UNIVERSITY OF GOTHENBURG
SCHOOL OF BUSINESS, ECONOMICS AND LAW

Transition Towards Autonomy: Incremental Cost-Benefit Analysis of Autonomous Hub-to-Hub Freight Transport - A Case Study of DFDS

Presented by Erik Gustavsson & Lewin Saile

Supervisor: Rickard Bergqvist

Master's thesis in Logistics & Transport Management

Spring 2025

Graduate School, School of Business, Economics and Law, University of Gothenburg, Sweden

Abstract

The study investigates the cost-benefits of introducing autonomous trucks, focussing on a stepwise transition across the SAE levels of autonomy.

A case study methodology is applied using mixed methods and data triangulation. Real-world operational data from the case company DFDS are combined with academic literature, industry insights, and semi-structured expert interviews. Scenario modelling and quantitative analysis are used to simulate cost impacts at different levels of autonomy.

Four cost scenarios are introduced to assess the economic viability of each autonomy level. For levels 1–3, a net-zero cost effect is identified as increased technology investment is balanced by modest operational savings. At levels 4 and 5, significant cost reductions of up to 50% are observed in the optimistic scenario, largely driven by lower driver-to-vehicle ratios and increased vehicle utilisation. In a pessimistic scenario, where labour costs remain unchanged, no significant cost advantage is realised.

Regulatory, legal, or technical implementation barriers are not taken into account. Given the rapid evolution of the autonomous vehicle industry, ongoing research and regular updates are essential.

In all scenarios, the risk of financial loss from adopting autonomous systems is minimal. Early-stage automation offers cost neutrality with potential upside in improved utilisation. The findings support early market entry strategies, especially for operators seeking competitive advantage through learning and ecosystem integration.

This study offers a focused, stepwise analysis of cost development across autonomy levels in contrast to prior research that often treats autonomy as a binary concept. By integrating real-world data with scenario-based modelling, it delivers a transparent and grounded perspective on the economic potential of autonomous freight transport.

Contents

1 Introduction **1**

1.1 Purpose . . . 2

1.2 Relevancy & Research Gap . . . 2

1.3 Research Question . . . 4

1.4 Structure of the Study . . . 5

2 Methodology **8**

2.1 Research Design . . . 8

2.1.1 Research Paradigm . . . 8

2.1.2 Case Study Approach . . . 9

2.2 Research Data . . . 9

2.2.1 Quantitative Literature Review . . . 9

2.2.2 Qualitative Literature Review . . . 10

2.3 Case Company: DFDS . . . 12

2.3.1 Description . . . 12

2.3.2 Data Collection . . . 13

2.3.3 Case Setting . . . 15

2.4 Limitations of Research Design . . . 16

2.5 Limitations of Scope . . . 16

2.6 Validity & Reliability . . . 18

2.7 Contributions . . . 19

3 Theoretical Framework **20**

3.1 Autonomous Concepts . . . 20

3.1.1 Definition . . . 20

3.1.2 Social & Commercial Adoption . . . 21

3.1.3 Autonomous Trucks . . . 22

3.1.4 Operational Design Domain . . . 23

3.2 Foundational Trends 24
3.2.1 Push Factors 26
3.2.2 Pull Factors 28
3.2.3 Developing & Grey Areas 29
3.2.4 Barriers 31
3.3 Market Strategy 33
3.3.1 Proactive 34
3.3.2 Passive 35
3.3.3 Collaborative 36
3.3.4 Defensive 36

4 Analytical Framework **38**
4.1 Total Cost Equation 38
4.2 Cost Analysis 38
4.2.1 Driver 39
4.2.2 Base Vehicle 41
4.2.3 Tech Stack 43
4.2.4 Insurance 48
4.2.5 Fuel 49
4.2.6 Repair & Maintenance 53
4.2.7 Tyres 54
4.3 Summary of Stepwise Cost Development 56
4.3.1 Level 1: Driving Assist 56
4.3.2 Level 2: Combined Assistants 56
4.3.3 Level 3: Supervised Autonomy 57
4.3.4 Level 4: Full Supervised Autonomy 57
4.3.5 Level 5: Full Unsupervised Autonomy 57
4.3.6 Conclusion 57

5 Scenario Analysis **58**

5.1 Scope 1: Single-route Contract Logistics 58
5.1.1 Base Scenario 58
5.1.2 Pessimistic Scenario 59
5.1.3 Optimistic Scenario 59
5.1.4 Futuristic Scenario 59
5.1.5 Findings 60
5.2 Scope 2: DFDS Swedish Hub Network 60
5.2.1 Annual Distance Sensitivity Analysis 61
5.2.2 Driver Count Sensitivity Analysis 62
5.2.3 Tech Stack Cost Sensitivity Analysis 62
5.2.4 Findings 64

6 Conclusions **67**
6.1 Key Findings 67
6.1.1 Foundational Trends 67
6.1.2 Market Entry 68
6.2 Reflection on Research Question 69
6.3 Recommendations for DFDS 70
6.4 Future Research Potential 71

References **I**

A Total Cost Equation **XV**

B Power Requirement Calculation **XVII**

C Transport Speed Classification **XIX**

List of Figures

1 Structure of the study 7

2 Exponential growth in autonomous transport research over time in contrast to the minor occurrence of "Trucks" 11

3 Transport modes and their respective frequency identified within the Scopus population 11

4 Overview of case settings for the single route and network scope 16

5 Classification of autonomous driving in the the SAE levels of driving automation framework (SAE, 2021) 21

6 Venn-diagram of underlying forces for autonomy in freight transport. 25

7 Strategic approaches to time and capture market dynamics at entry 34

8 Tech stack pricing and integration strategy for truck OEMs 44

9 Energy reduction achieved by slower transport speeds 52

10 Cost scenario framework clustering forecast uncertainties 58

11 Total transport cost development across autonomy levels under different scenario assumptions 63

12 Total transport cost per kilometre in the base scenario extrapolated for extended utilisation of fix-cost assets (annual mileage) 63

13 Total transport cost per kilometre in the base scenario tested for driver-to-vehicle ratios 65

14 Total transport cost per kilometre in the base scenario for level 5 autonomy, testing different tech stack cost assumptions 65

15 Targeted transport speed class derived from Gothenburg metro congestion data (TomTom, 2024) XIX

List of Tables

1 Overview of expert interview participants 14

2 Driver cost per kilometre under different autonomy scenarios 41

3 Truck cost per kilometre for battery-electric HGVs under current and projected price equilibrium conditions 44

4 Tech stack costs by scenario (based on 400.000 km lifetime distance) 48

5 Cost Development of Tech Stack Features (based on 400.000 km lifetime distance) 48

6 Insurance cost per kilometre under different autonomy levels 49

7 Fuel cost per kilometre under different autonomy levels at various speed (battery-electric truck) 53

8 Maintenance cost per kilometre under different autonomy levels (battery-electric truck) 54

9 Tyre cost per kilometre under different autonomy scenarios. 56

Acknowledgements

We would like to express our gratitude to Professor Rickard Bergqvist at the University of Gothenburg, School of Business, Economics and Law, for his invaluable supervision and support throughout this thesis project.

The authors also thank Mads Skovsgaard Rasmussen and colleagues at DFDS, providing guidance and industry insight that were essential to the case study. We thank DFDS for the opportunity to work within the organisation and for their support during the research process.

1 Introduction

At the 1939 New York World's Fair, industrial designer Norman Geddes, in collaboration with General Motors, introduced *Futurama*, a visionary exhibit showcasing the future of transportation: automated vehicles driving on smart highways (Geddes, 1940). Since then, autonomous driving has evolved from science fiction to technological ambition (Moravec, 1990), becoming increasingly relevant as computational power and sensor systems advance. In the early 2010s, these technologies had matured enough to enable the first autonomous prototypes in real-world traffic environments (Thrun, 2010), and today traditional commercial vehicle manufacturers (OEM) collaborate with technology companies and transport providers to test autonomous road transport solutions, showcasing feasibility and commercial potential.

The shift comes at a critical time for the distressed transport industry, as companies seek relief from rising costs and driver shortages (IRU, 2024). However, the path from prototype to scaled deployment remains uncertain. While some scholars foresee rapid disruption and a decisive shift toward automation-led economies, arguing that artificial intelligence will render traditional business models obsolete Brynjolfsson and McAfee (2014), others remain more cautious. For example, Edgerton (2007) challenges this assumption by highlighting the persistence of legacy technologies and patterns of gradual adoption, suggesting that existing infrastructure, established practices, and human expertise slow radical changes, leading to more incremental transformation. Saffo (2007) further stresses the underlying uncertainty by highlighting the common forecast fallacy to overestimate the short-term impact and underestimate the long-term impact of new technologies.

Contemporary developments highlight the accelerating progress in autonomous freight technology. In the United States, trials such as those conducted by Pony.ai and SANY (Steinberg, 2022) demonstrate significant advances in vehicle automation and integration. In parallel, European initiatives such as the MODI project MODI (n.d.) have been launched to evaluate industry readiness and assess the commercial viability of autonomous operations under real-world conditions on public roads.

Despite these advances, several short-term barriers continue to impede broader deployment. The fragmented regulatory framework across the European market (Sever & Contissa, 2024), coupled with underdeveloped infrastructure, presents substantial challenges

(Monios & Bergqvist, 2019). In addition to technological and regulatory challenges, there are considerable uncertainties regarding the long-term viability of the business models of logistics companies, which must adapt to the potentially disruptive impact of autonomous technology to deliver customer value and remain competitive (Turienzo et al., 2023).

While visionaries and researchers debate the end game and the ultimate future of transport automation, much less is known about the concrete roadmap of implementation. Clarifying this transitional roadmap is critical for transport providers looking to strategically position themselves in a rapidly evolving and potentially disruptive industry landscape.

1.1 Purpose

The purpose of the study is to evaluate the cost implications of introducing autonomous driving technologies in hub-to-hub contract logistics, with the aim of determining financial feasibility. Using the SAE levels of driving automation (SAE, 2021) as a framework, the study performs a stepwise cost-benefit analysis, linking the levels of autonomy to the underlying changes in cost structure.

The research is grounded on a case study of DFDS Logistics Sweden, whose operations along the Gothenburg – Borås corridor provide insights into real-world operational practice and cost structure. This is supported by public data and industry literature, allowing results to be contextualised and generalised beyond the specified use case.

In addition to assessing cost dynamics, the study explores potential future implications for business models enabled by automation. This forward-looking perspective aims to clarify the strategic relevance of adopting autonomous technology, particularly as the industry transitions from incremental automation to full-scale autonomous logistics.

1.2 Relevancy & Research Gap

Although the concept of autonomous driving has existed for decades (Geddes, 1940), the enabling technologies are only recently maturing and remain largely underutilised in commercial road transport operations, posing a significant investment risk for transport providers (Engholm et al., 2020). Although the need for digital transformation is widely recognised (Brynjolfsson & McAfee, 2014; Dong et al., 2021), adoption is expected to be incremental, following a stepwise transition rather than a sudden overhaul (Edgerton, 2007;

Saffo, 2007). Most of the literature covering autonomous driving focusses on abstract future scenarios in which all hurdles have been overcome and the envisioned technology potential is fully utilised. Hence, research on the broader impact and ripple effects induced by automated freight transport remains insufficient (Engholm et al., 2020). Reflecting on the current progress in automated freight transport (e.g., Hawkins, 2021; HHLA, 2021; MODI, n.d.; Kachwala, 2024; Gilroy, 2018) past trajectories of technology readiness timelines (e.g., Geddes, 1940; Moravec, 1990; Thrun, 2010; Skeete, 2018), a significant gap in addressing intermediate, more tangible implementation stages is recognised.

The study addresses this gap by examining the cost-benefit implications of autonomous deployment in hub-to-hub contract logistics. Autonomous adoption will also depend on the existence of a viable business case, without which the promised benefits of autonomous driving will not materialise in practice. This aligns with broader digitalisation trends, which challenge established value propositions and enable technology firms to enter traditional logistics markets (Loebbecke & Picot, 2015). Extracting the economic implications from a detailed perspective of cost-benefit analysis enables a more grounded understanding of how autonomous driving may affect freight transport operations. Rather than relying solely on high-level projections, the chosen approach begins with the identification of specific cost items and how they evolve across higher autonomy levels.

Contract logistics represents a complex service landscape that requires extensive operational coordination with multiple stakeholders. With advanced automation, collaboration and partnerships between industry actors are likely to remain critical (McKinsey & Company, 2016). However, in response to evolving customer demands, further improvements in transport-related services are required in order to remain competitive (Vasiliauskas & Jakubauskas, 2007). As roles and relationships evolve, it becomes essential to reassess the value-creating activities of each stakeholder. Among them, transport providers are arguably among the most affected and face pressing strategic decisions about their future role (Monios & Bergqvist, 2020).

Ultimately, understanding the financial feasibility of autonomous technology at each stage of deployment provides critical insight for strategic decision-making and business model objectives, directly addressed through the stepwise cost-benefit framework developed in this thesis.

1.3 Research Question

This study employs the following research question to address the identified gap in the research field. In addition, an explanation of the included wording and concepts is provided.

How will the stepwise implementation of autonomous driving affect the cost structure of transport operations, and what does it imply for attaining a commercially viable business model?

As presented, the authors find evidence that autonomous technology will gradually be introduced into public road transport operations (Engström et al., 2019; Mehlhorn et al., 2023; Edgerton, 2007). This approach differs from some accounts (Gruel & Stanford, 2016; Yazdanpanah et al., 2023) that neglect intermediate steps and focus solely on the binary effect between conventional and fully autonomous operations. As such, *stepwise implementation* highlights and reviews all steps presented in technological adoption that will eventually lead to the envisioned future. Thus, the study employs the widely used SAE (2021) framework to define *autonomous driving*, for which more reasoning is provided in Section 3.1.

In contrast to conventional review of business models (Athanasopoulou et al., 2019; Turienzo et al., 2023), the study isolates associated costs to focus on nuanced changes in the *cost structure*. Although this approach disregards any conceptual changes in the business model as well as the revenue potential, it allows for more concise insights and improved generalisation. The cost structure used is derived from common industry reports (ASEK, 2024; ATRI, 2023) and journal articles (Engholm et al., 2020) that employ a total cost of ownership perspective.

Furthermore, *transport operations* are considered the actual transport leg of a given supply chain that takes place on public road outside the sender and receiver's premises. This approach aligns with industry projections that the early implementation of autonomous trucks will be between hubs, where the operational domain is often restricted to highways (Hawkins, 2021; Engström et al., 2019; Lee et al., 2024). Hence, yard operations are not accounted for to allow for improved focus and generalisation. The European setting is applied, supporting a more narrow understanding of truck transport operations, allowing parameters to be discussed and tested more rigorously.

The implementation of autonomous freight transport will not progress solely due to external

pressures such as technological advances or regulatory support, but will require a profitable and scalable business model for transport companies (Müller & Voigtländer, 2019; Turienzo et al., 2023). Cost benefits (Wadud, 2017), coupled with sustainable business models (Fritschy & Spinler, 2019), will be necessary for adoption. Furthermore, due to infrastructure constraints, higher levels of autonomy on public roads in Sweden are expected to take several years to materialise (Monios & Bergqvist, 2019; Sever & Contissa, 2024). Therefore, achieving profitability in intermediary steps toward full autonomy will be essential for the industry's transition. However, there is uncertainty whether these intermediary levels can be operated to a cost benefit with respect to potentially steep upfront costs. As such, the objective formulated in the research question *commercially viable* is defined as a cost structure that yields a net-zero cost-benefit or positive returns for each level of autonomy.

1.4 Structure of the Study

The study is structured into four main parts: (I) an introduction to the research context and methodology, (II) a review of the literature addressing the conceptual factors for the development of autonomous driving, (III) a case study-driven analysis of the current business environment, the identification of operational domains suitable for autonomous freight transport, and an in-depth review of transport cost development in the context of predefined operational setups. Finally, (IV) a synthesis of findings, discussion, and conclusions aims to determine the overall feasibility. A visualised overview of this structure can be found in Figure 1.

Part I: Introduction & Methodology (Chapter 1–2)

The study begins with a general introduction to the research topic, its scope, and the underlying objectives for investigation, all captured within Chapter 1. Further, in Chapter 2, the methodological approach is outlined along the research paradigm applied by the study & the data collection methods used.

Part II: Literature (Chapter 3)

Chapter 3 provides a conceptual and contextual foundation for the study by exploring the technical, social and commercial dimensions of autonomous transport. It defines key con-

cepts such as autonomy and operational design domains, and critically examines factors that influence adoption across sectors, including task complexity, safety, and market maturity. The chapter also introduces the strategic relevance of hub-to-hub operations as a viable entry point for automation, and situates the case company DFDS within this evolving freight transport landscape.

Part III: Case Study (Chapter 4–5)

The third part of the thesis constitutes the core analytical section, where the research question is addressed through a structured three-chapter case study. The case of DFDS Logistics Sweden serves as a focal point throughout, providing operational context and empirical insights that are complemented by literature and industry data.

Chapter 4 develops a stepwise cost-benefit analysis based on the SAE levels of autonomy. It provides a detailed breakdown of how key cost items evolve, covering both capital and operational expenditures, and reviews these in a consolidated total cost perspective for each stage of autonomy.

Chapter 5 expands the analytical lens to examine the broader business implications of autonomous driving in two operational scopes. As such, a single route automation and a multi-route network are reviewed, to test parameter sensitivity. This analysis addresses the financial feasibility of the autonomous stepwise implementation and supports a comparative view across different levels of deployment.

Part IV: Findings, Discussion & Conclusion (Chapter 6)

In the final section, the insights from the case study are consolidated, discussed, and evaluated in light of the study's overall purpose and research question.

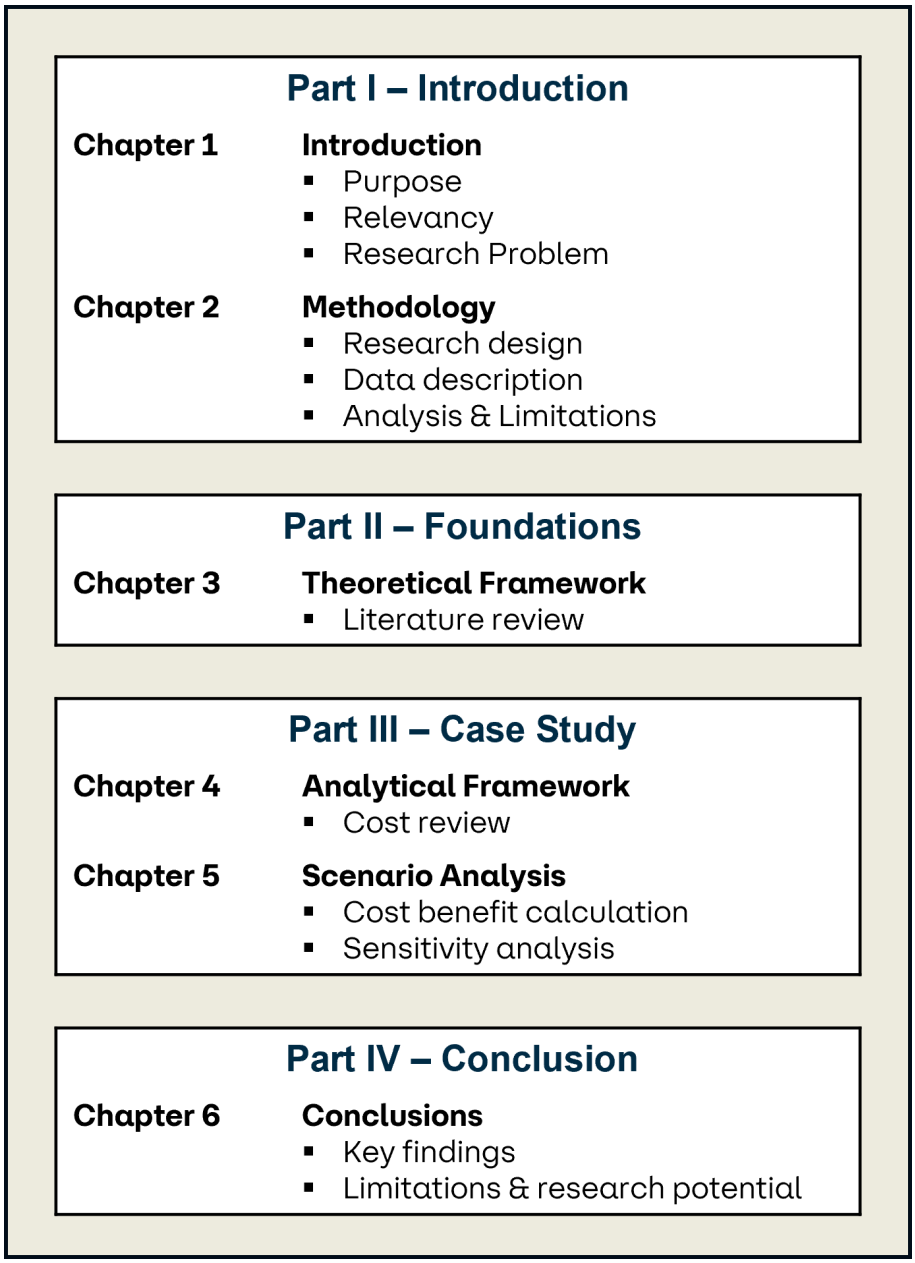

Figure 1: Structure of the study

2 Methodology

2.1 Research Design

2.1.1 Research Paradigm

The study employs a pragmatic paradigm that combines both qualitative and quantitative methods in order to explore the business implications of autonomous hub-to-hub freight transport. As such, the approach allows researchers to focus on the practical research question and employ a combination of methods deemed most suitable to address it (Bryman, 2007). This methodological flexibility allows for real-world orientation and captures the complexity found in the technological, organisational, and economic implications associated with autonomous driving (Venkatesh et al., 2013; Collis, 2021). By this, practical insights for the case company are intended to be derived from the combination of objective data analysis and subjective interpretation.

The mixed methods strategy is further used to capture both the numerical and contextual aspects of autonomous adoption, thus improving the study's ability to collect evidence and address both perspectives more effectively than a purely qualitative or quantitative approach alone (Yin, 2018). Quantitative data (e.g., cost per km, asset utilisation) are derived from case company operations and are supported by external sources. Qualitative data (e.g., strategy insights, operational considerations) are gathered through semi-structured interviews and collaborative sessions. These methods are closely integrated, with qualitative findings that form the structure and interpretation of quantitative analysis, reflecting the pragmatic foundation of the study.

The extraction of data from the case company and the complementing sources is carried out inductively since the projection of future costs for autonomous driving involves inherent uncertainty. To avoid bias, the authors let the data guide the outcome of the study (Bingham, 2023). The futuristic and unknown nature of the topic complicates the use of existing benchmarking cost frameworks, even though cost structures for today's operations such as ATRI (2023) and ASEK (2024) are used for comparative causes. Thus, the study does not test for any pre-designed hypothesis to hold or not, but instead investigates the costs in an inductive manner.

2.1.2 Case Study Approach

The study uses a case study design focused on DFDS Logistics Sweden, a transport provider currently investigating the potential deployment of autonomous freight solutions in its contract logistics operations. As such, the case company provides access to real-world operational data, existing cost structures, and stakeholder perspectives. Reflecting on the identified research gap that highlights the limited availability of cost analyses for autonomous freight transport providers, the use of a case study ensures the study's relevancy and legitimacy. The novelty of autonomous driving complicates fully describing it in a context where it has already occurred, supporting an exploratory case study approach over a descriptive (Baxter & Jack, 2015).

In contrast to multi-case studies, single-case studies are restricted in their ability to support theory building and replicability (Foster et al., 2021). However, by transparently deducting information from actual operations, the chosen methodology provides transferability to similar industry actors. Furthermore, the approach allows to investigate one industry actor more thoroughly (Flyvbjerg, 2006), which is considered beneficial due to the study's additional emphasis on business model implications.

