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Challenges of Autonomous Driving Trucks and the Impact on Logistics

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Abstract

In recent years, the concept of autonomous vehicles has gained considerable attention due to advancements in automation technology. In the logistics sector, these technologies are being developed and tested specifically for trucks. The innovative development of these technologies holds potential to drastically transform the logistics industry.

This research examines the potential impact of autonomous trucks on the logistics sector, focusing on their advantages and disadvantages, as well as the challenges they pose. According to various publication from private and public organizations, the deployment of autonomous trucks has the potential to increase road capacity, reduce traffic accidents, lower pollution, fuel consumption, and create more sustainable transportation systems. However, there are several challenges to overcome, including technological and legal challenges, safety concerns, and ethical considerations.

This research aims to provide insights into the current state of autonomous driving trucks, their implications on logistics sector, and the challenges they present by analyzing existing studies and publications. This research offers valuable information for logistics organizations, regulators, and researchers to evaluate the implications of this evolving technology on logistics industry.

Keywords
Autonomous Trucks, Logistics, Sustainability, Technology, Supply Chain, Safety, Reliability, Cost-effective, Technology constraints.

CONTENTS

1 INTRODUCTION

In the early 1950s, guided vehicles and automated transport systems were used in manufacturing industry in United States and Germany (Maurer, et al., 2016, p. 53) since then, several companies have started developing autonomous driving vehicles. Nowadays, autonomous vehicles are defined as applying technology to replace the human driver while directing a vehicle partially or entirely from its origin to its destination while avoiding obstacles on the road and adapting to traffic circumstances (University of Michigan, 2021).

“In the transition from horse carriages to automobiles, important obstacle-avoidance skills were lost” (Maurer, et al., 2016, p. 2). “It should not be forgotten that this technology can save many lives. Perfect technology may not yet exist, but certainly one that acts significantly better than humans” (Becker, 2021). Autonomous driving not only can have a reduction in the driver's workload but also that a driver may not be required. This innovation might be a game changer for logistics, truck drivers are subject to stringent restrictions that, among other things, specify driving hours and rest periods. The vehicle must stop a lot because of this, trucks that do not need a driver would not need to take these pauses and could move without stopping (Becker, 2021).

The implementation of autonomous vehicles has the potential to increase efficiency, reduce accident rates, improve traffic safety, and reduce environmental footprint. As technology facilitates more driving, it has been criticized for being unsafe, jeopardizing employment and increasing environmental pollution (Ryan, 2020). Dr. Jan Becker, an expert on autonomous driving, suggest that although the development of autonomous driving technology is benefiting many fields, the logistics industry can benefit the most. It can improve the efficiency, safety and sustainability of the logistics industry and meet the growing demands of truck drivers (Becker, 2021).

Autonomous trucks are becoming more common on the highway and are no longer a matter of science fiction in states like Texas and California. Anyhow, "safety drivers" are still behind the wheel (Metz, 2022). Vulnerabilities in every industry, but particularly in the retail sector, are revealed by digitization and other technological advancements, and now, pressure is beginning to build on logistics companies (Chottani, et al., 2018).

1.1 Purpose

How can logistics service providers deploy autonomous driving technology to maximize effectiveness and safety while minimizing risks and challenges? With the main research question highlighted, the research purpose is to analyse the challenges of autonomous driving trucks and their potential impact on the logistics industry. This research seeks to identify challenges in autonomous trucking and the potential benefits of implementing such technology. Research on autonomous driving trucks, and their impact on logistics can provide a better understanding of the benefits and limitations of using them in the logistics industry.

The research looks into how autonomous vehicles might improve logistical processes by lowering the risk of human mistakes, increasing productivity, cutting transportation costs, and reducing carbon emissions. Additionally, the research will look at ethical and legal issues that might prevent the broad adoption of autonomous vehicles. The research can offer insightful information to companies involved in the logistics sector, on how autonomous driving trucks may affect the direction of logistics and future transportation. This research aims to provide insights into the future of logistics and how autonomous trucking can contribute to its evolution.

1.2 Objectives

Within the confines of this research, the following questions aim to provide information regarding.

I. Identifying the challenges that autonomous trucks have in the logistics industry.
II. Evaluating the potential benefits of using autonomous driving technology by logistics companies.
III. Examine the potential effects.
IV. Concluding with recommendations for logistics companies considering implementing autonomous trucks.

With these objectives, the research can provide a comprehensive understanding of how autonomous driving trucks can impact the logistics industry and provide information on the adoption of this technology.

1.3 Conceptual Framework

Conceptual framework attempts to illustrate the primary subject of research in a visual and narrative method (Figure 1). This includes features, variables, and constructs in addition to their interactions (Matthew B. Miles, 2014, p. 20). The conceptual framework is an adaptive framework from (Winkelhaus & Grosse, 2020).

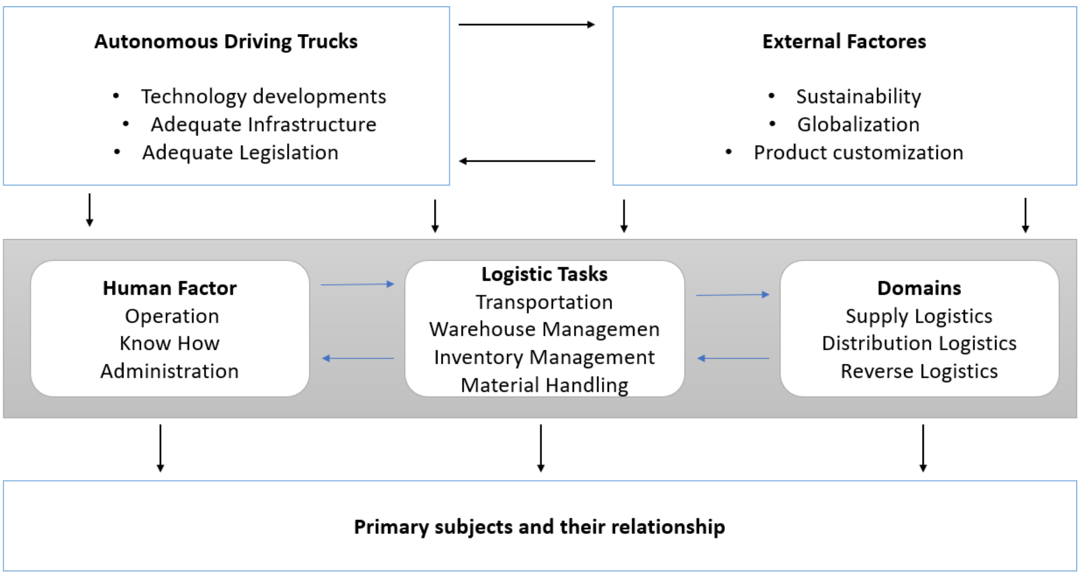

Figure 1. Conceptual Framework.

Framework combines external elements, technology advancements, the effects of the human component, and logistical tasks to present an overview of future autonomous driving truck applications and the factors implicated. According to (Winkelhaus & Grosse, 2020) these elements are already in place and support logistic operations.

Autonomous trucks are part of technological development. Are they a reality that most logistical companies will soon have in their fleet? According to (Wasinger, 2022), making forecasts is not possible at this point, thereby, it is difficult to predict with certainty when autonomous trucking will become the norm. Yet, it is certain that technology is developing, and as autonomous trucks get more affordable, more logistics companies will start to use them. However, autonomous driving trucks need a suitable infrastructure, regulatory framework, and are affected by external factors such as globalization. This technological advancement has implications for logistics as it completely or partially removes the human element from logistical tasks such as transportation.

Due to their potential to increase productivity and save costs, autonomous driving trucks have drawn increased attention in logistics sector (Daimler, 2020). Prior research has examined the advantages and disadvantages of autonomous driving trucks, including safety issues (Madhavan, et al., 2006), and the impact on employment (Brynjolfsson & McAfee, 2014, p. 176). Conducting this research is intended to use a multi-method quantitative method, critical realism, and interpretivism approach to explore the presumptions, phenomenology, trends, and issues in the logistics sector regarding autonomous trucks.

1.4 Scope and Delimitation

This research focuses on exploring the advantages and disadvantages of autonomous driving trucks in the logistics industry. The research aims to provide insights into the current state of autonomous driving technology and its implications in logistics sector. The research will specifically look into technological, ethical, safety, and legal challenges related to autonomous driving trucks (Figure 2).

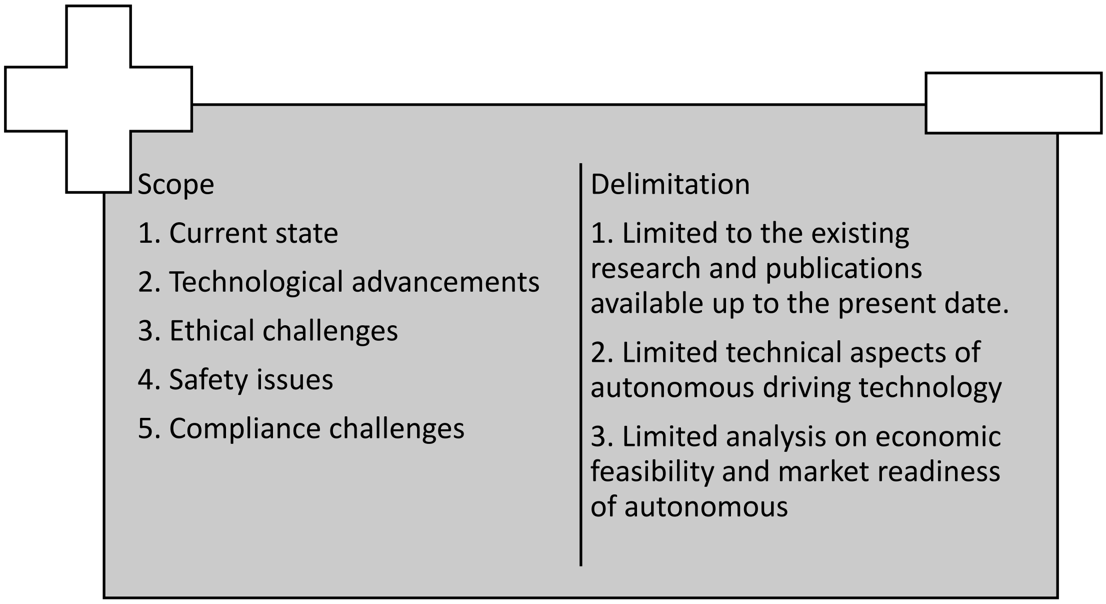

Figure 2. Research scope and delimitation

However, this research does not look into the technical aspects of autonomous driving technology in great detail. Primarily focuses on the broader implications and potential impacts of autonomous trucks on logistical operations, road capacity, safety, environmental sustainability, and costs. This research aims to provide a comprehensive analysis however it is limited to the existing research and publications available up to the present date. The findings and conclusions drawn from this are based on the information and insights provided by these sources. This research does not include a detailed analysis of the economic feasibility and market readiness of autonomous driving trucks. The research primarily focuses on the advantages and disadvantages of implementing this technology in logistics and the challenges that need to be addressed.

2 LITERATURE REVIEW

The literature review will provide a comprehensive view of the opportunities and challenges raised by autonomous driving trucks in the logistics sector. The review will include studies and publications from the North American and European logistics markets, relevant academic papers, business reports, and industry publications. Review will serve as the basis for data collection, analysis, and research methodology.

2.1 Definitions

2.1.1 Autonomous Driving

Models of trucks currently on the road already offer a semi-autonomous mode of operation, in which a truck or a human operator conducts an operation with varying degree of technology interaction. These trucks are referred to as autonomous trucks because they are controlled from other sources, such as satellites and advanced GPS (Global Positioning Systems) (Jin, et al., 2019). Autonomous systems are expected to be able to complete their tasks within a specified range without human assistance (Madhavan, et al., 2006).

