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Development Trajectories for Autonomous Electric Trucks

Identifying Important Aspects and Promising Development Paths

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Abstract

The road freight trucking sector is transforming, where autonomous electric trucks (AETs) could fundamentally reshape the industry. While stakeholders have identified short-term objectives and possibilities, a comprehensive understanding of long-term strategic development is lacking. This thesis aims to address this gap by investigating two main aspects to increase the understanding for future development. Firstly, identifying critical factors and capabilities necessary for developing the next generation of AETs, focusing on technological requirements, regulatory compliance, and market positioning. Secondly, develop and present possible development paths for AET deployment over a 2-5 year time horizon, ensuring feasibility and competitiveness.

Employing a qualitative methodology encompassing a literature review, industry study, and interviews, the research identified crucial development factors and a novel industry categorization based on environmental complexity, attributes, and stakeholders. Rigid and tractor-trailer form factors emerged as primary differentiators, leading to two distinct development trajectories based on development in operational design domains instead of developing for a specific market as the same operational design domain can exist in different markets.

Initial rigid truck deployment is in fenced-off environments, gradually expanding into rural areas. Deployment in urban settings would be the last step, but it is not expected within the time frame. Conversely, tractor-trailers should initially deploy in rural areas, aiming for expansion to highway operations, which is the main goal for this form factor. Finally, progressing towards semi-urban scenarios to increase the use case and enable end-to-end services. Key factors for success include a customer-centric view regarding the choice of sensors, form factor, and data collection to improve autonomous driving system capabilities. Identifying business models that address high upfront costs with operational efficiency is necessary for long-term success. Safety validation and public acceptance are further important to facilitate the deployment process.

Reshaping the supply chain and how truck utilization could further disrupt the industry and improve the benefits of AETs. Further research should focus on a smooth and economically viable transition to autonomous freight transport and investigate niche markets. This study provides actionable insights and a clear roadmap for stakeholders seeking to navigate the complex landscape of AET development and deployment.

Sammanfattning

Vägtransportsektorn genomgår ett paradigmskifte, där autonoma elektriska lastbilar (AET) utvecklas för att förbättra branschen. Sänkta driftskostnader, ökade hållbarhetskrav och operativ effektivitet är alla fördelaktiga faktorer som främjar AETs. Trots att kortsiktiga mål och möjligheter har identifierats i branschen saknas en heltäckande förståelse för långsiktig strategisk utveckling. Denna avhandling adresserar detta genom att undersöka två huvudområden för att öka förståelsen för framtida utveckling. För det första ska kritiska faktorer identifieras samt förmågor som är nödvändiga för att utveckla nästa generation av AET, med fokus på tekniska krav, säkerhet och marknadspositionering. För det andra ska möjliga utvecklingsvägar tas fram och presenteras där AETs kan implementeras och vara konkurrenskraftiga inom en 2-5 års horisont.

Denna studie använder en kvalitativ metod för att uppnå dessa mål genom att kombinera litteraturstudier, marknads- och konkurrentanalys samt intervjuer med personer inom industrin. Analysen visade flera faktorer för utvecklingen av autonoma lastbilar, vilket ledde till en kategorisering av områden baserade på miljöns komplexitet, attribut inom rutter och intressenter inom marknaden. Lastbilsegenskaperna "rigid" och "tractor-trailer" framkom som de primära differentierande faktorerna som har störst påverkan på utvecklingsvägen framåt. Följaktligen formulerades två distinkta utvecklingsbanor, var och en anpassad för de tidigare nämnda lastbilsegenskaperna för att underlätta framgång inom lastbilsbranchen. Dessa utvecklingsvägar baseras också på områden istället för marknader eftersom samma område kan existera i olika markander.

Initial implementering för egenskapen “rigid” sker i avgränsade miljöer, och expanderas gradvis till landsbygdsområden. Implementering i stadsmiljöer skulle vara det sista steget, men förväntas inte ske inom den satta tidsramen. “Tractor trailer” borde å andra sidan initialt implementeras i landsbygdsområden, med målet att expandera till motorvägskörning, vilket är huvudmålet för denna typ av lastbil. Slutligen fortsätter utvecklingen mot semi-urbana möjliggöra end-to-end rutter. Nyckelfaktorer för framgång inkluderar ett kundcentrerat perspektiv gällande val av sensorer, lastbilsegenskaper och datainsamling för att förbättra utveckla AET. Att identifiera affärsmodeller som adresserar höga initialkostnader med operativ effektivitet är nödvändigt för långsiktig framgång. Säkerhetsvalidering och allmän acceptans är ytterligare viktiga aspekter för att underlätta implementeringsprocessen.

Omformningen av leveranskedjan och hur lastbilar utnyttjas kan ytterligare störa branschen och förbättra fördelarna med AET. Ytterligare forskning bör fokusera på en smidig och ekonomiskt genomförbar övergång till autonom godstransport och undersöka nischmarknader. Denna studie ger praktiska insikter och en tydlig färdplan för intressenter som vill navigera i det komplexa landskapet av AET-utveckling.

Acknowledgments

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Firstly, we would like to thank our supervisor at the case company. We are grateful for the engagement and efforts throughout the project. The support and input from day one have been of great value. We are grateful for the opportunity to work with the case company and its employees, who have been inclusive and helpful. We would also like to thank all the interviewees who took the time to share their experience and insights with us. Secondly, we would like to show our appreciation to our university supervisor, Jenny Janhager Stier, who works in the Integrated Product Design department. Her guidance and support regarding structure and report have improved and elevated the project.

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Acronyms, Abbreviations and Vocabulary

ADS	Autonomous driving system
AET	Autonomous electric truck
AT	Autonomous truck
Edge Case	Events or interaction within a route were the outcome could not be predicted
Nondetermanistic Objects	Objects which are hard to predict, sush as humans and animals
Form Factor	Shape and size of the truck and cargo area
ODD	Operational design domain
TCO	Total cost of operation

1 Introduction

The following chapter outlines the background to provide an understanding of the trucking industry and the challenges associated with autonomous electric trucks (AETs). It is followed by the purpose and motivation for doing this research. The limitations of the study conclude the chapter.

1.1 Background

The current market of autonomous electric truck (AET) is well understood, but how the future will evolve is still uncertain. As the AET industry is relatively new with a rapid pace of development, nobody knows what the industry will look like in 10 years (Kelkar et al., 2024). There is a research gap in identifying important aspects for the development and deployment of the next generation of AETs in the next two to five years. This report aims to understand these critical aspects for the next generation of AET.

Road freight transportation accounts for roughly 20% of the total tonne-kilometers shipped worldwide (Greene, 2023). It is expected to expand further from its current state, with a projected increase of 25% by 2030 (European Commission, 2023). The industry faces changes due to political, economic, and demographic shifts and disruptive technological innovations. Environmental aspects are equally important, as the trucking industry emits 6% of the total emissions in the EU across all categories. Regulatory changes have increased the demand for a more sustainable trucking industry, aiming to reduce total carbon emissions by 90% by 2040 (European Commission, 2021). Another issue within the industry is the shortage of truck drivers, where a 17% deficit is estimated by 2028. Furthermore, the profit margins are low due to high competitiveness and high driver salaries, making the transition to new technology more challenging (Parviziomran, Elliot, and Bergqvist, 2024). Autonomous driving systems (ADS) have been identified as one of the innovative factors transforming road freight in the logistics industry (Pernestål et al., 2020; Yurtsever et al., 2020).

The ADS has evolved through different levels of automation, which are measured according to SAE levels of driving automation (SAE, 2021). AETs are on the rise and are starting to deploy across the industry in dedicated Operational Design Domains (ODDs) (Lee et al., 2020). These describe conditions where the driving automation system can operate and function according to its safety and technical capabilities. The AET will, in addition to ADS, also minimize the environmental impact on the freight transportation system, due to its fully electric characteristics (Ercan et al., 2022). Previous studies have identified several key factors to consider when entering a new market with an autonomous vehicle such as scenery, environmental conditions and dynamic elements (BIS, 2020).

The current and short-term direction of autonomous electric trucks is relatively clear for actors operating in the industry and researchers in the field. Companies strive to reach level 4 automation and develop a cost-effective business case, starting in confined areas (Engström et al., 2018; Hashimy and Rosines, 2021; Sindi and Woodman, 2021). However, the development path for autonomous trucks over an extended time horizon remains uncertain, requiring additional knowledge to determine the right direction and identify the most promising markets (Engström et al., 2018). Exploring new markets to understand customer needs and specific requirements better will facilitate future innovative solutions for AETs (Engström et al., 2018; MacMillan, 2014). The needs and challenges within the industry must be considered in the development of autonomous electric trucks to be feasible and competitive (Chen and Lu, 2020; Sindi and Woodman, 2021; Engström et al., 2018; Leih and Teece, 2016).

1.2 Purpose

The electric autonomous heavy freight industry remains an underdeveloped market, with multiple companies competing to become the market leaders in AET. Jesemann et al. (2021) and Shepherd and Patzelt (2021) identified the importance of a customer-driven approach in product innovation. This led to the purpose of the thesis to investigate specific segments within the heavy road freight industry, where development and deployment should aim towards. Identifying feasible paths and site-specific opportunities will enhance the development of the next generation of AETs, enabling them to gain a competitive advantage and achieve success.

Another objective of the thesis was to identify key success factors in the specific areas and industries crucial for developing and deploying innovative vehicles. Sindi and Woodman (2021) recommended six key considerations for commercializing autonomous trucks from a supply chain perspective in the future. Thus, this thesis will focus on a company perspective and the necessary considerations for developing the truck to achieve long-term success. It ensures that the development focuses on relevant metrics and informs the decision-making process from the company's perspective.

1.3 Delimitation

Due to regional limitations, this project will focus on the European and US markets as many companies operate in these markets today. Data and statistics vary from one market to another in terms of quantity and measurement metrics therefore these markets where chosen. The qualitative and quantitative data will allow the project to estimate trends and fill gaps within the existing research. The research will primarily focus on a 2-5 year horizon, including assumptions about the development of regulations, technology, and market adaptability, with limited consideration of the long-term path. This time frame was established as the near term challenges are relatively well understood and the time beyond this is really hard to accurately predict.

Legal issues relevant to the implementation and operation of autonomous vehicles will be addressed. However, this report will focus on requirements, considering the market landscape for the development of the next-generation AET.

2 Theoretical Framework

The following chapter lays out the theoretical framework for freight and AETs. It begins with general research on subjects such as current issues in heavy road freight and electrification, and subsequently proceeds to actors, future trends, and the actors within the market.

2.1 Electrification and Automation in Road Freight

The following section outlines the current perception of autonomous electric trucks and the challenges facing the heavy freight transport market. It highlights the divisions regarding operational design domains, levels of automation, and the impact of cost and safety on adopting autonomous electric trucks.

2.1.1 Current Issues Affecting the Industry of Autonomous Trucks

The transport industry has multiple challenges ahead, as changes in economic, social, and environmental concerns will benefit the implementation of autonomous trucks (Fritschy and Spinler, 2019). The road freight volume has increased by 22% from 2013 to 2022 (Iru, 2024b), and is estimated to increase 500% by 2050 (Stepper, 2023). Heavy-duty trucks account for 5% of the total CO_2 emissions globally (Olsson et al., 2023), and 6% within the EU (European Commission, no date b). The trucking industry will therefore face added pressure to become more sustainable, which must decrease the total carbon emissions by 55% by 2030 to reach the goal set by the EU (European Commission, 2021). Even with current policies aimed at decarbonization, CO_2 emissions from the transportation industry are estimated to increase by 16% by 2050, underscoring the need for change (OECD, 2021). The importance of reducing the environmental impact of road freight transport increases as the industry faces significant growth over the upcoming years in the EU (European Environment Agency, 2024).

Further challenges within the industry include the driver shortage. The US market is missing 80,000 drivers, while the European market is missing 200,000 drivers (Kelkar et al., 2024). These numbers are estimated to increase to 160,000 and 745,000 by 2030 and 2028, respectively. Consequently, companies cannot expand their businesses, significantly reducing productivity and revenue (Iru, 2024a).

The financial aspects regarding the sustainable transition are significant (Parviziomran, Elliot, and Bergqvist, 2024; Nadel, 2019; Nkesah, 2023; Matos and Perello-Marin, 2024). The market faces increased competition (Poliak et al., 2021) with low profit margins (Department for Transport, 2024) which further highlights the challenges associated with the transition to AETs which has as a high initial investment, despite estimations of AETs to decrease long-term costs (Link and Plötz, 2022).

2.1.2 Electrification of the Road Freight Transportation Industry

The electrification of road freight is a step in the right direction towards a more sustainable trucking industry, considering both environmental and economic aspects. Electric road freight vehicles are estimated to outperform current internal combustion engines in every use case and metric by 2035 (Unterlohner and Maier, 2022).

Battery-electric heavy-duty trucks have a significant advantage over their gasoline counterparts regarding sustainability (Scania, no date). Transforming the road freight industry to electric aligns with the goal set by the EU, where emissions from trucks should be significantly reduced by 2030 (European Commission, 2021). Batteries also supply the autonomous system with large amounts of power, which requires a stable power source with low latency to function correctly (GM, no date). However, being powered by batteries comes with challenges regarding the truck's limitations and the surrounding infrastructure.

The first challenge is the weight, as the heavy batteries occupy a portion of the total allowed weight as it not only puts more load on the axles, but also reduces the cargo capacity affecting the range (Giacobone, 2023; Engholm, Allström, and Akbarian, 2024). However, considering the total cost of operation (TCO), battery size, and charging strategies could be adjusted to optimize the ratio between distance and total amount of shipped goods to outperform traditional trucks (Baek et al., 2020; Link and Plötz, 2022; Karlsson and Grauers, 2023; Engholm, Allström, and Akbarian, 2024).

The second challenge is the surrounding infrastructure on different sites, hubs, and roads (Alanazi, 2023). Investments are needed in infrastructure and charging capabilities to utilize new roads. The infrastructure changes would increase the number of feasible routes and distances, both from a financial and technical point of view (Alanazi, 2023). With logistics changing, there is also a need for infrastructure to transform, and this development will rely on external stakeholders to evolve (Kim, Kim, and Park, 2022).

2.1.3 Autonomous Electric Trucks

AETs stand to disrupt the industry with their combination of electric and autonomous capabilities (Ghandriz et al., 2020), see Figure 1 for categories that build the foundation of an AET. Autonomous driving systems (ADS) are constantly improving and are operating in both personal vehicles and commercial trucks (Favarò, Eurich, and Nader, 2017). According to Chiao et al. (2024), autonomous trucks are estimated to be viable between 2028 and 2031.

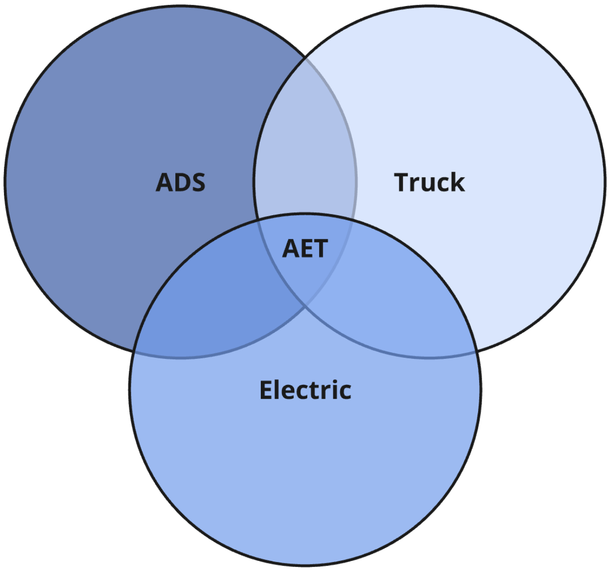


Figure 1: *Main components of an AET*

2.1.4 Level of Driving Automation

Different levels of autonomous driving systems (ADS) are often measured using definitions from the Society of Automotive Engineers (SAE, 2021). The standard has a scale ranging from 0 to 5, where level 0 has no automation, and level 5 is fully autonomous without human interaction. The primary focus for commercial deployment is from level 4 and above as it is the first level that does not require a driver within its domain (SAE, 2021). A driverless trucks is preferred since it allows for the financial and liability benefits of removing the driver to be competitive (Aboulkacem and Combes, 2020). Level 4 autonomous driving requires pre-determined driving conditions that specify where the vehicle can operate and outline the necessary technical and safety specifications for all scenarios. In contrast, Level 5 operates without restrictions and handles any driving conditions, enabling full autonomy in any environment. Levels 4 and 5 are the only fully driverless categories (SAE, 2021). In both level 4 and level 5, the vehicle can perform all driving tasks, with the main difference being that level 4 are only allowed in specific pre determined areas. In level 5, the vehicle should be able to handle any conditions at any given time, therefore not having any restrictions (SAE, 2021). According to Kelkar et al. (2024), level 5 automation will not be deployed on the European market until 2032, indicating that full self-driving in all conditions is still some time away.

2.1.5 Operational Design Domain

AETs with Level 4 automation are only allowed to drive in specified areas and conditions, such as weather and speed, in which the truck has been proven and validated to operate safely (Mehlhorn, Richter, and Shardt, 2023). These areas where the truck can operate safely in are refereed to as operational designed domains (ODDs).