This is further reflected in the study's interview strategy, where all hierarchical levels of the case company are consulted, in order to develop a deeper knowledge of the specific case compared to what would be feasible in multi-case studies.

Structuring the investigation by applying the stepwise framework of SAE levels (SAE, 2021) counters the oversimplified and binary treatment of automation often found in existing literature, where autonomy is reduced to the driver being either physically present in the vehicle or not. Instead, the study uses the framework, which is further described in Chapter 3, to gradually capture the change in operational and capital expenditures, thus analysing the cost benefits.

2.2 Research Data

2.2.1 Quantitative Literature Review

Autonomous transport is a rather recent technology and its impact on research is still scaling. In order to understand the extent of the field, a scraping of the *Scopus* research

database is conducted where all articles queried by the following search term are exported and further analysed:

(autonomous* OR driverless*) AND transport*

Accordingly, the population contains entries indexed with alterations of autonomous / driverless transportation. Hereby a total of approximately 27.000 papers is retrieved for further analysis in a Python environment. The scrape was last conducted in June 2025 with results for the ongoing year matching overall growth expectations.

To effectively filter articles from other research disciplines that employ similar wording (e.g., Biochemistry, Genetics, and Molecular Biology), titles and abstracts for transport modal terminology are scraped, removing all entries that do not relate to one or more transport modes. The step is necessary since, for instance, "logistics" or "freight" are not always contained within titles or abstracts and are often employed ambiguously.

A summary of the results is depicted in Figure 2 and 3, suggesting that interest in autonomous transportation has increased exponentially since the 1970s. Furthermore, the results suggest that existing research is mostly focussed on urban mobility (cars, buses, taxis, and rail applications) and delivery solutions (vans, drones), whereas transport applications in already automated areas (rail, air, sea) follow up. So far, research on truck transport is of minor interest, yet has grown proportionally with the combined research field over the years.

2.2.2 Qualitative Literature Review

Search Strategy

The qualitative literature review is initiated with a structured search in the Scopus database to identify peer-reviewed studies relevant to autonomous freight transport, business model adaptation, and cost analysis. Reference lists of key articles identified early in the process are manually screened to collect critical sources. In addition, the tool *Research Rabbit* is used to explore related literature based on citation networks.

In parallel, targeted keyword searches via *Google* are conducted to identify up-to-date material from grey literature and industry publications, including reports and news articles.

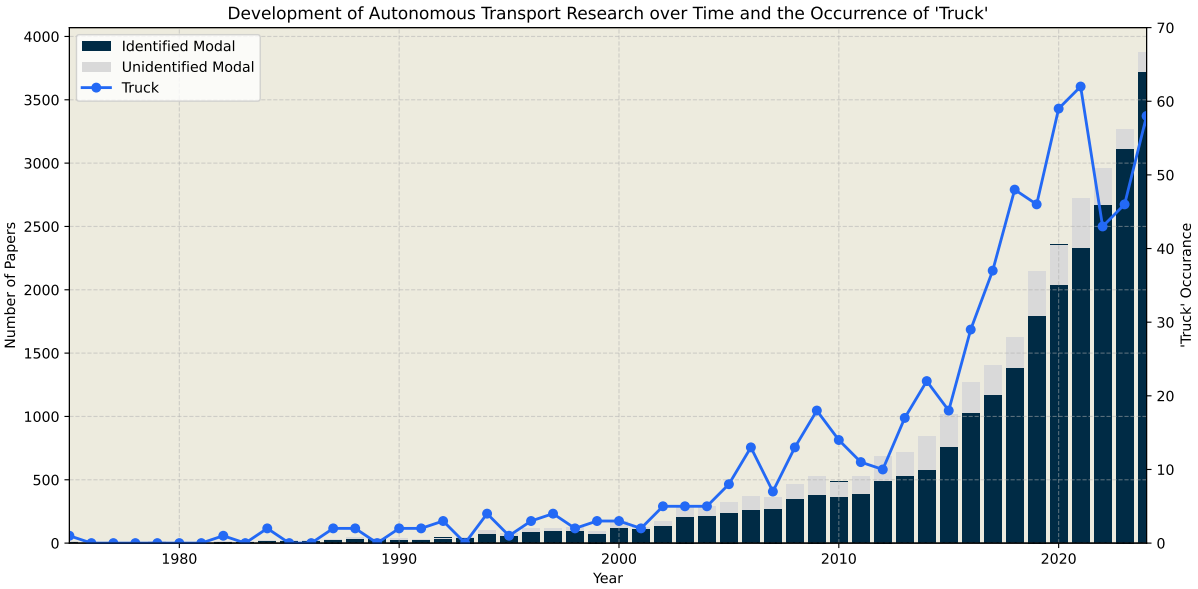

Figure 2: Exponential growth in autonomous transport research over time in contrast to the minor occurrence of "Trucks"

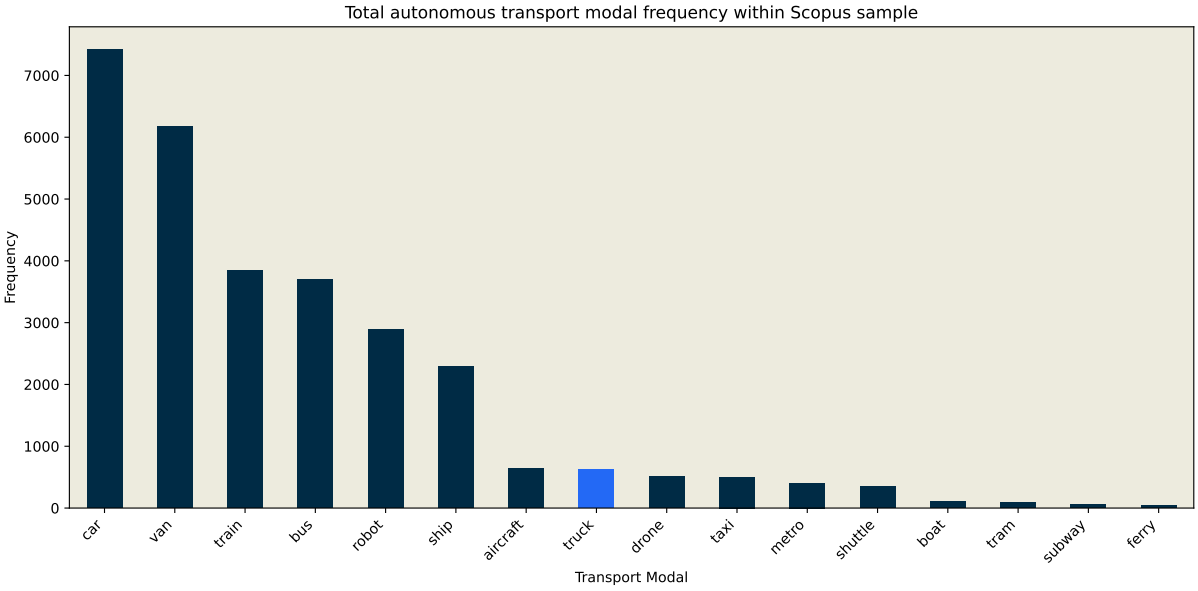

Figure 3: Transport modes and their respective frequency identified within the Scopus population

This is done to capture real-world data, emerging trends, and perspectives from practitioners. Combining sources enables the study to integrate scientifically grounded insights and contemporary industry perspectives.

Scope, Relevance & Selection Criteria

The literature review prioritises peer-reviewed articles from established academic journals to ensure methodological rigour and conceptual relevance. In addition, industry reports, newspaper articles, and grey literature are carefully screened to check for bias.

Deliberate effort is also made to include less cited or emerging research when offering alternative or conflicting perspectives. This approach aims to reflect the rapidly evolving and sometimes contested nature of the discourse around autonomous freight transport.

The literature is selected based on its direct relevance to autonomous driving, with a particular focus on distinguishing between transport modes and operational domains. Studies addressing individual truck operations within hub-to-hub logistics are prioritised to maintain alignment with the thesis case study and analytical scope. Where applicable, preference is given to literature reflecting European transport environments. In cases where the studies originate from other regions, the results are carefully contextualised to assess their applicability.

Given the rapid pace of technological and regulatory developments in the field, publication dates are critically considered. For works published before 2024, the findings are interpreted in the context of their publication date to account for outdated assumptions or early-stage technologies.

2.3 Case Company: DFDS

2.3.1 Description

DFDS is a well-established Danish logistics company with a long history of transporting people and goods to sea, as well as by road and rail. The company was founded in 1866 and has two main business areas, constituting the ferry division and the logistics division. In 2023, the logistics division represented about 45% of the company's total revenues, making it a cornerstone of the company's business model. Both ferry and land logistics operations

are active on routes across the European market (DFDS A/S, 2023).

The study emphasises the company's regional logistics division in Sweden and does so in two separate scopes. First, an isolated single short-range route is highlighted, accompanied by a cost-benefit analysis presented for the introduction of autonomous transport in this environment. Later, the analysis is scaled to encompass all DFDS hubs operated in Sweden to explore long-range parameters and potential associated network effects of the autonomous deployment.

2.3.2 Data Collection

Interviews

The study employs semi-structured expert interviews to gather accurate quantitative data for the study's cost analysis, as well as relevant qualitative insights of case company operations. The chosen interviewees for these are listed in Table 1, and were selected due to their occupational dispersion,in order to capture the holistic picture of both today's operations and predictions on autonomous future scenarios. This strategy also provides insights from various levels in the case company's organisation, improving analytical rigour. The study's interest in both operational data for the cost analysis, as well as strategic insights for the business model perspective further motivates the variety among interviewees.

The process of collecting relevant data and insights for the study includes engaging with people in various positions of the case company in order to identify the most relevant subject experts. The initial informants disclosed in Table 1 further assisted in identifying additional colleagues, that were subsequently interviewed. In cases where much of the required data for the cost analysis are gathered in initial sessions, later ones served to validate previously gathered information.

The interviews were conducted through online meetings of approximately one hour. Beforehand, the respondents were prepared with the interview topic, theme, and purpose. While some predetermined questions were prepared by the authors, the semi-structured form of the sessions is given priority to allow for insights to be gathered that were not expected by the authors in advance. With the permission of the participants, all conversations were recorded to avoid loss of information. All participants were anonymised afterwards.

Table 1: Overview of expert interview participants

Interview Reference	Occupation	Date	Duration
Informant 1	General Manager	10.03.25	1h
Informant 2	Data Consultant	26.03.25	1h
Informant 3	Traffic Planner	28.03.25	1h
Informant 4	Fleet Manager	04.04.25	1h
Informant 5	Procurement Manager	01.05.25	1h

Quantitative Data

Quantitative data form the basis for the cost-benefit analysis presented in Chapter 4, where financial implications are assessed across the SAE levels using the stepwise approach. Data collection is guided by a total cost of ownership perspective, which requires a comprehensive overview of all cost items affected by the gradual implementation of autonomous trucks, including both capital and operational expenditures. Cost data is gathered primarily in collaboration with experts from DFDS Logistics, involving mentioned semi-structured interviews and iterative discussions to identify, validate, and refine the relevant financial input. The resulting data set is then cleaned and structured to support further analysis across autonomy levels.

Qualitative Data

Qualitative data are used primarily to contextualise quantitative findings and to derive insights from real-world operations into business model adaptation and strategic implications. Insights are primarily collected from the semi-structured interviews. In addition, the authors recognise the impact of many informal discussions with colleagues and other researchers, as well as collaborative meetings with stakeholders and representatives from transport authorities and research institutions involved in the MODI project.

These interactions provide insight into operational practices, future expectations from various stakeholders, and organisational perspectives on automation, which helps to interpret the quantitative results shaping the roadmap for implementation. Qualitative input is particularly valuable in identifying areas where business model changes may occur, allowing the study to go beyond numeric estimates and incorporate real-world considerations from industry actors.

2.3.3 Case Setting

Scope 1: Single-Route Contract Logistics

The first scope focusses on a local short-range, hub-to-hub transport route operated under contract logistics agreements. This setting captures a key application area where autonomous trucking technology is expected to demonstrate operational benefits and early feasibility (Lee et al., 2024). The chosen route for the thesis is part of the EU-funded MODI project, which explores the deployment of level 4 autonomous driving technologies along a logistics corridor that runs from Rotterdam (NL) to Moss (NO) (MODI, n.d.). Through DFDS, the study uses the MODI project's Swedish use case route of Gothenburg–Borås, supporting the validation of its cost analysis and operational review within a realistic and industry-backed environment aligned with current strategic projections for autonomous hub-to-hub transport.

Contract logistics, the operational framework for these transports, involves long-term service agreements between transport providers and customers, differing from the spot market where ad hoc transport is purchased at market-driven rates (RXO, 2025). Transport providers such as DFDS carry out consistent and repeated flows over defined periods, fostering collaborative opportunities to optimise efficiency and tailor service provisions (Darko & Vlachos, 2022). Freight rates are negotiated and fixed in advance, offering predictability for both parties. Details of the parameters derived for this specific setting are presented in Figure 4.

Scope 2: DFDS Swedish Hub Network

The second case setting expands the scope from a single short-range route towards a network of interconnected hubs across southern Sweden. This environment reflects the broader transport operations of DFDS and provides a context for scaling the potential deployment of autonomous driving. As such, the chosen network consists of five truck terminals and warehouse hubs, located in the cities of Gothenburg, Jönköping, Borås, Helsingborg and Karlshamn, respectively. Figure 4 highlights the strategic placement of these hubs and the major freight corridors that connect them. While the earlier use case focused on a single corridor between the Roll-on Roll-off terminal in Gothenburg and the DFDS warehouse in Borås, this second setting considers the larger hub network as an integrated

system for autonomous hub-to-hub transport.

In general, the midrange hub network offers an important stepping stone between isolated route deployment and full autonomous operations across the European market, highlighting scalability and operational optimisation opportunities.

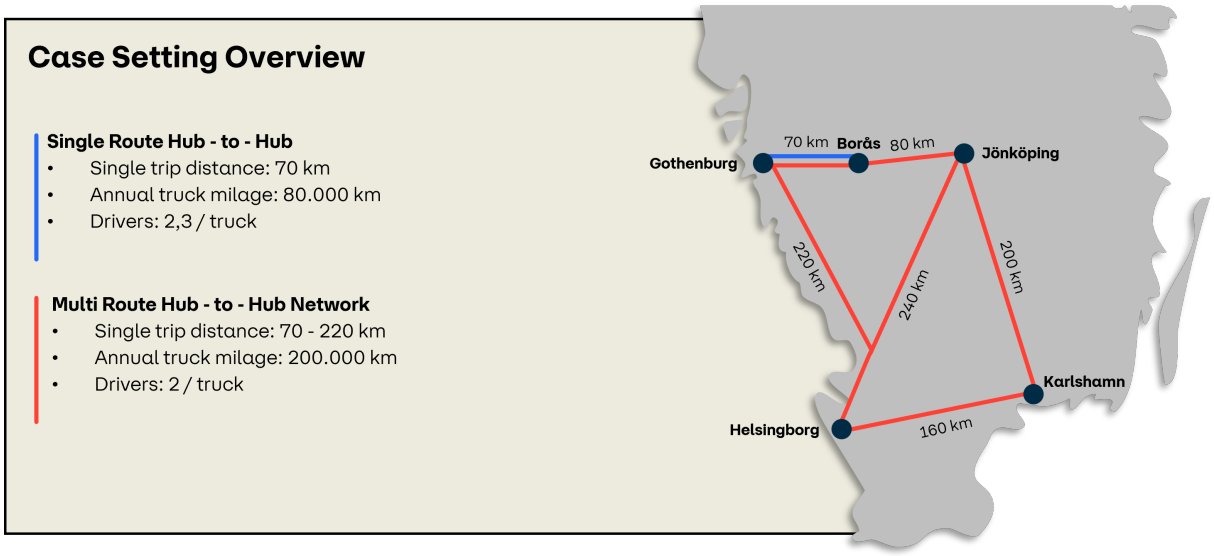

Figure 4: Overview of case settings for the single route and network scope

2.4 Limitations of Research Design

The case study approach employed in the thesis follows an exploratory bottom-up logic which, while suitable for capturing contextual detail, also presents certain methodological risks. Such approaches may result in overly complex or narrowly scoped theories that lack generalisability and do not contribute to the development of broader "grand" theories (Foster et al., 2021). Furthermore, the richness of qualitative data can lead to excessive detail that may unintentionally shift the focus away from the main research objective (Eisenhardt, 1989). The authors are aware of the underlying limitations of the research design and present appropriate mitigating measures or highlight limitations within the analysis and conclusion, where needed.

2.5 Limitations of Scope

The study operates under the assumption that the technological, regulatory, and social conditions fully permit the deployment of autonomous vehicles in the operational domains examined. Consequently, the analysis is restricted to questions of economic feasibility and

does not address broader challenges related to infrastructure, battery ranges, legal frameworks, or public acceptance. This assumption aligns with the forward-looking perspective of the research question, which relies on projections of future cost structures rather than current constraints. Consequently, current barriers, such as the limited availability of charging infrastructure or incomplete regulatory frameworks, are excluded from consideration.

The scope is also limited to the transport segment of logistics operations. Activities occurring within yards, terminals, or warehouses are deliberately excluded to ensure generalisability across use cases. Similarly, the analysis does not incorporate additional operational concepts such as vehicle platooning or dynamic routing. However, the underlying model and cost structure are adaptable and could be extended to simulate such scenarios.

It is further assumed that the freight rates remain constant at all levels of autonomy. This implies that revenues are not directly influenced by the implementation of autonomous technology. Freight rates are treated as exogenous market prices, which implies that the average rate transport providers receive for a given service is independent from it's level of autonomy. In this context, the adoption of autonomous technology does not automatically contribute additional value to the end customer. Improvements in service quality, reliability, or uptime are assumed to be offset by the complexity that customers may face when integrating such services into their existing processes. As such, autonomy is framed as an internal optimisation measure implemented by transport providers to improve cost efficiency, rather than as a service differentiator. To maintain ceteris paribus conditions, transport volumes are kept constant throughout the analysis. This also implies that increases in capacity through extended operational hours enabled by autonomous systems are not accounted for in the presented cost model.

In conclusion, the objective of the study is to isolate the cost-side effects of adopting autonomous technology. The analysis focusses on whether increases in selected cost items can be offset by reductions in others. The cost-benefit result at each SAE level is therefore interpreted as a proxy of the willingness of the transport provider to pay for the associated features. This willingness is argued to be derived not only from operational cost savings, but also from the strategic value unlocked by autonomy, as further discussed in Chapter 3.

2.6 Validity & Reliability

To ensure contextual precision and practical relevance, the study is conducted in close collaboration with a competitive transport provider in the Swedish contract logistics segment. This partnership provides real-world insights and data for major transport providers in the hub-to-hub section, ensuring accurate measures expected to improve the general applicability of the findings and therefore support the external validity of the study (Yin, 2018).

A stepwise analytical approach is used to address the risk of oversimplification of the autonomous concept. The use of SAE autonomy levels as a structural framework supports the way Yin (2018) advocates constructing validity by using correct operational measures. This framework aligns the analysis with widely accepted industry standards. The use of triangulated data strengthens internal validity by cross-verifying the information to determine its impact on the final results (Foster et al., 2021).

The scenario-building methodology further enhances the validity by enabling the transparent integration of diverse factors and assumptions. This approach illustrates a range of possible outcomes and also reduces the risk of deterministic conclusions. By simulating varying market and operational conditions, the study demonstrates high contextual validity, remaining practically grounded while maintaining analytical rigour (Foster et al., 2021). All key parameters are explicitly motivated and grounded in a combination of academic sources, industry publications, and real operational data.

In terms of reliability, the research design incorporates semi-structured interviews, which balance both consistency and flexibility. This method supports reproducibility by following a structured guide, while also allowing the emergence of new insights beyond the original expectations of the researchers (Yin, 2018). Quantitative data used for modelling and scenario development are transparently presented and derived from dispersed operational sources. This occupational spread among interviewees aims to improve the reliability of case study data, allowing cross-validation of gathered information. Where possible, these inputs were also validated against external benchmarks to ensure data integrity and reduce the likelihood of error. The underlying calculation methods are clearly documented, enabling reproducibility and verification of results.

Finally, efforts are made to mitigate bias throughout the study. Multiple perspectives are considered and explicitly discussed, and a scenario analysis is used to capture the range of

plausible futures. This methodological diversity helps protect against narrow assumptions and improves the objectivity of the conclusions.

2.7 Contributions

This study was conducted collaboratively by Erik Gustavsson and Lewin Saile, with equal contributions from both authors. Academic supervision and guidance were provided by Professor Rickard Bergqvist at the School of Business, Economics and Law, University of Gothenburg.

For the purpose of the case study, the authors were employed by the case company and received financial compensation for their work. Mads Skovsgaard Rasmussen, serving as Innovation Manager at DFDS, acted as industrial supervisor and oversaw the project on behalf of the company.

All figures and tables are the original work of the authors, unless explicitly stated otherwise.

The research design, data analysis, and interpretation were carried out independently by the authors. Generative AI tools from OpenAI (2025) were used exclusively for linguistic refinement but did not contribute to the conceptual or analytical content of the thesis and were therefore deemed appropriate under the Graduate School guidelines.

3 Theoretical Framework

To set the scene for the study's cost analysis, this chapter displays the background to the current state of autonomy in various sectors and use areas, including the transport industry. Furthermore, the underlying market structures that shape the recent development in autonomous driving within the road freight transport sector are also clarified. In addition, a section highlighting the business model perspective in terms of market entry strategies relevant to transport companies approaching autonomous technology is outlined.

3.1 Autonomous Concepts

3.1.1 Definition

Autonomy, originally a philosophical concept, describes an entity's ability or desire to self-govern and act independently of external control (Wood, 1991). Recent advances in artificial intelligence and machine learning have expanded the introduction of autonomous machines across industries (Moravec, 1990; Thrun, 2010). In transport, autonomy encompasses a spectrum from driver assistance (e.g., lane-centring, cruise control) to fully self-driving vehicles, structured by the SAE (2021) framework shown in Figure 5. This framework categorises the transition of control from independent human drivers (Level 0) to fully automated systems (Level 5), where more advanced vehicle capabilities correspond to higher levels of autonomy. The framework allows for standardised classifications in contrast to loosely defines terms such as *driverless* or *self-driving*. However, the application of the framework in real-world operations is not always strict, and its linear structure may oversimplify complex industry realities. Nevertheless, the framework is adopted as a supporting tool to structure the cost analysis.

Figure 5 presents the SAE framework that classifies the driving tasks performed by the human driver from those performed by automated features. Within five levels, tasks and responsibility are shifted from humans to the machine. Levels 1 & 2 introduce lower automation features to the vehicle such as lane-centring and emergency breaking, which are often marketed as driving assistants. A significant leap can be found in the evolution from level 2 to level 3, as the driver gains a supervisory role, although still being physically present in the vehicle and ready to take over control when needed. Level 4 allows the vehi-

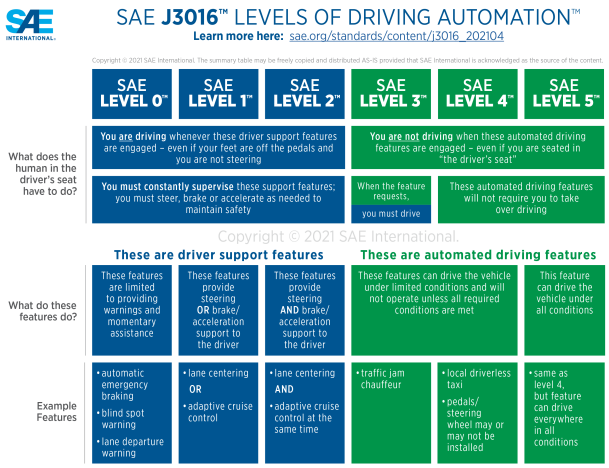

Figure 5: Classification of autonomous driving in the the SAE levels of driving automation framework (SAE, 2021)

cle to operate without a human driver being present in the vehicle in predefined operational environments such as highways; however, requires close supervision in for e.g. city traffic. Level 5 vehicles are capable of operating in any environment and therefore are considered fully autonomous.