Autonomous driving trucks rely on a variety of advanced technologies to operate safely and effectively. These technologies include light detecting and ranging (LIDAR), which utilizes light pulses to measure distances, global positioning system (GPS), cameras that capture visual data, accelerometers, and gyroscopes that continuously track position and movement, and radars that use energy pulses to detect and monitor objects in the vehicle's surroundings (United States Government Accountability Office, 2019) (Appendix 1).

There are six levels of autonomous driving (Figure 3), ranging from level zero (no driving automation) to level five (full driving automation), according to (Society of Automotive Engineers, 2021) (Appendix 2).

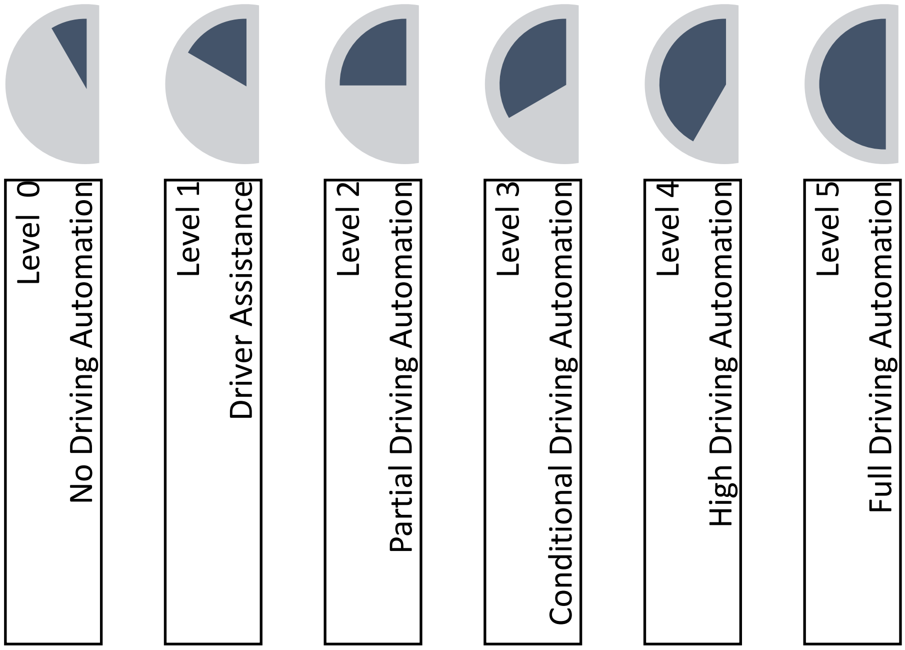

Figure 3. Levels of automation (Society of Automotive Engineers, 2021).

Functions that vehicles with level one autonomy offer automation capabilities like adaptive cruise control and lane departure warning, but most driving activities still require human intervention. In terms of level two autonomy, a vehicle is one that can accelerate and steer without human assistance but still needs to be monitored by a human. Vehicles with level three autonomy can carry out most driving activities without human assistance, however they still need input, such as when they run into unexpected road conditions. Vehicles at level four autonomy can handle every aspect of driving without assistance from a person, but only under certain circumstances, such as on unrecognized road or in a specific location. Vehicles with level five autonomy can operate in every driving situation or environment without the assistance of a human (Society of Automotive Engineers, 2021).

Additionally, connected autonomous vehicles (CAV), are vehicles that can communicate with other vehicles, and their surroundings using technology like vehicle to vehicle and vehicle to infrastructure communication (Talebian & Mishra, 2018). And platoon of autonomous trucks is a collection of two or more vehicles that move in a convoy, with the lead vehicle in charge of the convoy's speed and direction (Chottani, et al., 2018).

2.1.2 Logistic Service Providers

Companies known as logistics service providers (LSP) provide businesses and organizations with a variety of logistical services, such as transportation, warehousing, and inventory management (Jenkins, 2023). These categories are defined as follows (Figure 4).

- First-party logistics are companies that manage all its internal logistics.
- Second-party logistics provides transportation and shipment.
- Third-party logistics (3PL) companies are focused on offering logistics services to companies and organizations, frequently outsourcing logistics tasks that were previously performed internally.
- Logistic service providers that play a more strategic role in managing a company's logistics operations are known as fourth-party logistics (4PL) providers.
- Fifth-party logistic provider play more significant role in supply chain by building a vast supply network, these companies frequently serve as a single point of contact for all logistics-related aspects and coordinate the efforts of various third-party logistics (3PL) providers (De Leeuw, et al., 2015; Jenkins, 2023).

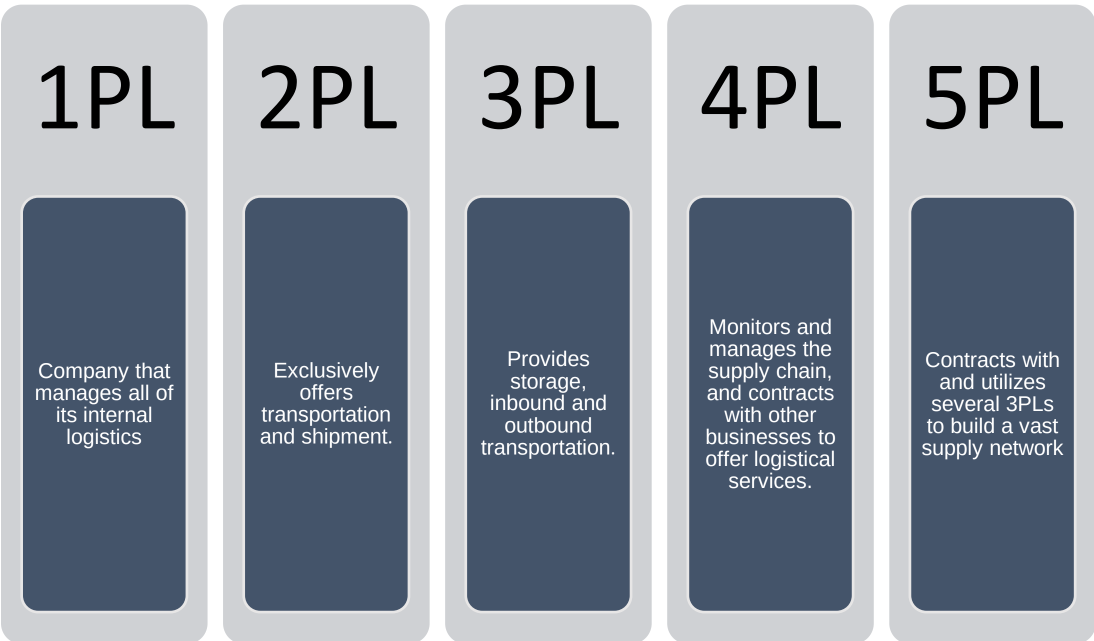

Figure 4. Different Logistic Service Providers (Jenkins, 2023).

Freight forwarders are companies with a focus on organizing the transportation of commodities, frequently utilizing a variety of modes, including air, sea, and land (Waterson, 2010). Reverse logistics providers are companies that specialize in managing the transportation of products from the final consumer back to the producer or distributor, frequently performing tasks like product returns, repairs, and recycling (Rogers & Tibben-Lembke, 1998).

2.2 Autonomous Driving Challenges

2.2.1 Technological Challenges

One of the main challenges in autonomous driving is maintaining the dependability and accuracy of the sensors and algorithms used to guide the vehicle (Anderson, et al., 2016). Systems that can accurately detect and respond to a range of road conditions as well as ensuring the safety and security of the vehicle's software and hardware are essential for functioning of the vehicle with autonomous technology (Jin, et al., 2019) (Figure 5).

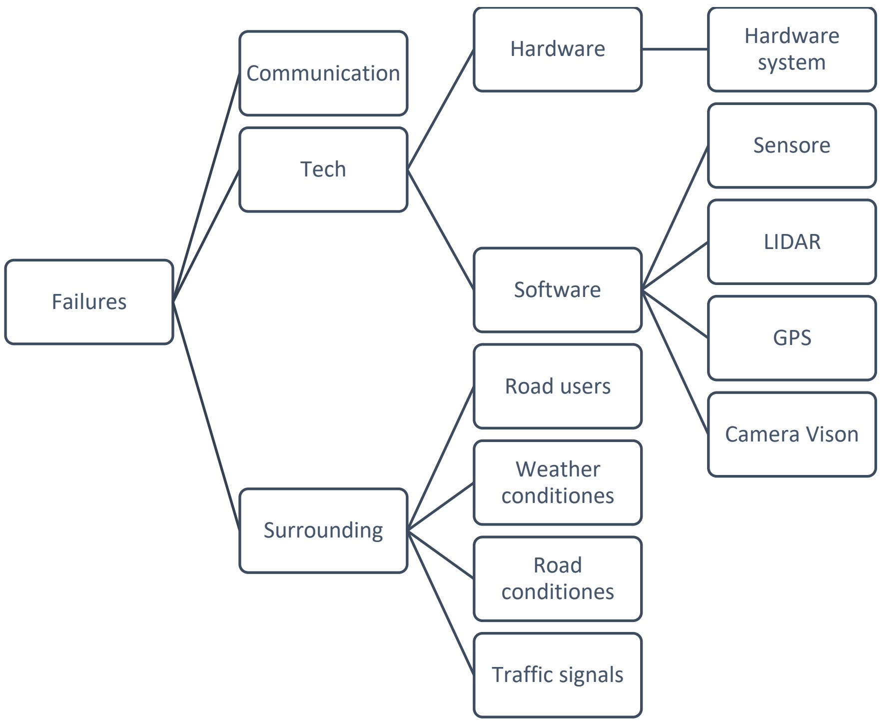

Figure 5. Failures related to autonomous technology (Jin, et al., 2019).

Autonomous vehicle related failures can be broadly classified into three categories.

- Hardware system failures.
- Software failures.
- Communication system failures.

Hardware system failures refer to failures in the physical components of the autonomous vehicles, such as platform hardware failures and sensor failures. Examples of sensor failures include LIDAR failure, GPS failure, camera vision failure, and internal sensor failure. Software failures refer to failures in the programming and coding of the autonomous vehicles. These failures can be caused by errors, or vulnerabilities in the software, and can result in malfunction of the vehicle. Software failures can also lead to accidents or other safety hazards. Communication system failures refer to failures in the communication systems that enable the autonomous vehicles to interact with other vehicles, infrastructure, and systems. These failures can be caused by issues with the autonomous vehicle's wireless communication hardware or software. In addition, autonomous vehicles are affected by external factors such as road conditions, surroundings, weather impact, construction zones, and traffic signals and signs. These failures can impact the performance of the autonomous vehicles and lead to safety hazards (Anderson, et al., 2016; Jin, et al., 2019).

2.2.2 Infrastructure Challenges

The existing infrastructure system can support the new technology to some extent. However, certain significant challenges with this infrastructure are brought up in a document published by (Richter, 2021) these issues include road markings and signs, for safe and effective navigation, autonomous driving trucks rely on road markings and signage. Most current road markings and signage, however, were not created with autonomous vehicles in mind, and thus may not be visible or clear enough for them to follow. This may cause confusion and navigational errors, which may be hazardous.

Communication infrastructure, to communicate data with other vehicles, the infrastructure, and control centres, autonomous driving trucks need a dependable and strong communication infrastructure. This covers mobile networks, dedicated short-range communication (DSRC) systems, and high-speed internet connectivity. Unfortunately, many places might not have enough capacity or coverage to meet these needs, particularly in rural or outlying locations. Infrastructure maintenance, for autonomous driving trucks to operate safely and effectively, highways, bridges, and tunnels must be kept in good condition (Richter, 2021).