Even though it is challenging to evaluate all real-life scenarios, extensive analysis, simulations, and tests make sure that AET can operate as safely as possible within specifications in the new domain scenarios (Ito, 2021). Generic evaluation of ODDs is still uncertain regarding the development of level 4 (Mehlhorn, Richter, and Shardt, 2023).To ensure safety and rigorous evaluation, autonomous vehicle testing in Sweden begins in pre-defined areas that closely mimic real-world scenarios. Functionality, hazard identification, and risk assessments are carried out on vehicles before the vehicles can operate in live traffic. (Sobiech et al., 2023).

AETs are currently operating in controlled environments, with a remote operator monitoring the truck at all times. Multiple companies are conducting tests on public roads to explore the possibilities of expanding the use cases for AETs. There is no generic definition of evaluating and defining ODDs (Yurtsever et al., 2020). A challenge is that the safety case can only be valid if the specified ODD remains the same at all times, including weather and unpredictable obstacles such as humans(Gyllenhammar et al., 2020). Using various redundant sensors will minimize the chance of failures and improve the safety case within the ODD (Yurtsever et al., 2020).

Public roads are not widely available for commercial level 4 operation, due to a lack of a compelling safety case, thus limiting the sites and routes where an AET could operate (Traton, 2022). Further challenges that need resolution when driving on public roads are that autonomous trucks have to comply with regulations, incident handling, and interaction with authorized personnel (Sobiech et al., 2023). Simple manual tasks such as placing warning triangles in emergencies are further requirements that have to be solved autonomously.

Sites and industries have different challenges and opportunities for deploying autonomous vehicles. Attributes of the surroundings are vital to determining the feasibility of the ODDs when exploring new operational domains for AETs. Studies have been clustering attributes to consider when choosing suitable domains. These are scenery, environmental conditions, dynamic elements, and connectivity, shown in Figure 2. Benchmarking which attributes could be solved with product-specific and technological requirements will help define the needs in different scenarios for different routes and sites (Mehlhorn, Richter, and Shardt, 2023).

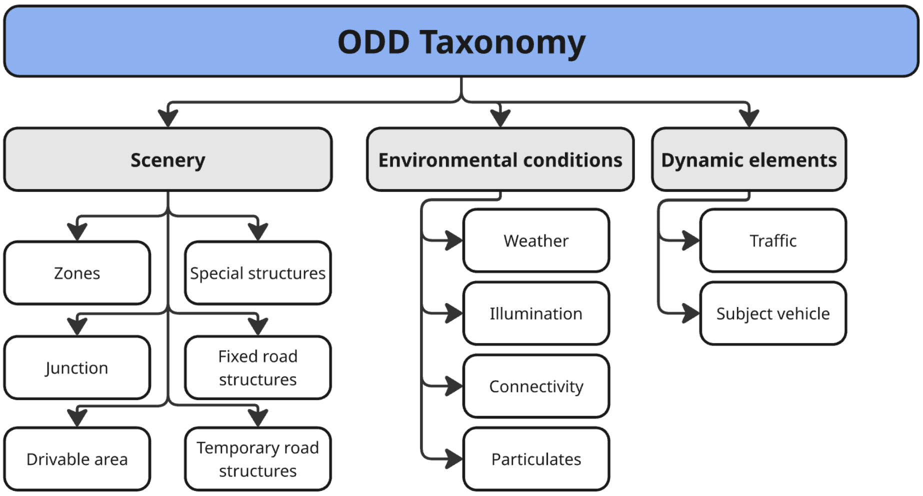


Figure 2: *Top level ODD taxonomy with primary and secondary attributes of the PAS 1883 (Mehlhorn, Richter, and Shardt, 2023)*

2.1.6 Financial Aspects of AET

The costs of autonomous electric trucks depend on several aspects, such as operational, acquisition, and development costs. Just removing the driver could significantly reduce total operating cost upwards of 30% based on salary alone (Wadud, 2017).

AET requires a significant initial investment before deploying, but could reduce the operational cost compared to conventional trucks, making it a long-term investment (Engholm, Allström, and Akbarian, 2024). This initial cost comes down to expensive hardware and software to enable the functions of the autonomous riving system (ADS). The ownership for early adopters in autonomous freight will have a higher cost of entry, as much of the development cost will likely be upfront (Wadud, 2017). The ADS is a newer technology that will be expensive to develop which reflects on the price for early adopters. Developing a robust and safe autonomous driving system will eventually replace the driver, thus resulting in long term cost reductions in operation. (Wadud, 2017; Engholm, Pernestål, and Kristoffersson, 2020). However, this also has other implications, as drivers sometimes perform tasks not yet solved with technology, such as loading and unloading. Regulations further require the truck to be supervised even though it drives autonomously (Engholm, Pernestål, and Kristoffersson, 2020). This could be done remotely via a remote operator, which eventually could monitor multiple trucks at the same time. These types of activities and the need for a remote operator cannot be ignored when looking at the total cost of operation.

Another way the high initial cost could be offset to reach profitability is through higher operational utilization. Engholm, Allström, and Akbarian (2024) highlights that AETs can be profitable compared to more traditional internal combustion engine trucks if their utilization is high enough. Another key component discussed for the profitability of AETs is the charging infrastructure in combination with battery capacity. The problem with batteries is that they are heavy and can limit cargo capacity, therefore not being as competitive on longer routes (Engholm, Allström, and Akbarian, 2024). Using lighter trucks with less range could be more cost-effective from a standpoint of total cost of operations (Earl et al., 2018). Batteries are also expensive, increasing the hardware cost of the truck. Others suggest that converting traditional internal combustion engine trucks to autonomous could be a short term solution to be cost effective on longer routes, since the battery capacity does not have to be considered (Kelkar et al., 2024; Karlsson and Grauers, 2023).

Autonomous trucks (ATs) has potential cost benefits in production and development compared to traditional trucks. The one with the most significant potential cost savings is the complete removal of the driver, where studies have shown that partial automation has no economic benefits (Aboulkacem and Combes, 2020). Furthermore, the driver's cabin accounts for as much as a third of the production cost of a traditional truck which is unnecessary for an autonomous truck (Engholm, Pernestål, and Kristoffersson, 2020). However, the expensive ADS system reduces some of the cost benefits from removing the cab short term.

Another major part of the cost for autonomous trucks, especially AET, is that the current infrastructure is not meant for this operation and, therefore, cannot support it (Hirsch, 2023). The infrastructure, such as charging points for AET or designated parking spots for all autonomous trucks has to improve. It was also highlighted by the fact that current business models within the trucking industry will have to change to reach the full benefit of autonomous trucks (Monios and Bergqvist, 2019a).

Current business models rely on a human driving the truck, which will not happen with an AT. Many business models are structured around the driver and will likely change when ATs are introduced (Monios and Bergqvist, 2019a). The new ATs and AETs will likely transition towards a service center business model where freight transportation is sold as a service instead of selling physical trucks, changing the market entirely. The commercial accepted range for a payback period ranges from 3-5 years. It is estimated that beyond 2030 the payback time for a battery electric truck will be somewhere in the range of 4-5 years indicating that they will become more cost effective in the future (Danielis et al., 2025; Burke et al., 2023).

2.1.7 Total Operational Costs for Autonomous Heavy Duty Road Freight

Longer transportation distances offered a greater cost reduction per kilometer, compared to shorter distances for autonomous trucks, mainly due to manual labor associated with driving and loading the truck (Kelkar et al., 2024). Studies comparing battery electric trucks and traditional trucks with and without ADS level 4 show that AETs are more cost-competitive over longer ranges per kilometer. However, their optimal speed is lower, at 60 - 80 km/h in most scenarios, mainly due to the trade-off in size and cost of a bigger battery (Ghandriz et al., 2020). Furthermore, the total cost of operations (TCO) was lower for smaller vehicles. These autonomous trucks further have the greatest profit margins compared to heavier trucks. The removal of the driver and loading efficiency are the main contributors to the reduction.

Lighter AETs have a greater TCO reduction than their heavier counterparts, suggesting that driver costs are the primary contributor to the reduction (Lee et al., 2023). Studies show that removing the driver completely could reduce the operating cost by 45% up to 65% in some cases (Lee et al., 2023). Further studies show that a greater relative reduction could be had with smaller trucks when converting them to autonomous electric trucks (Engholm, Pernestål, and Kristoffersson, 2020). Multiple studies suggest that the increasing utilization rate is an important aspect for AETs to be profitable compared to their counterparts (Engholm, Pernestål, and Kristoffersson, 2020; Bray and Cebon, 2022; Ghandriz et al., 2020). To drive on the highway, speeds up to 80 km/h are needed to deliver goods cost-effectively and on time (Bray and Cebon, 2022).

2.1.8 Legal and Safety

Accidents in the trucking industry are caused by human error in 90% of the cases (Kim, Kim, and Park, 2022). Since trucks with self-driving level 4 do not rely on a human driver, these accidents could be significantly reduced. However, these autonomous vehicles must prove safer before being allowed on major public roads (Prasetio and Nurliyana, 2023). Issues like liability, ethical concerns, allowed operational areas, and capabilities all need regulation (Sever and Contissa, 2024). A remote operator that can control the vehicle remotely is a big step towards autonomous driving because then a driver does not have to be present in the vehicle (Pillath, 2016). However, some countries do not allow autonomous operations without a human driver on board (Prokopiuk, 2024). These regulations are essential since one of the selling points of going autonomous is to remove the cost of the driver, enhancing the feasibility and the potential of AETs (Costello and Kirickhoff, 2019; Leslie and Murray, 2022).

Multiple incidents have been seen in the autonomous industry, raising concerns about the safety of autonomous vehicles on public roads. The ethics of responsibility, decision-making, and how safe is safe enough are also issues (Koopman and Wagner, 2017). In addition, improving the technical capabilities of sensors and detection systems on trucks is also needed (Yurtsever et al., 2020).

The complexity of mixed public traffic environments presents a substantial safety hurdle, primarily due to the demands placed on object recognition and the ability to handle unpredictable traffic scenarios which are referred to as edge cases (Fagnant and Kockelman, 2015). Technical and safety issues in edge cases are still barriers to overcome for commercial deployment (Engström et al., 2018). In terms of pedestrians and trucks, environments with minimal traffic have relatively low speeds, which eases regulation within these domains and is where most of the current deployments have been seen (Barosan et al., 2020).

In Sweden, AV operations are allowed under specific permits issued by Trafikverket. These permits are issued on a case-by-case basis, and several safety aspects need to be demonstrated before operation can commence (Hansson, 2020). This demonstration is to assure that the environment is suitable from a safety aspect as well as the AV being able to operate in a safe manner.

The acceptance of autonomous vehicles differs between demographics and geographical areas worldwide (KPMG, 2020). This study showed that the Netherlands, Norway, and the US had the highest overall readiness index within the EU and US. Looking at the regulatory perspective, the same study showed that the UK, the Netherlands, and Finland have the most supportive legislation.

2.2 Overview and Classification of the Heavy Duty Freight Segment

The following section aims to give an overview of the heavy freight segment in the transport industry and its different types of trucks. It also highlights different ways the same market could be segmented and classified.

2.2.1 Heavy Duty Road Freight Supply Chain Segmentation

The segmentation of road freight trucks has multiple factors to consider and take into account. The industry has multiple variables, and the characteristics of the trucks and the ODD taxonomy differ between the stages of the supply chain. This makes the segmentation complex, and depending on the characteristics of the route, the same vehicles could operate in a variety of industries and different parts of the supply chain.

The supply chain can be categorized into three use cases: first-mile, middle-mile, and last-mile (Hashimy and

Rosines, 2021). These cases differentiate based on distance, type of road and type of distribution site. The supply chain segmentation could be cross-linked to geographical environments. First, middle and last mile generally correlates to rural, highways, and urban environments respectively (Yurtsever et al., 2020). Others suggest that these categories can be broken down further as the middle-mile segment can be split into two use cases: one for longer distances on highways and the other for shorter distances between hubs (Dawkins and Gündoğdu, 2021).

Fenced-off areas such as ports and intermodal terminals should also be included in a modified, generalized supply chain, presented in Figure 3. These controlled environments are easier to operate in and can not be ignored as a possible initial step in the development path for AETs (Engström et al., 2018).

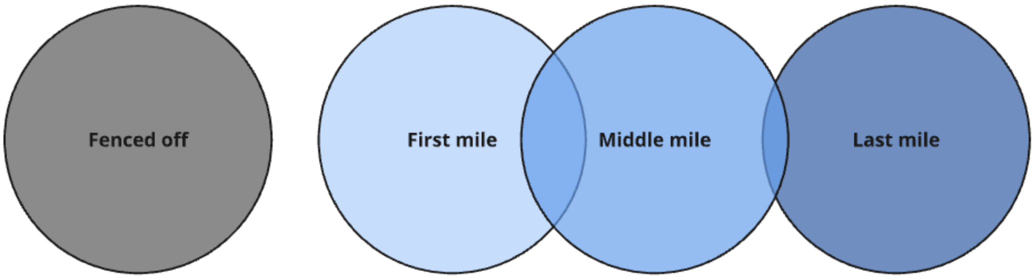


Figure 3: *Freight logistics segmentation*

Different industries have different routes to ship goods in the supply chain. The main differentiating factor making fenced-off areas memorable is that these areas are controlled environments, usually with a physical boundary. These are less complex to operate in as the number of pedestrians, cyclists, and non-authorized personnel has limited access (Van Meldert and De Boeck, 2016).

Ports and manufacturing sites, for example, have overlapping inland terminals, which enables shorter distances on public roads with repeatable routes (Notteboom, Pallis, and Rodrigue, 2021). The hinterland connections have seen an increase their utilization due to the freight volume handled by ports, and drayage yards have increased. Port-hinterland corridors can improve the handling of the incoming cargo of goods from ports (Behdani et al., 2020). There is also a necessity to better handle containers within the supply chain (Rodrigue and Notteboom, 2009). Further emphasis on integrating port-hinterland connections is necessary to be competitive in the market (Sdoukopoulos and Boile, 2020).

One way to cluster the supply chain corridors is according to the typology in Figure 4. These three stages showcase differences in fenced-off areas and how the value and functionality increase depending on the site.

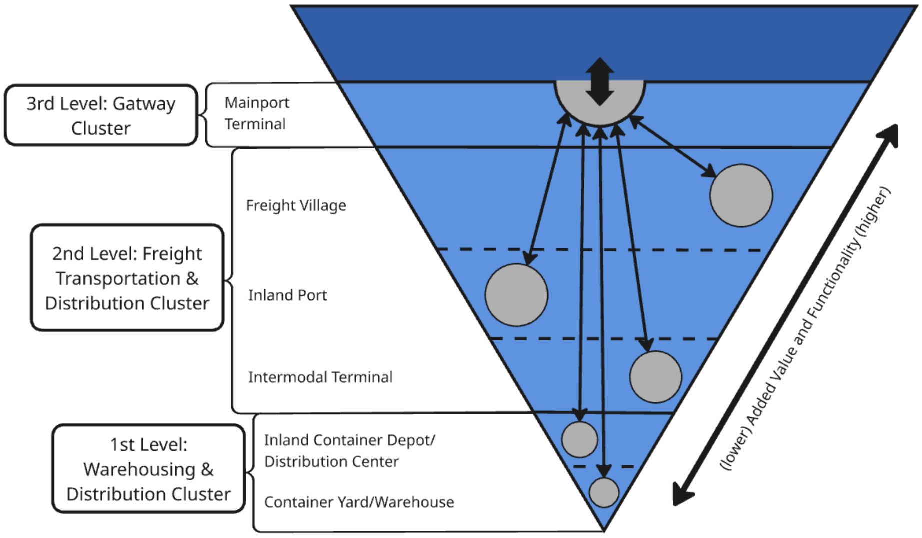


Figure 4: *Standardized logistics center hierarchy (Higgins, Ferguson, and Kanaroglou, 2012)*

The first level contains warehouses and distribution centers, which usually perform intermodal activities for various goods. Their primary function is transporting goods and containers within small areas to enable transloading or cross-docking. The second level includes freight villages, inland ports, and intermodal terminals to transfer goods between facilities in a greater geographical area. These are still intermodal transports, thus operating in relatively controlled environments and industrial sites; however, they utilize public roads to some extent. The third level is the Gateway cluster, which contains the most extensive scope of terminals and facilities. These clusters are active both within the area and connecting larger outgoing shipments.

2.2.2 Truck Classification of Heavy Duty Road Freight

Classifications and appearances around the world vary due to local regulations, where one example is that the length of the trucks is measured by the length of the trailer in the US, contrary to both the trailer and the tractor in the EU (Salati, Cheli, and Schito, 2015). The US classifies its trucks by rating 1-13, where the scale increases with the number of axles and type of truck (Federal Highway Administration, 2014). Weight is also a standard classification, which ranges from 1-8, where everything above class 7 is considered a heavy-duty truck in the US (U.S. Department of Energy, 2012). The EU has Class N1-N3 and O1-O4, which are power-driven vehicles used to carry goods and trailers (European Commission, no date a). This scale increases with the maximum weight of the vehicle.

