MESG
MESTRADO EM ENGENHARIA
DE SERVIÇOS E GESTÃO

# Who goes first? A roadmap for deploying truck platooning

*Miguel Ferreira Gomes Centeio Jorge*

**Master Thesis**

Supervisors: Dr. Sérgio Pedro Duarte; Dr. António Lobo

U. PORTO
FEUP FACULDADE DE ENGENHARIA
UNIVERSIDADE DO PORTO

2024-07-01

*I want to dedicate this work to my mother and father, who not only allowed but also motivated me to dedicate myself 100% to this master's degree without having to work simultaneously.*

*I want to thank my sister, Carolina, who provided me with many scientific insights throughout the thesis and served as a reference for what can be achieved in today's world by choosing an academic path.*

*I want to thank my girlfriend, Ana, who supported and patiently endured me tirelessly throughout the completion of the thesis.*

*I want to thank my four grandparents, who have always valued education and the pursuit of knowledge through schooling, especially my grandfather António, who passed away this weekend as I submit this thesis.*

*Lastly, I want to thank all the Professors who have guided me throughout my entire academic journey, especially Professors Sérgio Duarte and António Lobo, my supervisors, and Professor Jorge Grenha Teixeira, the master's program director, who has always been very available and helpful.*

## Abstract

This thesis systematically examines acceptance factors influencing TP. With this technology, groups of trucks travel closely together using automated driving support systems to improve fuel efficiency, and safety, and reduce $CO_2$ emissions. By leveraging Service-Dominant Logic (S-D logic) as a guiding framework, the study addresses key questions on regulatory challenges, the role of System Dynamics (SD) models, and the current state of TP technology. Key stakeholders include regulators, road operators, original equipment manufacturers (OEMs), logistic service providers, carriers, truck drivers, and peripheral drivers. Methodologically, stakeholder identification, robust data collection, and SD modeling form the core approach. The research reveals significant insights: clear and adaptable regulations are needed, collaborative efforts between regulators and OEMs can enhance innovation, and TP can offer substantial benefits in fuel efficiency and safety. Additionally, the study highlights the importance of addressing societal concerns, such as job displacement, through strategies like retraining programs. This research contributes to an understanding of the dynamic interplay between the TP ecosystem's technology, regulation, and acceptance factors, ultimately promoting a sustainable, efficient, and safe transportation future.

## Keywords

Truck Platooning; Regulations; Service-Dominant Logic; System Dynamics; Value Co-Creation

## Acknowledgments

I want to thank Professors Sérgio Pedro Duarte and António Lobo, my supervisors, and Professor Jorge Grenha Teixeira, the master's program director.

I want to thank all my family and friends.

This research was funded in whole by the Fundação para a Ciência e a Tecnologia, I.P. (FCT, Funder ID = 50110000187) under the project with DOI 10.54499/PTDC/ECI-TRA/4672/2020.

## Table of Contents

## List of Tables

## List of Figures

## List of abbreviations

TP - Truck Platooning

SAE - Society of Automotive Engineers

S-D Logic - Service-Dominant Logic

ERTRAC - European Road Transport Research Advisory Council

GHG - Greenhouse Gas

ICT - Information and Communication Technology

HMI - Human-Machine Interface

AVs - Autonomous Vehicles

CLDs - Causal Loop Diagrams

SD - System Dynamics

V2V - Vehicle-to-vehicle

V2X - Vehicle-to-everything

OEMs - Original Equipment Manufacturers

CCD - Charged-coupled device

# 1 Background and Context

## 1.1 Motivation

Transportation is often described as the lifeblood of contemporary societies, enabling the global movement of people and goods. Guerrero-ibanez, Zeadally, and Contreras-Castillo (2015) highlight that transportation serves as a crucial infrastructure for modern society, with its efficiency being vital for individual mobility, commerce, and the economic progress of nations. By 2015, road transport accounted for 75.8% of the EU's inland transport, measured in tonne-kilometers, maintaining a notable share since 2006, as explained by Nowakowska-Grunt and Strzelczyk (2019). This significant reliance on road transport, particularly in urban areas, has led to increased environmental concerns, prompting initiatives to phase out conventional vehicles by 2050 and achieve $CO_2$-free logistics in major cities by 2030.