3.1.2 Social & Commercial Adoption

Autonomy is increasingly embedded in both the consumer and industrial sectors. In consumer applications, autonomy improves convenience and user experience (Poletti, 2023; Ferraro et al., 2024), as seen, for example, in predictive algorithms in digital services (Gonçalves et al., 2024). In contrast, commercial and industrial contexts prioritise autonomy for its potential to improve efficiency, accuracy, and cost-effectiveness (André et al., 2018).

Although autonomy is often associated with recent advances in artificial intelligence, its application in engineered systems is well established. For example, autopilot functions have long been the standard in aviation (INC, 2025), and agriculture has adopted autonomously guided machinery to improve productivity (Papadopoulos et al., 2024). Manufacturing offers perhaps the most relevant use case, with the introduction of robotic arms in the 20th century in factory production lines, thus integrating automated processes for routine tasks such as welding and assembly (Szeszák et al., 2025). These deployments illustrate how autonomy can fundamentally reshape operations once cost and reliability thresholds are met.

However, in freight transport, commercial autonomy is still emerging. Compared to con-

trolled environments such as factories, farms, or airspace, public road networks pose higher variability and safety demands. This context explains why freight autonomy lags and supports the importance of stepwise adoption backed by cost-benefit validation, which is central to this study.

Although autonomy has transformed logistics-related sectors such as manufacturing and warehousing, its success in freight transport is less certain. This disparity arises from both technical and socio-economic factors that influence adoption developments. A primary technical distinction lies in the complexity of the task and the predictability of the environment. Manufacturing processes such as welding or painting are highly repetitive and occur in controlled settings, making them ideal for early automation (Upreti & Sridhar, 2024). In contrast, road transport unfolds in dynamic environments affected by weather, traffic, and human behaviour, introducing operational variability that complicates full autonomy (McKinsey & Company, 2024). Examples of this environmental complexity constituting a decisive barrier for autonomous deployment can also be found in other industries. For example, health care, while showing a high degree of automation in many regards, still awaits the realisation of fully autonomous surgical tasks due to the high risks involved and the constantly changing operational environment (e.g., human anatomy) (Banks, 2025).

Adoption is further complicated by increased safety and ethical considerations. Unlike industrial settings where automation failures often lead to material loss, autonomous errors in critical areas such as public road transport or healthcare can cause human harm and raise regulatory and liability questions that slow the implementation (Yazdanpanah et al., 2023; Constantinescu et al., 2021). This further connects to the social challenges associated with autonomy, applicable for most sectors, since its implementation raises concerns about the displacement of the existing workforce, which triggers resistance from workers and unions (Filippi et al., 2023). Together, these factors illustrate why freight autonomy faces unique and more general adoption barriers. Unlike environments where technological benefits clearly outweigh risks, freight transport requires a cautious, incremental approach grounded in evident cost-effectiveness.

3.1.3 Autonomous Trucks

The freight transport sector to a greater extent recognises the disruptive potential of autonomous driving, although full-scale adoption remains uncertain. Rapid advances in arti-

ficial intelligence have driven transformation across industries (Turienzo et al., 2023), and autonomous vehicles are identified as among the most impactful emerging technologies in logistics (Dong et al., 2021). However, implementation on public roads has lagged behind developments in confined industrial settings, where environmental control enables earlier deployment (Flämig, 2016; Engström et al., 2019).

Within road freight, hub-to-hub operations are emerging as a natural entry point for autonomous trucks. These routes offer a balance of long-distance economic gains and manageable environmental complexity, allowing early testing and potential cost reduction (TRATON, 2022b). In recent years, interest has intensified, with demonstration projects by Volvo, Waymo, and others, validating technical feasibility (Volvo AB, 2019; Hawkins, 2021). The first documented autonomous freight delivery was completed by the Otto company in 2016 (Fitzpatrick, 2016), marking a milestone in real-world deployment.

For private companies, the economic incentives are clear. Labour cost savings and the elimination of rest breaks make autonomous trucks financially attractive (Müller & Voigtländer, 2019). Safety is also expected to improve as the role of human drivers and, with it, human error is reduced. As Monios and Bergqvist (2019) argue, even level 3 autonomy on highways could yield meaningful safety benefits.

These shifts also have strategic implications for incumbent industry actors. OEMs are partnering with autonomous technology providers to maintain relevance and secure critical intellectual property. Technology providers are examples of new players entering the market, redefining the structure of the freight transport ecosystem, and challenging traditional value chains. Collaborations like Volvo & Aurora, Daimler & Torc, or Isuzu & Gatik illustrate how legacy firms are adapting to position themselves early in the emerging industry (Bishop, 2024).

In general, the subject of autonomy in transports has many promising characteristics for those who can take advantage of them, potentially being the biggest revolution that the industry has seen since containerisation (Cascetta & Henke, 2023).

3.1.4 Operational Design Domain

This section expands on the operational context introduced in Chapter 2 by detailing the specific domain in which autonomous freight transport is evaluated in the study. In the

context of vehicle autonomy, the operational design domain refers to the environmental, geographic, and operational conditions under which an autonomous system is expected to operate reliably (Mehlhorn et al., 2023).

Freight transport typically involves segmented operations, with different modes or vehicle types used for distinct legs of the journey (Mommens et al., 2020). In truck-based transport, this is reflected in the use of hub-to-hub operations, where trailers are moved between fixed points such as terminals or warehouses. These legs often involve highway driving and are separated from the more complex and variable first- and last-mile environments. The hub-to-hub model is common in the logistics industry and is central to the concept of contract logistics (Ogazón et al., 2025).

The hub-to-hub corridors represent a particularly suitable operational design domain for the early deployment of autonomous trucks (Engström et al., 2019). These routes typically offer consistent road conditions, limited interactions with pedestrians or cyclists, and well-understood traffic patterns. While dense urban areas or mixed-use roads may require level 5 autonomy to operate safely (SAE, 2021), highway-based hub-to-hub legs are more realistically achievable already at level 4. Lee et al. (2024) refers to this intermediary segment as the *autonomous leg*, positioned between tasks of the first and last mile, in their turn operated by human drivers.

In the context of this study, the DFDS hub network in southern Sweden offers a clear example of such an operational domain. The connected corridors of these hubs run primarily along national highways, enabling efficient and repeatable routes with lower environmental complexity. In addition to supporting autonomous deployment, the network aligns strategically with the multimodal operations of DFDS, linking ferry ports and distribution hubs to streamline internal transport flows (DFDS A/S, n.d.).

3.2 Foundational Trends

Transport is essential for continued economic growth, serving as the lubricant for the international trade and globalisation that the world economy relies on. This growing demand for goods transport is also mirrored in the Swedish setting, where commercial freight transports increased by over 35 percent between 2009 and 2022 (OECD, 2024).

As revealed, both commercial interests and more holistic macro-factors underpin the accel-

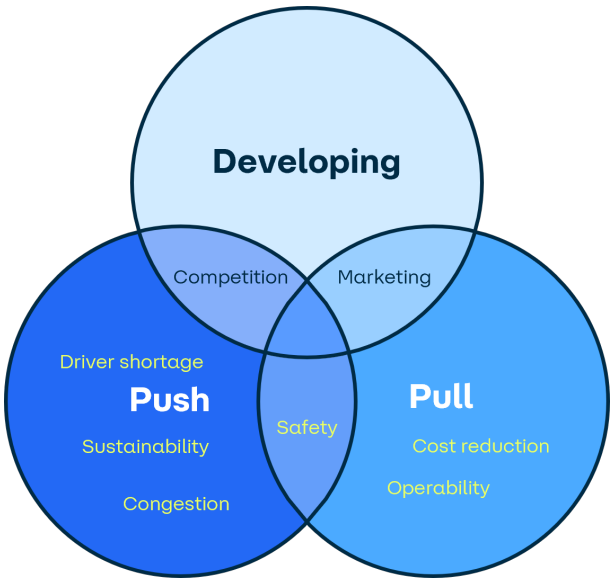

Figure 6: Venn-diagram of underlying forces for autonomy in freight transport.

eration of autonomous driving in the freight transport sector. Therefore, creating a framework by mapping these is a way to contextualise the underlying forces for autonomous implementation, *where* the main efforts for this will be carried out, and *who* will be the ones pioneering the transition. Hence, categorising these factors into *Push* and *Pull* serves to outline the nature of the main catalysts for the shift towards autonomous driving in the sector.

In addition to push and pull, a third category of *Developing* is identified, as not all factors accurately qualifies for either of the former alone, but instead are seen to emerge and be influential as the technology is adopted. These may in other words not be considered decisive for the shift to take place initially but instead arise along its implementation with the potential to be perceived as enablers for further implementation and development stages if or when the shift is made. To illustrate, these factors are perceived as insignificant until the initial implementation stages form but possess a snowball effect as the implementation and interest increases.

However, as some of the factors' belonging is perceived somewhat ambiguous, a nuanced illustration including also grey areas in between the categories of Push, Pull, and Developing is considered useful, supporting the use of a Venn diagram seen in Figure 6, with named categories and associated grey areas.

To motivate the various forces' positioning within the diagram, some of those considered main ones behind the autonomous shift from each category are contextualised deeper in the following section.

3.2.1 Push Factors

Macro-related factors constitute highly relevant underlying forces for the autonomous transition. While the study views the autonomous transition from an inside-industry perspective with the case company at hand, the reasoning behind the categorisation of push factors is their more systematic nature, lying out of the company's control and thereby rather catalysing the autonomous transition from the outside.

Driver shortages

One surrounding element pushing the shift towards autonomous is the resource scarcity derived from driver shortages being present in the freight transport industry. The conflicting issue of an extensive increase in international trade and demand for road freight transport and the decreasing attractiveness of the driver profession have created this alarming situation. One could think that an industry facing increased demand would lead to a rather enhanced attractiveness and prosperity of the sector, but many factors have contributed to the opposite development for truck drivers (Schuster et al., 2023).

With labour forming the largest cost item in transport total costs (Persyn et al., 2022; ATRI, 2023) and transport being a sector with small margins, development in driver salaries has been lagging while workload has accelerated. This scenario partly originate from the deregulation of the trucking industry (Monaco & Brooks, 2001), having the industry unilaterally competing on price due to the increased use of labour from low-wage countries. This has initiated a vicious circle as low pay in combination with increased and often heavy workload in poor and unsafe conditions for the drivers hinders the attraction of new labour. In addition, an ageing workforce (Newnam et al., 2020) and high employee turnover rates (Ji-Hyland & Allen, 2022) devalue the status of the profession. This ultimately reconnects with deteriorated safety, as professional skill decreases and skilled drivers are harder to recruit, potentially compromising safe road operations.

The deployment of autonomous technology has the potential to counteract the scarcity of drivers, as higher SAE levels of autonomous driving show the potential to support or even replace the role of manual drivers. Although an incremental deployment of technology requires a driver in the short to midterm, the assistance of autonomous driving systems could relieve manual operating tasks on routes that are more easily managed (Mohan &

Vaishnav, 2022). Alleviating driver shortages in these segments, leaving manual tasks to more cumbersome areas, would also require training of staff to operate the new technology, potentially revitalising the status of the profession (Schuster et al., 2023).

Sustainability

The transport industry accounts for about 25% of greenhouse gas emissions in Europe, thus significantly affecting the environment (EEA, 2025a). Climate change, due to its global presence and concerns, therefore serves as a good example of a push-related factor behind the transition towards more autonomous transports.

The European Green Deal and Fit for 55 package with the goal of reducing the net greenhouse gas emissions of the continent by 55% until 2030 and being the first climate-neutral continent by 2050 (European Comission, 2023), indicates the external pressure on the transport industry. Regulatory and political forces are considered principal for companies' environmental considerations. However, also internal gains could come along with more climate-friendly practices, justifying the inclusion of the category of (green) marketing described below in Figure 6, through its potential to enhance a companies' value proposition.

In response to climate-related goals, the emerging rollout of electric vehicles in the transport industry has already shown substantial reductions in carbon dioxide emissions from heavy-duty trucks (Irles, 2023). Although non-electric fuels can also be used for autonomous driving, electric vehicles are widely seen as the future of autonomous driving where both technologies mutually benefit each other (Monios & Bergqvist, 2019). In addition to the decrease in the use of fossil fuels, the environmental efforts of autonomous driving also include its potential to enable more fuel-efficient operations as vehicles achieve improved energy use (EEA, 2025a).

Congestion

With the number of new registrations steadily increasing in the EU for both passenger cars and commercial vehicles, complemented by indications of a longer service life of vehicles (EEA, 2025b; ACEA, 2024), congestion issues are a growing concern for the transport industry to address. As many underlying factors for the increase in the deployment of autonomy naturally converge due to their interdependencies, the topic of congestion reconnects

with both environmental issues and operational safety, as more dense traffic heavily affects air pollution and increases the inherent risk of accidents (Xu et al., 2024; Phan & Truong, 2024).

Congestion is also a major cause of late deliveries, adding significant costs for transport companies (Short, 2024). To counteract this issue, deviating the operating hours for commercial transport from peak hours could be a solution to spread the demand for road space and better utilise existing infrastructure (Saleh et al., 2022). As such, a solution could entail that autonomous transports are planned to avoid areas of peak congestion, such as highway ramps during commuting hours, to allow better traffic flows and more reliable routing.

Furthermore, autonomy brings promising potential for this type of operation, as off-peak driving is believed to have the potential to be combined with driving at slower speeds for fuel saving and hence cost reduction purposes (Fagnant & Kockelman, 2015). These two components are mutually effective due to the improved ability to drive slowly when the potential impact on other road users is more scarce. Compared to manual driving, autonomous driving during off-peak operations could potentially also benefit the discussion on dedicated autonomous operational design domains (Hassan et al., 2024).

The increasing issue of road congestion is for these reasons argued as a potential push factor for an autonomous deployment, argued to improve flexibility in operations and being mutually beneficial from an economic, environmental and safety perspective.

3.2.2 Pull Factors

The use of autonomous technology in freight transports has many attractive attributes from a corporate point of view and is considered primarily driven by cost reduction capabilities for transport companies (Engholm et al., 2020). This further motivates the study's cost-related focus in companies' future approach to autonomous driving, and it to be argued a main prerequisite for this transition to take place.

Cost Reduction & Operability

From a financial perspective, a reduction in driver wages and fuel costs proposes improvements to the cost structure of transport providers (Fritschy & Spinler, 2019).

Often, transport companies employ more drivers than they operate trucks to operate cer-

tain routes. This stems in part from requirements such as resting times and time-off, but also compensates for fluctuating customer demands (Informant 1 & 2). Relevant for the assigned MODI use case route, case study insights also point to vehicle utilisation from the perspective where autonomous driving benefits overall transport costs. The nature of contract logistic contracts can result in situations where the provided capacities exceed the actual need of the respective transport task on a given day. This often results in excessive idling times where machinery is not utilised as planned and thus creating uncovered costs.

Therefore, cost relief can be achieved from improved efficiency and accuracy in autonomously operated transports, connecting to the subject of operability, as improved transport planning and further vehicle utilisation are potentially enabled through fewer driver interactions and driver-engaged restrictions, such as rest stops (Monios & Bergqvist, 2019). In a fully autonomous future, these driver breaks could be completely omitted, allowing for stark improvements in vehicle utilisation (Mauler et al., 2022).

3.2.3 Developing & Grey Areas

Additional factors that do not strictly qualify as push or pull factors must be reviewed in order to also account for developing and grey areas, as presented in Figure 6.

Safety

External pressure in the form of regulations and political opinion drives the transport industry to become a safer sector (EEA, 2025a). As such, the European Commission aims to eliminate road deaths by 2050 (European Commission, 2019). In 2023, the fatality rate for crashes that included heavy goods vehicles on motorways in Europe was 23% (European Comission, 2023), highlighting the risk associated with trucks driving at high speeds. The safety risks are expected to increase due to the circumvention of traffic regulations by truck drivers, resulting in speeding and non-obedience of rest times as a consequence of increased international competition and market deregulation (Kuran et al., 2023). This puts both truck drivers and fellow road users in danger, considering that only 12% of the fatalities from heavy goods vehicle crashes concern the respective drivers themselves, and the rest constitute fellow, often more vulnerable road users (European Comission, 2023).

More autonomous technology in trucks, envisioned to ultimately remove the driver from the

equation, would not only prevent truck driver fatalities but is expected to generally enhance road safety extensively for all road users, with vehicle control no longer dependent on the human factor (Shetty et al., 2021; Informant 3). As reference, studies show that only by using today industrially adopted technologies such as automated emergency braking can reduce, for example, rear end crashes by close to 40% (Fildes et al., 2015), showcasing the safety potential of implementing autonomous features in driving.

Although several arguments point to the subject of safety as an external push factor mainly driven by outer pressures, the authors identify the issue to include some ambiguity in the way that it can also be considered a pull factor for an autonomous transition. This, due to an urge from internal industry actors to improve safety in their operations in order to provide their employees with secure working environments, hence experiencing less amount of hazardous events. This reasoning argues for the combination of forces behind improved safety in freight transport operations through autonomy, thus categorising the subject in a grey area between push and pull.

Competition

In line with the study's aim of outlining business model strategies in approaching autonomous implementation, the subject of competition, which highly connects to market entry strategies, therefore plays a vital role in an incumbent transport companies' positioning. The authors consider the factor mainly originating from external market pressure in regard to other transport companies that partner with technology specialists to prepare for the autonomous future (Bishop, 2024). However, despite this push-related view on competition, the subject also aligns with the developing category since it is rather a consequence of other incentives for autonomous driving being present, attractive enough for competitors to adopt these and constitute a threat. Thus, a pattern emerges that presents a steadily growing need to keep up with technology-ready competitors, who are gaining ground in the field. Competition has the ability to become an important factor for the autonomous transition in defining the future value proposition of companies and the continued prosperity in their segment.

A comparison of this projected effect of competition on the autonomous transition can be made with the exponential interest in autonomous transport within the research field, shown in Figure 2, which illustrates the potential of a snowball effect.

Marketing

The inherent potential of autonomous transports to improve areas such as customer value, environmental impact, and safety applies also to the subject of marketing. Although the internal urge to market the company in a favourable way from these perspectives is strong, the marketing of autonomous driving is not considered solely a company-driven pull factor (Informant 1). Instead, it should be viewed rather as a beneficial sequential effect from enjoying other more primary advantages of the technology. Adopting new technology has the ability to be perceived as innovative, sustainable, or a market leader from a customer perspective (Robertsone & Lapiņa, 2023), naturally connecting the subject of marketing with the one of competition.

The continued reasoning behind marketing as both a pull and a developing factor originates from its potentially growing evidence along with industry implementation. The effects of autonomous technology can be difficult to fully identify in the early stages (Gruel & Stanford, 2016), but instead materialise along the market deployment, as increasing evident test data on operative functionality has effects on credibility in the marketing of the concept. With market maturity improving accuracy on tangible effects gained from the technology, a snowball effect is also identified from a marketing perspective, and risks in terms of various types of *washing* (e.g., green-washing, tech-washing) are also likely to diminish.

3.2.4 Barriers

With the technology for autonomous trucks rapidly progressing, it is considered almost a given by the time that the surrounding barriers for its deployment are overcome. In that sense, technological maturity with regard to the systems deployed inside the truck does not necessarily constitute a persistent barrier. Although, just as the foundational trends argue for many underlying factors behind autonomy, multiple barriers also exist that may slow down or problematise its future commercial implementation. As in the case of enablers, it is left for future research to investigate these in detail. Their recognition within the study provides a deeper contextualisation of the vast complexity that is presented by the focussed industry environment.

Underpinning the diversity in potential barriers to autonomous implementation, Engström et al. (2019) mentions regulations, business models, organisational issues, and public attitude

to be a few. As autonomous technology advances at an increasingly rapid pace, a major restricting factor is identified through the necessary related regulations, currently unable to keep up with this development (Sever & Contissa, 2024). Current legislation still lags behind on addressing how higher-automated systems must recognise and interpret traffic signs, interact safely with other road users, and leverage real-time environmental data. However, the trend in autonomous driving shows progression in the regulatory area, exemplified by the General Safety Regulations introduced by the EU, which render several technological features mandatory in vehicles for increased safety purposes (European Commission, 2019).

Several of the barriers to the implementation of autonomous driving are interconnected. Further barriers exist of more interpersonal character, such as public acceptance and the general trust of people in autonomy (Chen et al., 2022). Although statistics argue that 90% of fatalities and injuries in traffic are related to human errors (European Commission, 2019), the perception of safety through human interaction (e.g., eye contact at cross-walks to signify crossing) provides an intuitiveness that is unavailable in driverless vehicles (Sever & Contissa, 2024).

Despite the vast leaps in technology for autonomous driving, some issues with regard to technological maturity are still applicable in the discussion of barriers to its deployment, as technology inside trucks is not the only kind needed in the complex system of freight transport. The industry involves many actors with associated systems and technological infrastructure that require future harmonisation and operational standardisation for autonomous trucks to integrate smoothly (Engholm et al., 2021). This holistic system approach with requirements from surrounding physical infrastructure (e.g., gate, terminal, warehouse enter and leave processes) and digital infrastructure (e.g., booking, traffic planning systems) need to be accounted for in the deployment of autonomous trucks.

With the study accessing the case company, focussing corporate costs and potential for autonomous business models, a main barrier is also identified in the need of a viable business case to be present when implementing the technology. By this, the previously described pull factor behind the autonomous transition can also be viewed as a potential barrier if not achieved.

3.3 Market Strategy

The future of radical innovations such as autonomous driving is uncertain, and related investments always carry inherent risks (Markides, 2005). This applies both to the doubling of processing power (Moore, 1965) and its respective importance in an ecosystem (Christensen et al., 1998), as dominant designs emerge and contingent path dependencies form (Mahoney & Schensul, 2006). In recent history, technological change has evolved at an increasing pace (Moravec, 1990), indicating that investments in the technological edge today might lose value significantly in the short term, as rapid development cycles outperform previous generations exponentially (Moore, 1965). Therefore, it is important to consider adequate market timing strategies when entering the market for autonomous transport.

Christensen et al. (1998) highlight that well established companies often struggle with disruptive innovations, as their culture prioritises existing customer needs and high-margin products. Novel technologies usually provide low initial margins and subsequently underperform in traditional strategy reviews. After a technology has matured, incumbent companies struggle to compete effectively with early adopting competitors. Furthermore, Christensen et al. (1998) recommend that large companies explore disruptive technologies in separate subdivisions that are not governed by existing boundaries. Companies that adapt their business models to novel technology early in its emergence can gain a competitive first-mover advantage. However, in dynamic industries, timing is essential. Christensen et al. (1998) find that a company's entry strategy into emerging markets correlates with its chance of survival: if a company enters the market before industry standards are established, it risks becoming outdated once rapid scaling and cost efficiencies take place post-standardisation.

The authors find that companies have a window of opportunity during which learning is related to lower risk just before dominant designs emerge. If leveraged successfully, firms can maintain leadership for the upcoming generations of technology. Adner and Kapoor (2010) further emphasise that early market entry is time sensitive and demonstrate that uncertainty can be reduced through vertical integration within the supply chain. By partnering with other stakeholders in an innovation ecosystem, companies can mitigate dependence risks and enhance their competitive advantage.

Cooper and Schendel (1976) outline strategic approaches on how to respond to technolog-

ical disruptions (Figure 7). *Proactively* investing in innovation is associated with high risks but can help incumbent companies compete with disruptors later on, while a *passive* approach allows companies to monitor industry developments before investing in resources. Another option is to *cooperate* with other stakeholders to share risk and strengthen the competitive position from early on (Adner & Kapoor, 2010). Finally, a company might decide to employ a *defensive* approach by withdrawing from the market at risk to focus on other core competencies to survive.