Lighter vehicles are primarily used in last-mile deliveries, whereas medium and heavy trucks are mainly used in the middle and last-mile segment (Gupta, 2025). Dividing the logistic industry by truck type shows how different form factors cater to different usages (Inbound Logistics, 2023), shown in Figure 5. The form factor refers to how the truck is configured given what type of cargo it is supposed to carry. Rigid and box trucks have the cargo area fixed to the chassis. Depending on the shipped goods, these come in multiple varieties, where the cargo area could be refrigerated or solely a shell. A tractor-trailer is a combination of a tractor unit with a separate trailer that is attached to the chassis. Specialized commercial trucks have a unique cargo area depending on the industry and the type of goods.

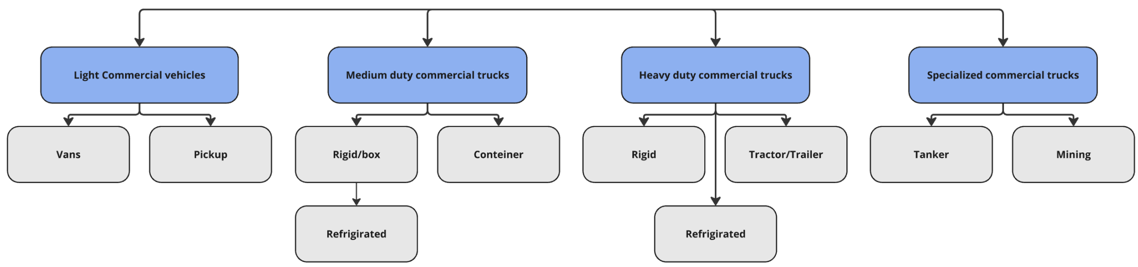


Figure 5: *Classification of how form factors correlate to different categories of commercial trucks*

The relationship between goods shipped and form factor is closely related. Choosing the right form factor determines the market size that could be targeted for the specific use case (Engström et al., 2018).

2.2.3 Road Freight Market Size and Distribution

Understanding the road freight industry, how goods flow in the network, and how it differs along the supply chain is critical. The most significant segment is long haul, which operates over distances of over 150 km (Mareev, Becker, and Sauer, 2017), and has a market share of 76% when looking at the amount of driven kilometers in the EU (Eurostat, 2024b). Short haul has a market share of 23% if measured by distance but is responsible for 76% of the total number of operations (Eurostat, 2024c). In general, rigid trucks travel shorter distances with less cargo and have a higher utilization rate than tractor-trailer setups (Eurostat, 2024e).

Palletized goods dominate the cargo type regarding the number of operations, especially on shorter distances (Eurostat, 2024d). However, the same data shows that shipping containers average a much shorter distance of

18 km/operation than the palletized 65km/operation. Another aspect of shipping containers is that they come in different sizes. 20 ft containers comprise 20% of the market, compared to 40 ft containers, which make up 78% of the containerized cargo shipments (Eurostat, 2024a).

Moving to the trucking industry in the United States, road freight transports approximately 72% of the weight in the domestic freight market (American Trucking Associations, no date). Distances below 160 km and 160-385 km are dominating, making up 36% and 38% respectively of the total weight transported throughout all distances (Bureau of Transport Statistics, no date). A forecast analysis of the 2050 market shows that these distances will account for 43% and 41% of the total weight traveled by trucks with a tractor trailer setup. However, 50% of the total distance traveled by semi-trucks will be between the distances of 160-800 km (Bridgelall, Jones, and Tolliver, 2023).

The market share of the US road freight transport by end user transports the majority of the goods, 31.5%, within the manufacturing segment. This compares to the European market as the same segment totals to 43.9% (Bureau of Transport Statistics, no date).

Estimation of the size of the global road freight market was approximately $2.7 trillion. Investigating the market size of specific segments is more difficult, mainly due to the lack of standardization of defining segments within the industry (Shoshani, 2009). Various classifications and poor data management in specific industries make it difficult to obtain accurate estimates. Disjointness in the classifications occurs when inputs are classified into multiple categories and may be counted twice (Shoshani, 2009). A lack of data in specific EU and US markets makes it difficult to say that the estimations are entirely accurate.

2.3 Actors and Trends

The future of autonomous vehicles is uncertain, with multiple factors affecting the outcome of the transformation towards self-driving level 4 trucks. Trends and actors within the market are presented and will indicate where the industry is headed.

2.3.1 Autonomous Vehicle Landscape

Currently, autonomous trucks are operating and are continuously tested in various environments. Controlled and fenced-off environments such as shunting, mining, and industrial sites have been primary locations for deploying level 4 automated trucks. Main benefits of these locations are lower speeds, less complex traffic, and highly repeatable routes over short distances. (Bridgelall, Jones, and Tolliver, 2023; Prokopiuk, 2024; Monios and Bergqvist, 2019b; Engström et al., 2018; Van Meldert and De Boeck, 2016). These locations have been the initial step for developing autonomous trucks before deploying them on public roads (Engström et al., 2018; Van Meldert and De Boeck, 2016; Shah and Piragine, 2018). While automated guided vehicles have a history in fenced-off material handling, they increasingly compete with AVs in controlled environments. Automated guided vehicles operate on fixed, low-speed routes, while autonomous trucks tackle the complexities of public roads (Van Meldert and De Boeck, 2016).

Several companies are trying to develop AVs with the technical capabilities to travel longer distances and on highways (Bridgelall, Jones, and Tolliver, 2023). Pilot projects and testing have been performed on public roads, as companies strive to develop trucks to operate on highway between hubs and exit to exit operations (Monios and Bergqvist, 2019b). Long haul road freight has been a targeted area by companies, as stakeholders within the autonomous industry are aiming towards hub-to-hub routes (Higgins, Ferguson, and Kanaroglou, 2012). Highway driving is expressed by academic and grey literature as a more realistic use case compared to urban environments, as it is less complex and has more predictable traffic conditions (Engström et al., 2018; Viscelli, 2018).

Increasing collaboration between OEM suppliers and software providers has emerged (Machado et al., 2021). Furthermore, efforts in collaborations with governments and universities have also been important (Lee et al., 2023). While technology and innovations are changing rapidly, these initiatives and joint ventures are important to increase the value proposition and core competencies (Machado et al., 2021).

When implementing AVs, money and politics can not be ignored (Stilgoe and Mladenović, 2022). Even if AV technology fails to realize its imagined potential, the research invested will most likely still impact other use cases. As the AV market is still in its infancy with very few commercial operations, viable business cases that turn a profit still seem to be some time away.

2.3.2 Future Trends

AETs can potentially change the market and patterns within the trucking industry. How the future will unfold and the commercialisation of the road freight industry for AVs is still uncertain (Engström et al., 2018; Monios and Bergqvist, 2019a). One change could be platooning, a technique where multiple AET follow a human-operated vehicle, improving the range, making transports more cost-effective and sustainable (Paddeu and Denby, 2021; Hou et al., 2023). Platooning could play a significant role in medium to long distances, but it has challenges regarding the driver's rest time and vehicle charging (Marzano et al., 2022). However, these trucks would still need the same level of automation and require infrastructure changes to not negatively impact the safety of other road users (Paddeu and Denby, 2021).

There are a few specific industries where autonomous trucks would be desirable. Controlled outdoor environments, like ports, could be utilized as an initial step for autonomous trucks. These are often less complex and not as uncertain, and have the potential to evolve into large-scale autonomous trucking on roads (Engström et al., 2018; Van Meldert and De Boeck, 2016). Manufacturing plants and warehouses with large quantities of goods transported between facilities could be more profitable. These sites also vary between fenced-off and open, which could help the incremental development of autonomous trucks. Short distances with repetitive transport flows where loading and docking can be standardized are desirable in the first stages of development (Engholm, 2021).

Bigger facilities are often close to major interstate roads and often located in industrial and commercial areas. These interstate roads are generally less occupied, and have a lower speed relative to highways (Viscelli, 2018). However, these types of operations sometimes require the truck to operate outside of its specified ODD, which could be solved by it being operated remotely via a remote operator. Another solution is to perform a trailer swap, where a manually driven truck takes over to finalize the route if it exceeds the ODD (Viscelli, 2018; Monios and Bergqvist, 2019b). Focusing on the highway could be highly profitable since that ODD environment is less demanding than driving in urban areas (Viscelli, 2018).

Research suggests that it is more beneficial to develop a high-performance AT in a limited ODD, instead of an AT with an unrestricted ODD that is less cost-efficient (Engholm, Kristoffersson, and Pernestal, 2021). The most likely pathway of deployment for autonomous vehicles, suggested by the authors, would be to explore the middle mile first, with the first and last mile assisted by human drivers. Starting with a middle mile could be further beneficial since it is estimated to have the most significant impact on lowering empty miles (Lee et al., 2024).

Adopting ATs in the long run will depend on several factors (Mondy, Enz, and Rust, 2025; Simpson et al., 2019). One of the main factors for autonomous trucks to succeed will be the adoption rate. It is worth highlighting that if the technology at the time of implementation does not improve, it will severely impact the adoption rate (Simpson et al., 2019). He also suggests in his report that avoiding bad publicity with autonomous trucks will be more important than generating good publicity. Negative publicity will hinder market penetration more than generating good publicity, which will increase market penetration.

Data on the shipping market trends suggests that autonomous vehicles and electrification are the main trends in road freight (Dohrmann et al., 2024). From a technological standpoint, these trends are anticipated to change the industry. Regarding social and business trends, circularity and supply chain diversification are expected to have the most impact within the industry.

Multiple independent researchers and analysts have estimated the future. Moving towards the long haul, timelines have been estimated for when fully autonomous trucks will be commercially available on the roads, as shown in Figure 6.

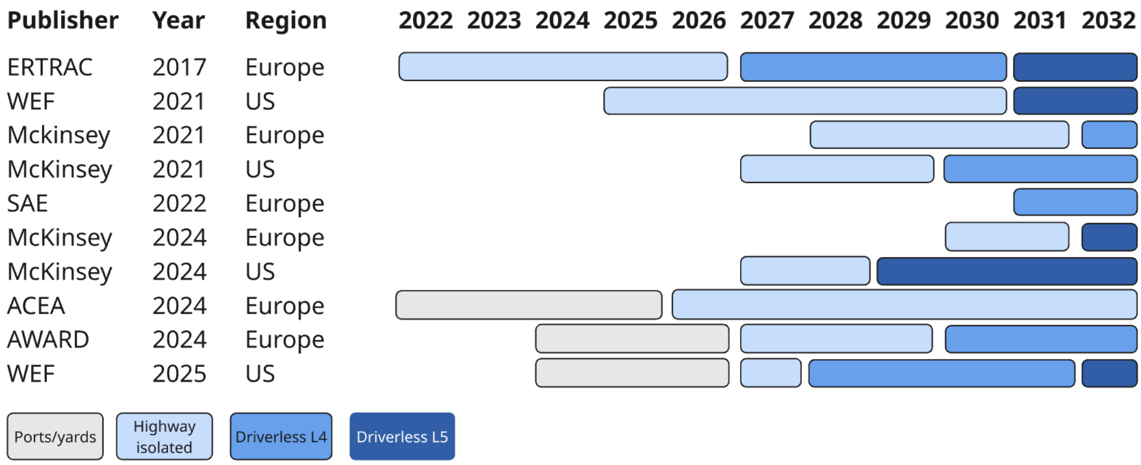


Figure 6: *Estimated launch for drivelers operations see Appendix A)*

3 Research Questions

The heavy road freight industry faces significant challenges, including sustainability, transportation efficiency and increased cost. Autonomous electric trucks are potentially solving these issues. Future development factors and deployment areas were presented as a gap, which requires further research to ensure a successful launch. The thesis will therefore analyze the critical aspects for the success of the autonomous electric truck, focusing on the US and EU markets. Furthermore, it aims to identify feasible development paths for autonomous electric trucks and their integration within the next two to five years. This timeframe was chosen as the coming years of development was known, and a longer time horizon would be hard to estimate due to rapid technology and market advancements.

From the literature study, the following questions emerged:
RQ1: What aspects are important to consider when developing autonomous electric trucks for future success?
RQ2: What are possible development paths for autonomous electric trucks within the next 2-5 years?

4 Method

The following chapter outlines the method for conducting this research. It starts with the research process and then covers all the methods used. For a visual representation of the process, see Figure 7.

Figure 7: *Overview of the research process*

4.1 Research Process

This research was structured to develop an extensive understanding of Autonomous electric trucks, heavy trucking market segmentation, and the heavy road freight transport industry, specifically the development of future AETs. A qualitative research strategy was adopted to explore and vividly describe the subject's complexities (Sofaer, 1999). This approach collected data from previous academic articles, market reports, stakeholders, and interviews to analyze and identify challenges and opportunities.

The process started with a literature study, where data from academic articles, statistical data sheets, and gray literature were collected and used to gain deeper insights into the subject. This established a foundation for understanding the current knowledge of the subject and revealed research gaps in existing literature.

The literature study was followed by an interview study conducted to gain insights from industry professionals. The interviewees were carefully considered and selected to gain insights into the research area. Interviews helped uncover hands-on experiences, behaviors, and research gaps that could not be accessed or understood through other mediums.

The process continued with a industry study that gave a deeper understanding of the industry. The industry study was approached broadly to capture as many aspects as possible. Data from official statistics sources, business reports, and articles from other actors in the market were targeted to fill research gaps and gain insights missing from established academic research.

Informal observations were conducted throughout the project to validate the interview and industry study findings. These observations were conducted in discussions and internal meetings with external stakeholders within the industry.

All information gathered was thereafter analyzed to identify important aspects for developing the next-generation AETs. The trajectory aimed to evolve development paths and find factors to focus on for market readiness in the next 2-5 years.

Grammarly, Scribbr, and the AI tool Gemini were used to improve readability and ensure an academic language. All tools have solely been used for grammar and spell checking to enhance the clarity and readability of the text. Prompts used when working with Gemini are detailed in Appendix B.

4.2 Literature Study

The literature study has been done to understand the current research landscape related to AETs, which has been a primary part of the research, and to identify research gaps (Linnenluecke, Marrone, and Singh, 2019).

The search engines used for literature gatherings were the KTH library, Google search, and Google Scholar. The keywords used were: *Autonomous electric trucks, Heavy duty trucks, Battery electric trucks, Autonomous vehicles, Road freight, Supply chain, TOC, ADS and ODD.*

Grey literature was carefully considered in the literature study and used to fill in research gaps in established research (Karolinska Institutet, 2023). Established research is generally more trustworthy but not always up to date. Therefore, articles regarding predictions and evaluations were used to gain valuable insight into these areas. The landscape of AETs is changing fast, which is why grey literature could give a better picture of what the market is doing today and why it was used (Paez, 2017).

The primary focus was on the financial, social, and sustainable aspects and the overall landscape of the autonomous heavy-duty truck industry. Due to limited research regarding AET, the knowledge gathering expanded to autonomous vehicles, battery electric trucks, and the heavy-duty trucking industry. However, it was limited to the EU and US markets.

An overview of the building blocks of autonomous electric trucks is illustrated in Figure 8. Regarding the financial aspects, areas such as software, development, hardware, and operational costs were all considered. From a technology standpoint, the focus was on ADS and truck hardware such as batteries and sensors. In logistics, the central area of investigation was focused on the heavy road freight industry and how this can be related to AETs. Regulations regarding self-driving vehicles were included in the literature study to investigate the legal aspects of AETs. The social impact of AETs was also included to investigate how the public sees AETs.

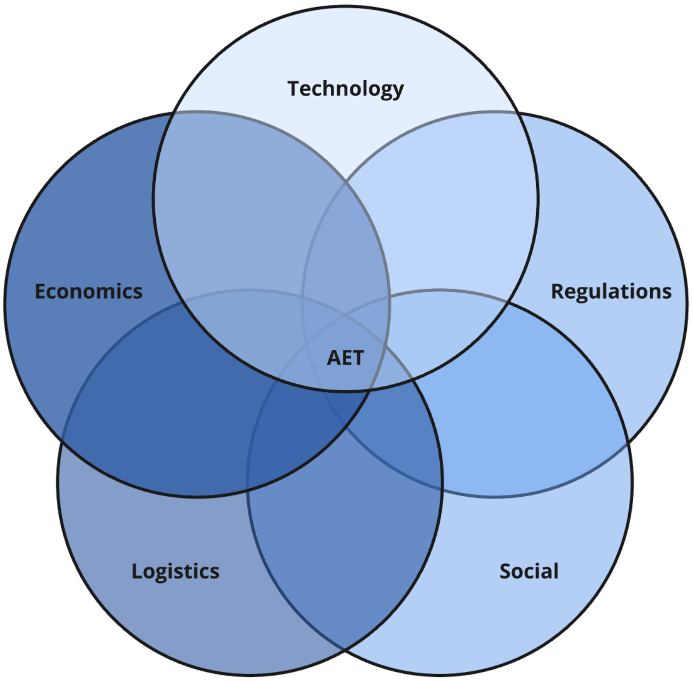


Figure 8: *Areas affecting AETs and their development that have been targeted in the literature study.*

4.3 Industry Study

Another focus area was to investigate AV market actors and road freight segments to understand further possibilities, how far the development has come in various industries, and their size. The area of investigation focused on actors operating in the space of autonomous vehicles and actors outside the trucking industry, active with cars and ADS software, were also included to benchmark all driverless systems on public roads. These areas where investigated by looking looking at press releases, financial reports, and their websites to see how far each actor has developed its product and what they are focusing on. A comprehensive timeline was thereafter created from the gathered data by mapping when an actor have launched improvements. What type of development or or expected launch was further included. Vehicle type and industry where further mapped across the stakeholders to identify where actors focus their development on in the future.