2.2.3 Workforce Challenges

Development of autonomous vehicles has the potential to significantly change the workforce, and the logistics sector in general. The workforce challenges in the logistic sector according to (International Transport Forum, 2017) states that the innovation this technology is bringing to the logistic industry is pushing this sector to certain challenges with job losses and new skill requirements. The findings according to the report are employment displacement, truck drivers and other workers in the logistics sector may lose their jobs because of the deployment of autonomously driven trucks. This could cause social and economic problems, especially in areas where the logistics sector employs many people. Reskilling and upskilling, to help workers transition to new positions in the logistics sector and solve the workforce challenges brought on by job displacement, reskilling programs will be required. Training programs will need to be developed to satisfy the unique demands of various workforce segments and to ensure that employees have the skills needed for new jobs in the sector. Recruiting and retention, to run and maintain autonomous driving trucks, the logistics sector will need to recruit and keep a new generation of workers. This can call for modifications to how the sector is presented and advertised to prospective employees, as well as the creation of new training and certification programs.

Need to implement coordinated initiatives by industry stakeholders, governments, and workforce development organizations to guarantee that the workforce is prepared for the changes ahead stress (International Transport Forum, 2017). In this report are identified numerous areas where workers will need to either learn new skills or modify their current skills to meet new responsibilities in terms of the new skills that will be required. They consist of digital literacy, to run and maintain autonomous driving trucks, employees will need to be competent in using digital technologies like telematics, GPS, and fleet management systems. Data analysis, to optimize logistics operations, a vast volume of data generated using autonomous driving trucks would need to be examined, to make appropriate judgments, employees will need to be able to assess and interpret this data. Remote monitoring and control will be needed for autonomous driving trucks, thus employees who can operate and maintain these systems will be essential.

2.2.4 Data Management and Cybersecurity

According to (Georgia, et al., 2021) the potential and challenges associated to data management and cybersecurity challenges are important. Data driven innovation is a major drive competitiveness and economic development. The growing volume of data produced by digital technologies also creates substantial challenges with cybersecurity and data management.

The General Data Protection Regulation serves as the foundation for the EU's data management framework. Establishes clear criteria for the collection, use, and storage of personal information and requires enterprises to implement the required administrative and technical security safeguards to protect customers' privacy. The report highlights the importance of using a risk-based approach to cybersecurity, which comprises determining the most crucial assets and vulnerabilities, ranking them in significance, and putting in place the required protections to lower the risks. The Report also emphasizes how important it is to increase cybersecurity awareness and education, particularly among small size enterprises, who might not have the resources to implement advanced cybersecurity measures. Several initiatives have been established by the EU to increase cybersecurity education and awareness, including European Cybersecurity Month (ECSM) (Georgia, et al., 2021).

2.2.5 Standardization

Interoperability and standardization are another challenge. To ensure that many systems can coexist harmoniously, and interoperability standardization is essential for the development of autonomous driving trucks (Hudi & Avary, 2021; International Organization for Standardization, 2023; 5GAA, 2023).
(Hudi & Avary, 2021) states that standardization is crucial parts in the development and use of autonomous vehicles.

(Society of Automotive Engineers, 2021) SAE standard was established and is a collection of specifications for autonomous cars standard provides a foundation for the design and testing of autonomous vehicle systems by defining the six degrees of driving automation, which ranges from zero automation (Level 0) to complete automation (Level 5). (International Organization for Standardization, 2023) (ISO) has developed several ITS (intelligent transportation systems) standards, which cover autonomous vehicle norms.

These standards address issues including data formats, communication protocols, and the necessary safety measures for autonomous cars. The development of common technological standards and protocols for autonomous cars is the subject of other initiatives and collaborations in addition to these standards. The (5GAA, 2023) Automotive Association, for instance, is a partnership between automotive and technology firms with the goal of creating standards for communication between automobiles and infrastructure.

2.3 Impact and Perception

2.3.1 Safety and Liability Concerns

Although technology for autonomous driving trucks has evolved recently, safety issues continue to be of the utmost importance. Some of those concerns are related to technology limitations (Koopman & Wagner , 2016). Cybersecurity is another challenge, the truck's systems could be the target of a cyberattack that could cause the truck to lose control or be maliciously altered, both of which pose safety issues (Garakani, et al., 2018). Liability and legal concerns, determining who is responsible for an accident involving an autonomous truck can be difficult because it may involve the truck's maker, software developer, sensor provider, or operator. This may result in issues with the law and regulations that could hinder the development and use of autonomous driving technologies (Altunyldiz, 2020).

The safety of autonomously driven trucks is an important priority for regulators and industry stakeholders, as are security concerns and challenges with regulation. The reliability of the technology, the trucks' ability to interact with other vehicles on the road, and the risks of accidents have all been questioned. Regulations are a crucial component in ensuring the safe operation of autonomous trucks (National Highway Traffic Safety Administration, 2017).

2.3.2 Economic and Environmental Impact

Deployment of autonomous driving trucks could significantly affect economies and the environment. Along with the potential for more efficiency and cost savings, also has the potential to have a smaller negative impact on the environment and emissions (Manyika, et al., 2013).

(Manyika, et al., 2013) states that deployment of these technologies will require logistic companies to make a significant financial investment. However, autonomous trucks are considered to Improved efficiency because they can operate around the clock, they can speed up logistics processes and cut down on delivery times. Sales may rise and customer satisfaction may improve as a result. Reduce emissions, it is expected that autonomous driving trucks will use less fuel than conventional trucks, which could result in a decrease in greenhouse gas emissions and other pollutants. By 2025, according to (Manyika, et al., 2013) autonomous driving trucks could cut carbon dioxide emissions worldwide by 4% to 15%. Deployment of autonomous driving trucks is probably going to cause disruption in the logistics sector by shifting worker roles and duties, lessening the demand for conventional logistics infrastructure, and developing new business models.

(Manyika, et al., 2013) emphasize that large investments in research and development, infrastructure, and personnel development would be required to fully exploit the potential of these technologies. To fully benefit from the potential of these technologies, the research predicts that an additional 20–30 trillion US dollars in global investment may be needed over the next 20 years. Governments, businesses in the private sector, and investors are only a few potential sources of this funding.

2.3.3 Public Perception and Acceptance

A study conducted by (Kyriakidis, et al., 2015) found that a wide range of variables, including perceived usefulness and usability, safety concerns, trust, age and gender, and individual experiences, have an impact on the public's acceptance of autonomous vehicles. These findings have implications for the development and use of autonomous driving trucks in logistics and autonomous vehicles in general.

According to the study, perceived benefits and usability are key determinants of public adoption of autonomous vehicles. Respondents were more in favour of accepting autonomous vehicles if they believed they were not practical and simple to operate. A significant obstacle to public acceptance of driverless vehicles is safety concerns, according to the study. If respondents thought autonomous vehicles were safer than conventional automobiles, they would be more willing to accept them.

The study discovered that age and gender are important indicators of the general public's acceptance of autonomous vehicles. For instance, male and younger respondents were more likely to accept the technology than female and older respondents. People's perceptions of autonomous vehicles are largely influenced by their own experiences with them. Those who had used autonomous vehicles in the past were more likely to accept the technology. Autonomous vehicles require public acceptance, and confidence in technology. Addressing concerns regarding safety and reliability of autonomous trucks is critical to gain public acceptance.

2.3.4 Regulatory Compliance

Several agencies in the European Union and the United States have conducted studies, and eventually the logistical industry and other businesses who decide to deploy autonomous trucks and autonomous vehicles will be presented with the regulatory frameworks and guidelines.

(International Transport Forum, 2017) recommends policymakers to set up regulations and standards for data security, liability, and insurance. The Coordinated, Connected and Automated Mobility (CCAM) program of the (European Commission, 2021) intends to regulate the deployment of autonomous driving technologies on European roads. The program involves several legislative and policy steps, including creating liability guidelines, the development of technical standards for automated and connected vehicles, and the encouragement of international cooperation. "Safe Integration of Automated Driving Systems-Equipped Commercial Motor Vehicles" policy statement from the (Federal Motor Carrier Safety Administration, 2019) highlights the agency's strategy for controlling the use of autonomous driving technologies in commercial motor vehicles. The policy covers standards for testing and certification, data protection, and cybersecurity and emphasizes the significance of safeguarding the safety of drivers, passengers, and other road users. The regulation requires that manufacturers of autonomous trucks design and implement testing programs to guarantee the dependability and safety of their products.

In the Europe and United States of America measures are being taken to put a regulatory framework in place to control the use and deployment of autonomous driving vehicles, with a focus on safety, reliability, and other risks associated that use autonomous technology in general and trucks in particularly.

3 RESEARCH METHODOLOGY

“The term research philosophy refers to a system of beliefs and assumptions about the development of knowledge” (Saunders, et al., 2019). This chapter adopts the "research onion" by (Saunders, et al., 2019) to provide a framework for the research method and philosophy.

3.1 Research Approach

This qualitative research aims to investigate the logistics industry's presumptions, phenomenology, trends, and challenges of autonomous driving trucks. To achieve this, the research will use critical realism and interpretivism as its philosophical approach to understand the complex and dynamic nature of the logistics industry (Figure 6).

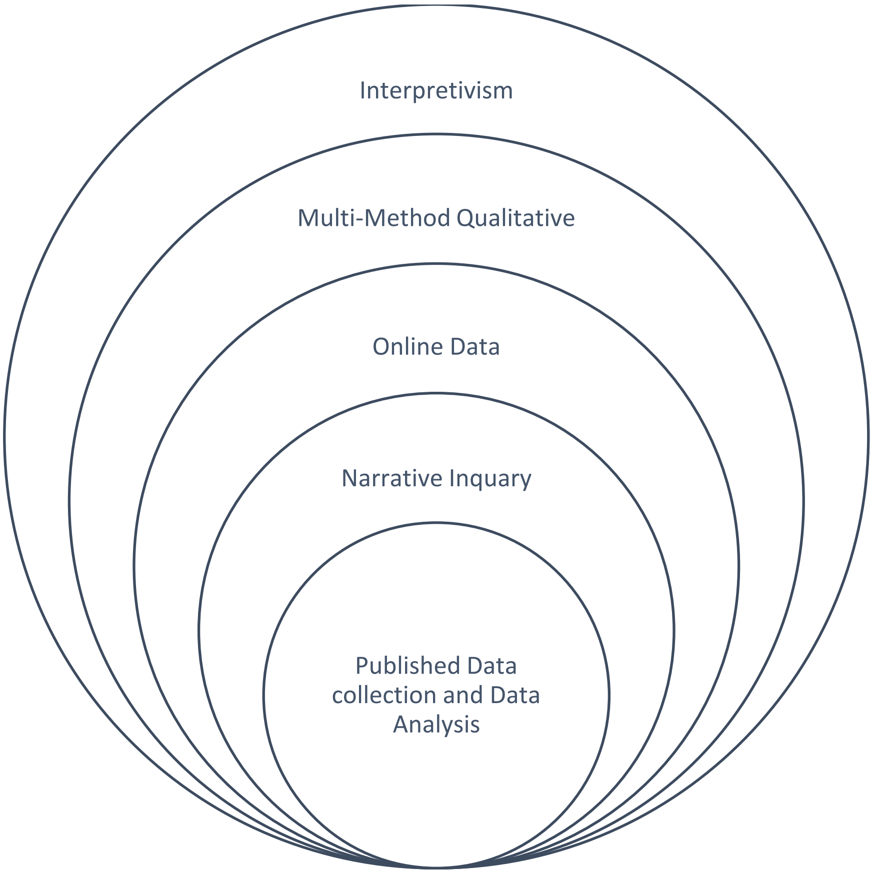

Figure 6. Research Onion adapted from (Saunders, et al., 2019).

The research will use a multimethod quantitative approach to collect data from a variety of sources, including archival research published and available online. The data collection and analysis methods highlighted in Figure 6 will be used to gather and analyse relevant data that align with the research purpose and objectives. The critical realist approach recognizes the complexity of the logistics industry, and interpretivism provides a framework for understanding subjectivity and perception in the field. This combination of approaches will enable the research to gain a comprehensive understanding of logistics industry assumptions, phenomena, trends, and challenges related to autonomous trucks (Saunders, et al., 2019).