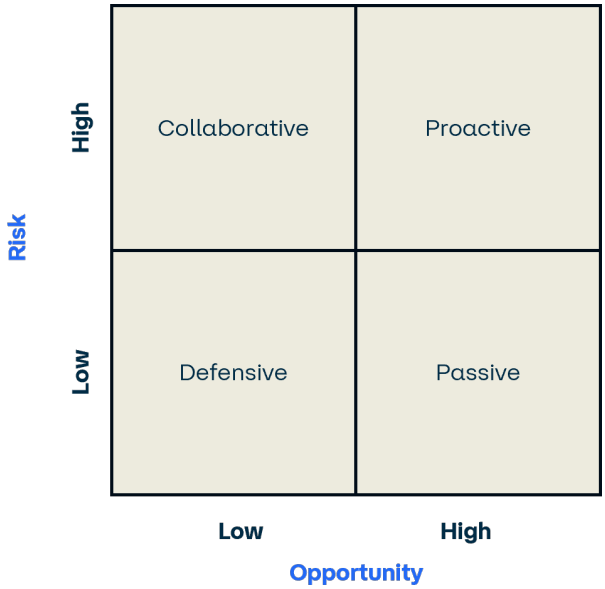

Figure 7: Strategic approaches to time and capture market dynamics at entry

3.3.1 Proactive

Being first to market can offer strategic advantages, but also exposes firms to considerable risks. Lieberman and Montgomery (1988) argue that technological leadership enables companies to secure proprietary technology, shape emerging industry standards, integrate supplier and distribution relationships early, and benefit from pre-regulatory goodwill or more favourable permit processes. In the context of autonomous freight, early adopters can secure critical freight corridors, access public infrastructure funding, and lock in key customer contracts before the market becomes saturated. Once customers have adapted to a system, switching becomes less attractive, as integration and operational lock-ins create high switching costs, which presents a dynamic particularly relevant for software platforms and integrated fleet management systems.

However, proactive entry is not without challenges. Latecomers can "free-ride" by learning costly mistakes from early movers and adopt improved strategies. Moreover, as dominant

designs and standards emerge over time, early investments can quickly become obsolete. Larger organisations, in particular, may struggle to pivot in response to these changes, risking establishing outdated strategies (Cooper & Schendel, 1976).

Gans and Stern (2003) highlight that firms entering early must carefully choose between competitive or cooperative commercialisation strategies. This choice often shapes the way the market evolves. Where intellectual property protection is strong, incumbents are better off cooperating with start-ups; where protection is weak, competition tends to dominate, as start-ups exploit incumbents' structural weaknesses. Critically, the degree of organisational, rather than purely technical, disruption determines the optimal strategy.

Finally, Markides (2005) emphasise that pioneers often have disproportionately high costs and face a greater risk of failure due to uncertainty around market acceptance, regulatory developments, and technology evolution.

3.3.2 Passive

A passive strategy implies that a company deliberately waits for the market environment to stabilise before committing significant resources. Firms adopting this approach aim to limit exposure to high uncertainty by awaiting clearer regulatory frameworks, technological maturity, and more predictable customer demand. By observing early movers, passive participants can capitalise on learning effects, reduce development costs, and avoid investing in potentially obsolete technologies (Cooper & Schendel, 1976).

However, as Christensen (2016) warns, disruptive technologies rarely seem attractive at the point when early investment would be most beneficial. Entering too early may lead to a mismatch between technological readiness and market demand, where customers are not yet prepared to embrace innovation. Companies must therefore balance cautious observation with the need to allocate sufficient resources toward innovation efforts, even when short-term profitability appears limited. Recognising and navigating internal organisational boundaries becomes critical in this context. The authors recommend that firms avoid applying a blanket strategy (always leading, always following) and instead adjust based on specific technological and market signals.

Markides (2005) further argue for a *Fast Second* strategy: companies can monitor the early experimentation phase, allowing weaker technologies to fail and dominant designs

to emerge. Once standards are established, firms with strong brands, capital resources, and distribution networks can enter the market quickly and scale effectively. The authors emphasise that success in this phase depends less on technical innovation and more on business model adaptation and operational excellence.

3.3.3 Collaborative

A collaborative strategy allows firms to participate early in market development while simultaneously mitigating risk through partnerships and alliances. By sharing the burden of technological uncertainty and resource investment, companies can improve their resilience and competitiveness during unstable early market conditions (Cooper & Schendel, 1976). Engström et al. (2019) argue that strategic partnerships between key stakeholders, including carriers, customers, OEMs, technology start-ups, and insurance companies, will be crucial to the effective deployment of autonomous freight systems. These alliances facilitate knowledge sharing, accelerate technological development, and enable ecosystem-wide readiness.

Collaboration can take various forms, including joint ventures, co-development agreements, and supply chain integration. Particularly in markets such as autonomous driving, where success depends on coordinated progress across infrastructure, regulation, and technology platforms, cooperative strategies offer firms an important advantage over isolated, independent efforts.

3.3.4 Defensive

In the face of disruptive technological change, some companies may find it strategically advantageous to withdraw from core markets that are at risk of obsolescence and instead focus on niche or adjacent opportunities. When faced with the prospect of autonomous hub-to-hub transport that makes traditional long-range trucking operations obsolete, a defensive strategy could involve repositioning toward edge services, such as providing first- and last-mile solutions, where human-driven operations may continue to retain relevance (Cooper & Schendel, 1976).

Tripsas (1997) highlights how technological change can lead to *competence destruction*, wherein a company's existing capabilities lose competitiveness in the face of new mar-

ket dynamics. Processes and assets that were once critical may become liabilities if they are poorly suited to emerging technologies. However, rather than being entirely displaced, some competencies may be reconfigured as complementary assets within the new ecosystem, allowing firms to maintain a degree of relevance and value. A defensive strategy is therefore not necessarily a passive retreat, but rather an active repositioning: firms seek to leverage their existing strengths in areas less directly exposed to disruption, ensuring survival and continued profitability even as the industry structure evolves.

4 Analytical Framework

This chapter presents the cost analysis and its main takeaways, summarised and visualised using the structure of the SAE autonomy levels. Hereby relevant prerequisites and assumptions are defined, followed by by an in-depth discussion of the cost items included in the analysis.

4.1 Total Cost Equation

The costs related to manual truck transport are well documented (e.g., ATRI, 2023; ASEK, 2024). In Appendix A, the study defines a total cost equation comprising associated fixed and variable costs directly impacted by the introduction of autonomous road transport. Cost drivers such as inflation, interest rates, and general wage trends are excluded as they are not directly affected by automation and therefore fall outside the purpose of the study. The cost analysis is grounded in real-world data from the MODI use case route, incorporating operational characteristics and volumes specific to current operations.

Although additional cost items do exist (e.g., taxes, tolls, licences, interest, and depreciation), these are excluded for two primary reasons. First, their relative cost share is negligible and unlikely to influence the viability of the business model. Furthermore, some cost items are highly specific to the way companies finance their operations and the geographical area they operate in, and, finally, they are not considered to shift significantly as a result of autonomy per se. For instance, taxes and tolls relate more to vehicle drivetrain (e.g., diesel vs. electric) than autonomy, and interest- and depreciation costs are mitigated in this case by the leasing-based financing approach currently used by the case company. The study thus prioritises a focused, autonomy-relevant cost model while acknowledging the presence of smaller peripheral items that do not materially impact the results.

4.2 Cost Analysis

A first step in mapping the stepwise approach to autonomous driving is to establish a baseline: the current commercial state of operations. This helps situate the industry within the SAE autonomy scale and serves as a reference for cost comparisons across automation levels.

Although current European legislation does not explicitly reference SAE levels, regulatory requirements currently limit autonomous truck operations to a maximum of level 3, where a driver must remain ready to take control (European Union, 2024). However, a distinction must be made between regulatory permissions and commercial adoption. Although level 4 testing is permitted on certain public roads (TRATON, 2022a), the industry standard in commercial deployment is closer to level 2, where advanced driver-assistance systems such as lane-keeping and automated braking are common (Slowik & Sharpe, 2018; Informant 1, 4 & 5). In the Swedish hub-to-hub freight context, the Volvo FH and Scania R Series dominate the market, together holding a 85% market share in 2024 (Mobility Sweden, 2025; Informant 4). Both models support advanced driver assistance systems features consistent with level 2 autonomy (Informant 4). It is also important to recognise that not all trucks on public roads meet this baseline. Many older vehicles with level 0 autonomy remain in operation (Informant 4 & 5), reinforcing the need for a comprehensive cost analysis across all SAE levels, not only the commercially dominant ones.

4.2.1 Driver

As the term *autonomy* directly implies, the question of human intervention in transports is central to any cost analysis. As discussed, the contribution of driver costs is highly significant and estimated to represent up to 40% of total transport costs (Pendergast, 2024; Persyn et al., 2022). This cost comes primarily from wages. In the case setting, truck drivers receive a salary based on collective union agreements (Informant 4). According to SCB (2024), the average monthly wage of a truck driver in Sweden is 2.925 €. To reflect the full cost borne by the employer, an employer contribution of 31,42% (Skatteverket, n.d.) is added along with an additional 10% to account for costs related to equipment, training, bonuses, overtime, and similar overheads (Informant 1).

The cost model assumes the averaged employment of 2,3 drivers per truck, therefore also accounting for rest regulations and varying customer requirements that may include continuous operations (e.g., three-shift operations). Historical wage data show an average annual salary increase of 2,06% from 2014 to 2022 (SCB, 2024), but consistent with the study's focus on costs influenced specifically by autonomy, general wage and inflationary trends are excluded. Based on salary data, annual range, and staff levels provided by Informant 4, the current driver cost per kilometre is derived.

With increasing vehicle autonomy at levels that still require the presence of the driver, the need for extended driver training is anticipated, both for performance and safety purposes (Murtaza et al., 2023). Although basic training is included in the 10% cost buffer, the increase in complexity of systems justifies its inclusion as a distinct subcategory. Currently, driver education remains relatively inexpensive, with standard training programmes (for example, one week every five years) not exceeding 1.000 € (Dekra, n.d.), suggesting minimal short-term impact on the total cost structure.

As automation further progresses, the short- to mid-term impact on driver-related costs is expected to be limited. Both case insights and the literature suggest that some form of driver role will remain necessary, even with advanced self-driving capabilities. This discussion is particularly relevant for level 4, the current focus of most highway automation pilots (SAE, 2022; MODI, n.d.). Although technology may support fully autonomous highway driving, the specific hub-to-hub context of this study imposes the assumption that manual or supervisory input is still required during the first and last mile segments (Mohan & Vaishnav, 2022; EEA, 2025a; Lee et al., 2024).

The relatively short MODI use case route (70 km), opposed to long-haul transport, further constrains the potential to reduce driver numbers. The high frequency of first- and last-mile operations reduces the relative share of highway driving, limiting opportunities for automation to replace human labour. In longer-haul scenarios, more optimistic assumptions in employee reductions per truck could be applied based on extended stretches of autonomous operation.

The most significant reduction in driver cost is anticipated at level 5, where vehicles are assumed to operate autonomously under all conditions (SAE, 2021; Skeete, 2018). While level 4 systems still require human intervention for certain segments, level 5 is expected to eliminate the need for an on-board driver under all circumstances. However, supervisory roles can persist in the form of remote supervision to monitor operations and intervene remotely when necessary, as well as roadside assistance crews to support stranded vehicles. Therefore, labour costs will not be fully eliminated in level 5 (Sever & Contissa, 2024).

Due to the lack of mature deployments and the high uncertainty around salary levels and operational protocols, the cost modelling for level 5 includes both pessimistic and optimistic scenarios.

Currently, DFDS employs up to 3 drivers per truck on specific routes, such as highly fre-

quented short-range contract logistics operations. On average, the fleet employs 2,3 drivers per vehicle (Informant 4). The study thus suggests a 2,3:1 ratio as a baseline for standard operations. Given the short route length, hence high frequency in shifts between highway and first- or last-mile driving, a pessimistic estimate also assumes the 2,3:1 employee:to-vehicle ratio, implying no reduction in driver costs compared to current operations. This set-up allows 24/7 operations if downtime (e.g. charging, etc.) is unstaffed. A moderate scenario models a 1:1 ratio, while the most optimistic case assumes a 1:2 ratio, reflecting higher efficiency in remote supervision of multiple vehicles and minimal need for backup staff.

The driver-to-vehicle ratio can be misleading if not contextualised within a 24/7 operational framework. In continuous operations, a truck does not require supervision at all times due to approximately 30% daily downtime for activities such as charging and loading. This leaves around 16 hours per day during which the vehicle requires monitoring. If a single remote operator in the optimistic scenario is responsible for overseeing six trucks per shift, then over the course of a full day, three operators would collectively manage those same six trucks due to working hours restrictions (8h working days) of the remote operator. This results in an effective ratio of 1:2 (three operators per six vehicles per day). The ratio thus reflects a daily staffing need, not a snapshot operational dynamic.

An overview of the resulting cost per kilometre in autonomy levels and personnel scenarios is provided in Table 2.

Table 2: Driver cost per kilometre under different autonomy scenarios

Level of Autonomy	**Scenario**	**Cost per km**
MD (Baseline)	2,3 drivers per vehicle	1,46 €/km
Level 1–3	2,3 drivers per vehicle	1,46 €/km
Level 4	Pessimistic (2,3:1)	1,46 €/km
	Optimistic (1:1)	0,63 €/km
Level 5	Pessimistic (2,3:1)	1,46 €/km
	Moderate (1:1)	0,63 €/km
	Optimistic (1:2)	0,16 €/km

4.2.2 Base Vehicle

In general, transport providers acquire vehicles through direct purchase or lease agreements with third-party financing entities. In the United States, vehicle hardware costs ac-

count for approximately 15% of total freight transport expenditures (ATRI, 2023), underscoring their critical role in determining the overall cost structure. Many transport providers pursue an asset-light strategy, opting to lease vehicles to maintain liquidity and reduce upfront capital burdens. This is also the case within DFDS, particularly for its battery electric fleet, which is currently entirely leased. While there are discussions to move towards a more asset-heavy approach that allows more flexibility in ownership in order to quicker adapt to changing customer flows (Informant 4 & 5), the study does, for the sake of generalisability and model consistency, assumes a fully leased fleet.

In the context of the sustainability goals of DFDS, the deployment of autonomous vehicles is inherently linked to the use of fully electric drivetrains and aligns with the current stepwise phase-out of traditional diesel engines. The base cost of a modern battery electric truck, such as the Volvo FM electric, is approximately 300.000 €, which translates into a monthly leasing fee of around 4.500 € (Informant 4 & 5). This fee already represents a fleet discount of up to 20% and includes regular maintenance services (Informant 4 & 5).

However, the market for battery electric trucks remains in a developmental phase with relatively high production costs and increasing price competition (Chinatruck, 2024; Bhattacharjee & Rittstieg, 2025). It is expected that, as the manufacturing scales and the market competition intensifies, the price of autonomous vehicle technology will gradually converge towards that of current diesel-based systems (IEA, 2024). The study uses the term *equilibrium pricing* to introduce a futuristic scenario, where price parity is achieved between legacy and novel technologies due to efficiency gains, increased supply, and standardisation. Similar logic underpins current assumptions regarding the future price of alternative fuels, where electric propulsion systems are projected to reach cost parity with diesel.

From a theoretical perspective, this development is consistent with Christensen et al. (1998) framework for disruptive innovations. In the early stages of their adoption, disruptive technologies tend to be more expensive, less efficient, and underperforming when compared to incumbent solutions. However, over time, as technology matures, performance improves while costs decline, allowing radical shifts in market structure and displacing existing solutions (Christensen, 2016). Further, Wright's law proposes that each cumulative doubling of production results in a fixed percentage reduction in unit cost. As the scale of production increases, the labour and overhead costs decrease exponentially and the total cost approaches the marginal cost of the materials (Wright, 1936). This dynamic provides a compelling argument for the long-term affordability of emerging transport technologies, in-

cluding autonomous vehicle systems.

Within the DFDS fleet, diesel trucks currently have a base purchase price of approximately 150.000 €, corresponding to a monthly lease rate of around 2.250 € (Informant 4). This alternative equilibrium cost perspective will be further utilised in Chapter 5 to explore long-term business model implications. Beyond the base vehicle, leasing firms or operators may incorporate optional configuration packages, either to tailor the vehicle for specific operational environments or to enhance its residual value for the secondary market post-lease. However, such configurations are expected to be similar across both manual driven and autonomous systems and thus are not examined in further detail in this study. Furthermore, within DFDS, for every 10th truck, a redundant truck is operated to cover scheduled maintenance and unscheduled breakdowns (Informant 4). However, these vehicles are usually older trucks that have been fully paid for and are rarely employed. Furthermore, the study assumes a similar quota for autonomous fleets and therefore does not include the indirect cost in the overall cost model.

In DFDS, vehicles are held for approximately 5 years in the fleet, where they travel from around 80.000 kilometres, if employed in a short-range contract logistics assignment, or up to 200.000 kilometres in long-haul transport. This amounts to a lifetime distance of 400.000 to 1.000.000 kilometres over a 5 year period. Vehicles used in the focal use case average towards the lower bound (Informant 4), therefore, this number is used as baseline. However, the study keeps the second estimate to evaluate feasibility in a dedicated long-haul domain for Scope 2.

The study argues that the cost of the base vehicle itself is unlikely to change substantially with increasing levels of automation. Although some cost reductions can be achieved, for example, through the elimination of the driver cabin and human-centred interfaces, these savings are likely to be offset by the need for redundancy in critical systems, such as the braking, steering and communication components. Such systems require additional hardware and software integration to meet safety and reliability standards (Boubakri & Gamar, 2021).

4.2.3 Tech Stack

Autonomous driving is enabled through a combination of sensors, advanced algorithms, and high-performance computational components (Thrun, 2010). Accounts of how they are

Table 3: Truck cost per kilometre for battery-electric HGVs under current and projected price equilibrium conditions

Use Case	Annual Distance	Current Cost	Equilibrium Cost
Contract Logistics (short range)	80 000 km	0,68 €/km	0,34 €/km
Long-haul (high utilisation)	200 000 km	0,27 €/km	0,14 €/km

integrated into the base truck and the respective price point vary. For the sake of simplicity, autonomous software is assumed to be included in the price charged for the hardware components / tech stack. In Figure 8 the study presents four strategic approaches to pricing the characteristics of the features of autonomous vehicles, derived from the automotive and transport literature, as well as insights from the case company. The framework contrasts modular vs. integrated configurations and cost-based vs. value-based pricing models.

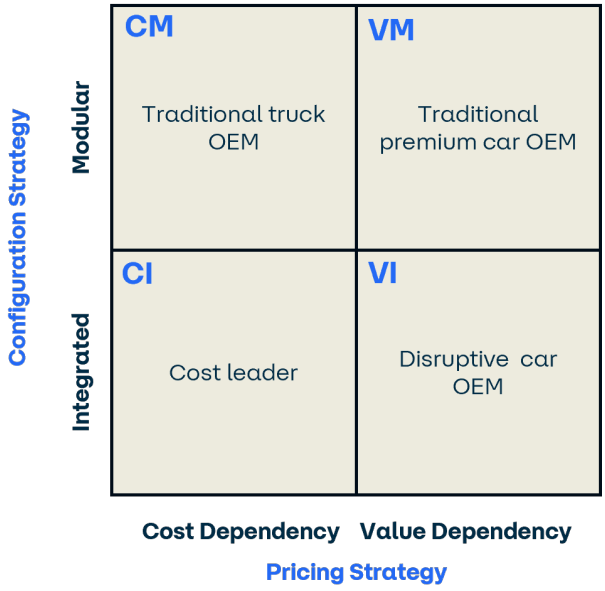

Figure 8: Tech stack pricing and integration strategy for truck OEMs

Cost Modular (CM)

Fleet operators have traditionally customised their vehicles to meet specific operational demands, with the total cost of ownership being a critical factor in maintaining profitability (Informant 4). This focus on cost efficiency has led OEMs to offer platform vehicles that can be configured flexibly with both OEM and third-party modules.

According to Riggs and Richardson (2024), the midpoint cost for level 4 autonomous hardware components is estimated to be in the range of 80.000 € with low-end configurations around 15.000 €. When applying a typical component profit margin of 15–20%, this results

in a total estimated price range of 20.000 - 100.000 €. McKinsey & Company (2025b) estimates component costs closer to the range of 5.000 € for passenger vehicles. Major auto OEMs such as Tesla, Mercedes, and BMW currently offer systems corresponding to level 2 or 3, including both software and hardware, for less than 10.000 €. Some cost-disruptive Chinese OEMs offer these systems at even a lower price point (Xiaomi, 2024). These developments suggest that a future cost-based modular pricing model for level 4 or 5 systems in trucks could settle at around 20.000 €, as purpose-built components and economies of scale are used. This is in line with the spread identified by Wadud (2017).

Value Modular (VM)

Premium automotive OEMs often employ value-based modular pricing strategies. Features are priced to reflect not only functionality, but also perceived prestige and brand differentiation, therefore, decoupling the price from actual costs. Furthermore, features are frequently bundled in packages, making cost transparency difficult. The final prices often reflect the market-specific willingness to pay (McKinsey & Company, 2025b).

This model enables high profit margins, as it appeals to the perceived value of customers rather than strictly their operational needs. Some scholars argue that autonomous trucks will yield significant operational cost savings over time (Price et al., 2020; Gölbaşı & Dagdelen, 2017). As a result, OEMs and suppliers might attempt to capture a portion of those savings by pricing features according to their value proposition, thus decoupling prices from the actual production cost. For example, Mercedes currently offers level 3 functionality in the EQS for approximately 9.000 € that requires an additional 4.000 € in supporting features (e.g., parking assist, infotainment, and lighting) to be configured (Mercedes-Benz, n.d.). BMW's i7 includes more of these features as standard, with a comparable technology upgrade priced at 3.500 € (BMW AG, 2025). Elvik (2020) reports that the average willingness of the customer to pay ranges up to 6.000 €, while McKinsey & Company (2025b) notes that two out of three potential buyers are willing to spend in the range of 10.000 € for these features.

Value Integrated (VI)

Some OEMs have adopted a strategy that combines integration-driven economies of scale with value-based pricing mechanisms. Tesla, for instance, installs the full hardware stack in every vehicle, regardless of whether the customer wishes to purchase autonomous features. These can be enabled anytime via over-the-air updates, for either a one-time fee or a recurring subscription. This model supports market flexibility and aligns with the findings of Elvik (2020), who note that 30% of consumers are not willing to pay upfront for autonomous features.

As of 2025, Tesla offers level 2 autonomy in the Model Y for 9.000 € or 100 €/month through subscription (Tesla, 2025). This dual-pricing approach accommodates both cautious buyers and those ready to commit. However, it should be noted that Tesla's hardware stack lacks LiDAR or radar components, which significantly reduces production costs compared to other OEMs, but is also inferior in its capabilities and therefore less suitable for commercial autonomous applications.

Cost Integrated (CI)

Chinese truck OEMs such as Sany, in partnership with software companies such as Pony.ai, are pioneering the mass production of purpose-built level 4 trucks (Steinberg, 2022). Although detailed pricing remains undisclosed, parallels may be drawn with Chinese passenger car OEMs, which have disrupted premium markets by offering feature-rich vehicles at highly competitive prices. The success of these firms is backed up by vertically integrated supply chains and lean development processes, which allow for high efficiency and cost control (Gundermann et al., 2024). For example, Xiaomi offers passenger cars with level 3 components at a base price of 35.000 € on the Chinese market (Xiaomi, 2024), illustrating that advanced autonomous functionality can be made affordable through integration and scale.

Estimating integrated costs is complicated. Furthermore, in a competitive environment where a vehicles' value proposition is directly related to its autonomous driving features, the authors foresee additional saving potential as profit margins are minimised and the standardisation helps to achieve further economies of scale. In this context, the study suggests that further price reductions of 30% in contrast to the *Cost Modular (CM)* approach

can be unlocked.