The other part of the industry study focused on segmenting the heavy road freight market. The segmentation was conducted by looking at statistical data and various market estimations. As some estimations varied greatly, multiple sources were summarized to give an average market size, which allowed for better and more accurate comparisons between segments. Specific data and isolated reports on heavy-duty trucks have not been studied in detail in each segments, such as ports, intermodal, and mining, due to lack of data availability. These reports presented their size estimations of heavy-duty trucks in percentage of total equipment within the industry and were used if no other data were available.

In the segmentation process, each segment was mapped to five different ODDs: fenced off/private, Industrial/Rural, Highway, semi-urban, and urban. These segments cover the whole heavy road freight market while giving an easier categorization to map self-driving capabilities instead of traditional market segments such as last mile, first mile, and last mile. The degree of difficulty and what is difficult in each ODD were also identified in this stage.

4.4 Interview Study

Another significant way of data gathering is semi-structured interviews. An interview guide was developed in advance with open-ended questions, see Appendix C. The questions were intended to allow the interviewee to speak freely about the subject and, therefore, describe how they see it.

Candidates were selected to give a broad view of the subject and include people with relevant backgrounds to give detailed answers to the questions (Bell, Bryman, and Harley, 2022). Most of the interviews were conducted at the partner company where the thesis was conducted. Thoughtful consideration was taken to get participants with different expertise, backgrounds, and interests to get as many perspectives as possible. Participants were contacted through internal communication channels and email, including a brief introduction of the research subject, and thereafter asked to participate. The interviews outside the company were conducted with researchers researching autonomous trucks and AETs found through the Royal Institute of Technology, and they were introduced to the research in the same way as the other participants. Other experts within the AV industry outside the company were also contacted in the same way but could not participate due to conflicts of interest.

The questions were designed with the following areas in mind: AET, autonomous vehicles, market segments, truck-specific limitations/needs, and how they see the heavy road freight market. The interview started with questions about the current landscape of AETs, followed by their applications and challenges. It proceeded with questions about technology, safety, and development. To conclude the interview, questions about the market, future outlook, and regulations were asked.

Twelve interviews were conducted in total, with all except one video-recorded. Interview durations ranged from 30 minutes to slightly over one hour. The interview process involved both researchers. One was responsible for leading the conversation and asking questions from the interview guide, while the other took detailed notes and asked clarifying and supplementary questions as needed. The recordings were a crucial addition to the notes, allowing for detailed review and ensuring no vital information was missed.

All interviews were conducted in English or Swedish, based on the preferred language, to avoid language barriers in formulating answers. To encourage the interviewees to speak freely, it was also explained to them that the data gathered from interviews would be presented anonymously and that all recordings would be deleted at the end of the project.

The location for the interviews was either in person or through Google Meet. In the case of in-person interviews, Google Meet was still used to record all the interviews except one. An overview of interviews can be seen in Table 1.

Table 1: *List of interviewees*

#	Interview type	Area of expertise	Duration (min)	Location	Recorded
1	Industry professional	Commercial	43	Google Meet	Yes
2	Industry professional	Commercial	46	Google Meet	Yes
3	Industry professional	Commercial	52	In person	Yes
4	Industry professional	Commercial	36	Google Meet	Yes
5	Industry professional	Software	46	In person	Yes
6	Industry professional	Software	50	Google Meet	Yes
7	Industry professional	Operations	58	In person	Yes
8	Industry professional	Operations	47	Google Meet	Yes
9	Industry professional	Operations	55	Google Meet	Yes
10	Industry professional	Safety	48	Google Meet	Yes
11	Industry researcher	Researcher	65	In person	Yes
12	Industry researcher	Business developer	60	In person	No

4.5 Informal Observations

Informal observations were made throughout the project to discuss and validate the findings from each study. These observations were made by participation in internal meetings where relevant topics related to the research were discussed. In addition to internal meetings, informal discussions with industry professionals were conducted to discuss findings and potential implications. The informal observations were used to validate the other findings and, therefore, were not a significant focus in information gathering in the project (Harvey, 2018). Examples of takeaways were interpreting stakeholder statements and regulations, and validating market sizes. It is worth noting that this continued throughout the study phase to get continuous feedback and ensure vital areas were included in the research.

4.6 Analysis

The data gathered from the literature study, interview study, and industry study have been the basis for analysing what is important to consider when developing the next generation AET.

Thematic analysis was used to identify interview themes and patterns (Braun and Clarke, 2006; Maguire and Delahunt, 2017). It was done by coding the interviews and started with going through each interview and creating initial codes from interesting findings in the data. It included coding for specific challenges, potential benefits of AET, required technology, regulatory aspects, and market opportunities. All interesting codes were highlighted during this phase, such as recurring opinions on regulatory challenges, technological limitations, or unique perspectives on AET market entry strategies. Thereafter, the codes were grouped based on shared concepts, underlying patterns, or recurring ideas related to the research questions. After the first theme division, this was repeated as the themes could be broken down further until the data sufficiently supported specific themes. The theme development process was iterative, with themes being revisited, refined, and sometimes merged or divided as a deeper understanding of the data emerged. These were then taken, and defining and naming themes were done with further refinement for clear distinction between them, and thereafter presented.

The analysis concluded by comparing and contrasting the data from all three studies. The comparative analysis aimed to triangulate the findings, validate insights, and identify convergence or divergence in perspectives from the literature, interviews, and industry study. It was done by comparing the results from each study with those of the other and seeing if they had the same results or if different results emerged. Comparisons were made in regulatory acceptance, technical and operational challenges, market segmentation, and future outlook and implications. The interviews were compared with the theoretical framework and the industry study, and similar themes and research were highlighted to show similarities and differences.

4.7 Creation of Development Path

The primary goal was to recognize aspects, similarities, and differentiators identified through the findings and analysis to find the most suitable development path for AETs in the next 2-5 years. Integrating data gathered through interviews, theoretical frameworks, and the industry study achieved a comprehensive understanding of emerging development trajectories. Comparative analysis revealed significant similarities and differences, which were subsequently analyzed to understand underlying problems, particularly focusing on the key differentiating factors.

The combination of data gathering through interviews and theory, combined with the industry study, gave an overview yet specific knowledge of emerging paths in the future. As the data was compared, similarities and differences emerged, which were analysed to understand the reasoning, mainly behind the differentiators.

Findings from the interviews, observations, and industry study led to the development of possible development paths and important factors to consider for long-term success. An initial comparison between the studies was made to gather information, concepts, and assumptions, which led to identifying two distinct development paths. These paths were subsequently formulated based on form factor, which emerged as a pivotal differentiator in the developmental process. Refinement of the solution was done through iterations by revising data and documentation from the interview and industry study to ensure key aspects were not missed and integrated in the recommended development paths.

4.8 Quality of Study

Qualitative research is interaction-based between the subject and the researchers, which makes validity and reliability difficult to assess (Lindgreen, Di Benedetto, and Beverland, 2020). Qualitative studies are often criticized for subjectivity, low reliability, and validity. This was mainly due to insufficient documentation (Sinkovics, Penz, and Ghauri, 2005). This was addressed by structured and systematic documentation of data and findings in each phase of the project.

Objectivity is completely unattainable when conducting qualitative studies (Bell, Bryman, and Harley, 2022). Recognizing this issue, efforts were made to ensure that the findings reflected the collected data through reviews and data collection from multiple sources.

Throughout the project, internal and external reviews were conducted. Internal reviews via presentations of sub-results in text verbally validated the project's trajectory and the veracity of data against established industry benchmarks. External reviews from the supervisor and peer students via part-time reports contributed an objective analysis, offering diverse viewpoints and supplementary clarifications crucial for a comprehensive assessment, to supplement the internal reviews.

The findings in this thesis are not case-specific, even though assigned by a specific company, as it takes a holistic approach to the overall industry of AETs, and the characteristics are not exclusively adjusted for the organization. Despite offering a valuable reference point for similar challenges, the study's transferability is not guaranteed; readers must independently evaluate its applicability to other contexts (Nowell et al., 2017).

This study emphasized reflexivity and rigorous ethical standards to ensure the credibility and integrity of the findings. Interview coding was initially done separately to ensure authenticity and avoid dependency and premature interpretations. To protect participant anonymity and confidentiality, we implemented several key measures. Specifically, all interviews were conducted and held anonymous throughout the process, only available for the authors to read, thus fostering trust and encouraging candid responses. Participants provided consent to recording before each interview, with full disclosure of the study's purpose and data usage. Furthermore, the interview protocol focused solely on data regarding the research questions from a broad perspective, and participants were instructed to avoid sharing detailed company-specific data. Finally, all recordings, notes, and transcripts were deleted after the final project was completed to ensure complete confidentiality.

5 Findings From the Industry Study

This chapter presents findings from the industry study by examining statistical data and actors operating within the industry. It also presents discoveries from market reports and business articles and explains how ODDs can cover the market.

5.1 Operational Design Domain Stages

The heavy road freight industry can be divided into various segments such as first, middle and last mile. Firstly, an identification of the road freight industry where trucks could operate was established and divided into five operational design domains (ODDs) to cover the heavy duty truck supply chain, illustrated in Figure 9. The five ODDs where chosen as these cover the heavy road freight supply chain. The middle mile segment was split into two ODDs as several factors such as speed, environment, and distances wary greatly in this segment. Therefore needing two ODDs to cover the segment adequately.

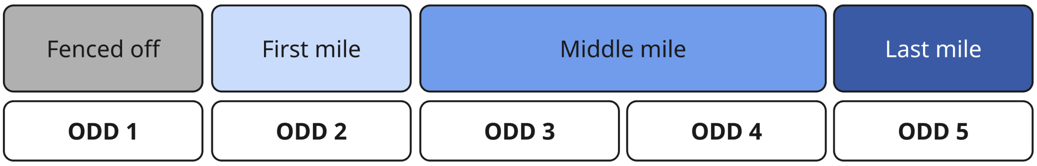


Figure 9: *Five stages to cluster the heavy road feight supply chain*

Looking at real scenarios, multiple attributes such as speed and the amount of people vary within the boundaries of an area and could overlap between stages. One route could include multiple stages from the supply chain. Looking at each deployment from start to finish is important. Since the division could be done in multiple ways, it was essential to get a broad view of the market and not miss any segments. Important factors were identified as deployment challenges to determining the difficulty level of each stage.

Environmental complexity describes the amount of nondeterministic objectives and non-predictable environmental obstacles. It is linked to the geographical area of the route, such as fenced-off, highway, rural, and urban. *Speed* and *distance* are two environmental challenges where routes that are shorter and with lower speed are easier to drive for an AET than longer routes with higher speeds.

Automation barriers within the industry indicates how well the surrounding infrastructure and stakeholders are adopting autonomous technology, where deployment in highly autonomous industries is easier. *Expanding use cases* is important for long-term success and exploring new ODDs without changing the structure of the

ADS or form factor of the truck. *ADS difficulty* describes how difficult it is to develop the ADS from a supply chain perspective. Where the number of stops and intensity of external traffic and infrastructure impact the development. *Competition* indicates how exploited the industry is by different stakeholders, and *market size* suggests how significant the segment is in value.

All factors are listed below in Figure 10, which ranks each factor is in each ODD. Based on their impact on the deployment of AETs, these scenarios were ranked from best to worst, with a scale from 1 to 6 based on findings from the market and industry study. The sum of the rankings shows how easy or beneficial it is to enter each market today.

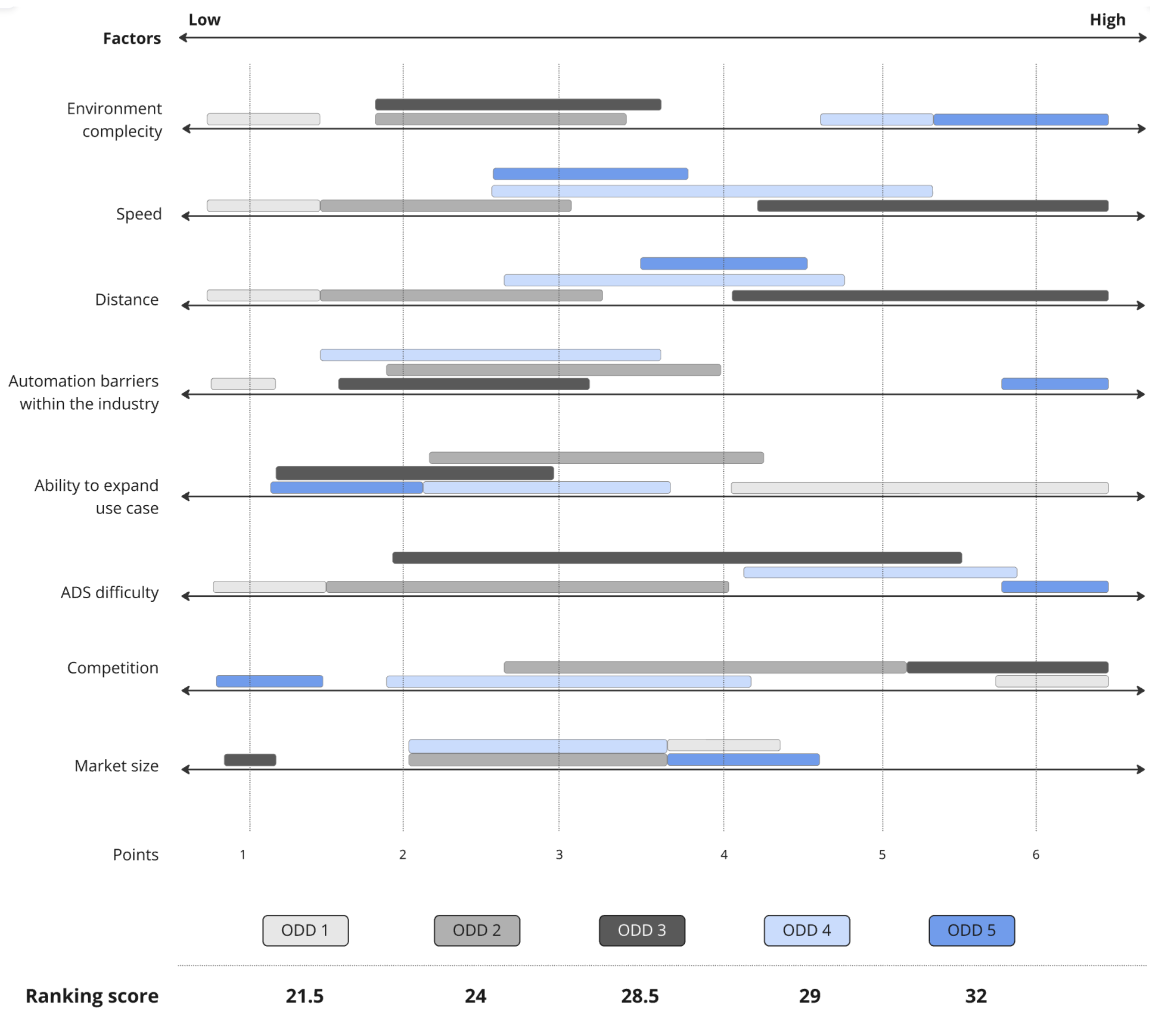


Figure 10: *Ranking of complexity in ODD stages*

The different ODDs that cover the market are shown in Figure 11. These ODDs can exist in different parts of the supply chain. The main issues identified when evaluating an ODD are the environmental complexity and speed within the area. A classification of the number of nondeterministic objects was translated into a further challenge: the distance the vehicle travels, especially for AETs, since the amount of unpredictable events encountered increases with longer routes. Further inclusion of the criteria above covers the complete picture of the difficulty level to enter the market, and the five stages were ranked from easy to hard. The complexity in the stages was mapped and described by the area where the trucks in that specific industry generally operate. Fenced-off areas are private or enclosed areas controlled and inaccessible to the public. Rural areas are located in the countryside or far away from cities, with few people. A highway is a main road, usually connecting two cities. Semi-urban areas are located close to towns, but are not as populated as urban areas in a city.