Theoretical research allows the research to develop a based on the data collected. This approach is particularly useful for exploring relatively new and complex topics such as autonomous trucks. This quantitative approach will enable the research to collect data from different sources, including archival research and case studies. This approach will allow the research to combine data from several sources, which will lead to a more thorough understanding of the topic. (Thomas , 2003).

3.2 Ethics and Quality

According to (All European Academies, 2017) the Fundamental Principles of Research Integrity published by the European Code of Conduct for Research Integrity provide the basis for good research procedures (Figure 7). They provide researchers with guidance on how to conduct research and how to address the intellectual, ethical, and practical challenges that research presents.

Figure 7. European Code of Conduct for Research Integrity Principals (All European Academies, 2017).

This research follows the principles of the European code of conduct for research Integrity. By assuring that all parts of the research are carried out in accordance with the highest ethical standards, and by adhering to the principles of respect, honesty, transparency, and responsibility outlined in the European code of conduct for research integrity. These criteria for data collection, analysis, and reporting have been followed, along with the research's ethical and responsible conduct principles. To avoid plagiarism or any other types of academic misconduct, credit is given to all sources that are used in the research and referenced in the report.

The quality of a research report depends on how well it meets requirements for rigor, accuracy, and completeness (Creswell, 2014). The essential parts of a high-quality research report, according to (Creswell, 2014), include the clarification and coherence of the research question and goals, a rigorous and relevant research design and methodology, suitable sample size and sampling methods, data collection and analysis that is in accordance with the research question and objectives, a clear and accurate presentation of the results, including data analysis where appropriate, and a thorough discussion of the implications.

The quality of this report is reflected in the clear research questions and objectives. Adhering to the recommended thesis structure of (Satakunta University of Applied Sciences, 2023). Appropriate methodology is selected that aligns with the research questions and objectives. Additionally, including a case study to validate the conclusions drawn from the literature review can provide valuable insights into the practical application for this research findings. The data collected from the literature review and case study are analysed carefully to ensure that the conclusions drawn are accurate and based on empirical evidence and reliable sources. Finally, the report concludes with relevant suggestions and recommendations based on the research findings.

3.3 Case Study

The case Research conducted by University of California and TuSimple (Press release, 2019) will be used as a model in accordance with the methodology of this research to validate the challenges and opportunities indicated in the literature review and contribute to a collection of data for statistical analysis, findings, and recommendations (Mixed Methods Case Study Research, 2019).

3.3.1 Company

TuSimple is an innovative technology company headquartered in San Diego, California, with a mission to develop cutting-edge autonomous driving solutions for the truck transportation sector. Since its founding in 2015, TuSimple has been in the forefront of developing artificial intelligence technology that allows heavy-duty trucks to operate autonomously at SAE level four (Cision, 2023).

With the use of a mix of cameras, radar, and LIDAR sensors, TuSimple's technology gives a truck a 360-degree view of its surroundings (Figure 8), enabling it to manoeuvre over challenging terrain and avoid obstacles. A high-definition mapping system is also a part of the technology, and it offers real-time updates on traffic patterns and road conditions. The capacity of TuSimple's technology to function in a "Level 4" autonomous driving mode, which implies the truck can run without human involvement in most driving circumstances (Society of Automotive Engineers, 2021), is a crucial aspect of the company's technology. A safety driver is still inside the vehicle, ready to take over if required. Around 3.5 million miles (56.3 km) of on-road testing and simulation testing in various scenarios have been used to test and validate TuSimple's autonomous driving technology and an overall 8 million miles (13 km) on-road driving (TuSimple, 2023).

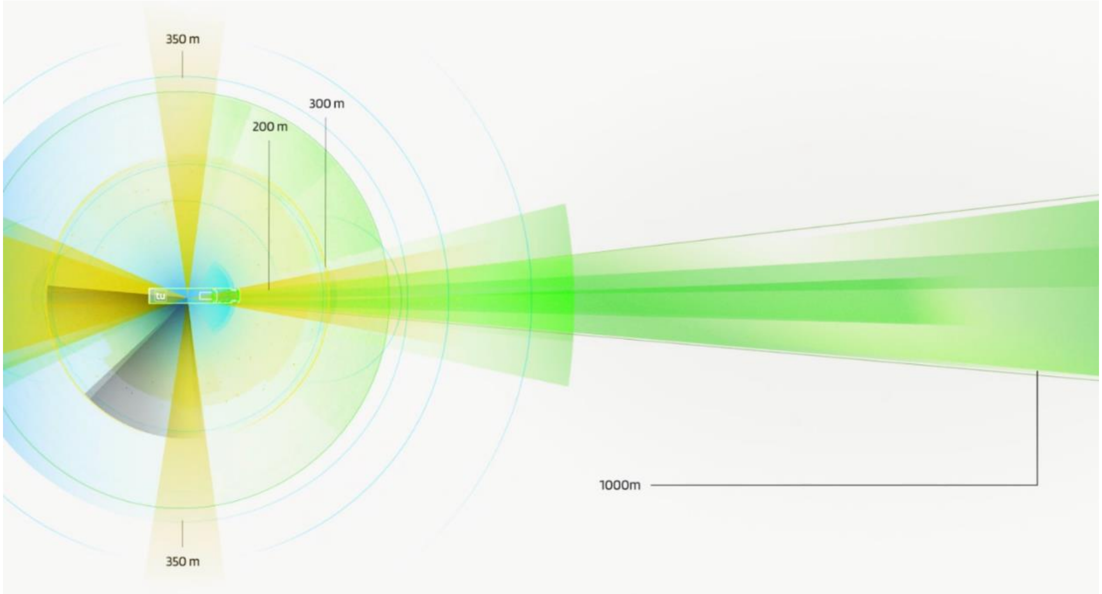

Figure 8. Detecting range technology of (TuSimple, 2023).

The company has a comprehensive safety program in place, including system testing, validation, and ongoing monitoring (Figure 9). (TuSimple, 2021) claims to have safety procedures and requirements higher than those established by agencies such as (Federal Motor Carrier Safety Administration, 2019) and the (National Highway Traffic Safety Administration, 2017).

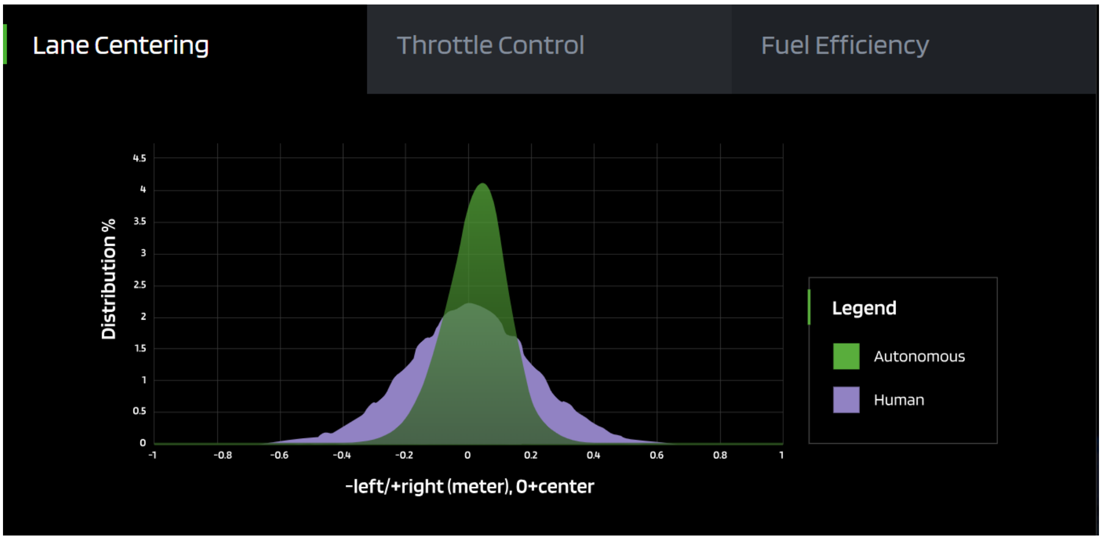

Figure 9. Lane Cantering comparison (TuSimple, 2023).

The autonomous driving system from (TuSimple, 2023) is built to recognize and react to possible safety risks including roadblocks, other cars, and pedestrians. The lane cantering, which is illustrated in Figure 9, is one element that the company has revealed to the public. It results in a 0+center lane of 4% as opposed to manual driving's 2% (Table 1). To give direction and supervision for its safety initiative, the company has also formed a Safety Advisory Council made up of professionals in autonomous vehicle technology, safety, and regulation (TuSimple, 2023).

Table 1. Number of Events per 16093 km of (TuSimple, 2023).

Event	Autonomous Technology	Human Operator Driving
Harsh Braking	0-2	8-10
Harsh Acceleration	11-16	99-106
Harsh Cornering	4-10	118-189

According to data published by (TuSimple, 2023) autonomous driving technology, as shown in Table 1, has significantly fewer harsh events when compared with a human operator driving and these result in less fuel consumption (Figure 10). ISO 26262 Functional Safety for Road Vehicles, IATF 16949 Automotive Quality Management System, and ISO/PAS 21488 Road Vehicles - Safety of the Intended Functionality are the standards that (TuSimple, 2021) claims are utilizing.

Lane Centering | Throttle Control | Fuel Efficiency

Speed (mph)	**0-30**	**30-40**	**40-50**	**50-60**
Autonomous (km/l)	3.49	5.43	5.91	5.56
Manual (km/l)	3.14	4.56	5.46	5.46
Difference	21%	17%	8%	3%

Figure 10. Fuel efficiency (TuSimple, 2023).

The information provided by the corporation regarding fuel efficiency is shown in Figure 10 and is divided into four categories according to the speed at which the trucks are driving. (TuSimple, 2023) claims that the efficiency is 21% higher than manual driving at 30 mph (48 km/h).

3.3.2 Case

Research conducted by University of California and (Press release, 2019), found that trucks were able to achieve a 10% decrease in fuel consumption when compared to traditional, human-driven trucks. As a result, a 15,000 US dollars annual fuel cost decrease for each car is anticipated. The study also found that autonomous trucks could maintain a consistent speed and reduce idle time, both of which contributed to improved fuel economy.
The fuel efficiency of (Press release, 2019) autonomous trucks may cut the transportation industry's major contribution to greenhouse gas emissions. Three TuSimple autonomous trucks were the subject of a six-month study that followed them through a 115-mile (185 km) route in Arizona according to (Press release, 2019) press release.

4 POTENTIAL OF AUTONOMOUS DRIVING

This chapter discusses the potential of autonomous trucks in the logistics industry. Examination of various ways in which autonomous trucks have the potential to transform the industry by comparing the data that is currently available with the claims made by the case company. The challenges presented in chapter two will also address the many questions raised by various public agencies regarding the safety, workforce, environmental, and economic impacts of autonomous driving technologies.

4.1 Real-World Autonomy Concept

Truck manufacturers, logistics service providers, and technology companies are collaborating to develop and implement self-driving trucks. Partnerships with Volvo-DHL, Volvo-Uber Freight, Volvo-Aurora (Volvo, 2023), UPS-TuSimple (Carey, 2022), are particularly notable. The Hub-To-Hub concept Figure 11 is one of the concepts that these important players in truck manufacturing, logistic service providing, and technology developers are testing and using.