Outlook

OEM pricing strategies for autonomous technology are likely to depend on their customer focus and integration approach. Companies targeting smaller fleet operators may prefer integrated solutions with fixed upfront or subscription pricing, while larger fleet customers may opt for modular configurations tailored to more specific operational domains.

In the short term, the *Cost Modular (CM)* scenario is assumed to be the most realistic approach for level 1 to level 4 systems, reflecting current trends in commercial pilots and procurement strategies. To encourage early adoption, more affordable tech stacks should be made available so that transport providers are willing to test the technology at manageable cost levels. With the introduction of purpose-built level 5 vehicles, OEMs are likely to shift towards *Value Integrated (VI)* to focus on the value proposition and optimise production costs.

As shown in Table 4, the resulting cost per kilometre varies greatly between the different pricing strategies. In addition, the identified price ranges deviate from the underlying logic introduced in Figure 8. In theory, cost integrated should be the cost leader whereas value modular is expected to entail the most expensive price range. However, the theoretical divide is not identified in the available market information and literature. The unexpected results further highlight the stark differences in geographical markets as well as the lack of accountable information from OEMs and hardware manufacturers. However, the overall cost per kilometre is relatively low if depreciated over a lifespan of 5 years at 80.000 km annually, thus only marginally contributing to the total cost of ownership of a vehicle.

The low relative cost share suggests that, over time, OEMs may increasingly adopt a *Value Modular (VM)* strategy as a means of maximising profit. As autonomy becomes more established and its operational benefits more measurable, pricing is likely to shift from cost-reflective to value-extractive models. However, this is not considered for the presented cost structure to avoid overcomplexity.

Table 4: Tech stack costs by scenario (based on 400.000 km lifetime distance)

Scenario	Estimated Price Range	Cost per km
Cost Modular (CM)	20.000–100.000 €	0,05–0,25 €/km
Value Modular (VM)	6.000–10.000 €	0,015–0,025 €/km
Value Integrated (VI)	9.000 €, or 100 €/month	0,023 €/km
Cost Integrated (CI)	14.000–70.000 €	0,035–0,175 €/km

Cost Development

Currently, the complete autonomous technology stack is not yet commercially available on the Swedish market. Following the stepwise implementation framework, the study proposes a staged cost development as illustrated in Table 5, which aligns with a *cost modular* pricing model for existing lower-level features and scales towards the anticipated costs for full autonomy. The authors expect the major investment in hardware and software to be completed by level 4, with no additional technological components introduced at level 5. The cost progression is structured into three stages, described in the following and summarised in Table 5:

Step 1: Initial deployment of basic driving assistance features at level 1, introducing smarter configurations, is estimated at 2.000 € (representing approximately 10% of the total cost of the tech stack). *Step 2:* Enhancement through advanced sensor technologies and integration of more complex assistance systems at level 3, increasing the cost to approximately 10.000 € (50% of the final cost). *Step 3:* Full deployment of the final autonomous driving hardware and software suite at level 4, culminating in a total estimated cost of 20.000 € (100%).

Table 5: Cost Development of Tech Stack Features (based on 400.000 km lifetime distance)

Level of Autonomy	Total Cost	Cost Development	Cost per km
MD (Baseline)	–	–	0 €/km
Level 1–2	2.000 €	0%	0,0125 €/km
Level 3	10.000 €	+500%	0,025 €/km
Level 4–5	20.000 €	+100%	0,05 €/km

4.2.4 Insurance

Insurance represents a frequently overlooked but important cost component in transport operations. Within the DFDS fleet, current insurance premiums amount to approximately

2.000 € per vehicle annually (Informant 4). According to Engholm et al. (2021), the introduction of autonomous driving is not expected to significantly alter overall insurance costs in the near term. Although autonomous technology has the potential to reduce accident rates, these savings are expected to be offset by higher repair costs associated with complex and expensive sensor and software systems. Currently, there is a lack of evidence for a more comprehensive review of cost development. Current assumptions are depicted in Table 6.

Table 6: Insurance cost per kilometre under different autonomy levels

Level of Autonomy	Annual Distance	Cost per km
Level 0–5	80.000 km	0,025 €/km
	200.000 km	0,01 €/km

4.2.5 Fuel

Fuel is the second-largest cost item in freight transport, accounting for 22% of total transport costs (Pendergast, 2024). Although autonomous vehicles may be powered by various fuels, including diesel and hydrogen, this analysis focusses on battery-stored electricity as the primary fuel. This choice is supported by the growing convergence of electrification and automation (Monios & Bergqvist, 2019), as well as the case-specific use of battery electric trucks (Volvo FH Aero and Volvo FM Electric) in the MODI use case route (Informant 4).

Autonomous technologies can influence fuel costs primarily through improvements in driving efficiency. Broader factors such as fluctuating energy prices or investments in charging infrastructure are acknowledged but excluded from the cost analysis in line with stated prerequisites, due to its high level of uncertainty and indirect impact from autonomy. For example, electricity prices in the Nordic region could fall by as much as 60% by 2030 if renewable energy targets are met (Navia Simon & Diaz Anadon, 2025), but such projections are omitted to maintain analytical focus. Other external factors influencing energy consumption (e.g., weather, road quality, traffic) are acknowledged but not included in the fuel cost modelling for similar reasons (Tu et al., 2024).

Regarding fuel consumption, manufacturer tests with 40t Volvo FH Electric trucks on highways report an average of 1,1 kWh/km at 80 km/h (The Mover, 2022). However, case-specific data indicates an average of 1,6 kWh/km for the MODI use case route (Informant 4), which is considered more representative of real-world conditions. This value is used to derive the cost per kilometre, based on the actual distances from the route and the cited

electricity price.

The gains in fuel efficiency due to automation are primarily associated with improved driving behaviour, such as optimised acceleration, braking, and coasting. Level 4 autonomous systems operating on highways are estimated to improve fuel efficiency by approximately 10% (Aurora, 2024; Andersson & Ivehammar, 2019; Tu et al., 2024; TuSimple, 2023), aligning with a moderate scenario of fuel consumption for driverless trucks depicted by Engholm et al. (2020). In earlier levels 1–3 where systems such as adaptive cruise control and brake assistance are still dependent on human input, the estimated efficiency gain is then approximately 5%.

The route's characteristics are particularly relevant in this context. The length of the MODI use case route and the operating design domain place it between long-haul and city transport conditions, limiting the extent to which stable speed benefits of long-haul autonomy can be realised. The literature highlights that steady speed has greater energy savings potential over longer distances and in low-congestion environments (TuSimple, 2023). In contrast, city driving offers efficiency gains through smoother acceleration and reduced variability in driver behaviour. Studies suggest that autonomy can significantly outperform human drivers in such contexts, yielding fuel savings beyond those achievable with only highway cruise control (Tu et al., 2024; Wadud et al., 2016). In more complex environments, including also vehicle cut-ins on highways, autonomous systems perform better and improve fuel efficiency (TuSimple, 2023).

Hence, fuel efficiency gains are best substantiated for level 4, where research supports up to 10% cost reduction. For level 5, additional efficiency improvements are expected due to projected extended operating hours, reduced idle time, and avoidance of peak traffic. Therefore, these operational improvements are projected to provide another 10% increase in the fuel efficiency gain (Aurora, 2024). However, due to the short distance of the use case route and its limited scope for benefits such as reduced resting time, these effects are included only in a more optimistic cost scenario.

The charging infrastructure is a critical enabler of autonomous electric trucking. Although capital costs for infrastructure development fall outside the scope of this study, access to high-performance chargers directly impacts operational costs. Charging currently mostly occurs at high-power depots (150–200 kW capacity) and is likely to be improved to 400 kW and beyond, as technology becomes available (Informant 4). Recent estimates of the price

for electric charging utilising high-power depots is estimated at 0,58 €/kWh (Parviziomran & Bergqvist, 2025). On average, a truck employed in short-range transport consumes 1,6 kWh/km (Informant 4). However, the concepts of *price* and *cost* should be handled separately. As such, the study discount 10% for fleet discounts and an additional 25% for VAT, so the actual *cost* baseline is instead around 0,62 €/km.

Today, diesel prices are set by an equilibrium of supply and demand, reflecting the actual willingness of customers to pay. Thus, the study argues that as the industry matures, price competition among charging providers will drive the prices toward the current equilibrium of diesel. This is reflected in the current sentiment of the passenger car market, as 65% of European consumers are not willing to pay a premium for electric mobility, half of which even require discounted prices to motivate the transition (McKinsey & Company, 2025a). Assuming current diesel prices are 1,50 €/litre, discounting 10% for fleet discounts and an additional 25% for VAT, the estimated true cost is instead around 1 €/litre. With the average fuel consumption for DFDS in short-range transport being 0,35 l/km (Informant 4), energy costs accumulate to 0,35 €/km. This is reflected as an alternative baseline and is explored in more detail in Chapter 5.

Furthermore, the standard drag force equation (see Appendix B for the calculation) implies that the power required to travel increases exponentially with speed, as highlighted in Figure 9. As such, if the transport speed is reduced from 80 km/h to 60 or 40 km/h, a reduction in the energy use of 19% and additional 17% can be achieved for a 40t HGV, respectively. This topic is commonly reflected as one of the main operational benefits of transforming to autonomy (Bray & Cebon, 2022; Aurora, 2024) and is discussed further in Chapter 5.

Given that fuel efficiency depends on various factors and can be limited by operational circumstances, the true potential for fuel cost savings from autonomy under optimal conditions could exceed the estimates of the study. Among other things, the role of vehicle speed emerges as a critical factor. The results depicted in Table 7 illustrate great potential for savings at slower speeds. Generally, the study argue that autonomous trucks must not obstruct existing road traffic, which is why a speed strategy that aligns with the overall traffic flow is proposed. During peak hours, where slow trucks could greatly increase the risk of congestion, a speed of 80 km/h is proposed, which is then reduced in medium-frequented hours to 60 km/h and finally to 40 km/h during off-hours. In Appendix C the study uses congestion data from TomTom (2024) to derive an estimate on how much time a truck would travel per speed class with respect to 24/7 operation. Although this approach does not

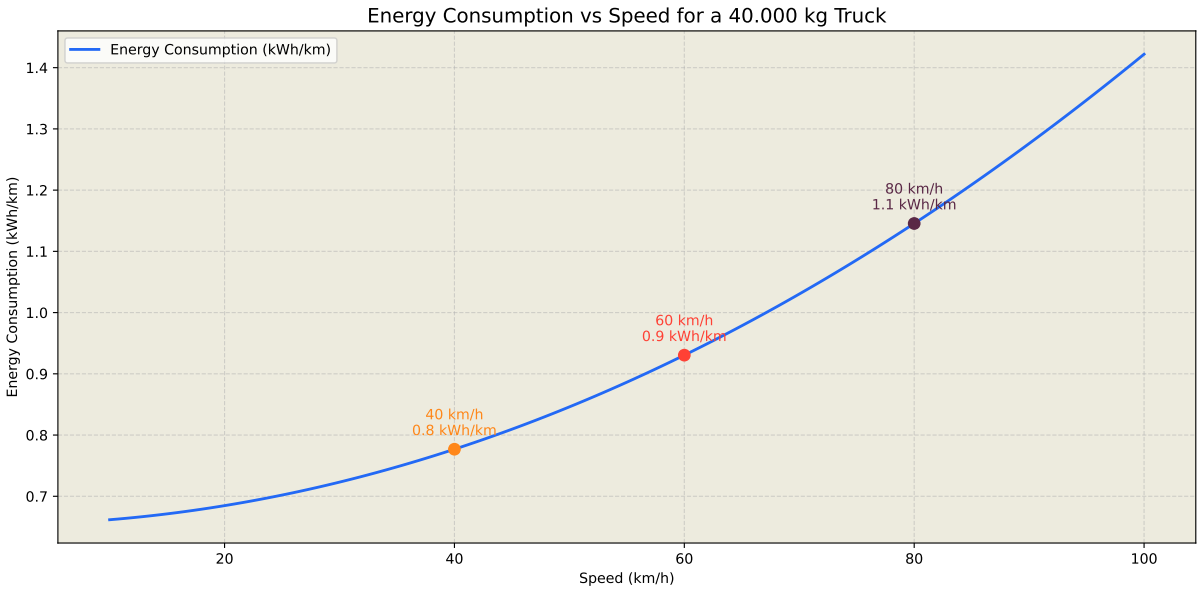

Figure 9: Energy reduction achieved by slower transport speeds

reflect speed reductions induced by pre-existing congestion in metropolitan areas, it helps to provide a rough estimate on overall road usage during a given day. The results of this suggest the following optimised operating speed split: 30% at 80 km/h, 36% at 60 km/h and 34% at 40 km/h.

In addition to speed, other autonomy-related aspects could also contribute in reducing fuel consumption and hence operational costs of trucks more extensively than previously outlined estimates. The concept of platooning, taking the form of several trucks driving in formation that allows a reduction in aerodynamic drag (Martínez-Díaz et al., 2021), is projected to significantly affect HGV:s fuel consumption in the future and should not be discarded when discussing fuel costs for autonomous trucks. With autonomous technology as an enabler for platooning operations, the study acknowledges that it is likely to be an important factor for higher levels of autonomy. However, the novelty of the concept implying highly speculative associated costs implications at the current stage has the study leaving its inclusion in the cost analysis to future research. The named complexity originates from the assumptions that need to be made in further estimating related costs. Currently unknown relationships within the platoon such as inter-vehicle distances, operating speeds, and varying levels of autonomy among included trucks imply mentioned uncertainty, jeopardising the desired accuracy of the analysis.

Table 7: Fuel cost per kilometre under different autonomy levels at various speed (battery-electric truck)

Speed	Level of Autonomy	Cost Development	Current Pricing	Equilibrium Pricing
80 km/h	MD (Baseline)	–	0,62 €/km	0,35 €/km
	Level 1–3	-5%	0,59 €/km	0,33 €/km
	Level 4	-5%	0,56 €/km	0,32 €/km
	Level 5	-10%	0,50 €/km	0,28 €/km
60 km/h	Level 5	-19%	0,41 €/km	0,23 €/km
40 km/h	Level 5	-17%	0,34 €/km	0,19 €/km

4.2.6 Repair & Maintenance

Current repair and maintenance costs for 40-tonne trucks in Swedish freight operations average approximately 0,11 €/km (ASEK, 2024). Research suggests that autonomous vehicles can reduce mechanical wear through smoother driving behaviour, potentially lowering routine maintenance needs (Wadud, 2017). However, in the early stages of automation, these savings may be offset by the higher complexity of systems inducing higher repair costs in an immature market. Engholm et al. (2020) supports this view, projecting a net neutral effect at initial autonomy levels and potential cost reductions of up to 25 % at level 5, driven by improved system maturity and consistency in driving behaviour.

In addition to cost-level changes, autonomy is expected to transform the underlying maintenance concepts. Tao et al. (2022) argue that the driver currently functions as a real-time sensor for emerging vehicle problems. Thus, reducing human interference with the truck will induce more predictive maintenance to ensure uptime. In addition, as operating hours increase and vehicles become less available for scheduled downtime, the complexity of autonomous systems can lead to more frequent breakdowns and unplanned maintenance events. Similarly, Škerlič and Sokolovskij (2020) note that while predictive maintenance improves operational safety and reliability, it has also led to a relative increase in total maintenance costs due to more proactive and technology-intensive routines.

It is important to note that DFDS includes repair and maintenance services within its vehicle leasing agreements (Informant 4). As a result, no separate distance-based maintenance costs are incurred during operations. This practice is consistent with broader industry trends, as noted by Sindi and Woodman (2021). The figures referenced in this section are therefore presented for contextual purposes and reflect general industry cost structures to support broader analysis across autonomy levels.

The study concludes that the adoption of autonomous operational procedures is likely to require more advanced predictive maintenance efforts, particularly once the driver is removed from the vehicle. In line with Engholm et al. (2020), a net zero change in repair and maintenance costs for levels 1–3 is assumed, where reductions in mechanical wear are offset by an increase in unit costs associated with emerging technologies. For level 4, the study propose a 10% increase in costs for maintenance to account for the increased dependence on predictive systems and the higher risk of unplanned downtime, consistent with the findings of Tao et al. (2022) and Škerlič and Sokolovskij (2020). Level 5, follow the general argument of Engholm et al. (2020) regarding the potential for significant cost savings. However, the study adopts a more conservative estimate of 10% cost reduction, offsetting the initial increase introduced at level 4. This adjustment results in level 5 maintenance costs returning to parity with the initial baseline. The findings are summarised in Table 8.

Table 8: Maintenance cost per kilometre under different autonomy levels (battery-electric truck)

Level of Autonomy	**Cost Development**	**Cost per km**
MD (Baseline)	–	0,11 €/km
Level 1–3	0%	0,11 €/km
Level 4	+10%	0,12 €/km
Level 5	-10%	0,11 €/km

4.2.7 Tyres

Tyre costs are a notable component of vehicle operating expenses for transport providers. The subject of tyre wear is influenced by several factors, notably the aggressiveness of braking and acceleration, as well as vehicle speed (Liu et al., 2022), for which improvements could be derived from increased use of autonomous features. This, as these features, in line with what is described in the fuel section, are entrusted with handling the throttle, steering, and braking more smoothly than human drivers. For lower levels, braking and acceleration assistance and adaptive cruise control used separately or in combination in level 1 and level 2 respectively, can thus reduce associated tyre costs. Braking and acceleration patterns also have a more substantial impact on wear than speed alone (Liu et al., 2022).

Another aspect is the predictive capabilities of autonomous systems that are expected to improve the maintenance and service of trucks. In terms of tyres, this could be done by

monitoring current tyre pressure and wear rate at an increasingly detailed level, using notifications to alert when it is time for tyre alignment or inflate the tyres, ultimately extending their lifespan, and hence lower the costs, at the same time as increasing road safety.

Although less quantifiable, factors such as road surface quality, development of tyre technology, and materials prices are acknowledged to influence tyre lifespan and associated costs. However, these are kept constant for all scenarios in the study due to their perceived independence from automation. The study also makes an important distinction between the cost developments that originate from the use of electric versus combustion vehicles and autonomous versus manual trucks. The increased weight of electric trucks due to their battery packs is a major factor in higher tyre wear (Haghani et al., 2024), potentially more so than the powertrain alone or the impact of autonomy features. Increased weight implies higher tyre pressure, leading to faster wear of the tread. This, in addition to an increased rolling resistance that is weight-dependent. In line with the study assuming electric vehicle utilisation across all levels, any tyre cost developments originating from heavier trucks are naturally not taken into account.

Manual trucks are totally dependent on driving behaviour, implying more harsh actions. Although Engholm et al. (2020) provides cost estimates for manual 40-tonne trucks, the perceived rapid development in tyre technology (Storm, 2025; Informant 4) has the study considering these estimates to run the risk of being obsolete and, hence, updating them from the baseline costs of the case study.

The costs of tyres in the analysis follow the logic of manual trucks serving as a baseline for which the cost calculation is performed using data from the case company. From there, projected decrease in cost derived from autonomous features are applied using upcoming argumentation. To form the baseline, the average cost of tyre purchase provided by Informant 4 is used, in combination with the number of tyres needed for a standardised truck operating the focused route. This is divided by the average lifespan of the tyres, again supported by the case company, ultimately resulting in the cost of tyres per kilometre.

Numbers for levels prior to level 2 are estimated to increase from completely or partially lacking features that allow smoother braking and speed regulation. Proceeding levels beyond level 2 are on the other hand expected to decrease tyre wear from extended vehicle manoeuvring not being performed by a human driver, entailing optimised speed and breaking / accelerating. As proposed for fuel costs, the initial driving assistants will only nudge

the driver to improve behaviour. As such, the study proposes an improvement in tyre costs of 5% for level 1–3 and once full autonomy is implemented, an additional 5% for level 4 and 5 respectively. This, as increased operation hours allow for off-peak driving, thus reducing traffic-related inefficiencies in line with arguments brought up for fuel consumption.

A summary of the tyre costs assumed in the study is presented in Table 9.

Table 9: Tyre cost per kilometre under different autonomy scenarios.

Level of Autonomy	Assumption	Cost Development	Cost per km
MD (Baseline)			0,019 €/km
Level 1–3	Assistant Driving	-5%	0,018 €/km
Level 4	Predictive Maintenance	-5%	0,017 €/km
Level 5	Optimised Operations	-5%	0,016 €/km

4.3 Summary of Stepwise Cost Development

In this section, the study provides an overview of categorical developments within each of the SAE autonomy levels. As the prior discussion suggests, the complexity of the respective cost items implies the need for a scenario-based analysis, which provides context and thus allows for accurate simulation. Such scenarios are explored in Chapter 5.

4.3.1 Level 1: Driving Assist

The introduction of basic driving assistance features (e.g., cruise control, braking support) reduces fuel consumption and tyre wear slightly, as the vehicle is operated more carefully. Technology costs increase to a small degree due to the addition of simple assistance systems, though the impact on total cost per kilometre remains negligible, as it is offset by the overall saving potential.

4.3.2 Level 2: Combined Assistants

At this stage, no additional cost changes are observed, as the major operational and technological effects of driving assistance are already introduced in Stage 1. The earlier levels of automation are mostly insignificant from the cost-benefit perspective, as the overall operation remains overshadowed by human interference and related costs.

4.3.3 Level 3: Supervised Autonomy

Again, at this stage, no major operational cost changes occur. The next level of technology is introduced, but its impact on the cost per kilometre remains insignificant.

4.3.4 Level 4: Full Supervised Autonomy

In an optimistic scenario, driver costs could be halved through remote supervision, while fuel efficiency continues to improve. Maintenance costs will increase significantly due to more predictive efforts, which in turn will improve tyre costs. In addition, the final technology stack is believed to be introduced to the vehicle, which, however, still contributes only marginally to total costs.

4.3.5 Level 5: Full Unsupervised Autonomy

Driver costs vary widely depending on the supervision strategy, ranging from no change to a drastic potential cost reduction. Fuel savings could become substantial through increased operational flexibility as speed is reduced. Finally, maintenance costs return to the baseline and tyre wear continues to improve.

4.3.6 Conclusion

Although the autonomous technology stack represents a considerable upfront investment that remains highly debated, its relative cost impact remains minor when distributed over the vehicle's lifetime even in the highest cost assumptions. Furthermore, the study recognises that removing the physical driver from the vehicle does not ultimately imply generous cost reductions, as the move will likely be partially offset by the creation of mandatory jobs supporting the vehicles operability. Finally, the trucks operational speed provides great potential for cost savings, but highly depends on its operational domain. The magnitude of change across cost structures varies significantly depending on specific deployment scenarios, which will be explored in greater detail in Chapter 5.

5 Scenario Analysis

The prior chapter highlights the complexity of many cost items which needs to be applied carefully in order to properly account for development and pricing uncertainties. As such, the study introduces four cost scenarios that cluster those uncertainties and allow for more holistic scenarios. Figure 10 presents the logic of these scenarios, which is discussed in more detail with regard to the automation of single routes in *Scope 1*. Further, the study utilise *Scope 2* to explore the sensitivity of key parameters and discuss implications in scaling autonomous operations beyond single short-range routes.