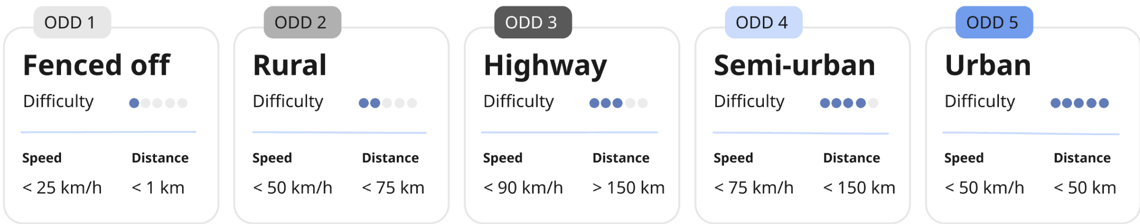


Figure 11: *ODD Stages that cover the market*

In fenced-off applications, form factors are highly industry-specific (e.g., ports, mining), limiting vehicle transferability to other ODDs. ODDs 2-4 cover first/middle-mile and hub-to-hub are dominated by heavy-duty rigid and tractor-trailer configurations, depending primarily on the route distance and cargo. ADS complexity increases from ODD 2 to ODD 4 primarily due to more demanding environments and higher speeds. Due to the added trailer joint and increased size, the articulated tractor-trailer form factor adds complexity across these ODDs. ODD 5, on the other hand, prioritizes agile, smaller commercial trucks with advanced ADS to handle complex operational settings in urban and city environments, primarily used for last-mile deliveries. As the findings suggest, AET development difficulties vary across different ODDs. Transitioning between ODDs will be a key challenge as it demands an enhanced ADS. ODD 1 is the simplest, and ODD 5 is the most challenging for the ADS, mainly due to the number of nondeterministic objects and speed.

When examining specific routes, viable for AETs, there might be instances of overlap between ODDs within the route. However, these routes should be identified and exploited as they can lead to a good transition between ODDs as the ADS improves to eventually cover the whole route.

5.2 Heavy Duty Trucking Market Size and Value

There is no universal taxonomy or standard of how the market should be segmented when estimating the size or value of a specific segment. However, the findings show that the conventional trucking market is often clustered by distance, area, and the type of shipped goods to calculate each market size. The market estimation is based on the heavy-duty truck segment within each investigated area with the data coming from market researchers and business reports. The global market was estimated due to lack of sufficient data within the EU and US markets alone. Table 2 shows the market size in billions of dollars for each industry. A complete table of all reviewed sources is presented in Appendix D. The by far largest market for heavy-duty trucks is the long haul segment. Some market segment estimations overlap, such as middle-mile and retail, which refers to the type of goods shipped and customers, not the specific site or route.

Table 2: *Market value of heavy road freight in different industries see (Appendix D)*

Industry	**Description**	**Market size $ B**
Mining	Mining and construction sites	19.9
Terminal tractor	Tractors operating in yards, ports and warehouses	4
Shunting	Move and organize containers ans trailers within yards	3.5
First mile	First distance from manufacturer to distribution center	33.5
Middle mile	Distance between DC/WH to DC/WH	56
Last mile	From terminal to end customer	17
Long haul	Long distances, both cross and regional	733
Retail	Consumer goods from terminal to terminal or end customer	75
Intermodal	Transportation between multiple types of transportations	40

An illustration of the supply chain is visualized in Figure 12. It highlights that some markets are not directly transferable to a specific site or route, but can be linked to the ODDs presented in the Figure 11, it also highlights how the supply chain is structured and what parts are connected or overlap. Terminal tractors, shunting, intermodal, and mining are all industries within fenced-off areas. First, highway, middle, and last miles translate into ODD 2,3,4,5. The retail market includes shipped goods that are shipped directly to the end customer. This underscores that the first, middle, and last mile can all be included when calculating the retail market size, depending on the operational area and distance of the route.

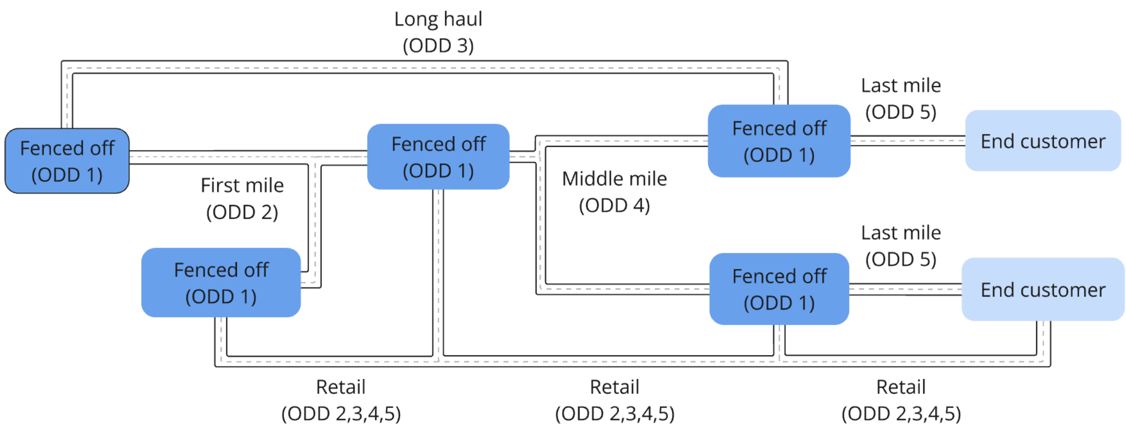


Figure 12: *Illustration of supply chain*

5.3 Autonomous Trucking Market Actors

The industry study looked at the market and actors that make autonomous trucks and ADS software to gain a holistic view of the EU and US industry. Since the ADS aspect is the main barrier for newcomers to enter the market, autonomous vehicles such as cars have also been included.

The stakeholders in the autonomous industry were investigated and segmented based on their type of vehicle, as shown in Figure 13. This highlights many actors working with heavy-duty autonomous trucks, targeting public roads and the conventional road freight supply chain. Some companies focus more on cars and consumer vehicles, but these are still relevant due to their advanced ADS. Several companies are also working on particular form factors in yards and ports, primarily focusing on fenced-off areas.

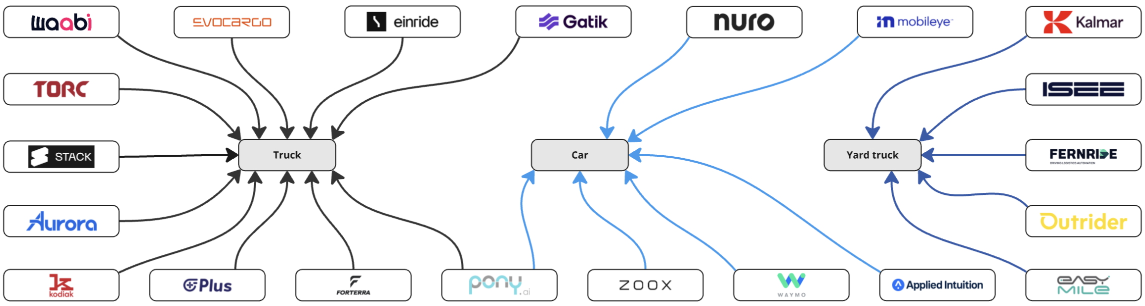


Figure 13: *Market actors linked to vehicle type*

The actors of the autonomous vehicle industry within the EU and the US were analysed and connected with their respective areas of operation, as shown in Figure 14. These areas are where they are currently operating or where they are building their business. From this perspective, there is a larger spread of focus areas. It is worth noting that most actors focus on highway and port/yard operations.

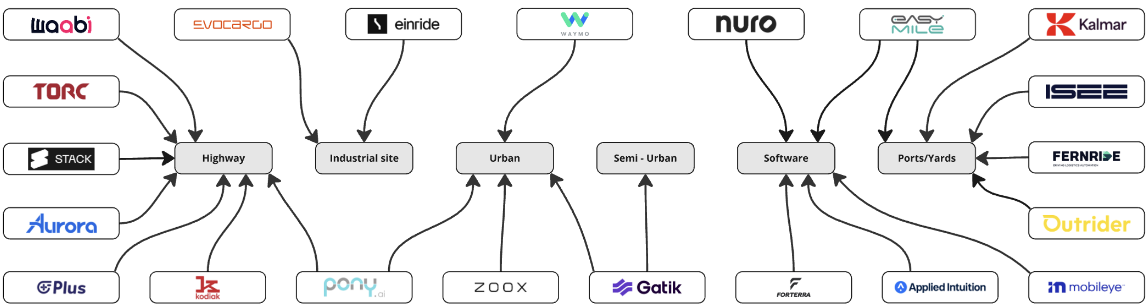
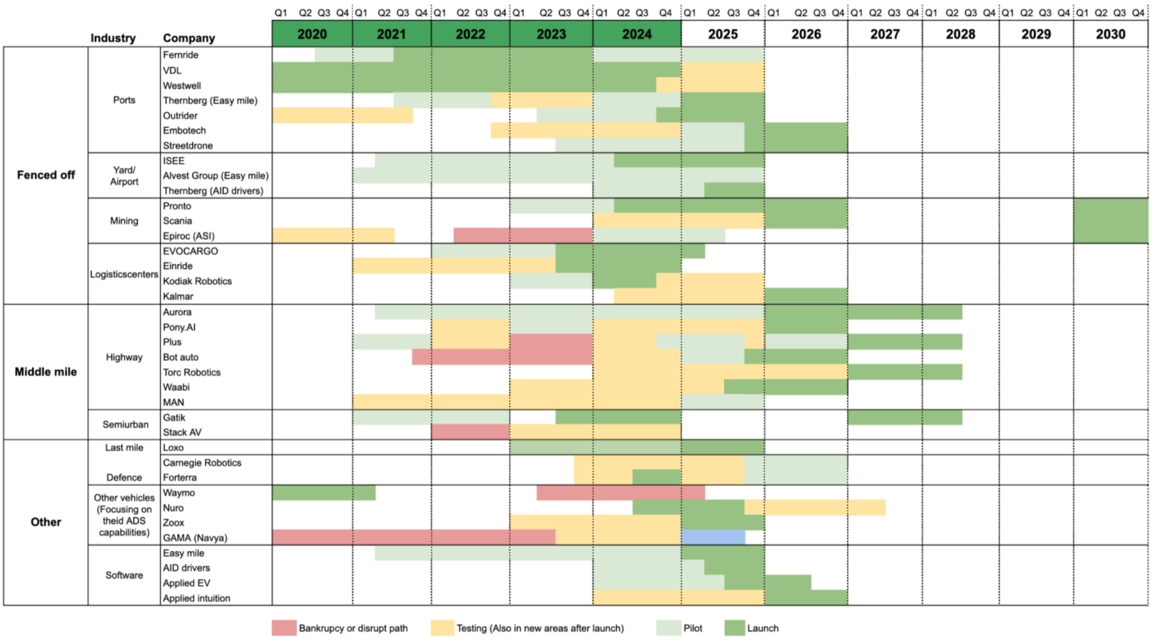


Figure 14: *Focus area of market actors*

The autonomous trucking industry is constantly under development, and specific industries and sites have advanced in developing and deploying autonomous trucks. To further understand how far each actor has come in their targeted areas, a timeline was developed to understand their current progress and expectations, as seen in Table 3. It maps out the timeline of current developments within each specific segment. Furthermore, future focus areas and predictions were presented to understand the industry's direction.

Table 3: *Market actors timeline (for detailed timeline see Appendix E)*



Ports and yards within fenced-off areas have come furthest in terms of the number of companies that have been able to deploy commercially. Fenced-off logistics centers are also starting to deploy commercially and are exploring deployment on public roads to a broader extent. Most companies focusing on highway and semi-urban environments expect a commercial launch on the public road in 2026. Software companies generally collaborate with OEMs, where the majority test or conduct pilot projects on public roads.

6 Result from Interviews and Informal Observations

The interview results are presented below and are structured according to the emerging themes from the thematic analysis.

6.1 Considerable Factors When Choosing Routes and Sites

Interviewees explained how predictability of the area and routes is important for validation when deploying vehicles to drive safely in all scenarios. The interviewees presented aspects of the areas and operational design domains (ODDs) where level 4 Autonomous trucks are used. The most important factors when determining the routes, which were hard to predict, were the weather and the amount of nondeterministic objectives, such as pedestrians, animals, cyclists, and other human-driven vehicles. It was important to consider the type of weather within the domain which affects the geographical locations. Some areas had challenges with dust, while others had challenges with snow. However, it cannot be traced to a specific route or site; rather, it affects the choice of region or state. Nondeterministic objects, on the other hand, affect the routes directly, regardless of the region or country. This aspect was used to cluster specific routes when considering where to drive, since the difficulty, both from an ADS and safety perspective, correlates with increasing nondeterministic objects. Even though the actions of nondeterministic objects are difficult to predict, the number of objects is relevant as an increased amount of objects increases the difficulty level of the area. Fenced off, rural, highway, and urban were descriptions of typical areas of operations. The number of nondeterministic objects and the ADS difficulty vary in these areas, where fenced-off areas would be the easiest and urban areas would be the most difficult to operate in.

Form factor, type of goods, and weight were further aspects to consider before launching AETs. These were explained to depend upon the type of customer and site, which affects the physical capabilities of the trucks. AETs have to be able to compete with already existing trucks and would require at least the same capacity and efficiency to be considered. Most interviews mentioned the form factor of the truck as highly influential in addressable markets. Several interviews also highlighted that the form factors in fenced-off applications are specialized and highly optimized for a specific task. Rigid trucks are predominantly used on shorter routes with less cargo, as their loading time is short, which increases efficiency. Tractor-trailers are mainly used on longer routes with larger amounts of cargo.

It was further explained that the physical capabilities, as well as the technical ADS capabilities, differ between routes. Transferability between operational domains and sites was explained as important for long-term success and has to be considered in the decision-making process. Most interviewees explained the importance of having a customer- and site-oriented development path to create a competitive business case in the long term. Eventually, finding a common denominator between targeted sites would enable incremental improvements as the knowledge and capabilities gathered in one ODD could more easily be transferred to another. Finding routes within the development path with similarities in form factor and ADS capabilities would increase the long-term feasibility and competitiveness.

6.2 Technical Aspects Affecting Development of the ADS

The autonomous driving system (ADS) was explained as the heart of the AET, as it is responsible for the behavior and interviewees emphasized that the ADS was the most challenging and expensive part of the truck's development. Interviewees explained how form factor and sensor placement affect the development of the ADS and impact the path for future improvements. As noted by multiple interviews, the ADS system would have to be incrementally developed rather than radically changed. Observations in meetings also confirmed this.

Interviewees working with software further explained the importance of correct choice and placement of sensors and form factor from the beginning, as it affects the structure of the ADS. Sensors are needed to navigate the truck through different environments, and various sensors are attached with different functions and capabilities. Examples of differences were made between rigid and tractor trailer trucks, as rigid trucks have fixed chassis and sensors. Tractor trailer have a modular chassis where sensors cannot be placed in the same spot across all trailers around the world due to cost restrictions. This would result in different types and placements for sensors between the trucks, which impacts the fundamental structure of the ADS.

Edge cases were described as unpredictable events critical for the ADS in enabling commercial deployment. Interviewees explained how the ADS was built upon machine learning and how the amount and quality of input data were essential for a successful launch. Collecting data in real-world environments was necessary to train the algorithms to handle the edge cases. Safety and software interviewees emphasized the need to collect large amounts of route-specific data to train the algorithm to handle as many unpredictable scenarios as possible. It was explained that virtual simulations were used to improve further the truck's capabilities and test scenarios for validation. However, these simulations were not as reliable and could not replace real-world data and testing.

The ADS replaces the driver in maneuvering the truck from point A to point B. However, interviews stated that certain journey aspects have not yet been solved autonomously. Loading, safety inspections of the truck, and interactions with other vehicles were examples of tasks the driver currently performs that are outside of the capabilities of the ADS. It was explained that these issues were not urgent or critical for the short-term success of autonomous trucks, as they could be done manually at the site and described as easily solved if needed. Interviewees explained how light indicators could help with outside interaction to show the vehicle's state in various modes, such as stand by, operating, or loading.

Interviewees highlighted the impact of the battery as another technical aspect and how it affects the range, loading capacity, and chassis requirements. Long routes with heavy loads require large batteries, which are bulky and expensive. Interviewees who brought up the battery did not see it as a barrier for future development but rather as something that has to be considered and improved to remain cost-efficient and competitive.

6.3 Cost Effectiveness and Creation of Business Case

All interviewees mentioned the importance of cost regarding autonomous electric trucks. It was a common agreement that the initial investment of AETs was higher than that of a regular truck, mainly due to the ADS and battery cost. In contrast, the total cost of operations and the environmental impact were explained to be reduced daily, making it a positive return on investment in the long term. Interviewees explained how autonomous trucks can increase efficiency and utilization rate, which is important to reduce costs. Finding repeatable and high-frequency routes where deliveries are made multiple times daily is the most desirable.

Even though autonomous trucks replace the driver with the ADS, they still need a remote operator to monitor the truck due to regulations, according to the interviewees. Interviewees explained that directly replacing the driver with a remote operator would not decrease costs. However, a remote operator would have the ability to monitor multiple trucks at the same time, which would increase the profitability. Further benefits of a remote operator are that it does not do the driving, but only monitors. It would further be part of the solution to the driver shortage, as the truck drivers do not have to be away on the road for extended periods.