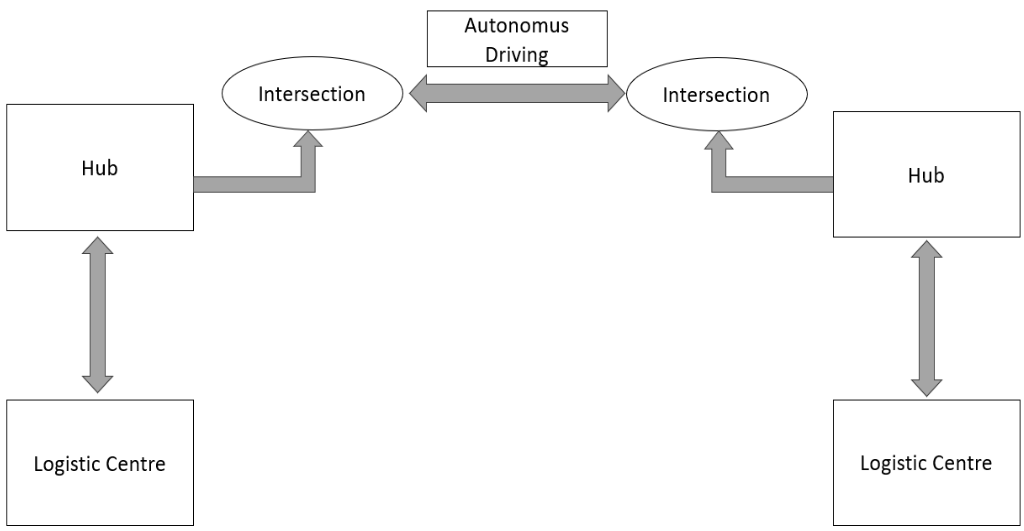

Figure 11. Hub to Hub concept.

According to (Deloitte, 2021) Hub-to-hub autonomous trucking is the concept of using autonomous trucks to transport goods between warehouses or distribution centers (Appendix 3). In this concept, human drivers would drive the trucks from their starting location to a designated location close to a highway, at which the trucks would switch in the autonomous mode and proceed on the highway. As the trucks approach their destination, they would navigate to a transfer site near an off ramp, where a human driver would take over for the final part of the journey on local roads. This approach aims to keep humans in control of tasks such as cargo loading and delivery in local areas, while allowing autonomous truck fleet operators to focus on operating trucks in a more controlled environment on the interstate highway.

The partnership between TuSimple and UPS to operate autonomous vehicles on multiple routes began in 2019, according to a Reuters article (Carey, 2020). One of the routes, which TuSimple has been operating autonomous trucks since 2019, is a 120-mile (193-km) route between Phoenix and Tucson, Arizona. Between Dallas to Houston, Texas, another route that is 1,600 km (1,000 mi) long. Furthermore, since 2020, TuSimple has been operating autonomous trucks on a 950-mile (1,500 km) route between Ontario and Phoenix, Arizona utilizing the hub-to-hub ore point to point concept (Carey, 2020).

Testing by several companies, including (TuSimple, 2023) and (Volvo, 2023), has shown that the hub-to-hub concept can be implemented. This approach is designed to minimize human factors in logistics tasks like long driving and has a significant impact on the overall efficiency of the supply chain. Although the concept is still being tested, current technology supports its potential for success.

4.2 Safety

One of the main advantages of autonomous technology is safety, compared to traditional driving trucks, autonomous trucks include several safety advantages, such as the elimination of human error, advanced safety features, faster reaction times, more reliable safe driving, eliminated driver fatigue, and real-time data analysis (TuSimple, 2023).

According to (Slootmans, 2023) road safety observatory report, heavy goods vehicles (HGV) crashes in 2020 count 2496 fatalities, and their share in the total number of fatalities in the EU27 is 14% (Figure 12).

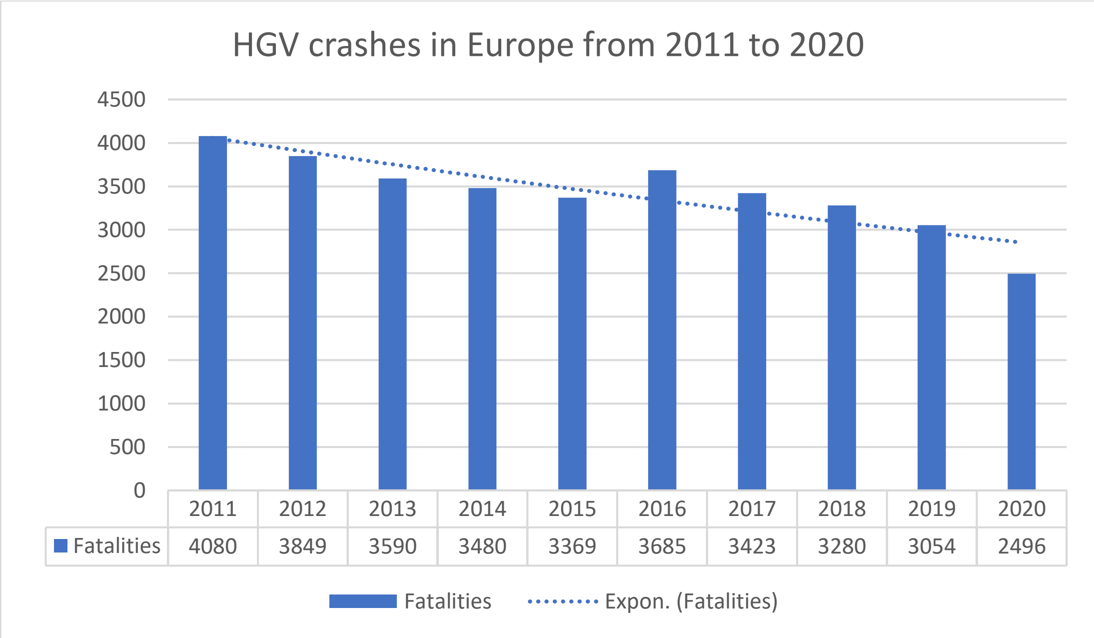

Figure 12. HGV crashes in Europe (Slootmans, 2023).

Over the past years, there has been a significant reduction in the number of fatalities resulting from freight accidents. Between 2011 and 2020, the number of fatalities in heavy goods vehicle crashes has decreased by 39% (Slootmans, 2023). This is a positive development that reflects the efforts made by policymakers, industry stakeholders, and road safety professionals to improve the safety of road transport. However, despite this progress, heavy goods vehicles remain involved in fatal road accidents. Hence, there is still a need for continued efforts to enhance the safety of freight transport and reduce the number of fatalities on European roads.

(Slootmans, 2023) reports that 53% of all fatalities in HGV accidents occur on rural roads, 23% on highways, and 23% on urban roads (Figure 13).

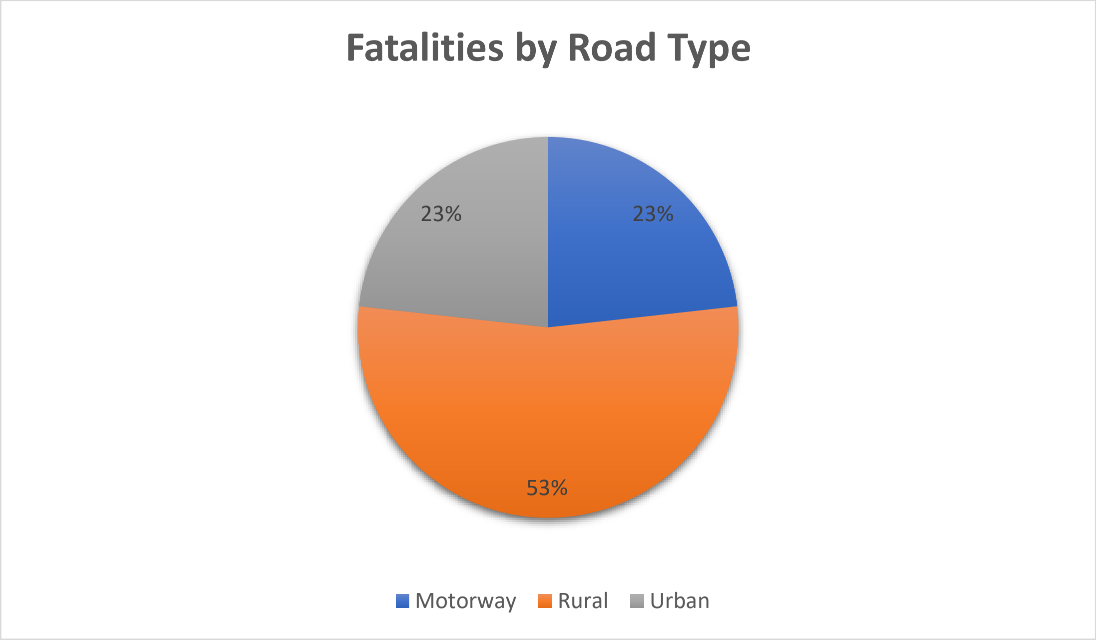

Figure 13. Fatalities by road type (Slootmans, 2023).

The fact that 50% of fatal crashes occur in rural areas, where infrastructure and other obstacles such as narrow roads and poor visibility are more present, highlights the need for more attention to improving infrastructure. According to (Insurance Institute for Highway Safety, 2023) most fatalities in heavy goods vehicle accidents are occupants in smaller vehicles. Trucks can underride smaller vehicles in collisions because they frequently weigh 20 to 30 times as much as passenger cars and have a higher ground clearance. HGV crashes in United States are illustrated in Figure 14.

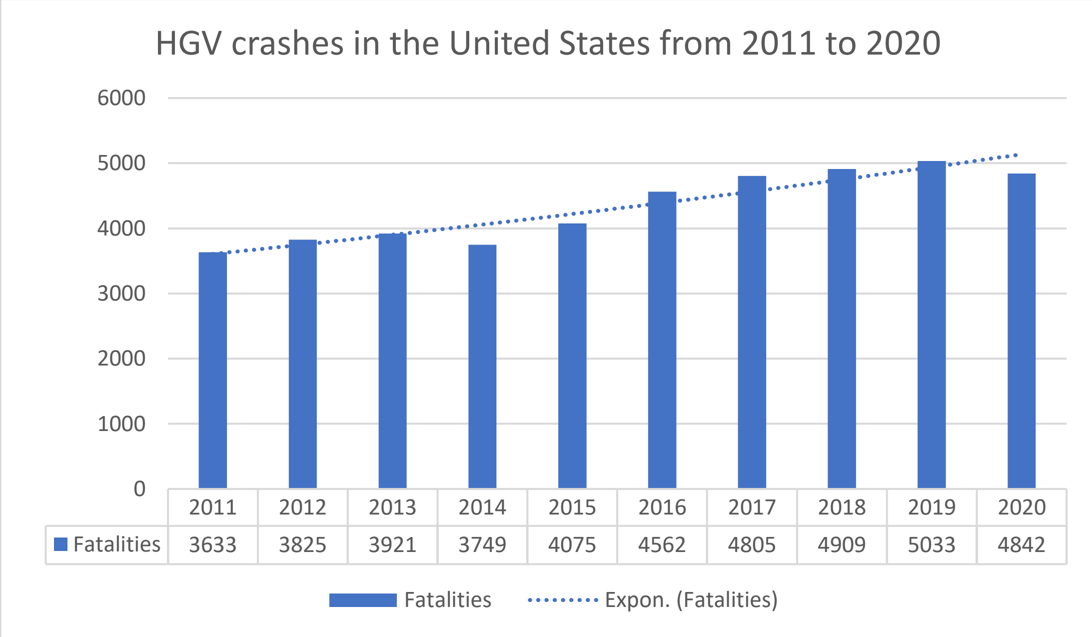

Figure 14. HGV crashes in United States (Statista Research Department, 2023).

In 2020, there were approximately 4,842 fatal crashes involving large trucks in the United States, marking a decrease of approximately 4% from the previous year (Statista Research Department, 2023). Although there has been a decrease in accidents involving HGVs in Europe in United States, we see an increase from 2011. Fatal accidents continue to occur due to various factors. Some of those factors are illustrated in Figure 15.