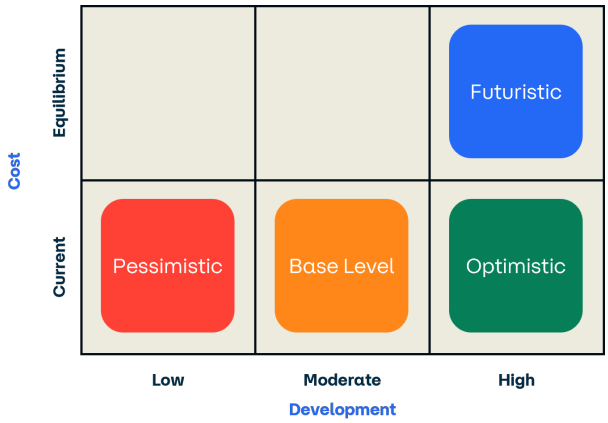

Figure 10: Cost scenario framework clustering forecast uncertainties

5.1 Scope 1: Single-route Contract Logistics

The purpose of the case study is to closely align with realistic operational parameters. As such, the Gothenburg–Borås freight corridor is used as a reference for short-range hub-to-hub freight transport under contract logistics contracting. In the following, the different scenarios are applied to review the overall cost-benefit development at all levels of autonomy. Each scenario is hereby reviewed independently and summarised in Figure 11.

5.1.1 Base Scenario

The *base level* scenario contains moderate estimates for all cost items under current pricing conditions. Thus, the study presents a conservative forecast that does not expect major operational changes from the employment of autonomy for the initial levels 1–4. As such, key parameters are set to 2,3:1 drivers employed throughout level 1–4 and 1:1 for level 5.

Furthermore, the operating speed is set to 80 km/h for an annual mileage of 80.000 km.

5.1.2 Pessimistic Scenario

In the *pessimistic* scenario, the study takes a sceptic approach to the achievable elimination of human workforce. It is argued that removing the driver from the vehicle will only shift the headcount to remote operators and an increase in assistance personal, thus not actually reducing the number of people necessary to operate a truck. This could be due to inertia in the implementation phase of higher automation levels or low maturity and user knowledge at companies in the transport industry. Therefore, a 2,3:1 driver ratio is employed throughout level 1–5 whereas the remaining parameters do not deviate from the base-level scenario.

5.1.3 Optimistic Scenario

In contrast to the base level, the *optimistic* scenario envisions improved operation conditions. As such, fewer people are employed per truck in the higher levels of autonomy in addition to the deliberately reduced transport speed in off-peak travel hours. Thus, a 2,3:1 driver ratio is employed for level 1–3, 1:1 in level 4 and 1:2 in level 5. Furthermore, the study uses the 30/36/34 split for driving at 80/60/40 km/h to determine mixed fuel consumption, as motivated earlier.

5.1.4 Futuristic Scenario

Later stages of autonomy are only expected to fully materialise in the long-term planning horizon. This implies a higher uncertainty of market price averages, which, as introduced earlier, are likely to follow an additional development towards existing hardware and energy prices. To account for these uncertainties, the study proposes a *futuristic* cost scenario. Hereby, parameters are adopted from the optimistic scenario under equilibrium pricing assumptions instead of the current pricing level employed in the optimistic scenario. This affects the costs of fuel and base vehicle, for which the estimates are depicted in Table 2 and Table 7. It is important to stress that the futuristic scenario lowers costs across all levels of autonomy proportionally and therefore does not constitute of a separate cost-benefit assumption. Instead, the scenario aims to highlight the overall development that total transport costs could face.

5.1.5 Findings

Figure 11 illustrates the aggregated cost development across the SAE levels, categorised by the cost items introduced in Chapter 4 and compared across the scenarios defined in Chapter 5.

In the base scenario, the findings suggest that the cost structures remain largely unchanged up to level 4 autonomy. A significant cost reduction of approximately 30% is achieved only with full unsupervised autonomy at level 5, primarily due to the stark reduction in driver-related expenses.

Under the pessimistic scenario, where the assumption of reduced headcount is discarded, the introduction of autonomous technology yields negligible cost benefits. This outcome underscores the critical importance of labour cost savings in justifying the adoption of autonomy.

In contrast, the optimistic scenario demonstrates considerable savings earlier in the transition. At level 4, a 30% cost reduction is observed, reflecting improved operational efficiency through more effective deployment of autonomous systems. A further 30% reduction at level 5 results in a total cost savings of up to 50% compared to traditional manual operations.

Lastly, the futuristic scenario projects additional savings independently of the autonomy level, driven by broader market maturity and alternative pricing mechanisms. This scenario assumes structural changes in cost components such as fuel and vehicle investment, further enhancing the economic viability of autonomous freight transport in a future context.

5.2 Scope 2: DFDS Swedish Hub Network

In alignment with the study's objective to assess the applicability of autonomous driving under varying operational applications, this section extends the focus from a single-route analysis to a scaled-up network perspective. Specifically, the analysis incorporates the DFDS logistics hub network in southern Sweden to explore the sensitivity of the cost model to variations in key parameters introduced in Chapter 4.

The sensitivity analysis is performed based on the assumptions of the base scenario introduced in Section 5.1, using parameter ranges derived from empirical case data. These

ranges are selected to reflect the realistic operational conditions encountered by DFDS within the Swedish market.

5.2.1 Annual Distance Sensitivity Analysis

The distance parameter in the total cost equation employed in the study captures the utilisation rate of fixed-cost assets. Consequently, components such as driver wages, base vehicle investment, tech stack expenditures, and insurance premiums are considered fixed and do not scale proportionally with increasing annual driving distance. This sensitivity analysis treats annual distance as an independent variable to explore how varying utilisation levels impact the cost structure across different levels of vehicle autonomy. While short-range hub-to-hub contract logistics typically average around 80.000 km/year, vehicles deployed on medium-haul routes can reach up to 200.000 km/year under current manual operations (Informant 4).

For the purposes of the sensitivity analysis, fixed costs are assumed to remain constant, regardless of the distance driven. This assumption is consistent with earlier arguments suggesting that the benefits of autonomous driving become more pronounced with increased road time and reduced operational complexity. Higher autonomy levels are expected to reduce idle periods, mitigate time lost to unassigned activities, and smooth operations across long-distance routes. However, lifecycle constraints, such as the total operational mileage capacity of the trucks, charging requirements, and maintenance intervals, introduce practical limits on how much fixed costs can be diluted.

A key trade-off identified in this context is the one between the average vehicle speed and achievable annual travel distance. Although reducing speed can significantly increase energy efficiency and lower fuel costs, it limits the total annual distance a truck can cover. This trade-off becomes particularly relevant for fully autonomous systems, where the optimal balance between speed, cost, and utilisation must be evaluated. Scaling up annual distance effectively increases the utilisation of capital expenditures, thereby improving cost efficiency. This principle reflects the well-established concepts of economies of scale in transport operations. However, this study advances the discussion by quantifying the actual cost-saving potential linked to increased distance.

Figure 12 illustrates the effect of scaling the annual driving distance from 80.000 to 200.000 km across all autonomy levels under the base scenario. The results reveal a potential cost re-

duction of approximately 60% of the cost per kilometre, underscoring the critical role of distance in unlocking the economic benefits of autonomous transport systems.

5.2.2 Driver Count Sensitivity Analysis

A key motivation behind the deployment of autonomous driving technologies lies in the potential to reduce the number of drivers required per vehicle. In current short range hub-to-hub operations, this ratio is typically as high as 2,3 drivers per truck. This accounts for multiple shifts per day and time off for individual drivers, ensuring continuous availability. In contrast, for medium- to long-range operations, such as those considered in the extended network scope, operators generally maintain a nearly 1:1 driver-to-vehicle ratio as drivers rest in the vehicle. For level 5 autonomous operations under the base scenario, the study assumes a ratio of 1:1. Under optimistic assumptions, a further reduction to 1:2 is explored, implying that each remote operator could supervise around four autonomous vehicles on average, as reasoned in Chapter 4.2.1.

Figure 13 presents the sensitivity analysis results for level 5 operation at both 80.000 and 200.000 km/year utilisation. The analysis reveals that driver count is a highly influential parameter in the cost model, especially in low-utilisation contexts. Cost sensitivity to head-count is disproportionately higher for short-range operations, where fixed costs must be amortised over fewer kilometres. Conversely, in high-utilisation settings, the cost impact of driver count is more muted as the cost is spread over a larger distance base.

The analysis underscores the significant economic inefficiencies associated with under-used driver-vehicle allocations in short-range transport. For example, reducing the driver-to-vehicle ratio from 2,3 to 1 leads to a cost saving of approximately 0,82 €/km in short-range (80.000 km/year) operations, while the same adjustment yields a saving of roughly 0,23 €/km in mid-range (200.000 km/year) contexts. This further highlights the importance of integrating autonomous technologies to improve cost-efficiency in low-distance use cases as well as the potential in scaling operations.

5.2.3 Tech Stack Cost Sensitivity Analysis

As discussed in Chapter 4, there is considerable uncertainty as to how autonomous driving technology will be integrated into commercial vehicles, as well as the way it will be priced

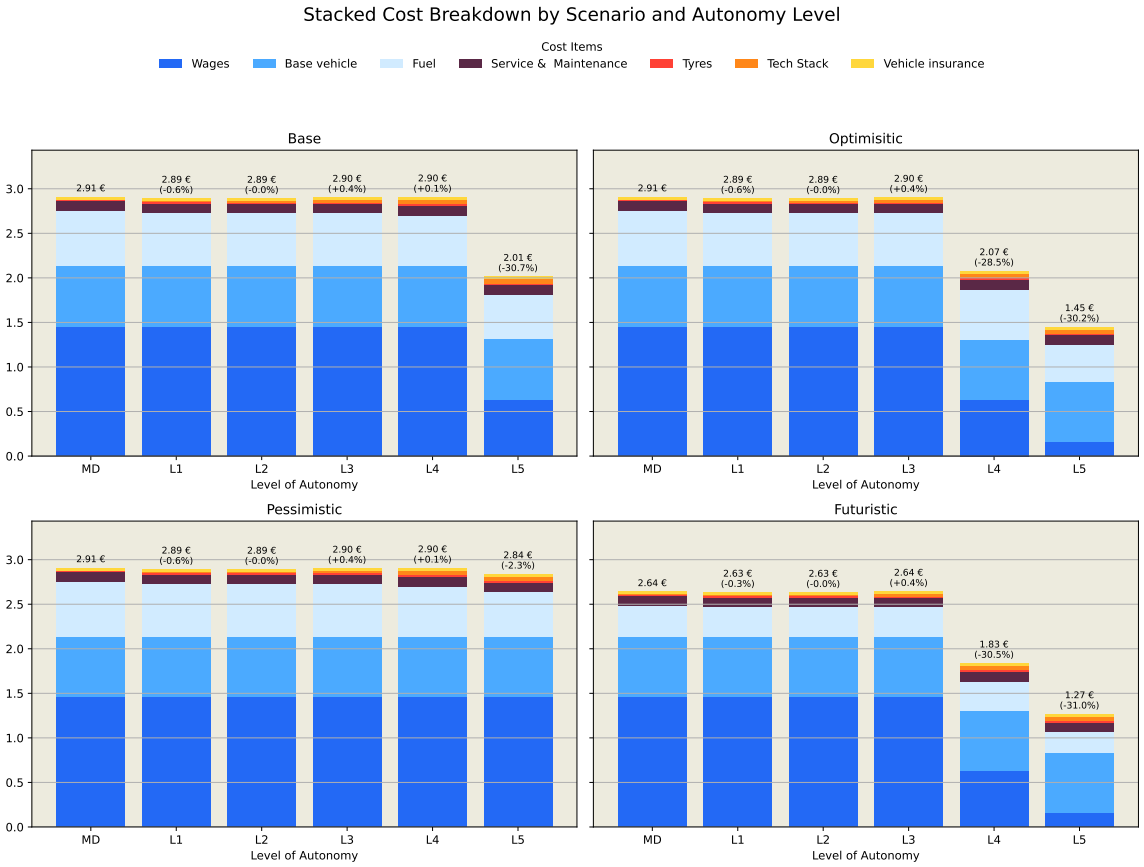

Figure 11: Total transport cost development across autonomy levels under different scenario assumptions

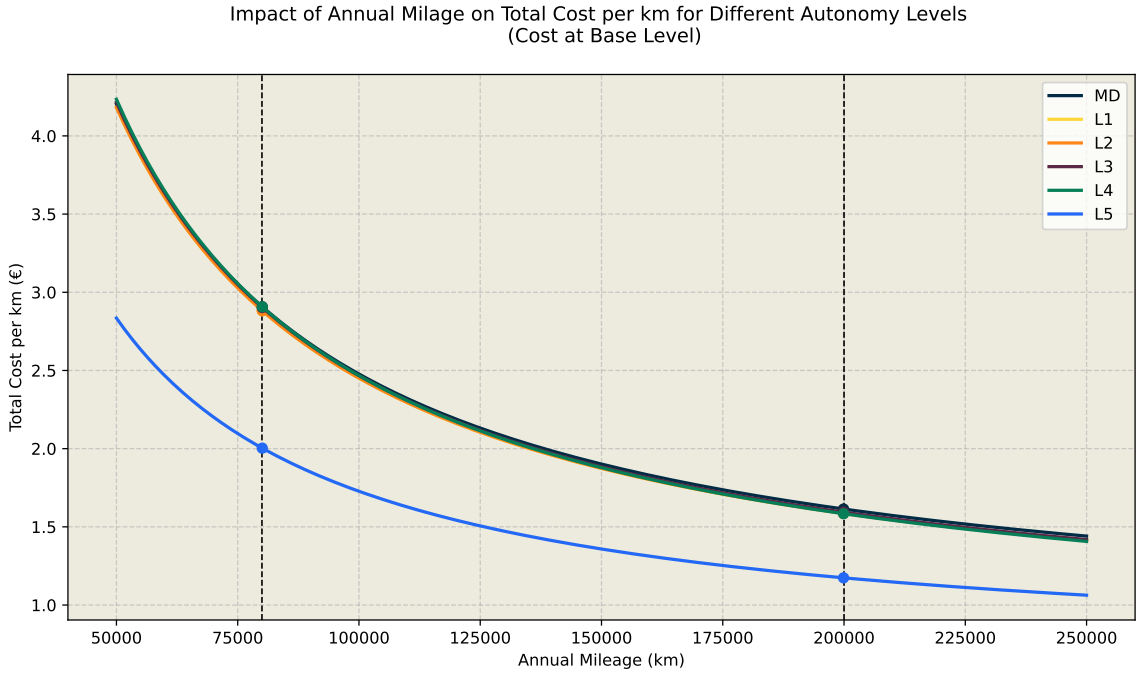

Figure 12: Total transport cost per kilometre in the base scenario extrapolated for extended utilisation of fix-cost assets (annual mileage)

by technology providers. In the study, the cost of a full level 5 autonomous driving system is estimated at a moderate 20.000 €, derived from existing but limited industry references. However, due to the scarcity of transparent data and the evolving state of the market, the reliability of this assumption is restricted. To address this uncertainty, a sensitivity analysis is performed to assess the impact of variations in the cost of the technology stack on the overall cost per kilometre. Figure 14 presents the findings of this analysis. A 50% reduction in technology cost (to 10.000 €) results only in a marginal decrease of approximately 0,01 €/km in total transport cost. Conversely, doubling the cost to 40.000 € results in an increase of merely 0,02 €/km. Even when the cost is exaggerated to 100.000 €, the total cost per kilometre increases by only around 0,06 €/km.

These results demonstrate that from a transport provider's perspective, variations in the upfront technology cost have only a minor impact on the overall cost structure. This is mainly due to the long operational lifetime of trucks, which allows fixed investments to be amortised over substantial distances. However, alternative pricing mechanisms are worth considering. If technology providers implement a usage-based pricing model, where the cost of autonomy scales with the kilometres transported, the impact on total transport costs could be more substantial. Under such a scheme, the tech stack would shift from a fixed to a variable cost component, potentially significantly altering the cost-benefit dynamics of adopting autonomous solutions. However, the findings of the study suggest that even in less favourable pricing scenarios, the cost advantages of automation remain sufficiently robust to absorb substantial cost increases.

5.2.4 Findings

A high annual mileage substantially improves the cost-efficiency of transport operations by enabling stronger economies of scale. This effect is particularly relevant for capital-intensive technologies such as autonomous driving systems, where high utilisation helps amortise steep upfront investments. Moreover, operational efficiencies unlocked by autonomy, such as reduced idling and optimised routing, can further increase vehicle mileage, thus reinforcing the economic case for full autonomy.

Among all cost components, driver expenses emerge as the most influential factor. In short-range operations, where vehicles are often underused yet fully staffed, reducing the headcount, through either improved scheduling or remote supervision, can yield substantial

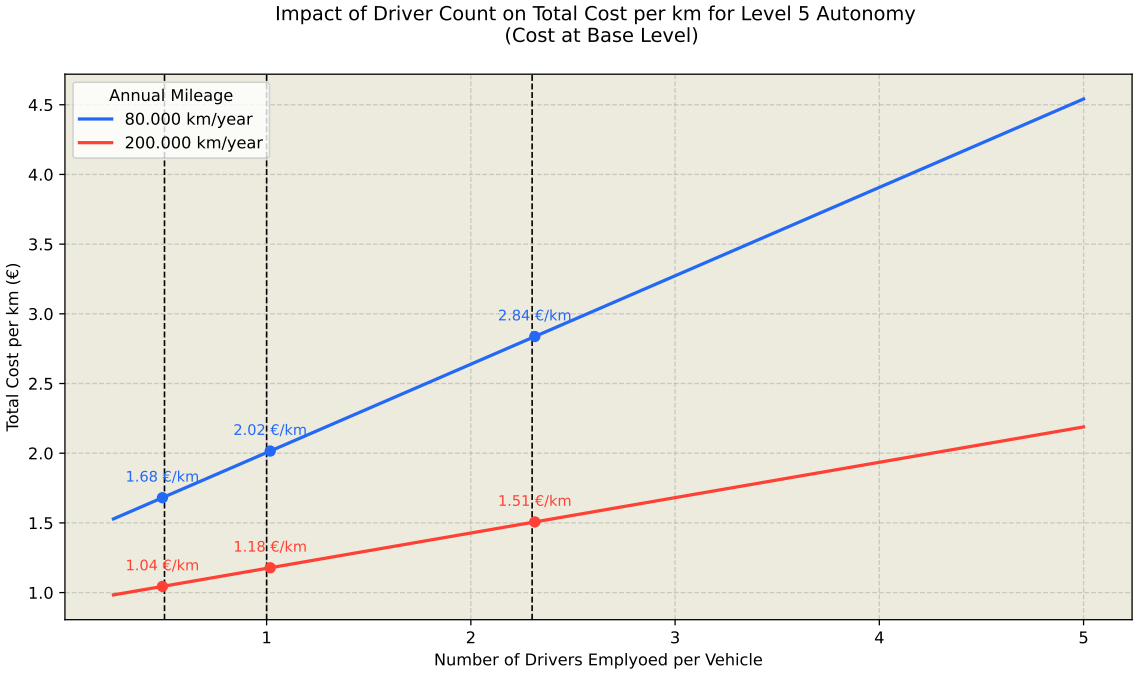

Figure 13: Total transport cost per kilometre in the base scenario tested for driver-to-vehicle ratios

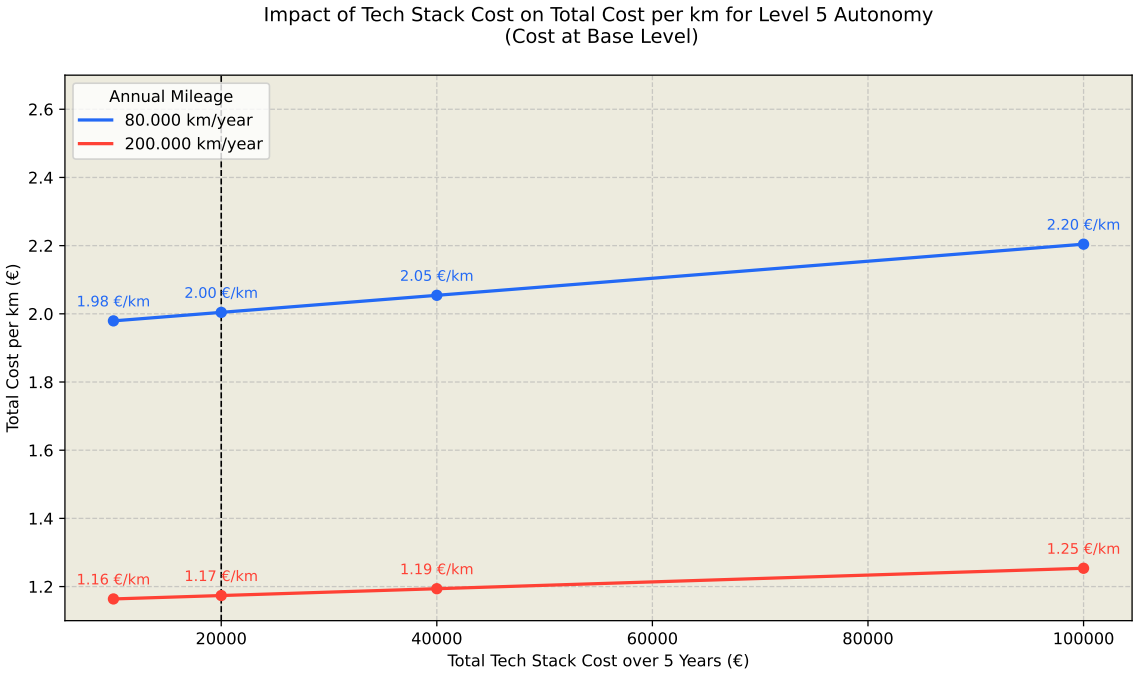

Figure 14: Total transport cost per kilometre in the base scenario for level 5 autonomy, testing different tech stack cost assumptions

savings. In contrast, long-haul scenarios typically gravitate towards a more efficient 1:1 driver-to-vehicle ratio, limiting the potential for cost reduction in this regard.

In particular, the analysis also reveals that variations in tech stack costs have only a marginal impact on total cost per kilometre. Even substantial changes to the purchase price of autonomous systems result in relatively small differences in operating costs. This indicates that advanced autonomous solutions, even if priced aggressively, can still deliver a net economic benefit as they drive operational efficiency.

Finally, the findings highlight a high degree of scalability from a single-route setup to a broader network context. As fixed cost components (e.g., vehicle, insurance, tech stack) are more effectively distributed across longer distances, total cost per kilometre decreases sharply with increased utilisation. This reinforces the strategic value of deploying autonomous solutions in use cases with high vehicle use.

6 Conclusions

6.1 Key Findings

Here, the concepts of foundational trends and market entry strategies that are discussed in the theoretical framework of Chapter 3, are reflected in the context of the result of the study analysis.

6.1.1 Foundational Trends

The study confirms that increased automation could help mitigate driver shortages, although not completely eliminating driver-related roles. Instead, the drivers role evolves towards remote supervision and support staff. Significant workforce reductions only begin to appear in the base scenario at level 5 and the optimistic scenario from level 4 and beyond. The driver-to-vehicle ratio does not drop binary, but instead gradually shifts as autonomy advances. Furthermore, the study presents evidence that despite the gradual reduction in driving responsibilities, new tasks in remote supervision and roadside assistance could divert existing jobs to new roles.

Improvements in fuel and energy efficiency are observed at all levels of autonomy, driven by more consistent and efficient driving patterns. However, substantial environmental gains only become evident at higher autonomy levels (4–5), especially in scenarios featuring variable speed and off-peak transport, where fuel savings and emissions reductions are most attainable.

Autonomy benefits traffic solutions through, for example, off-peak operations that help alleviate congestion, emissions, and safety risks. These benefits are primarily achievable at level 5, where operational flexibility increases as the driver is physically removed from the vehicle. Although predictive features (e.g., maintenance, tyre monitoring) are expected to enhance safety, the study also highlights potential safety risks from the integration of low-speed autonomous vehicles into mixed traffic environments and the lack of human supervision exceeding the scope of sensors.

The study's scenario analysis shows that significant cost reductions are only achieved at higher autonomy levels, particularly level 5, where savings stem from reduced driver costs

and improved fuel efficiency. Although pessimistic scenarios show minimal benefits, other scenarios suggest increasing economic viability, supporting the idea that cost-effectiveness is a key pull factor for adoption. Although the current state of operations has not yet reached this threshold, the industry's active pursuit of level 4 autonomy reflects a recognition of its near-term cost savings potential.