Currently, global warming is intensified by increased $CO_2$ emissions, primarily from vehicles that rely on petroleum as their fuel source, which emits $CO_2$ upon combustion. Tsugawa (2014) states that, in Japan, the transportation sector consumes roughly 20% of the nation's total energy, with automobiles alone being responsible for about 90% of this consumption. In 2011, $CO_2$ emissions from the transportation sector amounted to 222 million tons, constituting 18% of the nation's total emissions (1,240 million tons), with 91% of these emissions stemming from automobiles. Enhancing fuel efficiency in internal combustion engine vehicles is therefore directly correlated with reducing $CO_2$ emissions.

Reducing $CO_2$ emissions from trucks is vital for energy conservation and combating global warming, according to Tsugawa, Jeschke, and Shladover (2016). The authors highlight that traditional road transportation faces major concerns such as fuel savings, personnel costs, safety, high congestion, lack of comfort (from the driver's perspective), transportation capacity, and convenience. In Japan, the trucking industry struggles with minimizing operating costs and coping with an aging driver population. In 2010, personnel and fuel costs constituted 36% and 18% of total expenses respectively. The number of elderly truck drivers is rising, while the proportion of younger drivers is decreasing due to Japan's declining population. Truck automation could help alleviate the shortage of heavy truck drivers, a trend also observed in Europe and North America, albeit with varying numerical values. Additionally, the European economy faces serious threats from an overloaded trans-European roadway network, attributed to various factors including opaque infrastructure costs and suboptimal traffic system organization.

Truck Platooning (TP), a transformative solution to these challenges, involves a group of trucks traveling closely together, benefiting from communication technology and vehicle automation. Tsugawa, Jeschke, and Shladover (2016) describe how TP, using cooperative adaptive cruise control (CACC) and lane-keeping systems, offers significant energy efficiency benefits. When vehicles travel in a platoon, aerodynamic drag decreases due to drafting, particularly effective at higher speeds where drag increases exponentially. This results in substantial energy savings. Automatic speed control and cooperative vehicle following further enhance energy optimization by smoothing acceleration and deceleration and reducing speed fluctuations in traffic. These measures not only save energy but also decrease emissions of pollutants, including $CO_2$. While the primary aim of TP is not crash avoidance, its facilitation by vehicle-to-vehicle communication enables faster reactions to potential issues than human drivers, enhancing safety. Additionally, TP could address the shortage of heavy truck drivers.

In platoon driving, a convoy is formed by two or more vehicles, with the lead vehicle being manually driven. The following vehicles are electronically connected and maintain a close distance. Castritius et al. (2021) states that these vehicles operate in a semi-automated mode, where a system takes control of both lateral and longitudinal aspects, but the driver needs to stay alert. This is categorized as Stage 2 automation, according to the Society of Automotive Engineers (SAE, 2018). Tsugawa (2014)'s report provides a technical description of a specific convoy used in an experiment, involving a group of trucks—three heavy trucks and a light truck—traveling closely together at a constant speed of 80 km/h with a gap of 10 meters between each truck. Various technologies are employed for functions such as lane keeping, speed control, collision avoidance, and gap keeping. Each truck is equipped with machine vision units for lateral control, including charged-coupled device (CCD) cameras and active vision systems for robustness. Sensing systems for longitudinal control consist of radar and 2-dimensional lidar. Vehicle-to-vehicle (V2V) communications facilitate real-time data sharing among trucks, aiding in maintaining desired speed and gap distances. The lateral and longitudinal control systems operate independently for each truck, ensuring reliability and fault detection. Essentially, TP is promoted as a safer and more environmentally friendly method for long-distance freight transport, which can result in reduced transportation expenses and simpler driving tasks.

## 1.2 Problem Definition

In the changing field of transportation, stakeholder perspectives often present both opportunities and challenges. Sérgio Pedro Duarte, Cunha, et al. (2023) highlight that while some stakeholders recognize certain advantages, they also perceive these as potential obstacles, emphasizing the need to consider stakeholders' requirements and perceived risks. Their research underscores the importance of involving regulators and road operators in establishing regulations and creating optimal conditions for implementation. This involvement ensures a balanced consideration of benefits and risks for all parties involved. Given the diverse range of actors - drivers, technology, infrastructure, and regulation - and the complexity of their relationships, an integrated and systemic approach is necessary.

