck Commercialization, *no location*, May 2024

[30] Marcellin, F., How airports can act as testbeds for autonomous vehicles. Airport Technology, *no location*, May 2018

[31] MarketsandMarkets, Airport Automation Market Size, Share, Industry Growth, Trends, and Analysis 2028, *no location*, January 2024

[32] Mehra, A., Market Leaders - Forklift Market, *no location*, November 2022

[33] Mok, K., Changi prototypes smart tech to transform future airport operations, *no location*, February 2023

[34] Research And Markets, Airport Logistics System Global Market Report 2024, *no location*, May 2024

[35] Research And Markets, Global and China Forklift Industry Report, 2020-2026, *no location*, May 2020

[36] Research And Markets, Forklift Trucks Market - Growth, Trends, COVID-19 impact, and Forecasts (2023-2028), *no location*, April 2023

[37] Serban, A., Poll, E., & Visser, J., A Standard Driven Software Architecture for Fully Autonomous Vehicles, *no location*, February 2020

[38] SICK, Automation in intralogistics: Perfecting the automated forklift truck, *no location*, October 2022

[39] Siwik, W., Autonomous Trucking Projects in Europe, *LinkedIn*, January 2024

[40] Siwik, W., Startups Paving the Way for Yard Truck Automation, *LinkedIn*, April 2024

[41] Statista, U.S.: automated guided forklift market size 2021-2027, *no location*, September 2023

[42] UNCTAD, Handbook of Statistics 2023, *no location*, December 2023

[43] UNCTAD, Key Freight Transport-related Data, *no location*, June 2024

[44] UNCTAD, Review of Maritime Transport 2023, *no location*, September 2023

[45] VisionNav Robotics, Automated Agility: The Power of Self-Driving Forklifts, *no location*, December 2023

[46] Volvo Autonomous Solutions, The Volvo VNL Autonomous — Proving the Way Forward, *no location*, May 2024

[47] Volvo Trucks, Volvo Trucks Official Website, *no location*, April 2024

[48] Wadhwani, P., Forklift Market Size - By Product (Warehouse, Counterbalance), By Fuel Type (Diesel, Electric, Gasoline & LPG/CNG), By Class (Class I, Class II, Class III, Class IV, Class V), By End Use (Chemical, Industrial, Logistics, Retail & E-commerce), & Forecast 2024 – 2032, *no location*, January 2024

[49] Wadhwani, P. & Ambekar, A., Autonomous Forklift Market Size - By Product (Warehouse, Counterbalance), By Navigation Technology, By Application (Manufacturing, Warehousing, Material Handling, Logistics & Freight), By End-User Industry, By Tonnage & Forecast, 2024 – 2032, *no location*, May 2024

[50] Wilson, N., British Airways to roll out robot baggage carriers at Gatwick Airport, *no location*, March 2024

[51] Wood, I., Changi Airport to pilot autonomous electric baggage vehicles, *no location*, May 2024

[52] YIT, The Future of Forklift Technology: Top industry trends this year, *no location*, May 2024