6.1.2 Market Entry

The timing of market entry is critical to avoid unnecessary risks and to seize early opportunities. Prominent literature points to the high uncertainty associated with entering the autonomous trucking market prematurely, particularly due to unclear technology trajectories and evolving standards. However, the study's scenario analysis reveals that high initial investments in autonomous technology, especially at lower levels, have only marginal impact on total cost per kilometre. This significantly lowers the financial barrier for early movers and makes early stage adoption more attractive than assumed in advance.

At more advanced autonomy levels 4–5, the analysis demonstrates substantial cost savings potential. These savings are primarily driven by reductions in driver-related expenses and improved operational efficiency through adaptive speed strategies. Depending on the deployment context and supervision model, level 5 autonomy can lead to up to 50% cost reductions under optimistic assumptions. This underscores both the potential and the strategic necessity of engaging with autonomous solutions early to remain competitive in the long term.

Although early adoption carries the risk of committing to technologies and standards that may later be displaced, this risk is partially offset by the benefits of learning, ecosystem integration, and the ability to shape future standards. Waiting too long thereby increases the risk of being outcompeted by more agile players who have already secured key positions in the market. The strategic *window of opportunity* likely occurs just before the technology matures and dominant designs are not yet locked in. As the market matures, a self-reinforcing dynamic is likely to emerge as increased adoption accelerates learning, reduces technology costs, and intensifies competitive pressure. Firms that engage early in this cycle are better positioned to capture value and establish durable competitive advantages before margins compress.

That being said, early entry is not feasible for all organisations. The *fast second* strat-

egy identified in the literature offers an alternative. By closely observing early adopters, companies can enter the market with more refined business models, avoiding early-stage missteps while still capturing significant strategic value. The analysis suggests space for niche strategies since, although large players may prioritise long-haul autonomous freight due to greater economies of scale, smaller or regional operators could find profitable positions in short range hub-to-hub logistics. This is supported by the findings that short-range operations can still be economically viable, especially when driver optimisation and route control are leveraged effectively.

6.2 Reflection on Research Question

This section concludes the study by addressing the main research question. First, it outlines how stepwise implementation of autonomous driving affects the cost structures of transport, and then reflects on the implications for commercially viable business models.

How will the stepwise implementation of autonomous driving affect the cost structure of transport operations?

The analysis reveals that levels 1–3 of autonomy have a close to net zero effect on overall cost structures, regardless of the scenario applied. Marginal savings in variable costs (e.g., fuel and tyre wear) are effectively offset by increased fixed costs, particularly from the technology stack. These early stages, while laying the technological foundation and providing additional benefits (e.g., safety and sustainability), do not yet yield meaningful economic gains.

Level 4 marks the first significant changes in cost dynamics. At this stage, wage-related expenses begin to decrease due to improved driver-to-vehicle ratios enabled by remote operation and supervision. This trend is consistent across all but the pessimistic scenario, which assumes that human roles are simply redistributed rather than reduced. Level 5 amplifies these effects, particularly in the optimistic scenario, where operational speed adjustments and full autonomy unlock exponential cost savings. In total, the study finds that levels 4 and 5 yield potential cost reductions ranging from 30% to 50% compared to manually operated trucks, depending on the scenario. These savings are driven by reduced labour costs, increased fuel efficiency, and better utilisation of fixed-cost assets.

In addition, the study highlights that scaling autonomous operations to medium- and long-haul routes further enhances cost efficiency. Longer distances allow for greater benefits from speed optimisation and enable the dilution of fixed costs over higher annual mileage. This scalability strengthens the case for autonomy in network-based logistics operations.

What does it imply for attaining a commercially viable business model?

The scenario analysis has several strategic implications for developing viable business models in autonomous freight transport. Although significant cost advantages are concentrated in the later stages of autonomy (particularly for long-haul operations), the upfront technology costs associated with early levels (1–3) are found to be relatively minor in the overall cost structure. Contrary to common industry concerns, these initial investments do not present major financial barriers. This lowers the threshold for initial adoption and suggests that early investment may be more feasible than anticipated.

However, the financial returns on these early investments are unlikely to materialise until higher autonomy levels are achieved, which could lead some companies to delay adoption in anticipation of future improvements. This dynamic introduces a strategic tension: while early deployment can offer long-term advantages (e.g., ecosystem readiness, learning curve benefits), the delayed realisation of cost savings may slow the pace of market adoption.

6.3 Recommendations for DFDS

With market strategy conclusions supporting early entry into autonomous transport and that initial investments do not conflict the future potential of the technology, DFDS should continue their current collaborative approach in adopting autonomy for short- to mid-range operations. This allows testing and demonstrating the feasibility of the technology in controlled and manageable domains. As technology matures, DFDS is advised to take a proactive rather than passive position, appropriate for a company of their scale and market influence in hub-to-hub contract transport, enabling strategic investments in both the technology and the necessary infrastructure.

The scope for the company's autonomous operations should be considered scaled sooner rather than later if surrounding infrastructure with economic viability is at hand. This is due to

proven cost-related scaling effects over longer distances, improving uptime and economies of scale, particularly for major cost drivers such as fuel, driver wages, and capital assets such as vehicles and associated technologies.

6.4 Future Research Potential

While this study provides a focused cost-benefit analysis of autonomous freight deployment, several important areas remain for future research. Due to the evolving nature of the technology and the uncertainty surrounding long-term operational impacts, some parameters were deliberately kept constant to maintain analytical clarity. However, expanding the scope to incorporate these variables would enrich the understanding of the full economic and strategic implications of autonomy.

One key area for further investigation is the fuel efficiency potential of advanced autonomous strategies, such as platooning. While this study acknowledges the concept, dedicated modelling is required to quantify its impact in real world conditions in different traffic environments and operational scales. Similarly, the exclusion of external infrastructure costs, such as charging stations or remote operations centres, presents a limitation of the study that requires further investigation. Future research should assess different infrastructure ownership and financing models, particularly in relation to cost sharing between private operators and public stakeholders.

Labour dynamics also remain a critical unknown. Although this study explores supervision ratios in theoretical scenarios, the actual responsibilities, effectiveness, and staffing requirements for remote operation remain to be fully understood. Research that examines the roles, costs, and training needs of remote operators would provide more realistic insight into one of the most influential cost drivers in freight transport autonomy.

Finally, the regulatory environment and its timeline for adaptation will significantly shape the pace and feasibility of large-scale deployment. Comparative studies across jurisdictions could clarify which legal frameworks enable or inhibit progress and how operators could navigate these in strategic planning.

These areas offer significant opportunities to refine and expand the economic models presented in this study. Addressing them would strengthen both academic insight and practical guidance for firms considering the transition to autonomous freight transport.

References

ACEA. (2024, September). *New EU commercial vehicle registrations.* Retrieved 2025-05-16, from https://www.acea.auto/figure/new-commercial-vehicle-registrations-in-eu/

Adner, R., & Kapoor, R. (2010). Value creation in innovation ecosystems: how the structure of technological interdependence affects firm performance in new technology generations. *Strategic Management Journal*, *31*(3), 306–333. doi: 10.1002/smj.821

Andersson, P., & Ivehammar, P. (2019). Benefits and Costs of Autonomous Trucks and Cars. *Journal of Transportation Technologies*, *9*(2), 121–145. doi: 10.4236/jtts.2019.92008

André, Q., Carmon, Z., Wertenbroch, K., Crum, A., Frank, D., Goldstein, W., ... Yang, H. (2018). Consumer Choice and Autonomy in the Age of Artificial Intelligence and Big Data. *Customer Needs and Solutions*, *5*(1-2), 28–37. doi: 10.1007/s40547-017-0085-8

ASEK. (2024, April). *Analysmetod och samhällsekonomiska kalkylvärden för transportsektorn* (Tech. Rep. No. 8.0). Borlänge: Trafikverket. Retrieved from https://bransch.trafikverket.se/for-dig-i-branschen/Planera-och-utreda/Samhallsekonomisk-analys-och-trafikanalys/samhallsekonomi/analysmetod-och-samhallsekonomiska-kalkylvardenasek/

Athanasopoulou, A., de Reuver, M., Nikou, S., & Bouwman, H. (2019). What technology enabled services impact business models in the automotive industry? An exploratory study. *Futures*, *109*, 73–83. doi: 10.1016/j.futures.2019.04.001

ATRI. (2023, June). *Operational Costs of Trucking* (Tech. Rep.). Minneapolis, Minnesota: American Transportation Research Institute. Retrieved 2025-04-03, from https://truckingresearch.org/2023/06/atris-newest-operational-costs-research-details-spikes-in-equipment-wage-and-total-costs-in-trucking/

Aurora. (2024, April). *Research: Autonomous Trucks Can Reduce Emissions and Fight Climate Change.* Retrieved 2025-04-16, from https://ir.aurora.tech/news-events/press-releases/detail/94/research-autonomous-trucks-can-reduce-emissions-and-fight

Banks, J. (2025, March). *The Ghost in the Machine: Will AI Open the Door to Fully Autonomous Robotic Surgery?* Retrieved 2025-05-15, from https://www.embs.org/pulse/articles/the-ghost-in-the-machine-will-ai-open-the-door-to-fully-autonomous-robotic-surgery/

Baxter, P., & Jack, S. (2015). Qualitative Case Study Methodology: Study Design and Implementation for Novice Researchers. *The Qualitative Report*. doi: 10.46743/2160-3715/2008.1573

Bhattacharjee, D., & Rittstieg, M. (2025, March). Boosting zero-emission truck adoption. *McKinsey & Company*. Retrieved 2025-05-02, from https://www.mckinsey.com/industries/logistics/our-insights/can-zero-emission-trucks-become-viable-and-what-will-it-take-to-boost-adoption

Bingham, A. J. (2023). From Data Management to Actionable Findings: A Five-Phase Process of Qualitative Data Analysis. *International Journal of Qualitative Methods*, *22*, 11. Retrieved 2025-05-26, from https://journals.sagepub.com/doi/epdf/10.1177/16094069231183620?src=getftr&utm_source=scopus&getft_integrator=scopus (10.1177/16094069231183620) doi: 10.1177/16094069231183620

Bishop, R. (2024, May). *Isuzu And Gatik Go All In To Scale Up Driverless Freight Services.* Retrieved 2025-04-24, from https://www.forbes.com/sites/richardbishop1/2024/05/30/isuzu-and-gatik-go-all-in-to-scale-up-driverless-freight-services/

BMW AG. (2025, January). *Preisliste BMW i7.* Retrieved from https://www.bmw.de/de/neufahrzeuge/bmw-i/i7/bmw-i7-limousine.html#preisliste

Boubakri, A., & Gamar, S. M. (2021). A New Architecture of Autonomous Vehicles: Redundant Architecture to Improve Operational Safety. *International Journal of Robotics and Control Systems*, *1*(3), 355–368. doi: 10.31763/ijrcs.v1i3.437

Bray, G., & Cebon, D. (2022). Operational speed strategy opportunities for autonomous trucking on highways. *Transportation Research Part A: Policy and Practice*, *158*, 75–94. doi: 10.1016/j.tra.2022.01.014

Bryman, A. (2007). Paradigm Peace and the Implications for Quality. *International Journal of Social Research Methodology*, *9*(2), 111–126. doi: 10.1080/13645570600595280

Brynjolfsson, E., & McAfee, A. (2014). *The second machine age: work, progress, and prosperity in a time of brilliant technologies*. New York: W. W. Norton & Company.

Cascetta, E., & Henke, I. (2023). The seventh transport revolution and the new challenges for sustainable mobility. *Journal of Urban Mobility*, *4*. doi: 10.1016/j.urbmob.2023.100059

Chen, Y., Shiwakoti, N., Stasinopoulos, P., & Khalid Khan, S. (2022). State-of-the-Art of Factors Affecting the Adoption of Automated Vehicles. *Sustainability*, *14*(11), 6697. doi: 10.3390/su14116697

Chinatruck. (2024, November). *Chinese electric heavy-duty trucks are caught up in a price war.* Retrieved 2025-05-02, from https://www.chinatruck.net/news/chinese-electric-heavy-duty-trucks-are-caught-up-in-a-price-war/

Christensen, C. M. (2016). *The Innovator's Dilemma : When New Technologies Cause Great Firms to Fail* (3rd ed.). Boston, Massachusetts: Harvard Business Review Press.

Christensen, C. M., Suárez, F. F., & Utterback, J. M. (1998). Strategies for Survival in Fast-Changing Industries. *Management Science*, *44*(12), S207–S220. Retrieved from https://www.jstor.org/stable/779725

Collis, J. (2021). *Business Research: A Practical Guide for Students* (5th ed ed.). London: Macmillan Education UK.

Constantinescu, M., Voinea, C., Uszkai, R., & Vică, C. (2021). Understanding responsibility in Responsible AI. Dianoetic virtues and the hard problem of context. *Ethics and Information Technology*, *23*(4), 803–814. doi: 10.1007/s10676-021-09616-9

Cooper, A. C., & Schendel, D. (1976). Strategic responses to technological threats. *Business Horizons*, *19*(1), 61–69. doi: 10.1016/0007-6813(76)90024-0

Darko, E. O., & Vlachos, I. (2022). Creating Valuable Relationships with Third-Party Logistics (3PL) Providers: A Multiple-Case Study. *Logistics*, *6*(2), 38. doi: 10.3390/logistics6020038

Dekra. (n.d.). *Berufskraftfahrer Weiterbildung Lkw/Bus - Wochenseminar.* Retrieved 2025-04-15, from https://www.dekra-akademie.de/produkte/berufskraftfahrer-weiterbildung-lkwbus-wochenseminar

DFDS A/S. (n.d.). *Terminal Services | Freight Shipping Services | DFDS (INT).* Retrieved 2025-02-25, from https://www.dfds.com/en/freight-ferries-and-logistics/terminal-services

DFDS A/S. (2023). *DFDS Annual Report 2023.* Retrieved 2025-01-29, from https://assets.ctfassets.net/mivicpf5zews/2i59XdMhwaRbABYhbwMemg/febc2eecc54ee631deff8e940310d459/DFDS_ANNUAL_REPORT_2023.pdf

Dong, C., Akram, A., Andersson, D., Arnäs, P.-O., & Stefansson, G. (2021). The impact of emerging and disruptive technologies on freight transportation in the digital era: current state and future trends. *The International Journal of Logistics Management*, *32*(2), 386–412. doi: 10.1108/IJLM-01-2020-0043

Edgerton, D. (2007). *The shock of the old : technology and global history since 1900*. New York: New York : Oxford University Press.

EEA. (2025a, January). *Autonomous freight transport.* Retrieved 2025-02-25, from https://www.eea.europa.eu/en/analysis/publications/transport-and-environment-report-2022/annex-3-autonomous-freight-transport/annex-3-autonomous-freight-transport

EEA. (2025b, February). *Transport and Mobility.* Retrieved 2025-03-14, from https://www.eea.europa.eu/en/topics/in-depth/transport-and-mobility

Eisenhardt, K. M. (1989). Building Theories from Case Study Research. *The Academy of Management Review*, *14*(4), 532–550. doi: 10.2307/258557

Elvik, R. (2020). The demand for automated vehicles: A synthesis of willingness-to-pay surveys. *Economics of Transportation*, *23*. doi: 10.1016/j.ecotra.2020.100179

Engholm, A., Kristoffersson, I., & Pernestal, A. (2021). Impacts of large-scale driverless truck adoption on the freight transport system. *Transportation Research Part A: Policy and Practice*, *154*, 227–254. doi: 10.1016/j.tra.2021.10.014

Engholm, A., Pernestal, A., & Kristoffersson, I. (2020). Cost Analysis of Driverless Truck Operations. *Transportation Research*, *2674*(9), 511–524. doi: 10.1177/0361198120930228

Engström, J., Bishop, R., Shladover, S. E., Murphy, M. C., O'Rourke, L., Voege, T., ... Demato, D. (2019). Deployment of Automated Trucking: Challenges and Opportunities. In *Road Vehicle Automation 5* (pp. 149–162). Springer, Cham. (doi: 10.1007/978-3-319-94896-6_13)

European Comission. (2023). *Facts and Figures Buses / coaches / heavy goods vehicles* (Tech. Rep.). Retrieved from https://road-safety.transport.ec.europa.eu/statistics-and-analysis/data-and-analysis/facts-and-

European Commission. (2019, March). *Road safety: Commission welcomes agreement on new EU rules to help save lives.* Retrieved 2025-04-04, from https://ec.europa.eu/commission/presscorner/detail/en/ip_19_1793

European Union. (2024, July). *Regulation (EU) 2019/2144 of the European Parliament and of the Council* [Database]. Retrieved 2025-02-26, from https://eur-lex.europa.eu/eli/reg/2019/2144/2024-07-07/eng

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

Ferraro, C., Demsar, V., Sands, S., Restrepo, M., & Campbell, C. (2024). The paradoxes of generative AI-enabled customer service: A guide for managers. *Business Horizons*, *67*(5), 549–559. doi: 10.1016/j.bushor.2024.04.013

Fildes, B., Keall, M., Bos, N., Lie, A., Page, Y., Pastor, C., ... Tingvall, C. (2015). Effectiveness of low speed autonomous emergency braking in real-world rear-end crashes. *Accident Analysis & Prevention*, *81*, 24–29. doi: 10.1016/j.aap.2015.03.029

Filippi, E., Bannò, M., & Trento, S. (2023). Automation technologies and their impact on employment: A review, synthesis and future research agenda. *Technological Forecasting and Social Change*, *191*. doi: 10.1016/j.techfore.2023.122448

Fitzpatrick, A. (2016, October). *Watch Uber's Self-Driving Trucks Make a Beer Run.* Retrieved 2025-03-03, from https://time.com/4544135/uber-otto-self-driving-trucks-budweiser-beer/

Flyvbjerg, B. (2006). Five Misunderstandings About Case-Study Research. *Qualitative Inquiry*, *12*(2), 219–245. doi: 10.1177/1077800405284363

Flämig, H. (2016). Autonomous Vehicles and Autonomous Driving in Freight Transport. In M. Maurer, J. C. Gerdes, B. Lenz, & H. Winner (Eds.), *Autonomous Driving: Technical, Legal and Social Aspects* (pp. 365–385). Berlin, Heidelberg: Springer. doi: 10.1007/978-3-662-48847-8_18

Foster, L., Sloan, L., Bryman, A., & Clark, T. (2021). *Bryman's social research methods* (6th ed.). Oxford: Oxford University Press.

Fritschy, C., & Spinler, S. (2019). The impact of autonomous trucks on business models in the automotive and logistics industry–a Delphi-based scenario study. *Technological Forecasting and Social Change*, *148*. doi: 10.1016/j.techfore.2019.119736

Gans, J. S., & Stern, S. (2003). The product market and the market for "ideas": commercialization strategies for technology entrepreneurs. *Research Policy*, *32*(2), 333–350. doi: 10.1016/S0048-7333(02)00103-8

Geddes, N. B. (1940). *Magic Motorways*. Random House.

Gilroy, R. (2018, November). Volvo Launches Transport Service Using Fully Autonomous Trucks. *Transport Topics*. Retrieved 2025-03-02, from https://www.ttnews.com/articles/volvo-launches-transport-service-using-fully-autonomous-trucks

Gonçalves, A. R., Pinto, D. C., Shuqair, S., Dalmoro, M., & Mattila, A. S. (2024). Artificial intelligence vs. autonomous decision-making in streaming platforms: A mixed-method approach. *International Journal of Information Management*, *76*. doi: 10.1016/j.ijinfomgt.2023.102748

Gruel, W., & Stanford, J. M. (2016). Assessing the Long-term Effects of Autonomous Vehicles: A Speculative Approach. *Transportation Research Procedia*, *13*, 18–29. doi: 10.1016/j.trpro.2016.05.003

Gundermann, S., Janssen, R., Rüger, M., Pillich, S. M., Sprink, P., & Schreck, T. (2024, September). *Cost-efficient automotive production -Rising to the challenge* (Tech. Rep.). Roland Berger.

Gölbaşı, O., & Dagdelen, K. (2017). *Equipment Replacement Analysis of Manual Trucks with Autonomous Truck Technology in Open Pit Mines* (No. 19-20). Colorado School of Mines.

Haghani, M., Ghaderi, H., & Hensher, D. (2024). Hidden effects and externalities of electric vehicles. *Energy Policy*, *194*. doi: 10.1016/j.enpol.2024.114335

Hassan, S. E., Andruetto, C., & Posch, A. (2024). The role of battery electric vehicles in off-peak hour deliveries: Sustainability assessment of a case study in Stockholm. *Cleaner Logistics and Supply Chain*, *13*, 100175. doi: 10.1016/j.clscn.2024.100175

Hawkins, A. J. (2021, August). Waymo is building a hub for its autonomous trucks in Texas. *The Verge*. Retrieved 2025-03-02, from https://www.theverge.com/2021/8/18/22628836/waymo-autonomous-truck-hub-texas-ryder

HHLA. (2021, October). *Zukunft des Güterverkehrs - HHLA.* Retrieved 2025-03-02, from https://hhla.de/medien/news/detailansicht/zukunft-des-gueterverkehrs

IEA. (2024, May). *Global EV Outlook 2024* (Tech. Rep.). International Energy Agency. Retrieved from https://iea.blob.core.windows.net/assets/a9e3544b-0b12-4e15-b407-65f5c8ce1b5f/GlobalEVOutlook2024.pdf

INC, A. M. R. (2025, March). *Autopilot Systems Market to Reach $10.6 billion, Globally, by 2033 at 6.4% CAGR: Allied Market Research.* Retrieved 2025-05-14, from https://www.globenewswire.com/news-release/2025/03/11/3040694/0/en/Autopilot-Systems-Market-to-Reach-10-6-billion-Globally-by-2033-at-6-4-CAGR-Allied-Market-Research.html

Irles, S. (2023, February). *Battery electric trucks emit 63% less GHG emissions than diesel.* Retrieved 2025-02-18, from https://theicct.org/battery-electric-trucks-emit-63-less-ghg-emissions-than-diesel/

IRU. (2024, September). *Europe Truck Driver Shortage Report 2023* (Tech. Rep.). Retrieved 2025-02-18, from https://www.iru.org/resources/iru-library/europe-truck-driver-shortage-report-2023

Ji-Hyland, C., & Allen, D. (2022). What do professional drivers think about their profession? An examination of factors contributing to the driver shortage. *International Journal of Logistics Research and Applications*, *25*(3), 231–246. doi: 10.1080/13675567.2020.1821623

Kachwala, Z. (2024, August). California issues draft regulations for operating autonomous trucks. *Reuters*. Retrieved 2025-03-02, from https://www.reuters.com/business/autos-transportation/california-issues-draft-regulations-operating-autonomous-trucks-2024-08-30/

Kuran, C. H. A., Njå, O., & Braut, G. S. (2023). Conceptualizing the bending and breaking of rules in the heavy goods transport sector. *Safety Science*, *166*. doi: 10.1016/j.ssci.2023.106235

Lee, C., Dalmeijer, K., Van Hentenryck, P., & Zhang, P. (2024). Optimizing Autonomous Transfer Hub Networks: Quantifying the potential impact of self-driving trucks. *EURO Journal on Transportation and Logistics*, *13*. doi: 10.1016/j.ejtl.2024.100141

Lieberman, M. B., & Montgomery, D. B. (1988). First-Mover Advantages. *Strategic Management Journal*, *9*, 41–58. Retrieved from https://www.jstor.org/stable/2486211

Liu, Y., Chen, H., Wu, S., Gao, J., Li, Y., An, Z., ... Li, T. (2022). Impact of vehicle type, tyre feature and driving behaviour on tyre wear under real-world driving conditions. *Science of The Total Environment*, *842*. doi: 10.1016/j.scitotenv.2022.156950

Loebbecke, C., & Picot, A. (2015). Reflections on societal and business model transformation arising from digitization and big data analytics: A research agenda. *The Journal of Strategic Information Systems*, *24*(3), 149–157. doi: 10.1016/j.jsis.2015.08.002

Mahoney, J., & Schensul, D. (2006). Historical Context and Path Dependence. In R. Goodin & C. Tilly (Eds.), *The Oxford Handbook of Contextual Political Analysis.* Oxford University Press. doi: 10.1093/oxfordhb/9780199270439.003.0024

Markides, C. C. (2005). *Fast second: how smart companies bypass radical innovation to enter and dominate new markets* (P. A. Geroski, Ed.). San Francisco: Jossey-Bass.