Service-dominant logic (S-D logic), as explained by Vargo (2011), provides a comprehensive framework centered on value co-creation within interconnected service ecosystems. Frow and Payne (2011) further, explore the complexities of this model by examining the interplay between value propositions and creation among diverse stakeholders. This illuminates how understanding value propositions within broader systems, rather than isolated interactions, enhances our grasp of value generation within networks.

Human beings are excellent problem solvers, a skill refined through evolutionary pressures where quick decisions ensure survival. Kirkwood (1998) explains that people tend to attribute problems to immediate causes, a strategy effective for simple issues. However, as problems become more complex, such as in cross-functional or strategic management, this approach falls short. This challenge is exemplified by companies grappling with long-standing issues despite having time to adapt. Despite personnel changes, organizations often struggle to break free from old behavioral patterns that impede change.

In this context, Ylén and Hölttä (2007) observe System Dynamics (SD) is about using dynamic models in real-world scenarios such as decision-making and production. These models, though complex and nonlinear, help understand systems that may not be easily analyzed theoretically. Structural analysis, focusing on feedback loops, gives insights into potential behaviors, even though it is somewhat speculative without precise data. These models are handy for optimizing systems, predicting outcomes, and designing controls. For instance, they can help minimize fluctuations in labor supply or anticipate changes in market prices. In managing rapid shifts, such as sudden increases in demand for engineers, tailored control designs can prevent disruptive oscillations in the system.

Integrating these insights, it may be beneficial to adopt the concept of "driving as a service," which merges the relational requirements of TP with contemporary service principles (Sérgio P. Duarte et al. 2024). This involves applying an S-D logic, a viewpoint that sees every interaction within an economy as a service-to-service exchange, to develop a comprehensive systems approach to the TP ecosystem, as perceived by service facilitators such as regulators and road operators, but it also intersects with the principles of SD due to the complexity of TP systems, allowing for dynamic modeling and prediction of outcomes. By incorporating SD methodologies, stakeholders can gain deeper insights into the potential behaviors of the system and design effective controls to mitigate disruptions and optimize performance. Thus, by embracing both S-D logic and SD, a more comprehensive and robust approach to driving as a service can be achieved, addressing the diverse needs and challenges of all stakeholders involved.

However, it is important to recognize that adopting a services engineering approach in the realm of TP, integrating S-D logic and SD may pose challenges. These could include issues related to data availability, stakeholder collaboration, and regulatory compliance. Thus, it is crucial to carefully consider these factors and develop strategies to overcome potential obstacles. In this context, the proposed research seeks to address the following research questions:

- RQ1: Regulatory challenges in TP - What are the primary challenges associated with TP from a regulatory perspective?
- RQ2: SD’s role in addressing regulatory challenges - How can an SD model, through its Causal Loop Diagrams (CLDs), offer insights and solutions to the regulatory challenges posed by TP?

In essence, according to Sérgio Pedro Duarte, Cunha, et al. (2023), regulators and road operators play a central role in shaping the landscape of TP, ensuring a balance between safety, infrastructure, and operational efficiency. On the one hand, regulators set foundational rules, such as safety protocols and infrastructure standards. On the other, road operators implement and manage these guidelines on the ground. Their interdependent relationship requires clear communication and mutual understanding, ensuring that as technology evolves, both regulations and operations remain relevant and aligned.

Value co-creation is essential in collaboratively shaping the regulatory landscape. Sérgio Pedro Duarte, Lobo, et al. (2023) explain that this approach is crucial, both for the effective deployment of technology and to address stakeholders’ concerns and maintain the overall integrity of the transportation ecosystem, assuring a harmonized approach where innovation, safety, and efficiency intersect. In fact, Galvagno and Dalli (2014) propose that by aligning their objectives and resources, these entities cultivate an ecosystem with mutual benefits, underscoring the essence of value co-creation in advancing the transportation sector.