Several interviews described that exploring feasible business cases was important and highlighted examples within the taxi industry that emphasized that. The driver is exchanged 1 - 1 in the taxi case, where a remote operator monitors multiple cars, making it easy to estimate the profitability. Regarding this, interviewees explained how autonomous trucking suppliers must rethink the current supply chain to showcase a profitable business case for AETs, focusing on the return on investment and economy of scale necessary to compete with today's conventional trucks. The remodeling of the supply chain can be seen in the interviewees' statements that the new autonomous technology could change the flow of goods. Multiple smaller trucks driving stints could replace the long haul routes. It was explained to be speculative and depends on multiple supply chain and logistics stakeholders.

6.4 Implications of Safety and Public Acceptance

As stated by all interviewees, safety is the most important factor for long-term success. Several interviewees described that the consequence of having an accident will most likely make the company go under and that this has already happened to several companies in the autonomous driving industry. Validation and managing edge cases were further discussed as important challenges to solve. Interviews highlighted that an iterative approach will most likely be needed with incremental steps of proving safety along the way.

Proving safety was explained as important for deployment and gaining public trust and acceptance. Thus, careful considerations and actions must be taken to deliver a safe product in all environments and cases where the system is allowed. Interviewees described how autonomous trucks would increase road safety, but the expectations must be realistic. The public has to understand that the rate of accidents would decrease, but it would never be zero.

All interviewees agreed that continuous collaboration with governments and stakeholders is important for developing AETs. It was explained how regulations had to be adjusted for autonomous vehicles and how much work had to be done to enable faster, reliable, and safe deployments.

6.5 Targetable Operational Industries and Domains

Most interviewees specified the US as the most promising market geographically due to favorable regulations and public acceptance. However, it was further explained that the impact of failure could be greater in the US, as seen with previous companies due to the regulatory landscape.

The middle mile sector, including hub-to-hub and long haul, was the most promising segment amongst almost all interviewees for future deployment. These segments cover longer routes over highways and in semi-urban environments. According to several interviews, a big market with a great flow of goods and repeatable routes makes the long-distance routes compelling. However, it was highlighted that this was not expected to be viable without a safety driver in the near future. However, the software and operational professionals agreed that isolated highway diving could be done soon. Despite the high speeds required, which increase the difficulty and safety concerns, the main issue was the adjacent environments, such as entering and exiting the road. These interviewees thought that the near future would focus on fenced-off areas and nearby routes, as the capabilities of the ADS would not be mature enough for highway driving on public roads.

There was disagreement among the interviewees regarding fenced-off areas. Some interviewees explained that these controlled environments were optimal as an initial step. On the other hand, some interviewees explained that the market size is relatively small and that some of these sites require specialized trucks not used anywhere else in road freight. Ports and construction were brought up as examples where the form factor is adjusted for the specific task, which would not be preferable if the long-term goal is to transfer the capabilities to public roads.

Industrial and nearby routes in rural areas were explained as an alternative to highway and hub-to-hub driving, as they have fewer nondeterministic objects, lower speeds, and higher shipment frequency. Interviewees explained how operating in these environments could allow for incremental improvements of the ADS and excellent transferability to other domains for expansion.

7 Analysis

AETs are innovative, and many stakeholders, such as ADS developers, OEM manufacturers, and governments, are somehow involved in deploying these trucks. The industry is still in its infancy, and data and knowledge regarding the future are unknown, partly because the industry is changing fast and partly because it is new. Kelkar et al. (2024) identifies a research gap regarding the development and feasible paths of the future of autonomous trucks, that was substantiated by multiple interviews.

The literature, industry, and interview study were analyzed to find similarities or differences and compare and evaluate data and knowledge from multiple perspectives for a deeper understanding.

7.1 Regulations and Public Acceptance

Unanimously agreed from literature (e.g. Prasetio and Nurliyana, 2023) and the interviews is that AETs will not be accepted by the public if they are not safe. However, there were divided opinions on whether or not the safety needs to be improved or if regulations need to loosen up to allow a realistic deployment of AETs. Academic literature focuses on the regulatory aspect, suggesting that the regulations are not well adjusted for AETs (Hasiri and Kermanshah, 2024), which was also brought up by some interviews and emphasizes the complex regulatory challenges facing AETs. These are mainly issues regarding deployment where it is hard to classify and validate machine learning models. Both stress (e.g. Lee et al., 2023) the need for collaboration and communication between companies and regulators to have a realistic and achievable deployment plan. There are also significant differences between countries and states, which should be considered when choosing specific markets (KPMG, 2020). The US has the highest score in technology and innovation, due to its innovative approach towards AI and advanced infrastructure. The UK, the Netherlands, Finland, and the US have the highest score for supporting AV regulations.

Public acceptance is acknowledged as an important aspect. Statistics (e.g. Kim, Kim, and Park, 2022) and stakeholders suggest that autonomous vehicles are safer in most scenarios compared to a human driver. Some interviewees agreed that AETs are probably already safer and more reliable in some scenarios than human drivers, but the expectations must be realistic. The benefits of autonomous vehicles must be greater for the public to accept a widespread launch for AETs. Some interviews also highlighted that knowing what is safe enough to deploy in different areas is hard. The readiness index by KPMG (2020), shows that the Nordic countries top the chart regarding public acceptance of autonomous vehicles, followed closely by the US.

7.2 Technical and Operational Challenges

Literature focuses more on the progress from a market view with all stakeholders (Kelkar et al., 2024), while interviews view the progress from a company perspective. As highlighted in the industry study, many companies today have focused on a specific market area. The interviews brought up the technical difficulties for companies going from one ODD to the next, and instead, focusing on the long-term goal in terms of form factor, sensors, and industry, when designing and developing the truck, it was agreed to ease the transition between ODDs.

Both statistics (e.g. Gupta, 2025) and interviews found that the form factor differs greatly in European and North American markets and between use cases. The industry study further identified that the form factor differs between industries, which was stressed by the interviews as an important factor to consider when developing a new AET. Rigid trucks are mainly used for shorter distances with lighter loads, primarily in the EU. Tractor-trailers dominate the US, primarily on longer routes with heavy loads. The interviews also discussed that switching from factor is complex, costly, and requires extensive truck hardware and ADS components modifications. The interviewees made a clear distinction in routes based on the form factor. At the same time, the academic literature rarely covered it as a differentiator and did not consider form factor when looking at routes (Chiao et al., 2024). Types of goods and distances are further differentiators pointed out by interviewees, which affect the requirements and capabilities of the truck and are not covered in the literature. These factors were explained to affect the physical requirements of the truck, depending on the industry and which ODD they operate in.

Customer-centric design is a well-known concept in the literature (Fornell et al., 2020), and aligned with the interviews, as they agreed that sites and capabilities differ between customers and markets. Sensor type, placement, and modularity are other important key factors for long-term success, which interviewees touched upon. Interviewees, in contrast to literature, emphasized the importance of sensor placement, form factor, and the modularity of parts and how it affects the future deployment of AET. Literature focused on how different sensor types are better for certain conditions, especially from a safety perspective (Vargas et al., 2021).

Apart from environmental benefits, electrification was an important aspect to consider in terms of TCO and initial investments. Literature has been analyzing the TCO, range, and loading capacity of AETs regarding the size and weight of the battery (Engholm, 2021). It could be a limiting factor on longer routes or when hauling heavy loads, but was not the primary concern of the development. Interviewees did not mention the battery as a primary barrier for AETs within the horizon of 2-5 years, but agreed that it affects the cost of the vehicle.

Both interviewees and the literature (e.g. Vargas et al., 2021) have brought up broader geographical challenges. Harsh weather conditions were considered an issue and an important aspect. Interviewees and literature (e.g. Vargas et al., 2021) noted rain, ice, and dust were challenges that affected the capabilities of the sensors, and therefore the ADS and the capabilities of the vehicles. Weather and regulations were considered a challenge from an operational standpoint throughout the whole market, and mainly affected the geographical location of deployment. Interviewees and literature (e.g. Sever and Contissa, 2024) agreed that North America generally offers more favorable conditions than the EU regarding testing regulations.

7.3 Market Segmentation and Use Cases

The interviews and literature (e.g. Engström et al., 2018; Van Meldert and De Boeck, 2016) agreed in terms of feasible starting points where specific ODDs have been pointed out as the first step of the deployment of AETs on public roads regarding the capabilities of the ADS. Fenced-off areas in controlled environments are the easiest, whereas high-speed public roads in crowded urban areas are the most difficult (Hashimy, Colasis, and Rosinés, 2024). However, the interviewees further explained that fenced-off areas often require specific requirements and capabilities, which do not always translate into other ODDs for further development. Concentration of stakeholders and market size of each use case are also factors in finding feasible industries with suitable ODDs where autonomous trucks could be deployed (Hashimy, Colasis, and Rosinés, 2024). Therefore, fenced areas might not always be the best starting point for long-term success.

Research indicates that shorter routes in relatively controlled environments are the next step for autonomous trucks (Engström et al., 2018). Interviewees gave broader insights on the supply chain, while academic and grey literature mainly focused on longer distances (Fritschy and Spinler, 2019). The small sample of literature approaching the broad supply chain supports the findings from the interviews. Shorter routes within hinterland areas present an easy operational environment, making them an attractive initial deployment target on public roads (Higgins, Ferguson, and Kanaroglou, 2012). These routes further enable incremental development to expand its ODD when the capabilities of the ADS and regulations allow for it. Specifically, port-hinterland connections involving container transport represent some of the shortest routes while facilitating a substantial volume of freight movement. As seen in the studies, and literature (e.g. Sdoukopoulos and Boile, 2020), this could evolve into a promising market segment for autonomous trucks, particularly after initial successes in more controlled, fenced-off environments. However, it is important to acknowledge that this segment represents a relatively limited share of the overall transportation market (Hashimy, Colasis, and Rosinés, 2024).

Highways emerged as the most significant segment, and it was clear from the interviewees working with ADS that highway driving was relatively easy despite its high speeds and the amount of traffic. The difficulty comes when entering and exiting the highway and driving to nearby hubs, where mixed traffic has to be considered, which was confirmed by (Kim et al., 2024). Most of the hubs are located close, but not directly connected with the highway, which requires the truck to handle more complex environments. It has been suggested in the literature that this problem can be solved by manually operating the truck onto the highway and thereafter allowing it to drive autonomously (Viscelli, 2018).

Other industries, such as retail, have been mentioned by literature and interviewees was seen as potential use cases. Commercial papers vaguely describe this segment regarding routes and ODD, mainly focusing on the type of goods shipped and end location see Appendix D. Therefore, the retail segment, which offers a significant volume, especially with the increase in E-commerce, was tough to specify and categorize (Andrei, Scarlat, and Ioanid, 2024). This segment goes into multiple stages of the supply chain, making the definition vague and challenging to cluster, and therefore not referred to as a stage in the development path.

A market actor analysis in an evolving market was conducted by analyzing the literature and business reports in multiple rounds. The market has evolved fast, and these have to be updated frequently to be relevant. Multiple interviewees mentioned that most companies rely on funding and that there have been many bankruptcies within the field. The industry study identified that the active stakeholders mentioned in reports change yearly (Hashimy, Colasis, and Rosinés, 2024). Furthermore, the progress of companies in the field is kept a secret within the organisations, allowing only published information to be included. The market size estimations differ between papers, mainly due to what they cover, which was supported by the interviewees and observations. The results will vary depending on how the calculations are performed and which areas are included. Information regarding market size from academic literature is scarce. However, when mentioned, the findings aligned with both the commercial reports (e.g. Chiao et al., 2024) and the direction of the interviewees.

The different stages in the supply chain further vary in characteristics, where nondeterministic objects, speed, distances, and traffic environments all present challenges for AETs, where less is generally easier (Hashimy, Colasis, and Rosinés, 2024). The most predominant challenge mentioned by interviews and research was the amount of nondeterministic objects, like humans and animals, in specific ODDs (Sushma and Kumar, 2022). The regulatory challenges and safety requirements also generally increase with the number of people often in the semi-urabn and urban ODD.

Another major factor brought up was how the difficulty level increases with speed. Distance was the final factor, where interviewees explained that it is not the distance itself, but the longer the distance, the greater the chance of exposure to different edge case scenarios. If the route is short and repeatable, it is easier to specify which obstacles and events may occur and, therefore, also easier to specify the ODD (Engström et al., 2018).

7.4 Future Outlook and Implications

The interviews and articles suggest that there might be changes in the infrastructure regarding autonomous vehicles, and that solutions for manual labour eventually have to be solved autonomously. However, the same articles (e.g. Monios and Bergqvist, 2019b) also stated that it will take time. Both literature (e.g. Monios and Bergqvist, 2019b) and interviews explained that the driver shortage mainly affects long haul operations. However, studies exploring the TCO perspective found that shorter distances have the most significant cost reduction in operations (Lee et al., 2023). These shorter routes were also said to have the most significant changes in the supply chain, as multiple smaller trucks could outperform their bigger counterparts from an operational cost and efficiency perspective.

Both literature (e.g. Fritschy and Spinler, 2019; Lee et al., 2023) and interviews agreed that TCO and the economic perspective were important when finding use cases. Utilizing multiple trucks in the same fleet, monitored by one operator, enables the benefits for AETs to achieve economies of scale (Engholm, Allström, and Akbarian, 2024). A common theme was that the supply chain must be adjusted to fully benefit from what AETs could bring (Chen and Lu, 2020). The literature stated that there was a need for change in infrastructure regarding sites and how the supply chain operates. The interviewees continue on the same topic, explaining that the supply chain has to be rethought and that processes most likely will have to change in the future. Both interviewees and literature (e.g. Hasiri and Kermanshah, 2024) agreed that connectivity also is an important aspect of the future success of autonomous trucks. Interviewees, pointed out that connectivity differs greatly depending on geographical area and must improve to ease the deployment of AETs.

The development of the AET should focus on specific sites and locations and consider the future direction of the ADS. Both literature (e.g. Engström et al., 2018; Vargas et al., 2021) and interviews stated that end-to-end data needs to be collected in quantity to evolve the capabilities of the autonomous system and prove validity in edge cases. Keeping the long-term goal in mind, incremental improvements could be made to the ADS when exploring new use cases to increase efficiency and save costs. As machine learning is used, the more accurate and the larger the quantity of data, the better the ADS will perform(Duguleană et al., 2024). Collecting data from areas and routes where the truck will operate was important, as stated by the literature (e.g. Katreddi, Kasani, and Thiruvengadam, 2022) and interviews.

8 Choosing Trajectory

This chapter explains the important factors necessary to successfully deploy AETs, derived from the interview findings and analytical framework analysis. Two different trajectories were developed based on the form factor of the truck.

8.1 Development Path

Identifying the specific ODD the truck will operate in rather than focusing on industries is essential, as ODDs could be the same throughout different industries. It will ease the recognition of feasible routes that are more specific to the truck's capabilities. The primary factors identified with developing the truck and the ODD are the number of nondeterministic obstacles, speed, and form factors. The first two are included in the division of the ODD. The latter form factor greatly influences feasible and targetable routes and the type of goods the truck can carry.

The rigid truck is generally better on shorter routes regarding the TCO, as loading time is shorter for goods due to the rigid trucks relatively low capacity. A tractor-trailer setup, on the other hand, does not have to be static at the loading bay when loading and unloading as the tractor can pick up an already loaded trailer. They also have more cargo to transport, meaning the trailer could have a longer load time. The swapping of trailer allows the tractor-trailer truck to be utilized at a high rate and spend as much time as possible transporting large amounts of goods over great distances to keep the cost down. It is essential with AETs, as a low TCO is correlated with high utilization. Each ODD is mapped to the dominating form factor operating today in that ODD, illustrated in Figure 15.

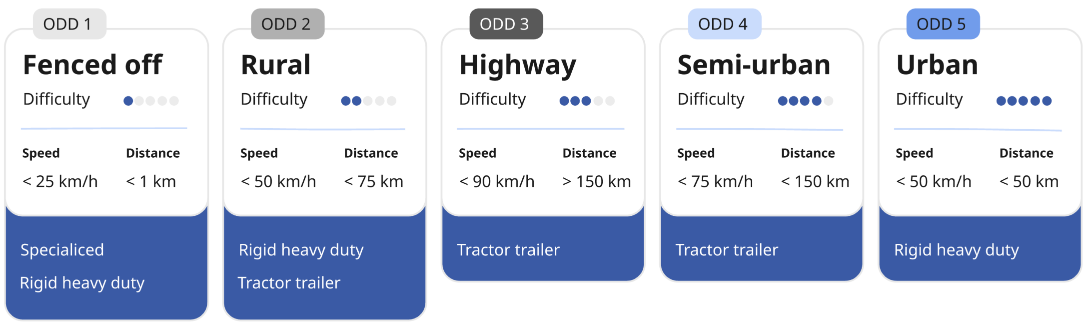


Figure 15: *ODD areas linked to form factor*

Two main themes emerged as the most promising development paths: one based on a rigid truck setup and the other on a tractor-trailer setup. As identified in the findings and analysis, the form factor differs between industries. It was also found that switching form factor is complex and costly and requires extensive truck hardware and ADS components modifications.

8.2 Development Path I - Rigid AETs

The development path for rigid trucks that are the most feasible is fenced off to rural and finally urban environments as seen in Figure 16.