Martínez-Díaz, M., Al-Haddad, C., Soriguera, F., & Antoniou, C. (2021). Platooning of connected automated vehicles on freeways: a bird's eye view. *Transportation Research Procedia*, *58*, 479–486. doi: 10.1016/j.trpro.2021.11.064

Mauler, L., Dahrendorf, L., Duffner, F., Winter, M., & Leker, J. (2022). Cost-effective technology choice in a decarbonized and diversified long-haul truck transportation sector: A U.S. case study. *Journal of Energy Storage*, *46*. doi: 10.1016/j.est.2021.103891

McKinsey & Company. (2016, January). *Automotive revolution – perspective towards 2030.* Retrieved 2025-01-21, from https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/disruptive-trends-that-will-transform-the-auto-industry/de-DE

McKinsey & Company. (2024, September). *The business case for autonomous truck fleets* (Tech. Rep.). Retrieved 2025-02-07, from https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/will-autonomy-usher-in-the-future-of-truck-freight-transportation

McKinsey & Company. (2025a, February). *The electric-vehicle transition: A consumer view* (Tech. Rep.). Retrieved 2025-04-25, from https://www.mckinsey.com/features/mckinsey-center-for-future-mobility/our-insights/new-twists-in-the-electric-vehicle-transition-a-consumer-perspective

McKinsey & Company. (2025b, January). *The future of autonomous vehicles* (Tech. Rep.). Retrieved 2025-04-13, from https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/autonomous-drivings-future-convenient-and-connected

Mehlhorn, M. A., Richter, A., & Shardt, Y. A. (2023). Ruling the Operational Boundaries: A Survey on Operational Design Domains of Autonomous Driving Systems. *IFAC-PapersOnLine*, *56*(2), 2202–2213. doi: 10.1016/j.ifacol.2023.10.1128

Mercedes-Benz. (n.d.). *Mercedes-Benz Car Configurator EQS.* Retrieved 2025-05-30, from https://www.mercedes-benz.de/passengercars/configurator.html

Mobility Sweden. (2025). *Databas Nyregistreringar.* Retrieved 2025-02-26, from https://mobilitysweden.se/statistik/databas-nyregistreringar

MODI. (n.d.). *MODI Project.* Retrieved 2025-01-27, from https://modiproject.eu/about/

Mohan, A., & Vaishnav, P. (2022). Impact of automation on long haul trucking operator-hours in the United States. *Humanities and Social Sciences Communications*, *9*(1), 1–10. doi: 10.1057/s41599-022-01103-w

Mommens, K., van Lier, T., & Macharis, C. (2020). Multimodal choice possibilities for different cargo types: Application to Belgium. *Research in Transportation Business & Management*, *37*. doi: 10.1016/j.rtbm.2020.100528

Monaco, K. A., & Brooks, T. J. (2001). Deregulation and wages in trucking: A time series phenomenon — A time series approach. *Research in Transportation Economics*, *6*, 55–69. doi: 10.1016/S0739-8859(01)80006-8

Monios, J., & Bergqvist, R. (2019). The transport geography of electric and autonomous vehicles in road freight networks. *Journal of Transport Geography*, *80*, 102500. doi: 10.1016/j.jtrangeo.2019.102500

Monios, J., & Bergqvist, R. (2020). Logistics and the networked society: A conceptual framework for smart network business models using electric autonomous vehicles (EAVs). *Technological Forecasting and Social Change*, *151*. doi: 10.1016/j.techfore.2019.119824

Moore, G. E. (1965). Cramming more components onto integrated circuits. *Electronics*, *38*(8). Retrieved 2025-03-22, from http://cva.stanford.edu/classes/cs99s/papers/moore-crammingmorecomponents.pdf

Moravec, H. (1990). *Mind Children - The Future of Robot and Human Intelligence*. Harvard University Press.

Murtaza, M., Cheng, C.-T., Fard, M., & Zeleznikow, J. (2023). Preparing drivers for the future: Evaluating the effects of training on drivers' performance in an autonomous vehicle landscape. *Transportation Research Part F: Traffic Psychology and Behaviour*, *98*, 280–296. doi: 10.1016/j.trf.2023.09.013

Müller, S., & Voigtländer, F. (2019). Automated Trucks in Road Freight Logistics: The User Perspective. In U. Clausen, S. Langkau, & F. Kreuz (Eds.), *Advances in Production, Logistics and Traffic* (pp. 102–115). Cham: Springer International Publishing. doi: 10.1007/978-3-030-13535-5_8

Navia Simon, D., & Diaz Anadon, L. (2025). Power price stability and the insurance value of renewable technologies. *Nature Energy*, *10*(3), 329–341. doi: 10.1038/s41560-025-01704-0

Newnam, S., Koppel, S., Molnar, L. J., Zakrajsek, J. S., Eby, D. W., & Blower, D. (2020). Older truck drivers: How can we keep them in the workforce for as long as safely possible? *Safety Science*, *121*, 589–593. doi: 10.1016/j.ssci.2019.02.024

OECD. (2024, October). *Annual transport trends* (Tech. Rep.). Sweden: OECD. Retrieved 2025-04-03, from https://data-explorer.oecd.org/vis?df[ds]=DisseminateFinalDMZ&df[id]=DSD_TRENDS%40DF_TRENDS&df[ag]=OECD.ITF&dq=.A.....&lom=LASTNPERIODS&lo=5&to[TIME_PERIOD]=false

Ogazón, E., Anaya-Arenas, A. M., & Ruiz, A. (2025). Designing hub-based regional transportation networks with service level constraints. *Transportation Research Part E: Logistics and Transportation Review*, *195*. doi: 10.1016/j.tre.2025.103991

OpenAI. (2025). *ChatGPT.* Retrieved from https://chat.openai.com

Papadopoulos, G., Arduini, S., Uyar, H., Psiroukis, V., Kasimati, A., & Fountas, S. (2024). Economic and environmental benefits of digital agricultural technologies in crop production: A review. *Smart Agricultural Technology*, *8*. doi: 10.1016/j.atech.2024.100441

Parviziomran, E., & Bergqvist, R. (2025). Decarbonization costs for the Swedish heavy-duty road fleet: Circular economy insights on electric truck batteries. *Transport Policy*, *160*, 1–14. doi: 10.1016/j.tranpol.2024.10.033

Pendergast, J. (2024, September). *Owner-Operator Expenses for Running a Trucking Company.* Retrieved 2025-04-01, from https://altline.sobanco.com/owner-operator-expenses/

Persyn, D., Díaz-Lanchas, J., & Barbero, J. (2022). Estimating road transport costs between and within European Union regions. *Transport Policy*, *124*, 33–42. doi: 10.1016/j.tranpol.2020.04.006

Phan, D. C., & Truong, L. T. (2024). Traffic Congestion and Safety: Mixed Effects on Total and Fatal Crashes. *Sustainability*, *16*(20), 8911. doi: 10.3390/su16208911

Poletti, N. E. d. B., Gita Venkataramani Johar. (2023, June). *The Trade-Offs of Autonomous Products: Efficiency vs. Experience.* Retrieved 2025-05-14, from https://www.ama.org/2023/06/06/autonomous-products-make-our-lives-easier-but-do-they-deprive-us-of-meaningful-experiences/

Price, R., Cornelius, M., Burnside, L., & Miller, B. (2020). Mine planning and selection of autonomous trucks. *Springer Series in Geomechanics and Geoengineering*, 203–212. doi: 10.1007/978-3-030-33954-8_26

Riggs, W., & Richardson, E. (2024, July). *Estimating the Cost of Autonomous Vehicles* [SSRN Scholarly Paper]. Rochester, NY: Social Science Research Network. Retrieved 2025-04-11, from https://papers.ssrn.com/abstract=4998828 doi: 10.2139/ssrn.4998828

Robertsone, G., & Lapiņa, I. (2023). Digital transformation as a catalyst for sustainability and open innovation. *Journal of Open Innovation: Technology, Market, and Complexity*, *9*(1). doi: 10.1016/j.joitmc.2023.100017

RXO. (2025, January). *Spot vs. Contract Rates: The Difference in Truckload Shipping.* Retrieved 2025-04-25, from https://rxo.com/resources/shipper/contract-vs-spot-rates/,https://rxo.com/resources/shipper/contract-vs-spot-rates/

SAE. (2021, April). *Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles.* SAE International. Retrieved 2025-01-22, from https://www.sae.org/content/j3016_202104 doi: 10.4271/J3016_202104

SAE. (2022, October). *Timeline SAE Level 4 Driving automation.* Retrieved 2025-03-27, from https://www.sae.org/site/news/2022/10/the-autonomous-level-4-horizon

Saffo, P. (2007). Six Rules for Effective Forecasting. *Harvard Business Review*, *85*(7/8), 122–131. Retrieved from https://hbr.org/2007/07/six-rules-for-effective-forecasting

Saleh, M., Chowdhury, T., Vaughan, J., Wang, A., Mousavi, K., Roorda, M. J., & Hatzopoulou, M. (2022). Climate and air quality impacts of off-peak commercial deliveries. *Transportation Research Part D: Transport and Environment*, *109*, 103360. doi: 10.1016/j.trd.2022.103360

SCB. (2024, March). *Genomsnittlig månadslön, kronor efter sektor, Yrke (SSYK 2012), kön och år. PxWeb.* Retrieved 2025-03-28, from https://www.statistikdatabasen.scb.se/pxweb/sv/ssd/START__AM__AM0110__AM0110A/LoneSpridSektorYrk4A/table/tableViewLayout1/

Schuster, A. M., Agrawal, S., Britt, N., Sperry, D., Van Fossen, J. A., Wang, S., ... Cotten, S. R. (2023). Will automated vehicles solve the truck driver shortages? Perspectives from the trucking industry. *Technology in Society*, *74*. doi: 10.1016/j.techsoc.2023.102313

Sever, T., & Contissa, G. (2024). Automated driving regulations – where are we now? *Transportation Research Interdisciplinary Perspectives*, *24*. doi: 10.1016/j.trip.2024.101033

Shetty, A., Yu, M., Kurzhanskiy, A., Grembek, O., Tavafoghi, H., & Varaiya, P. (2021). Safety challenges for autonomous vehicles in the absence of connectivity. *Transportation Research Part C: Emerging Technologies*, *128*. doi: 10.1016/j.trc.2021.103133

Short, J. (2024, December). *Trucking's Annual Congestion Costs Rise to $108.8 Billion.* Retrieved 2025-05-16, from https://truckingresearch.org/2024/12/truckings-annual-congestion-costs-rise-to-108-8-billion/ (Section: ATRI Press Releases)

Sindi, S., & Woodman, R. (2021). Implementing commercial autonomous road haulage in freight operations: An industry perspective. *Transportation Research Part A: Policy and Practice*, *152*, 235–253. doi: 10.1016/j.tra.2021.08.003

Skatteverket. (n.d.). *Arbetsgivaravgifter.* Retrieved 2025-04-01, from https://skatteverket.se/foretag/arbetsgivare/arbetsgivaravgifterochskatteavdrag/arbetsgivaravgifter.4.233f91f71260075abe8800020817.html

Skeete, J.-P. (2018). Level 5 autonomy: The new face of disruption in road transport. *Technological Forecasting and Social Change*, *134*, 22–34. doi: 10.1016/j.techfore.2018.05.003

Slowik, P., & Sharpe, B. (2018, March). *Automation in the long haul: Challenges and opportunities of autonomous heavy-duty trucking in the United States* (Tech. Rep.).

Steinberg, A. (2022, July). *Pony.ai and SANY Establish Joint Venture to Develop Next Generation of Autonomous Trucks for Mass Production.* Retrieved 2025-04-17, from https://www.businesswire.com/news/home/20220727006184/en/Pony.ai-and-SANY-Establish-Joint-Venture-to-Develop-Next-Generation-of-Autonomous-Trucks-for-Mass-Production

Storm, J. (2025, February). *The Future of Tire Technology: Smarter, Safer, and More Sustainable.* Retrieved 2025-04-24, from https://www.niradynamics.com/latest/the-future-of-tire-technology-smarter-safer-and-more-sustainable

Szeszák, B. M., Kerékjártó, I. G., Soltész, L., & Galambos, P. (2025). Industrial Revolutions and Automation: Tracing Economic and Social Transformations of Manufacturing. *Societies*, *15*(4), 88. doi: 10.3390/soc15040088

Tao, X., Mårtensson, J., Warnquist, H., & Pernestål, A. (2022). Short-term maintenance planning of autonomous trucks for minimizing economic risk. *Reliability Engineering & System Safety*, *220*. doi: 10.1016/j.ress.2021.108251

Tesla. (2025). *Full Self-Driving (Supervised) Subscriptions.* Retrieved 2025-04-15, from https://www.tesla.com/support/full-self-driving-subscriptions

The Mover. (2022, January). *Volvo's heavy-duty electric truck put to the test.* Retrieved 2025-03-28, from https://www.themover.co.uk/news/2022/01/19/volvo-s-heavy-duty-electric-truck-put-to-the-test

Thrun, S. (2010). Toward Robotic Cars. *Communications of the ACM*, *53*(4), 99–106. doi: 10.1145/1721654.1721679

TomTom. (2024, December). *Gothenburg traffic report 2024.* Retrieved 2025-04-28, from https://www.tomtom.com/traffic-index/gothenburg-traffic/

TRATON. (2022a, October). *Advanced legal framework in the EU.* Retrieved 2025-02-26, from https://traton.com/en/newsroom/stories/legal-framework-in-the-eu-driverless-through-europe.html

TRATON. (2022b, October). *Interview with Berylls: Autonomous driving as a business model.* Retrieved 2025-02-21, from https://traton.com/en/newsroom/stories/berylls-autonomous-driving-business-model.html

Tripsas, M. (1997). Unraveling the Process of Creative Destruction: Complementary Assets and Incumbent Survival in the Typesetter Industry. *Strategic Management Journal*, *18*, 119–142. Retrieved from https://www.jstor.org/stable/3088213

Tu, H., Zhao, L., Tu, R., & Li, H. (2024). The energy-saving effect of early-stage autonomous vehicles: A case study and recommendations in a metropolitan area. *Energy*, *297*. doi: 10.1016/j.energy.2024.131274

Turienzo, J., Cabanelas, P., & Lampón, J. F. (2023). Business models in times of disruption: The connected and autonomous vehicles (uncertain) domino effect. *Journal of Business Research*, *156*, 113481. doi: 10.1016/j.jbusres.2022.113481

TuSimple. (2023). *Autonomous Fuel Efficiency Study* (Tech. Rep.).

Upreti, A., & Sridhar, V. (2024). Effect of automation of routine and non-routine tasks on labour demand and wages. *IIMB Management Review*, *36*(4), 289–308. doi: 10.1016/j.iimb.2024.09.001

Vasiliauskas, A. V., & Jakubauskas, G. (2007). Principle and benefits of third party logistics approach when managing logistics supply chain. *Transport*, *22*(2), 68–72. doi: 10.1080/16484142.2007.9638101

Venkatesh, V., Brown, S. A., & Bala, H. (2013). Bridging the Qualitative-Quantitative Divide: Guidelines for Conducting Mixed Methods Research in Information Systems. *MIS Quarterly*, *37*(1), 21–54. doi: 10.25300/MISQ/2013/37.1.02

Volvo AB. (2019, June). *Vera's first assignment: Volvo Trucks presents an autonomous transport between a logistics centre and port.* Retrieved 2025-03-03, from https://www.volvogroup.com/en/news-and-media/news/2019/jun/news-3336083.html

Wadud, Z. (2017). Fully automated vehicles: A cost of ownership analysis to inform early adoption. *Transportation Research Part A: Policy and Practice*, *101*, 163–176. doi: 10.1016/j.tra.2017.05.005

Wadud, Z., MacKenzie, D., & Leiby, P. (2016). Help or hindrance? The travel, energy and carbon impacts of highly automated vehicles. *Transportation Research Part A: Policy and Practice*, *86*, 1–18. doi: 10.1016/j.tra.2015.12.001

Wood, A. W. (1991). Unsociable Sociability: The Anthropological Basis of Kantian Ethics. *Philosophical Topics*, *19*(1). Retrieved from https://www.jstor.org/stable/43154098

Wright, T. P. (1936). Factors Affecting the Cost of Airplanes. *Journal of the Aeronautical Sciences*, *3*(4), 122–128. doi: 10.2514/8.155

Xiaomi. (2024, April). *Xiaomi SU7: A Revolutionary EV Experience.* Retrieved 2025-04-15, from https://www.mi.com/global/discover/article/

Xu, S., Sun, C., & Liu, N. (2024). Road congestion and air pollution -Analysis of spatial and temporal congestion effects. *Science of The Total Environment*, *945*. doi: 10.1016/j.scitotenv.2024.173896

Yazdanpanah, V., Gerding, E. H., Stein, S., Dastani, M., Jonker, C. M., Norman, T. J., & Ramchurn, S. D. (2023). Reasoning about responsibility in autonomous systems: challenges and opportunities. *Ai & Society*, *38*(4), 1453–1464. doi: 10.1007/s00146-022-01607-8

Yin, R. K. (2018). *Case study research and applications: design and methods* (Sixth edition ed.). Thousand Oaks, California: SAGE.

Škerlič, S., & Sokolovskij, E. (2020). Analysis of heavy truck maintenance issues. *Pomorstvo*, *34*(1), 24–31. doi: 10.31217/p.34.1.3

A Total Cost Equation

To calculate the total costs for different vehicle utilisation rates as depicted in Figure 12, the following cost equation is defined as detailed:

$$C_{\text{total}} = \frac{C_f}{d} + C_v$$

where:

- C_f is the sum of fixed costs,
- d is the annual distance a truck travels,
- C_v is the sum of variable costs per kilometre.

The fixed cost is computed:

$$C_f = C_{driver} + C_{vehicle} + C_{tech} + C_{insurance}$$

where:

- C_{driver} is the total sum of annual costs for drivers employed per truck,
- $C_{vehicle}$ is the total cost per base vehicle discounted for a 5 year lifespan,
- C_{tech} is the total cost of the autonomous technology stack integrated into the base vehicle discounted for a 5 year lifespan,
- $C_{insurance}$ cost of annual insurance.

The variable cost is computed:

$$C_v = C_{fuel} + C_{service} + C_{tyres}$$

- C_{fuel} cost of fuel or energy per kilometre,
- $C_{service}$ cost of service and maintenance discounted per kilometre,

- C_{tyres} cost of tyre wear per kilometre.

This equation is used for all cost calculations and simulations.

B Power Requirement Calculation

To estimate the energy demand of a heavy-duty electric truck, such as a Volvo FH, at various speeds, a physics-based model is applied. The total resistive force acting on the vehicle is the sum of aerodynamic drag and rolling resistance:

$$F_{\text{total}} = F_d + F_r$$

Aerodynamic drag is computed using the standard drag force equation:

$$F_d = \frac{1}{2} \cdot \rho \cdot C_d \cdot A \cdot v^2$$

where:

- F_d is the drag force in newtons (N),
- $\rho = 1,225\,\text{kg/m}^3$ is the air density at sea level,
- $C_d = 0,65$ is the drag coefficient (typical for a streamlined truck),
- $A = 9\,\text{m}^2$ is the frontal area of the truck (approximate value for a Volvo FH),
- v is the vehicle speed in meters per second (m/s).

Rolling resistance is estimated using:

$$F_r = C_{rr} \cdot m \cdot g$$

where:

- F_r is the rolling resistance force (N),
- $C_{rr} = 0,006$ is the rolling resistance coefficient for heavy trucks,
- $m = 40.000\,\text{kg}$ is the mass of the vehicle,
- $g = 9,81\,\text{m/s}^2$ is the gravitational acceleration.

The instantaneous power required to overcome these forces at a given speed is calculated as:

$$P = F_{\text{total}} \cdot v$$

This value is converted to kilowatts (kW) for interpretability:

$$P_{\text{kW}} = \frac{P}{1000}$$

To estimate the energy consumption per kilometre (kWh/km), the power is divided by the vehicle speed (in km/h):

$$\text{Energy}_{\text{kWh/km}} = \frac{P_{\text{kW}}}{v_{\text{km/h}}}$$

The results of this calculation are presented in Figure 9.

C Transport Speed Classification

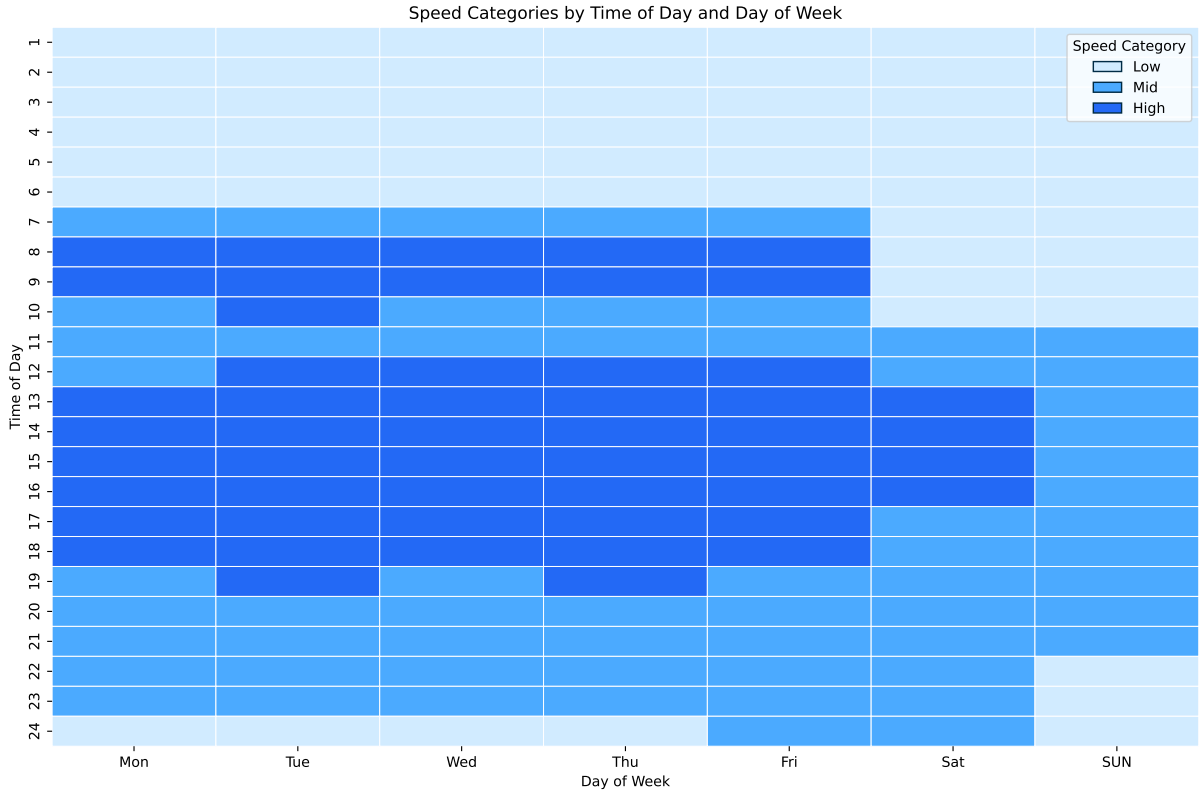

Figure 15: Targeted transport speed class derived from Gothenburg metro congestion data (TomTom, 2024)