This research aims to contribute to the existing body of knowledge by elucidating the complex interplay between regulation, technology, and operational dynamics within the TP ecosystem. By addressing these research questions, we can enhance our understanding of the challenges and opportunities inherent in TP regulation and develop strategies to foster innovation, safety, and efficiency within the transportation sector.

Under the project TRAIN, and to support the development of safe and attractive conditions for implementation, requirements regarding the different dimensions of the TP ecosystem are identified via focus groups with three road operators, operating in Portugal, and two interviews with Portuguese regulators. The focus groups and interviews highlighted the interdependence between the actions of regulators, road operators, and vehicle manufacturers. This mutual dependency between technological evolution and regulatory developments emerges as a governance challenge caused by uncertainty, stressing the need for implementing co-creation processes to support the development of solutions that potentiate acceptance. Specifically, there is a clear need for shared decision-making to foster the acceptance of these systems.

## 1.3 Summary

This chapter provides background and context for the research on TP. It highlights the following key points:

- **Transportation's importance:** Transportation is crucial for modern societies, enabling the movement of goods and people.
- **Environmental concerns:** Road transport is a major source of $CO_2$ emissions, prompting initiatives for cleaner alternatives.
- **TP as a solution:** TP offers potential benefits like reduced fuel consumption and emissions while addressing driver shortages.
- **Challenges of TP:** Challenges include technical aspects (interoperability, communication), operational aspects (safety, efficiency), and regulatory aspects (uncertainties, need for clear guidelines).
- **Use of S-D Logic:** The research employs S-D logic as a theoretical framework to support the systemic study of TP.
- **Focus of research:** The research is investigating regulatory challenges surrounding TP and how SD can be used to address them.

# 2 Advancing Freight Transport: A Review of Strategic Roadmaps, System Dynamics, and Service-Dominant Logic

Freight transport is on the edge of a major transformation driven by decarbonization, automation, and digitalization. This chapter examines strategic roadmaps, SD, and S-D logic to explore the future trajectory of freight transport, with a focus on road transport in the EU. By examining existing frameworks and identifying key challenges, this chapter aims to present a view of the advancements and barriers in this evolving sector.

## 2.1 Overview of Existing Roadmaps

The European Road Transport Research Advisory Council (ERTRAC) has envisioned a sustainable and efficient freight transport system. Their focus pivots on decarbonization, automation, and inter-modality to holistically uplift the transport infrastructure, particularly in road transport. While road transport dominates the EU's modal split, aligning objectives with other transport modes remains pivotal.

According to Schnell-Lortet and Jacob (2019), road transport, specifically heavy-duty vehicles, plays an indispensable role in the EU economy. Yet, the environmental repercussions are significant, as these vehicles contribute substantially to greenhouse gas (GHG) emissions. On the safety front, advancements have curbed fatalities, but the journey towards utmost safety is ongoing.

ERTRAC’s report supports that the freight transport sector is on the verge of revolutionary changes, catalyzed by digital transformation, e-commerce, automation, and connected infrastructures. These forces not only promise efficiency but also reshape traditional logistics paradigms. However, significant advancements are still needed, particularly in vehicle performance enhancements, energy transitions, digital service integrations, infrastructure improvements, and societal perceptions, all of which collectively shape the future trajectory of freight transport in Europe.

Nevertheless, there are some implementation barriers in freight transport. First, the report explains business model challenges and the need to continuously change due to EU-level regulations as one of them. Also, swift connectivity, which is a must, related concerns arise since achieving comprehensive connectivity is a journey riddled with challenges, from outdated ICT systems to looming security threats. Lastly, there are some information exchange obstacles since in an era dominated by digital platforms, ensuring seamless, secure, and standardized data exchange becomes critical. Addressing issues like data ownership, privacy, and governance becomes essential for fostering trust and operational efficiency.