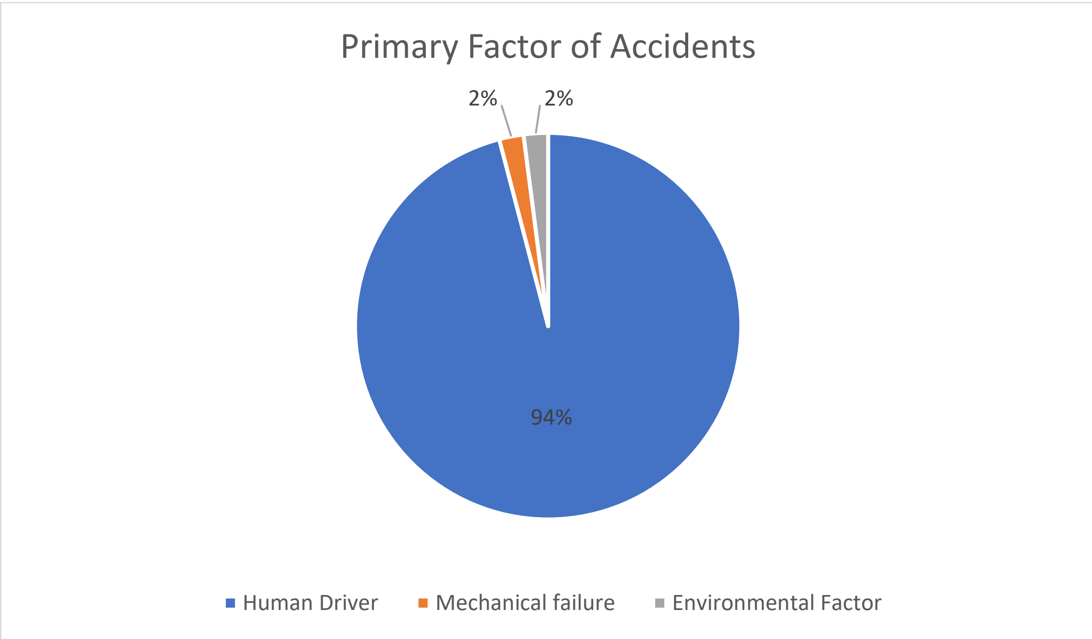

Figure 15. Factors of accidents (United States Department of Transportation, 2018).

In research conducted by (United States Department of Transportation, 2018) the driver was discovered to be the primary factor contributing to 94% of accident cases. Failure of a vehicle component was related for around 2% of accidents, and environmental factors were related for another 2%. Factors related to human errors are listed in Table 2.

Table 2. Human factors that contribute to accidents (Bucsuházy, et al., 2019).

Term	Factor
Long term	Not paying attention while driving
	Not paying attention while driving
	Violation of traffic rules
Short term	Risky overtaking
	Alcoholism and/or the use of psychotropic drugs
	Panic reaction
	Fatigue, and tiredness
	Incorrect assessment of the circumstances
	Limited view
	Physical and mental disability

Human elements that influence the possibility of an accident according (Bucsuházy, et al., 2019) are shown in Table 2. The fundamental conclusion that human element under the influence of alcohol, medications and/or inaccurate evaluation, judgment, and irresponsibility contribute to accidents that frequently result in fatalities are the long and short-term factors according to (Bucsuházy, et al., 2019).

Autonomous driving trucks, operating at the current level four standard as defined by (Society of Automotive Engineers, 2021), have the ability to run without human involvement in most driving circumstances, effectively eliminating many of the human factors that contribute to accidents. The extensive testing conducted by the case company, as shown in Table 1 of chapter three, demonstrates that this technology has the potential to significantly improve safety. As technology continues to develop, companies such as TuSimple and Volvo are at the forefront of efforts to make our roads safer.

4.3 Workforce

According to (International Transport Forum, 2017) the logistic industry is facing workforce problems due to the innovation this technology is bringing, including challenges related to job losses and new skill needs. In 2019 transport-related jobs employed 11.6 million individuals aged 15 and over (Figure 16), transportation sector makes up to 6% of the employed workforce and 3% of the total population of Europe (Eurostat, 2020).

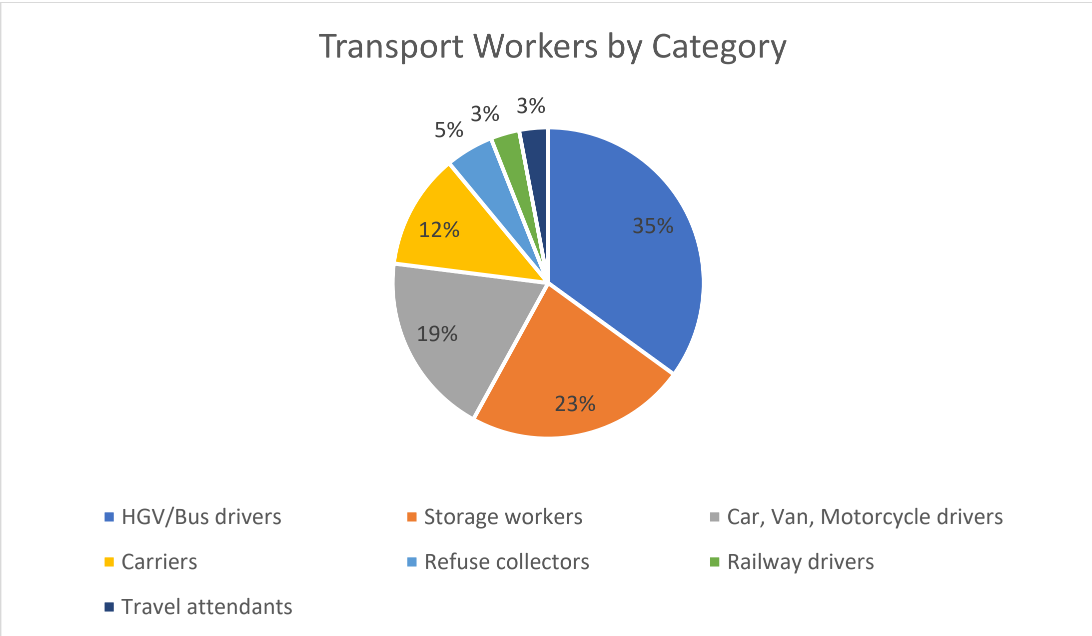

Figure 16. Transportation employment by category (Eurostat, 2020).

Companies in Europe were anticipating a 17% driver shortage in 2021, according to research by the (International Road Transport Union, 2021). The research also investigated the causes of the driver shortage and found that a lack of qualified drivers was the primary factor. (International Road Transport Union, 2022) predicts that 30% of drivers will retire by 2026, while the pace of younger replacements is 4 to 7 times lower. Driver demand in Europe has increased by 44% between January and September 2021. By 2026, there may be a two million drivers' shortfall in Europe.

In United States of America logistic companies are facing the same challenges as in Europe. In 2021 were an anticipation of 80,500 vacancies needing to be filled in trucking sector, the requirement for 162,000 additional drivers by 2030 is anticipated to make this shortfall worse (Placek, 2022) (Figure 17).

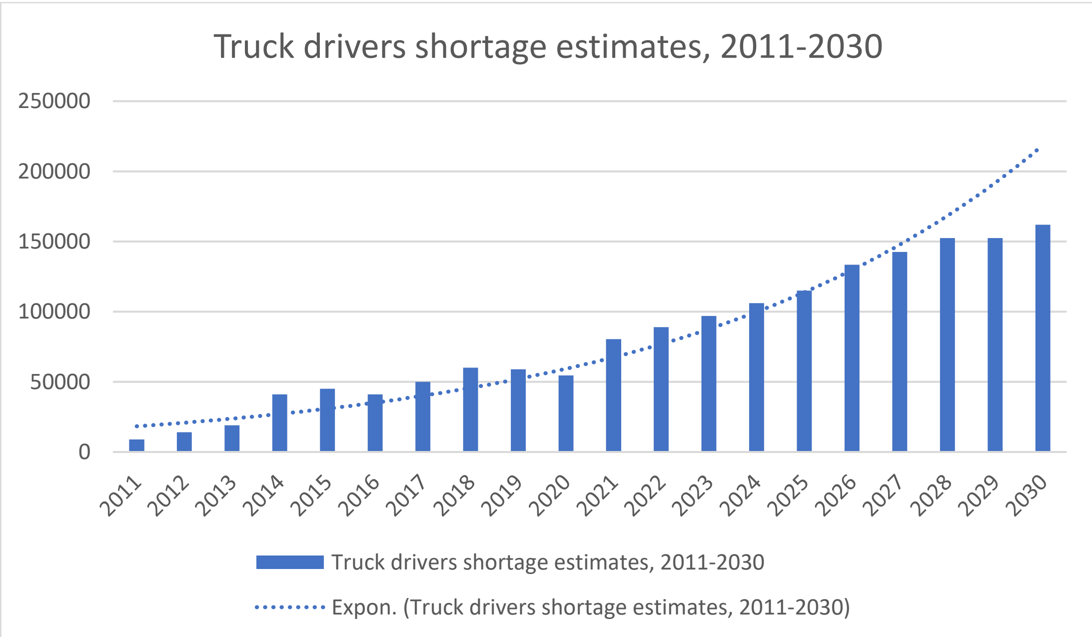

Figure 17. Truck Drivers Shortfall in USA (Placek, 2022).

According to the (International Road Transport Union, 2021), the reasons of this shortfall in Europe include a lack of trained drivers, a negative perception of the profession, working conditions, the challenge of attracting young people, and the challenge of attracting women to the profession.

The logistics industry has a significant share of employment in Europe, the United States, and globally. However, this sector is facing challenges due to an anticipated increase in the shortage of workforce, as predicted by the (International Road Transport Union, 2021; Placek, 2022; Eurostat, 2020).
In chapter two of the report by (International Transport Forum, 2017) highlights that the deployment of autonomously driven trucks could displace employment, causing job loss for truck drivers and other logistics workers. This could

result in social and economic problems, particularly in regions where the logistics sector is a significant employer. The report stresses the need for coordinated initiatives by industry stakeholders, governments, and workforce development organizations to ensure that the workforce is prepared for the upcoming changes.

The new professions that could emerge include digital literacy, data analysis, remote monitoring, and control. The hub-to-hub concept, described in chapter five's real-world autonomy concept, could potentially help mitigate the shortfall in the workforce. This concept still requires a workforce, and a gradual transition may be a viable solution for implementing this new technology, training the workforce, and avoiding any potential social and economic challenges.

4.4 Economics

The implementation of autonomous driving trucks has the potential to significantly lower costs for the trucking sector, making it a more financially viable option for companies operating in logistics. (Manyika, et al., 2013) predicts that advantages of increased safety, time savings, improved productivity, and reduced fuel consumption and emissions may have a cumulative economic effect of 200 US billion to 1.9 US trillion per year by 2025 if authorities authorize autonomous driving and the public accepts the concept. Global costs by logistic functions are illustrated in Figure 18.

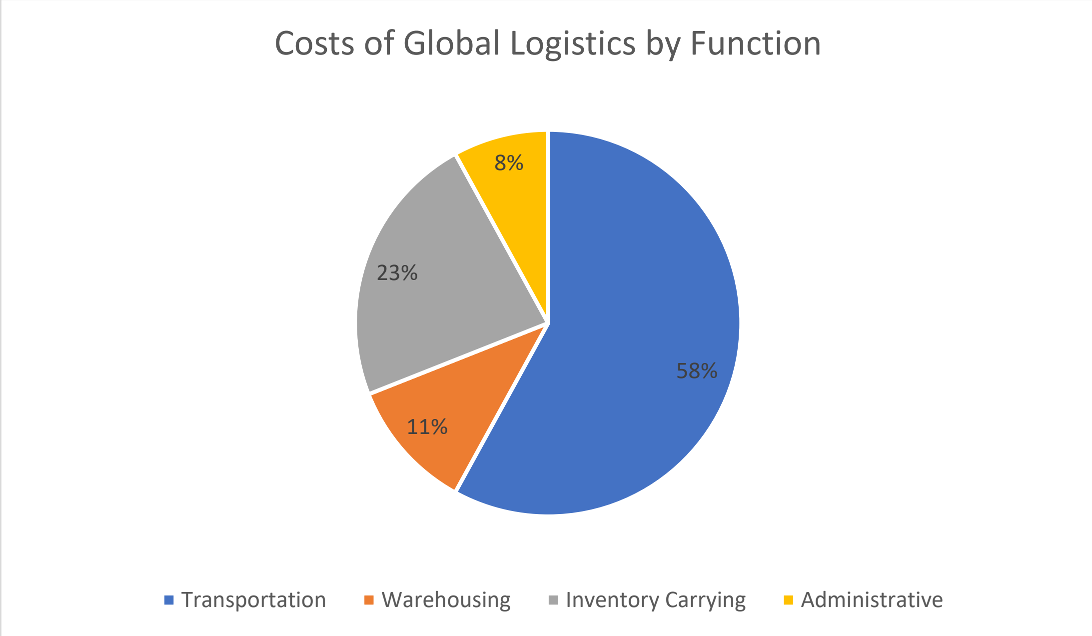

Figure 18. Costs logistics by function (The Geography of Transport Systems, 2018).