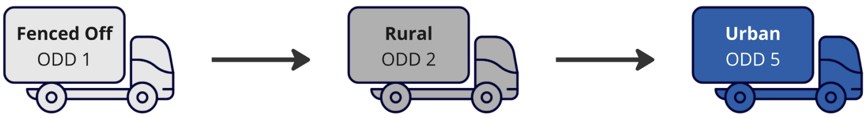


Figure 16: *Development of rigid form factor*

8.2.1 Fenced Off - ODD 1

Industrial and manufacturing settings are the primary targets for fenced-off environments due to the volume and type of goods shipped within the sites and the low entry barrier. Evolving into the rural application includes areas adjacent to ports and transport flows in and out of port areas. The current terminal tractors and other specialized autonomous trucks operating in fenced-off areas are prohibited on public roads. Therefore, the need for an AET in these overlapping industrial and private areas increases. It gives a competitive advantage as the trucks are utilized in overlapping settings and could therefore increase the efficiency in these high-volume routes.

8.2.2 Exploring Public Road and Rural Areas - ODD2

Moving away from fenced areas to deploy on public roads should be in hinterland areas with short distances between terminals. Industrial and manufacturing sites are also promising as they usually have high flows of goods. A rising trend in connecting the port-hinterland makes it a promising use case with repeatable routes and already existing efforts in automation. These could also be used for hub-and-spoke deliveries to local distribution centers near ports or industrial sites. Containers, mainly from ports, are traveling the shortest routes on average on public roads, which is a good first step to deploy.

Clusters of factories and manufacturing companies are usually located within areas where rigid trucks are the primary choice due to their maneuverability. Wholesale and manufactured goods are delivered multiple times daily, enabling the AET to have a high utilization rate. Rigid trucks are generally utilized on shorter routes and are a good fit between manufacturing sites and terminals in industrial areas, with significant pallets and bulky goods flows.

These routes are short, high-volume runs with few nondeterministic objectives. A swap body form factor application would further increase the use case in rural environments, enabling multiple industries to have an adaptable cargo space for specific tasks. Especially in the case of ports, given that their primary cargo type is containers. Highway and semi-urban environments generally include longer routes with higher loads, which are unsuitable for rigid trucks. Therefore, these ODDs have been identified as non-favorable for rigid trucks and not on the development path.

8.2.3 Final Stage in Urban Settings - ODD5

Finally, urban environments are the last application for rigid trucks, even though this domain most likely will expand beyond the timeline of 5 years. Deliveries in urban cities are the most challenging setting for any autonomous truck due to the number of nondeterministic objects and the complex environment. However, many trucks operate in this setting, which could eventually be exchanged for autonomous trucks when the ADS is mature enough. The need for electric trucks in this setting is increasing due to environmental goals. A more compact, rigid truck is more desirable in a city where maneuverability is important.

8.3 Development Path II - Tractor Trailer AETs

As most heavy road freight is transported with a tractor-trailer setup, developing an AET to tackle these challenges was particularly interesting. Figure 17 shows the suggested path for the tractor-trailer development.

Figure 17: *Development of tractor trailer form factor*

8.3.1 Initial Deployment in Rural Areas - ODD2

The main goal for a tractor-trailer is to be utilized on highways and high-speed country roads, which is the largest market. Companies must develop ADS capabilities to get the truck from the fenced-off sites to the highway to achieve that. The market analysis suggests that the chassis of tractor trailers within fenced-off applications are specialized and unsuitable for public roads. However, the targeted routes within the rural application should be as simple as possible, with sufficient flow of goods to incrementally expand ADS capabilities.

8.3.2 Deployment on Highway - ODD3

There is an increased incentive to build local hubs close to the highway, which would ease the deployment of autonomous trucks on highways. However, these infrastructure changes take time and are not expected to be in place within 2-5 years. Even though highways are the most competitive segment in terms of players' size, the market size is still big enough to be feasible. The development path should therefore go through rural areas with developing capabilities towards highways. The goal is to find specific customer deployments in rural applications where a tractor-trailer setup could be developed, allowing for future expansion.

8.3.3 Developing Capabilities Towards Semi-Urban Areas - ODD4

As the ADS and infrastructure capabilities develop, trucks will appear in semi-urban environments. These routes are not necessarily the primary use case for tractor-trailer trucks, but will probably have some use cases in the future. Utilizing semi-urban environments enables the truck to go from end to end and further widen its use case and feasibility. Semi-urban capabilities would enable the truck to drive end-to-end to hubs and facilities away from the highway. Expanding to these capabilities could increase utilization and decrease the TCO of the truck, making the entire route driverless.

8.4 Development Factors

Multiple factors contribute to developing the next generation of AETs. Understanding and determining the domain and industry in which the truck will operate is important. Being able to handle loads and industry specific cargo is essential to compete. Rigid trucks have to be able to load at least a 20-foot container, preferably a 40-foot container, as it is a standard measurement for the routes in ports. A rigid body with adjustable tail lift could also be preferable for palletized shipments where loading bays vary in height. Palletized goods are also the primary cargo type for a tractor-trailer which would need to be designed accordingly. Both of these form factors would need chassis capable of handling the weight of the desired cargo. It could therefore impact the size of the battery, which determines the range, speed, and the amount of goods capable of being transported.

Sensors and computing power are essential for navigating the trucks through the roads. There are multiple different types of sensors, which all serve different purposes. The end goal of determining which areas and industries the truck should operate in determines the placement and type. The required sensors should be able to handle the final target, as it allows for incremental improvements when the ADS is mature. If not, changing types and placements could impact the data structure, and the software must be redesigned. Modularity and redundancy are important as they improve the truck's safety and validity. However, more sensors require more computing power, which is expensive. Balancing tradeoffs between cost and capabilities are important.

Another aspect found was external communication with the surrounding environment. Lights and indications of the status could help improve and increase the public's trust. Colored lights could indicate when the truck is operating, loading, standby, or operated remotely, making it easier to understand its mode.

9 Discussion

The following chapter discusses the future of AET development and key considerations that should be considered with limitations and future work concluding the chapter.

9.1 Navigating the Landscape of AETs: Development Paths and Key Considerations

The successful deployment of AET depends on multiple factors, including the ADS capabilities, economic competitiveness, and customers' willingness to invest in innovation. Furthermore, effective communication and collaboration with governments and external stakeholders are important for navigating these complexities and ensuring future success. Its also better do develop based on the ODD than on the market as several markets can have similar ODDs. This is therefor also inline with the two suggested development paths that are based on developing in ODDs.

The path regarding the overall development and timeframe for AETs generally aligns with previous results. However, the realization of this path is reliant upon external stakeholders, governments, and technical improvements. It includes the incentives for the development of necessary infrastructure and the adaptation of regulations. AETs are further limited by safety considerations, regulatory frameworks, and public acceptance, necessitating a focused approach on feasible ODDs with safe operations. Some states in the US offer the most autonomous, friendly regulations, as well as stable weather conditions, which is beneficial and probably the reason why most actors are active in these areas. In contrast, the EU offers better connectivity at a broader scale, which is further important for a commercial launch and daily operations. Notably, incorporating remote operation capabilities, particularly in scenarios where ODDs overlap, such as adverse weather conditions, is important for future success and deployments.

From a long-term strategic perspective, it is crucial to determine whether or not the ultimate goal involves scaling operations and expanding to other use cases. If future targeted ODD differs from the primary, the initial development efforts should proactively account for this. Sensors with extended range capabilities should be incorporated, even if not required in the initial ODD. It allows for a smoother transition to more demanding ODDs and eventually reduces cost in the long run. Moreover, the development path suggests focusing on specific ODDs, rather than broad market segments. It is because a particular ODD can exist across various markets, allowing for a more targeted and effective development process.

The development path further reflects the current state of knowledge, as the advancement and adoption of autonomous technology will outpace supporting infrastructure development. Given the importance of long-term goals and the necessity for operational scalability, the primary ODDs and market segments should ideally be closely related. While other feasible alternative ODDs might emerge from the developed path, careful it is necessary to consider potential cost implications associated with significant market shifts.

The difficulty level of the ODDs scales from easy to hard, which derives from the ranking criteria from the findings. As mentioned, there are overlapping areas between the ODDs, depending on how the ODD is defined. Highway driving, is manageable and relatively easy for ADS to handle. However, the road onto the highway and hub connections might expose the ADS to unfamiliar and challenging areas closer to the semi-urban ODD. However, if remote driving is available, these distances could be managed by an operator who remotely controls the vehicle in areas that the ADS cannot handle. Thus, the remaining distance that makes up the longest distance is still available for the capabilities of the ADS and could still be competitive in the near term.

Truck size, transport distance, geographical location, and the type of goods transported are all valid segmentation criteria, yielding distinct market segmentations. Evaluating market size, location, the number of competitors, and their progress in the targeted segment indicates where deployment could be feasible. The tractor-trailer setup dominant in the highway market is fragmented with many actors. However, this ODD offers the most significant market and manageable ODD, making it a feasible target. The rigid truck setup, suggested to be developed in hinterland areas, offers a relatively small market compared to highway driving. Though stakeholder engagement, less complex ODD, and highly automated surrounding infrastructures with lots of operations make it a feasible starting point for these trucks, as this form factor is easier to develop.

Adopting a broader, more holistic view of the supply chain, which integrates multiple relevant metrics within overarching categories, offers a more effective approach compared to industries clustered by the content of the goods and distance. It allows for a mapping of market segments to the specific ODD capabilities of AETs, thereby providing a more nuanced understanding of potential market fit and facilitating market value estimation.

9.2 Limitations

Several limitations should be acknowledged when interpreting the findings of this report. The diversity of interview participants encountered certain constraints. Accessing a broad spectrum of interviewees was difficult due to potential conflicts of interest. Furthermore, candidates currently employed by other companies often hesitated to share their thoughts as they had disclosable information and insights, which naturally limited the range of perspectives captured.

Another significant limitation was the accessibility to data and statistics in various industries. Comprehensive data specifically concerning AETs are not yet widely available. General data on heavy road freight trucks related to specific routes were unavailable, especially those covering shorter distances. This lack of readily accessible data has posed a challenge in conducting a detailed analysis. Moreover, the precise estimation of the total addressable market was proven challenging. While the provided figures offer a valuable indication of the market's potential size, this landscape's complexities and evolving nature introduce a degree of uncertainty in achieving accuracy by the decimal.

Finally, the industry study encountered difficulties stemming from how companies communicate their positions. Organizations tended to report their progress with carefully chosen language, potentially preventing a completely transparent understanding of their true intentions and achievements. Obtaining an entirely unbiased and unfiltered view of the stakeholder landscape was challenging.

9.3 Future Research

Several key areas require further investigation to build upon the insights gained in this report. Firstly, a more detailed view into each identified use case is crucial. These insights allow a nuanced understanding of various industries' challenges, opportunities, and unique customer needs. Such focused analysis would pave the way for more tailored and impactful solutions for targeted markets.

Secondly, the significance of robust data collection methodologies has emerged as a critical area regarding the ADS and machine learning systems. Accessible high-quality and quantity of real-world data is important as it is the primary building block of the ADS. Research must be directed towards strategies for large-scale data acquisition to address end-to-end use cases and handle edge cases effectively. Investigating innovative and scalable data collection techniques will be essential for building safe and adaptable systems to improve ADS capabilities.

Finally, the importance of safety on public roads and the public acceptance of AETs are challenges to address. Covering safety concerns is crucial for widespread deployment and facilitating wider adoption. Future work should focus on developing comprehensive safety cases to streamline deployment in new areas. It could further enhance the understanding of accessibility, ultimately fostering greater trust and accelerating the integration of these technologies in day-to-day operations.

10 Conclusion

This thesis identifies key aspects for developing AETs in general ODDs and, thereafter, defines feasible development paths in the near future within a time horizon of 2-5 years. An extensive theoretical framework consisting of academic literature and statistical data was made. Continuing with an industry and market study, together with interviews, several findings emerged.

Key aspects for developing the next generation of AETs in the near future include *safety*, *form factor*, and *ADS capabilities*, which include sensors and data. The ADS capabilities are strongly related to where the truck can operate safely, especially in edge cases where events are hard to predict. Nondetermanistic objects, speed, and distance were the most important aspects. Also, tied to safety is the regulatory challenge that comes with deploying AETs. As discovered, autonomous vehicle regulations vary greatly depending on the country and region. The more controlled the operational area is, the easier it is to deploy. However, this can also hinder development in the long term as recruitment in these areas is often very different from that of other ODDs.

Feasible development paths for AETs in the next 2-5 years appears to diverge based on vehicle form factor and target a specific ODD and not a market. An approach starting in controlled ODDs and progressively expanding to ODDs with a more complex environment with high utilization is recommended for rigid trucks. Rigid trucks are not articulated, making them easier to develop. They have been demonstrated to have the most significant TCO reduction on shorter routes. If capabilities and safety can be improved and validated, these AETs could eventually deploy in urban environments.

The most promising path for AETs with the tractor-trailer setup is to deploy on simple routes with heavy loads in rural areas to improve deployment capabilities on highways thereafter. Even though fenced-off areas are easier, the current tractor trailers in that field have other requirements compared to the trucks on public roads, which are not beneficial for future expansion towards highways. The recommendation is therefore to find the rural roads where autonomous operations will be safe and allowed.

The most significant competition is in fenced-off areas, which are the easiest and where actors have come the furthest. Moving towards public road applications, the longer highway routes have the most significant market share. The highway was identified as the primary goal for most actors with a tractor-trailer setup. Considering stakeholders and market size when targeting specific ODDs is important for long-term success.

Ultimately, success in the autonomous freight transport industry with AETs hinges on balancing technical innovation with practical considerations, such as proving safety, gaining public acceptance, finding feasible deployment routes, and establishing viable business cases. It will require continuous collaboration with governments, regulatory bodies, and industry stakeholders, and a focus on data collection and refining machine learning models for deployment.

In conclusion, several key factors, such as safety, form factor, ADS capability, data, regulation, and public acceptance, will impact the success of AETs in the road freight industry. Different paths in developing the next generation AET will have their own challenges in the coming years. One path may be better depending on how the market changes in the coming years.

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Appendix

A Progress Estimation Timeline Data

Publisher	Titel	Year	Market	URL
ERTRAC	Automated driving roadmap	2017	Europe	https://www.ertrac.org/wp-content/uploads/2022/07/ERTRAC_Automated_Driving_2017.pdf
WEF	Autonomous Trucks: An Opportunity to Make Road Freight Safer, Cleaner and More Efficient	2021	US	https://www3.weforum.org/docs/WEF_Autonomous_Vehicle_Movement_Goods_2021.pdf
McKinsey & Company	What's next for autonomous vehicles?	2021	Europe	https://www.mckinsey.com/features/mckinsey-center-for-future-mobility/our-insights/whats-next-for-autonomous-vehicles#/
McKinsey & Company	What's next for autonomous vehicles?	2021	US	https://www.mckinsey.com/features/mckinsey-center-for-future-mobility/our-insights/whats-next-for-autonomous-vehicles#/
SAE	Hopeful but closer scrutiny for SAE Level 4 automation	2022	Europe	https://www.sae.org/news/2022/10/the-autonomous-level-4-horizon
McKinsey & Company	Will autonomy usher in the future of truck freight transportation?	2024	Europe	https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/will-autonomy-usher-in-the-future-of-truck-freight-transportation
McKinsey & Company	Will autonomy usher in the future of truck freight transportation?	2024	US	https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/will-autonomy-usher-in-the-future-of-truck-freight-transportation
ACEA	Automated and autonomus driving	2024	Europe	https://www.acea.auto/files/ACEA_Automated_and_autonomous_roadmap.pdf
Award	Roadmap towards connected and automated heavy-duty vehicles for logistics operations	2024	Europe	https://www.ccam.eu/wp-content/uploads/2024/09/101006817_Deliverable_46_Roadmap-towards-connected-and-automated-heavy-duty-vehicles-for-logistics-operations.pdf
WEF	Autonomous Vehicles: Timeline and Roadmap Ahead	2025	US	https://reports.weforum.org/docs/WEF_Autonomous_Vehicles_2025.pdf

B AI Prompts

Review the following academic text and do advanced spell checking. The goal is to improve its clarity, correct grammatical errors, and check for spelling mistakes. Also, consider making the language more precise and appropriate for an academic context.

C Interview Guide

Part 1: Introduction

We are masters students, working with autonomous electric heavy duty trucks.

We are investigating key factors for developing physical attributes for future autonomous electric trucks in specific operational design domains. Our main questions are:

1. What are specific requirements of autonomous electric vehicles in specific ODDs?
2. What is the most promising development path for autonomous electric trucks in the next 2-5 years?

The interview will be presented anonymously in the report and all interviews will be deleted after the project and we are the only ones handling the material.

Is it okay if we record/transcribe the interviews?

1. What is your name
2. What is your role in the company

Part 2: Interview guide

I. Current Landscape & Needs:

1. **Industry Needs & Pain Points:**
   - What are the primary needs and pain points of trucking companies that autonomous technology could potentially address (e.g., driver shortage, fuel costs, safety, efficiency)?
   - Which of these are the *most* important?
2. Which are factors to consider when choosing segments or ODDs för AET?