Transportation costs of global logistics count for 58 % of logistic functions (Figure 18). Given the significant percentage that transportation has in logistics automation could potentially reduce some of the costs. Some of the main costs are shown in Table 3.

Table 3. Costs related to truck transportation (Williams & Murray, 2020).

Variables	Fuel
	Purchase of truck or trailer
	Repair, maintenance
	Insurance
	Licenses
	Tolls
Fixed	Wages
	Benefits

In the trucking mode of transportation are included costs related to truck and labour (Table 3) (Williams & Murray, 2020). As of average annual operation costs are as follows in Figure 19.

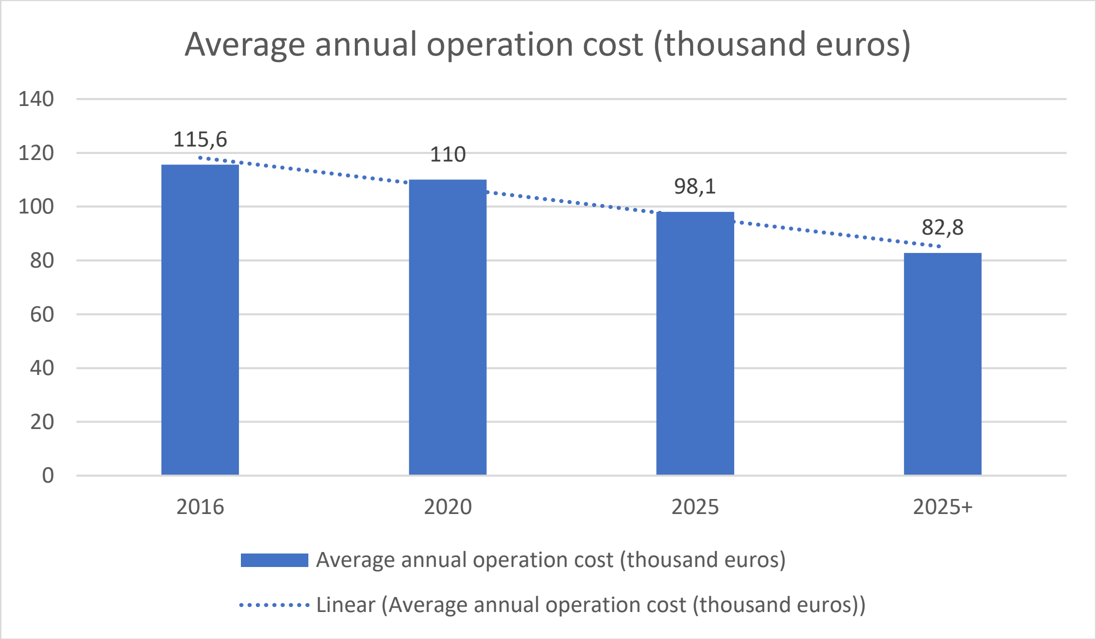

Figure 19. Annual cost savings with autonomous trucks (Kessel, 2017).

According to (Kessel, 2017) by 2025, autonomous driving trucks are expected to reduce driver-related costs by a significant 30%, making self-driving trucks an enticing prospect for freight companies (Figure 19). Additionally, the case company study conducted by the University of California and (Press release, 2019) in 2019 revealed that autonomous trucks could achieve a 10% reduction in fuel consumption compared to traditional, human-driven trucks. This could result in an anticipated annual fuel cost savings of 15,000 USD per truck. Additionally, the study found that autonomous trucks could maintain a consistent speed and reduce idle time, leading to improved fuel economy, as illustrated in Figure 10.

In conclusion, the implementation of autonomous trucks has the potential to significantly reduce costs for the trucking industry. Studies have shown that autonomous trucks can achieve a 10% reduction in fuel consumption, resulting in an anticipated annual fuel cost savings of $15,000 per truck. Additionally, autonomous trucks can maintain a consistent speed and reduce idle time, leading to further improvements in fuel economy (Press release, 2019). The use of autonomous trucks can also reduce labour costs by up to 30% by 2025, making it an appealing option for freight companies (Kessel, 2017). Overall, the adoption of autonomous trucks can lead to significant cost savings and increased efficiency in the transportation of goods.

4.5 Environmental

The use of autonomous driving trucks has the potential to significantly reduce the transportation sector's negative effects on the environment, making it more sustainable and effective. According to (European Parliament, 2023) HGV count for 27.1 % of harmful emissions (Figure 20).

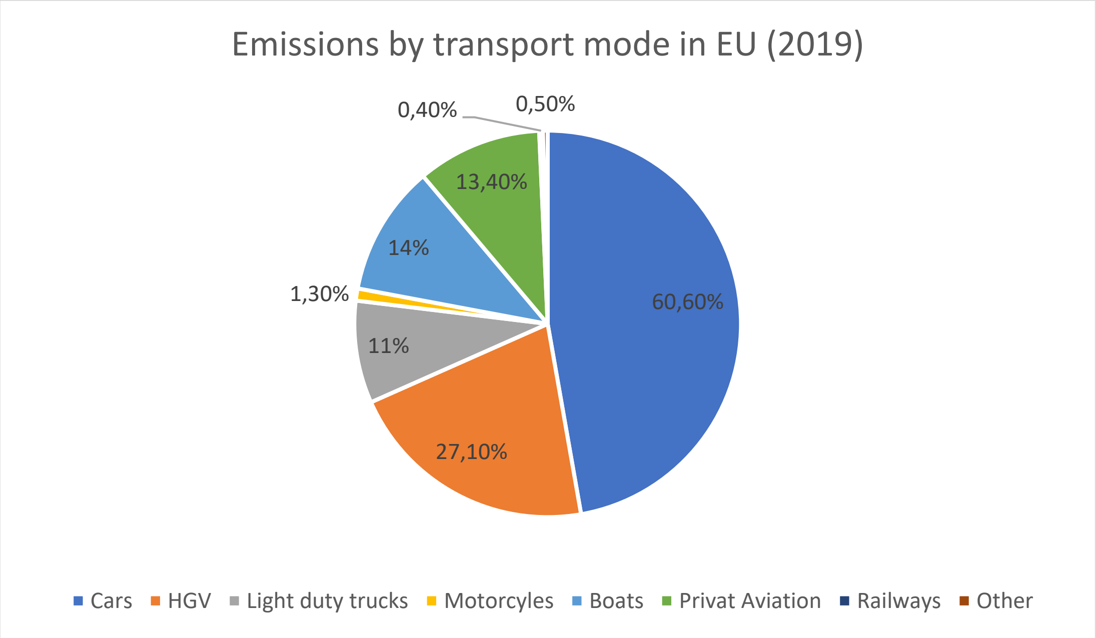

Figure 20. Environment emission by transport mode in EU (European Parliament, 2023).

Private vehicles, heavy duty trucks and light duty trucks account for most of the harmful emissions released into the environment. According to (Tiseo, 2023) with almost 37% of all transportation-related emissions in the US in 2021, light-duty trucks are the biggest contributor. Medium and heavy-duty trucks were the second largest source of emissions in the transportation sector in 2021. Passenger vehicles accounted for about 20,7% of all transportation emissions in the United States (Figure 21).

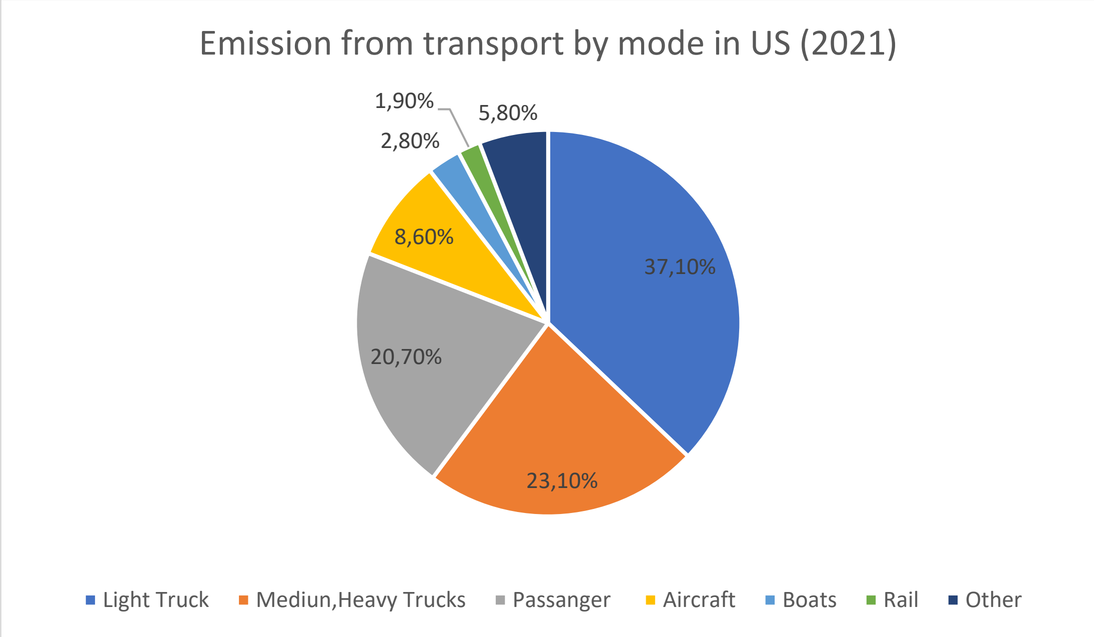

Figure 21. Environment emission by transport mode in United States (Tiseo, 2023).

Heavy duty trucks are responsible for a significant number of emissions, as they typically use more fuel and travel longer distances. However, the emergence of autonomous driving trucks has the potential to reduce the environmental impact of the transportation industry. As mentioned in chapter four and chapter five, the case company study conducted by the University of California and (Press release, 2019) in 2019 revealed that autonomous trucks could achieve a 10% reduction in fuel consumption compared to traditional, human driven trucks which could reduce the emissions from HGV.

(TuSimple, 2023) suggests that autonomous driving trucks can significantly reduce deadhead and related emissions by optimizing routes and minimizing the need for human drivers. In addition, these trucks can avoid truck stops and rest areas, which eliminates the need for idling and reduces emissions. Furthermore, autonomous driving trucks can reduce the need for overnight idling, which is particularly beneficial for long haul trucking, where idling can account for up to 28 hours per week. The capacity of autonomous trucks to monitor speed limits also leads to less variation in the posted limit, resulting in lower fuel consumption and less wear and tear on the vehicle (Table 1).

5 DISCUSSION AND CONCLUSIONS

In accordance with the purpose and objectives established in chapter one, this chapter provides conclusions by incorporating the information gathered from various sources in chapter two and chapter four, in accordance with the research methodology. Chapter two provide review of existing literature and studies related to the topic. Chapter four presented results and analysis conducted by various reliable sources that align with the objective of this research. This chapter provides conclusions based on data collected that align with the theoretical framework established in chapter one.

5.1 Conclusions

How can logistics service providers deploy autonomous driving technology to maximize effectiveness and safety while minimizing risks and challenges is the purpose of this research set in chapter one. Autonomous driving trucks pose some challenges, but their deployment offers benefits that can impact logistics companies. Based on literature reviews and published studies, the following conclusions in accordance with the research objectives can be drawn.

I. Autonomous Truck Challenges: Several challenges have been identified through literature review in chapters two and four. These challenges include technological limitations, as further advancements are needed. Infrastructure challenges arise due to the existing infrastructure not being designed with this technology in mind, making it difficult for autonomous trucks to accurately identify road characteristics and signs, which may lead to malfunctions. Job losses, safety concerns, and cybersecurity issues are also major topics impacting public perception and posing significant challenges. Additionally, the lack of regulation and standardization, despite some government and public agencies initiating legislation, presents a challenge for the further development of this technology.

II. Autonomous Driving Benefits: Data from various studies and case studies demonstrate that the benefits of autonomous driving technology have the potential to significantly transform not only the logistics sector but other industries as well. Some benefits include enhanced safety, as human errors are a leading cause of accidents that can be reduced with this technology. Despite concerns about job losses, logistic companies implementing this innovation will still require human workforce, and it may create new job opportunities. Additionally, there are economic benefits, as evidenced by case studies showing that trucks operating with autonomous technology are more efficient, resulting in reduced fuel consumption, the ability to operate continuously, and a positive environmental impact.

III. Potential Effects: The potential effects of these innovative transportation technologies are many. As previously mentioned, they have the potential to revolutionize the logistics sector by greatly impacting fast goods delivery, shortening lead times, and making logistics operations more efficient. It may contribute to creating a safer working environment for personnel and improving road safety. The adoption of autonomous driving technology in logistics can lead to significant advancements and improvements in the industry.

IV. Success Factors: The technology and implementation of autonomous driving in trucks are still in their early phases, with various technology development companies and truck manufacturers working on developing and testing the technology. A significant factor in the success is the collaboration between logistic companies, manufacturers, and public organizations. Many companies have taken the initiative to explore these collaborations, and in certain states, legislation and regulations are being put in place. However, there is still much work to be done to fully benefit the potential of autonomous driving in the logistic industry.

5.2 Discussion

Despite that research in this filed show that autonomous trucks are more environmentally friendly, the argument that the benefits of these vehicles in terms of reduced emissions may be exaggerated because the technology is still in its early stages and a variety of other factors can also have an impact on emissions it is a discussion topic. Concerns about the safety of autonomously driving trucks are being raised and the introduction of autonomous driving trucks may result in job losses for truck drivers, raising concerns about the possible impact on employment is another topic that requires discussion.

To understand more regarding the potential benefits and challenges of autonomous driving trucks, a variety of study subjects could potentially be studied. Since this technology is still in its early stages, relevant research topics might include safety and dependability by examining accident data, carrying out simulations, and assessing developments in safety standards and laws. Another topic is the advantages and drawbacks of autonomous driving trucks from an economic perspective, including how it will affect the workforce and the most recent economic statistics.

Further study is required to determine the most effective strategies to support this technology since widespread adoption would necessitate substantial investments in infrastructure and technological advancement. Public perception and acceptability are other research areas.

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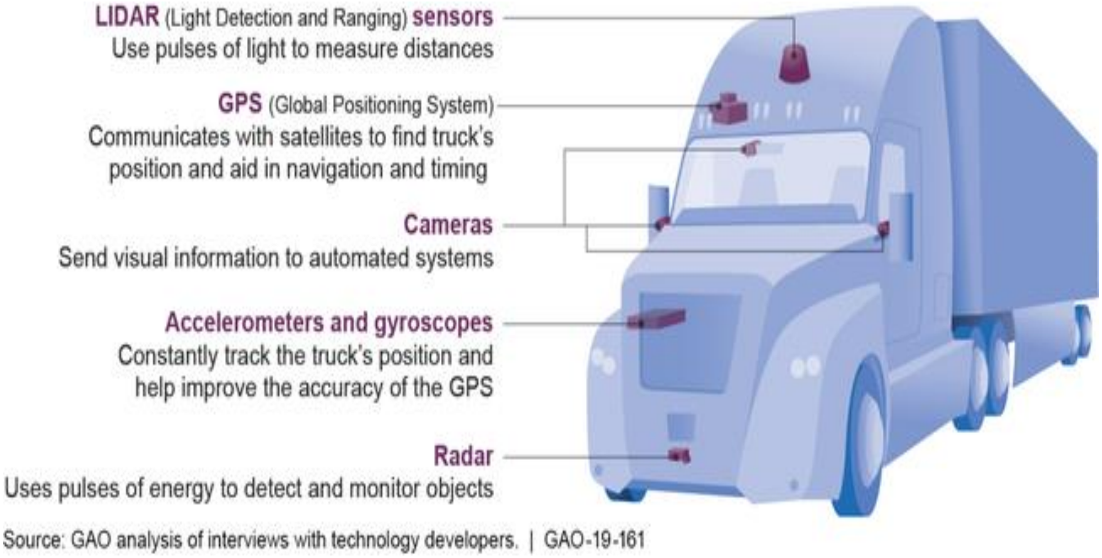
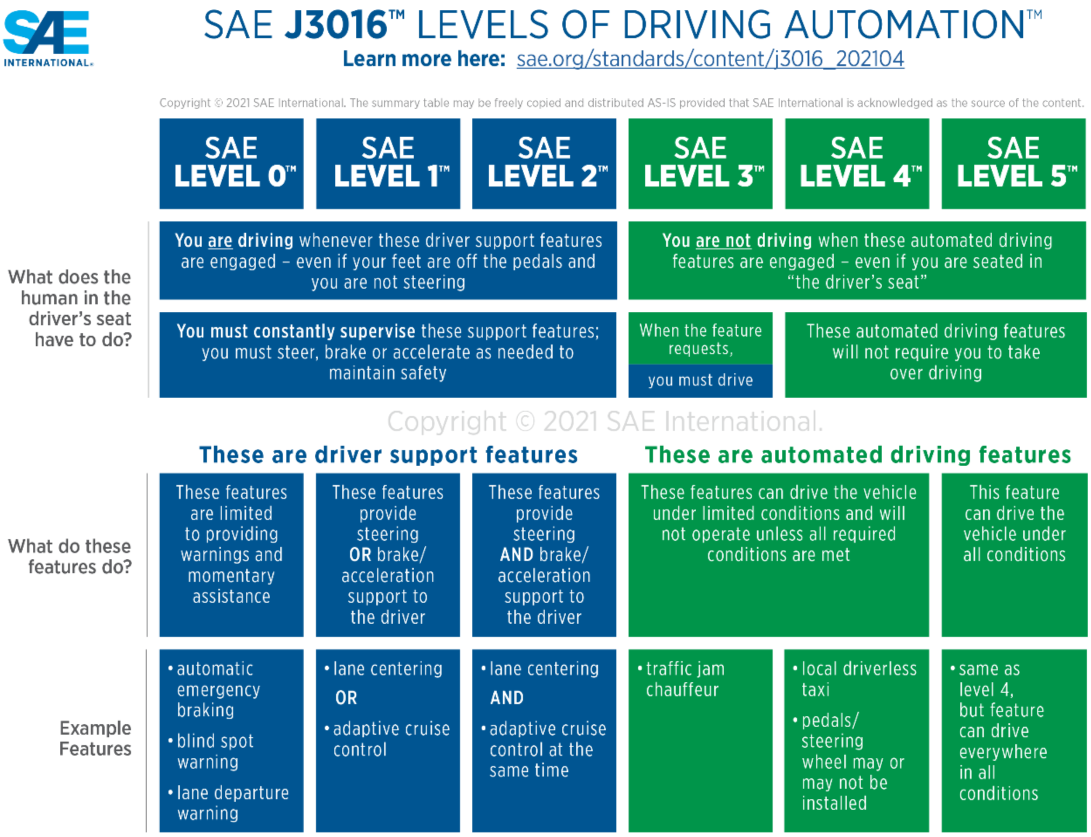
APPENDIX 1



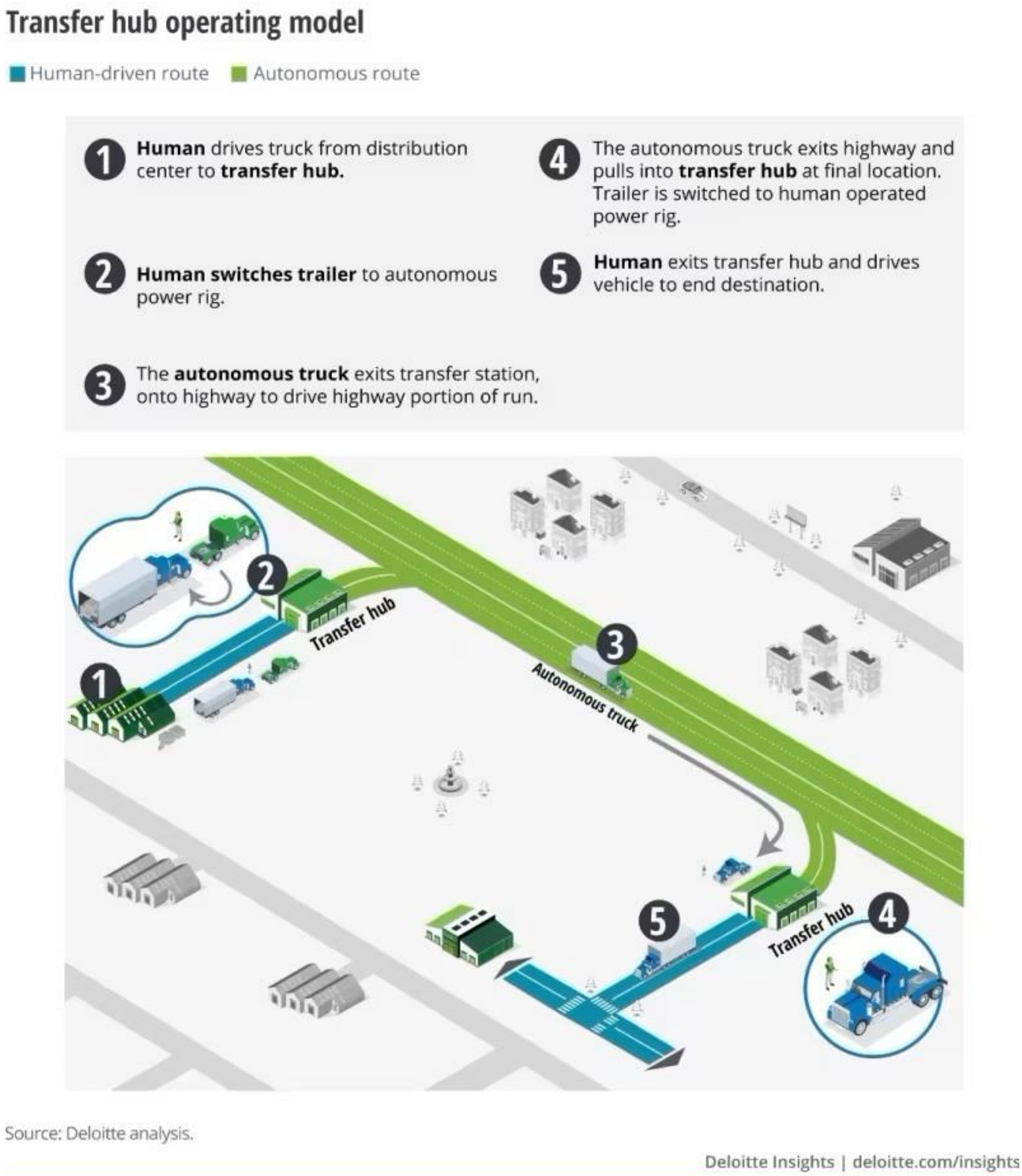
Appendix 1. Autonomous technology by (United States Government Accountability Office, 2019).

APPENDIX 2



Appendix 2. Levels of automation by (Society of Automotive Engineers, 2021).

APPENDIX 3



Appendix 3. Model of operating developed by (Deloitte, 2021).