II. Autonomous Trucking Applications & Potential:

3. **Promising Applications:**
   - What are the most promising commercial applications for autonomous trucks (e.g., specific routes, cargo types, industries), and why do you see potential in these areas? Can you provide specific examples? ODD?
4. **AET's Value Proposition (Beyond Cost Savings):**
   - Beyond cost savings, what other benefits could AETs provide to the trucking industry and/or your business specifically?

III. Challenges & Barriers to Adoption:

5. **Deployment Challenges:**
   - What are the main challenges you see with commercially deploying AETs?
6. **Barriers to Widespread Adoption:**
   - What are the most significant barriers to the widespread adoption of autonomous trucking? (e.g., technological, regulatory, economic, social)? Which is most important?
   - Which barriers do you think are the most difficult to overcome?
7. **Perceived Risks & Challenges:**
   - What are the biggest perceived risks or challenges associated with adopting autonomous truck technology? (Directly addresses concerns.)
8. **Barriers to Your Adoption:**
   - What are the biggest barriers preventing adoption of autonomous trucks *today*?

IV. Technology & Development:

9. **Critical Technological Developments:**
   - What are the most critical technological developments that you believe will have the greatest impact on the future of autonomous trucking? Why do you consider these advancements so crucial?
   - Batteries and sensors
10. **Essential technical Advancements/Capabilities:**
    - What technological advancements or capabilities are *essential* for the widespread adoption of autonomous trucks?
11. **Essential physical Advancements/Capabilities:**
    - What physical requirements are *essential* for the widespread adoption of autonomous trucks?
    - How does the truck's form factor differ in different segments?
    i. How does it impact the trucks and their deployment
    ii. Where are they driving
12. **Data & Connectivity's Role:**
    - Beyond the technology itself, what role will data and connectivity have in the successful deployment of AETs?
13. **AI's Role:**
    - What is your perception of the role of AI in the development of autonomous trucking?
14. **Next Generation AETs:**
    - What is crucial for the next generation of AETs?
    - What do you think the next generation AETs will be capable of?
15. **Current Limitations:**
    - What are the main limitations in regards to AETs *today* in your opinion?
    - What do you think needs to be solved to make AETs commercially viable?
16. **Operating Conditions:**
    - What are the most challenging operating conditions for AETs?
    - What are the easiest operating conditions?
    - Is it more challenging to have an autonomous truck than a car?
    - Why do you think autonomous cars have come further than trucks?

V. Market & Future Outlook:

16. **Market Readiness:**
    - Do you think the market is ready for ATs? Why or why not? What are the remaining hurdles to widespread adoption?
17. **Market Analysis Factors:**
    - What are the most crucial factors to consider when analyzing the autonomous trucking market and its various segments?
18. **Recent Trends:**
    - What changes in trends have you noticed in the AT/AET landscape recently? (e.g., technological advancements, regulatory shifts, investment patterns)
19. **Key Adoption Factors:**
    - Based on your understanding of the industry, what are the key factors for adoption of AET? Do these factors vary across different segments of the trucking industry?
20. **Market Forecast (5 Years):**
    - Where do you see the AT/AET market in the next 5 years?
21. **Long-Term Market Forecast (10+ Years):**
    - Where do you see the market going in the long term (10+ years)?

22. **Largest Use Case:**
   - What part of the trucking market do you think has the largest use case for AET? Why do you think these are more suitable?
23. **Logistics Chain Impact:**
   - What part of the logistics chain do you see AET replacing?
   - How would you divide the logistics, a simplified version
   - Benefits and issues with them?
24. **Risk Management Lessons:**
   - Are there other industries that have risk management practices where AETs can learn from?
25. **Optimal Deployment:**
   - With consideration to both the trucking market and technical capabilities, where do you think it is best to deploy the next generation of AETs?

VI. Regulations & Evaluation:

26. **Regulatory Changes:**
   - How do you think the regulations will change in the future in regards to AET?
27. **Technology Development Changes:**
   - How do you think the development of technology in regards to AET will change?
28. **Regulatory Bodies & Government Policies:**
   - What role do you see regulatory bodies and government policies playing in the development and adoption of autonomous trucking?
29. **Evaluation Criteria:**
   - What specific criteria would you use to evaluate autonomous trucks? Does this differ from how you evaluate traditional truck investments?
30. **Adoption Influencers:**
   - What factors do you think would influence the decision to adopt autonomous trucks?

VII: Additional

Is there anything else you would add that you think we should consider?

Is there somebody that you think is important for us to talk to in regards to this subject?

Thanks for the interview!

Are you okay with reaching out if we have any more questions?

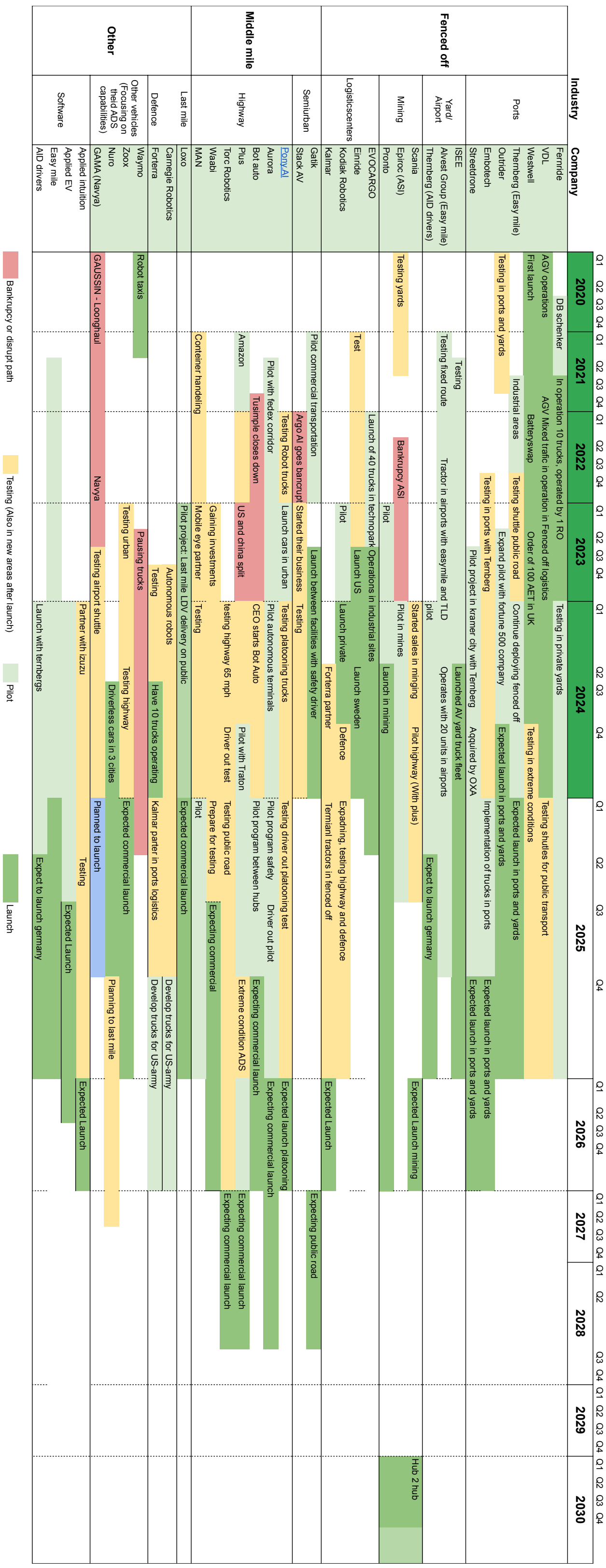
D Global Market Values

Market Gloabl	Size	Publisher	Heading	URL	Access date
Terminal tractor	$1.20 Billion	Gracey Cummins	Terminal Tractor Market Share Expected to Grow with Healthy CAGR by 2032	https://www.linkedin.com/pulse/terminal-tractor-market-share-expected-grow-healthy-cagr-cummins-dppnf	2025-04-01
	$0.75 Billion	Spherical insigts	Global Terminal Tractor Market Insights Forecasts to 2032	https://www.sphericalinsights.com/reports/terminal-tractor-market	2025-04-02
	$1.40 Billion	Markets and Markets	Terminal tractor market Size, share and analysis	https://www.marketsandmarkets.com/Market-Reports/terminal-tractor-market-153834794.html	2025-04-02
	$3.00 Billion	Grand view research	Port Equipment Market Size & Trends	https://www.grandviewresearch.com/industry-analysis/port-equipment-market-report	2025-04-02
	$3.10 Billion	Market research future	Global Yard Truck Market Overview	https://www.marketresearchfuture.com/reports/yard-truck-market-27915	2025-04-06
	$12.50 Billion	Market Research Intellect	Terminal Truck Market Size and Projections	https://www.marketresearchintellect.com/product/global-terminal-truck-market-size-and-forecast/	2025-04-06
Avarage	**$3.66 Billion**				
Shunting	$10.03 Billion	Market Research Intellect	Shunt Truck Market Size	https://www.marketresearchintellect.com/product/global-shunt-truck-market/	2025-04-01
	$1.50 Billion	Data Intelo	Shunt Truck Market	https://dataintelo.com/report/global-shunt-truck-market	2025-04-01
	$1.80 Billion	Predictive Market Moves	Shunt Truck Market	https://sites.google.com/view/predictive-market-moves/home/market-reports/shunt-truck-market	2025-04-01
	$2.77 Billion	Wise Guy reports	Shunt Truck Market	https://www.wiseguyreports.com/cn/reports/shunt-truck-market	2025-04-07
	$0.80 Biliion	The Market Reports	Global Shunt Truck Market Research Report 2025	https://www.themarketreports.com/report/global-shunt-truck-market-research-report	2025-04-07
	$3.38 Biliion				
First mile	$33.43 Billion	Global Market Insights	First Mile Delivery Market Size	https://www.gminsights.com/industry-analysis/first-mile-delivery-market	
Avarage	**$33.43 Billion**				
Middle mile	$50.75 Billion	Global Market Insights	Middle Mile Delivery Market Size	https://www.gminsights.com/industry-analysis/middle-mile-delivery-market	2025-04-01
	$57.56 Billion	360iResearch	Middle Mile Logistics Market by Offering	https://www.360iresearch.com/library/intelligence/middle-mile-logistics	2025-04-01
	$57.56 Billion	ASD Reports	Middle Mile Logistics - Global Forecast 2024-2030	https://www.asdreports.com/market-research-report-654338/middle-mile-logistics-global-forecast	2025-04-03
	$58.76 Billion	The business research company	Middle Mile Logistics - Global Forecast 2024-2030	https://www.thebusinessresearchcompany.com/report/middle-mile-delivery-global-market-report	2025-04-04
Avarage	**$56.16 Billion**				
Last	$16.45 Billion	Horizon	Europe Last Mile Delivery Market Size & Outlook, 2023-2030	https://www.grandviewresearch.com/horizon/outlook/last-mile-delivery-market/europe	2025-04-01
	$20.58 Billion	Research and Markets	Last Mile Delivery Market Report 2025	https://www.researchandmarkets.com/reports/5980378/last-mile-delivery-global-market-report#rela1-5792790	2025-04-01
	$16.68 Billion	Introspective Market Research	Last Mile Delivery	https://www.globenewswire.com/news-release/2024/12/03/2990865/0/en/Last-Mile-Delivery-Set-to-Grow-at-a-Remarkable-Reach-USD-318-83-Billion-by-2032-CAGR-of-9-1-from-2024-2032.html#:~:text=Last%20Mile%20Delivery%20Market%20Size,9.1%25%20From%202024%2D2032.	2025-04-07
	$10.24 Billion	Global Market Insights	Last Mile Delivery Market Size	https://www.gminsights.com/industry-analysis/last-mile-delivery-market	2025-04-07
	$19.44 Billion	Market research future	Global Last Mile Delivery Market Overview	https://www.marketresearchfuture.com/reports/last-mile-delivery-market-22138	2025-04-07
	$17.83 Billion	Precedence Research	Last Mile Delivery Transportation Market Size	https://www.precedenceresearch.com/last-mile-delivery-transportation-market	2025-04-07
Avarage	**$16.87 Billion**				

Long haul	$745.11	Billion	Market Research Intellect	Long Haul Trucking Market Size	https://www.marketresearchintellect.com/product/global-long-haul-trucking-market/	2025-04-01
	$940.00	Billion	The business - Research company	Long-Distance General Freight Trucking Global Market Report 2025	https://www.thebusinessresearchcompany.com/report/longdistance-general-freight-trucking-global-market-report	2025-04-01
	$516.00	Billion	Market research future	Long Distance General Freight Trucking Market Overview:	https://www.marketresearchfuture.com/reports/long-distance-general-freight-trucking-market-30681	2025-04-03
	$730.78	Billion	Research and Markets	Long Distance General Freight Trucking Market	https://www.researchandmarkets.com/report/long-distance-general-freight-trucking?srsltid=AfmBOop7zaezlyX5mlbmzB3KTBdfTRqWibwNCJKm6O2gAqiS2Hg9xNHx	2025-04-03
Avarage	**$732.97**	**Billion**				
First and last mile	$123.00	Billion	Research and Markets	First and Last Mile Delivery Market Report 2025	https://www.researchandmarkets.com/reports/5792790/first-last-mile-delivery-market-report?srsltid=AfmBOooTzB0NTMOUp6yNuSyNsOVmN0sgbOgJAr9_YjzVcXXoOTHVZMzY	2025-04-01
	$175.80	Billion	Industry ARC	First & Last Mile Delivery Market	https://www.industryarc.com/PressRelease/4095/First-And-Last-Mile-Delivery-Market	2025-04-01
	$95.53	Billion	Transparency market research	First & Last Mile Delivery Market	https://www.transparencymarketresearch.com/first-last-mile-delivery-market.html	2025-04-03
	$36.80	Billion	MMR	First and Last Mile Delivery Market: Global Industry Analysis and Forecast 2032	https://www.maximizemarketresearch.com/market-report/global-first-and-last-mile-delivery-market/35552/	2025-04-03
Avarage	**$107.78**	**Billion**				
Retail	$66.75	Billion	Grand view research	Retail Logistics Market Size, Share & Trends Analysis Report	https://www.grandviewresearch.com/industry-analysis/retail-logistics-market	2025-04-01
	$76.56	Billion	Research Nester	Retail logistics market	https://www.researchnester.com/reports/retail-logistics-market/6257	2025-04-01
	$77.61	Billion	Market research future	Global Retail Logistics Market Overview	https://www.marketresearchfuture.com/reports/retail-logistics-market-11543	2025-04-03
	$77.53	Billion	KBV Research	Global Retail Logistics Market Size	https://www.kbvresearch.com/retail-logistics-market/	2025-04-03
Avarage	**$74.61**	**Billion**				
Mining	$23.00	Billion	Globe Newswire	Global Mining Truck Market Size	https://www.globenewswire.com/news-release/2024/06/30/2906262/0/en/Global-Mining-Truck-Market-Size-To-Worth-USD-33-8-Billion-By-2033-CAGR-Of-3-88.html	2025-04-09
	$33.00	Billion	Precedence Research	Mining Logistics Market Size, Share and Trends 2024 to 2034	https://www.precedenceresearch.com/mining-logistics-market	2025-04-09
	$28.00	Billion	Grand View Research	Mining Logistics Market Size & Trends	https://www.grandviewresearch.com/industry-analysis/mining-logistics-market-report	2025-04-09
Avarage	**$28.00**	**Billion**				
Intermodal	$42.50	Billion	Allied Market Reseach	Intermodal Freight Transportation Market Size	https://www.alliedmarketresearch.com/intermodal-freight-transportation-market-A49990	2025-04-03
	$42.90	Billion	Grand View Research	Intermodal Freight Transportation Market Size	https://www.grandviewresearch.com/industry-analysis/intermodal-freight-transportation-market-report	2025-04-03
	$37.20	Billion	Technavio	Intermodal Freight Transportation Market	https://www.technavio.com/report/intermodal-freight-transportation-market-industry-analysis	2025-04-06
Avarage	**$40.87**	**Billion**				
Total	$2,670.00	Trilion	Globe Newswire	Freight Trucking Market	https://www.globenewswire.com/news-release/2024/07/08/2909781/0/en/Freight-Trucking-Market-to-Reach-USD-3768-1-Billion-in-2032-Driven-by-increasing-E-commerce-industry-and-innovation-in-Supply-Chain-According-to-SNS-Insider.html	2025-04-01
	$2,900.00	Trilion	Imarc	Freight Trucking Market Size	https://www.imarcgroup.com/freight-trucking-market	2025-04-02
	$2,739.00	Trilion	Fortune Business insights	Freight Trucking Market Size	https://www.fortunebusinessinsights.com/freight-trucking-market-105069	2025-04-03

	$2,400.00	Trilion	Skyquest	Freight Trucking Market Size, Share, and Growth Analysis	https://www.skyquestt.com/report/freight-trucking-market	2025-04-08
	$2,856.00	Trilion	The brainy Insights	Freight Trucking Market Size	https://www.thebrainyinsights.com/report/freight-trucking-market-13927?srsltid=AfmBOop82bOYenXAX8Kovb8UZhjrA5vhiVU5hvVTZFZIBGFz50Li0Lvk	2025-04-09
Avarage	**$2,713.00**	**Trilion**				

E Detailed Market Actors Timeline



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