A strategic roadmap for road freight transport is then suggested pointing out the need for adaptable transport solutions where intelligent logistics and smart infrastructures smoothly and continuously facilitate freight deliveries, aiming to redefine transport efficiency through Physical Internet 2030 and a huge focus on decarbonization. Also, targets by application domain are advocated in ERTRAC’s report as one of the main progress points where each application domain, be it Confined Areas, Hub-To-Hub, Open Roads, or the Urban Environment, comes with its unique set of challenges and opportunities. From leveraging automated vehicles in ports to championing zero-emission vehicles in urban landscapes, the roadmap charts a detailed trajectory. In addition, the alignment of vehicle, infrastructure, and labor evolution underscores Europe's strategic approach to forging a sustainable transport future. With the electrification of short-distance vehicles and the continuous advancement of

ICEs, Europe stands at the forefront of transformative transport. At the same time, the continent's comprehensive infrastructure blueprint not only adapts roads but also pioneers energy supply systems and refines traffic management. However, the ascent of automation in the transport sector introduces a challenge, urging the need for training and reskilling for a skilled labor force prepared for tomorrow's opportunities. Emphasizing a holistic vision, Europe's transport strategy focuses on harmonization, digitalization, and modularization, positioning collaboration and innovation as pivotal pillars for its connected transport future.

Later, in a report from the same organization, Gräter et al. (2022) further suggest some main points for Connected, Cooperative, and Automated Mobility (CCAM). The authors explain that European Commission envisions a transformative transport system by 2050 that centers on users, integrates varied transport modes, and promotes automation and connectivity, while also emphasizing safety, inclusivity, and sustainability. Also, the report shows this ambitious goal is further detailed in the “Agenda 2030”, which maps out complex automated driving specifics for different terrains such as highways, urban locales, and rural areas, covering everything from technological prerequisites to societal advantages. In addition, the analysis of the ERTRAC report suggests the period leading up to 2040 is crucial, emphasizing the attainment of Green Deal objectives, leveraging artificial intelligence, encouraging citizen participation, ensuring product approval, and realizing the transport visions outlined in “Agenda 2030”. As mentioned before, the main guidelines that are foundational to this evolution are safety standards, technological progress, robust infrastructure, and synergistic business models. In essence, Europe's transport trajectory intertwines forward-thinking strategies, cutting-edge innovations, collective efforts, and an unwavering commitment to eco-friendliness and effectiveness, with its roadmap guiding the way through the intricate modern transport landscape.

## 2.2 Key Concepts and Theories

### 2.2.1 Service-Dominant Logic

Contemporary shifts prioritize intangible assets like skills, information, and relationships, transitioning from producer-centric to consumer-centric perspectives. Lusch and Vargo (2004) present arguments to emphasize that academic focus now centers on exchange processes rather than static goods, highlighting the evolution from mechanics to dynamic systems. The prevailing microeconomic model, which occasionally engages goods in exchange, may not be the most fitting for modern marketing. Instead, emphasizing competencies — intangible, dynamic human skills, and knowledge — might offer a more relevant perspective. This suggests that a service-centred dominant logic is superseding the traditional goods-cantered paradigm in marketing thought.

Contrary to the prevailing traditional paradigm, through S-D logic organizations can enhance their performance rather than merely optimizing it. Lusch and Vargo (2006) advocate that the external environment is no longer perceived as uncontrollable; instead, it can be leveraged for improved outcomes. The authors contend that the conventional limits separating producers and consumers are becoming increasingly blurred. They emphasize that value emerges from collaborative interactions between providers and beneficiaries, facilitated by the synergistic use of resources and competencies. Within this framework, each participant contributes to the creation of value, benefiting both themselves and others. This perspective highlights the contextual essence of value, indicating that its interpretation is shaped by situations and interactions.

Value creation has an evolving nature in today’s digital and interconnected world. Lusch, Vargo, and O’Brien (2007), emphasize the importance of collaboration, co-production, and information technology. As mentioned before, S-D logic sees service as the active use of dynamic resources, like skills and knowledge, to benefit another party. Unlike traditional views, S-D logic places services above goods in importance. Here, services can be directly offered or facilitated through goods. The essence of competition in S-D logic lies in how effectively a firm deploys its resources to fulfill customer needs compared to its competitors. Thus, for businesses aiming for long-term competitive advantage, understanding, and mastering service provision becomes crucial both in tactics and strategy. Lusch, Vargo, and O’Brien (2007) argue that specialized knowledge is what truly drives this advantage. As companies became more specialized over time, they formed broader networks and the key to this is the ability to collaborate effectively, which is crucial for projects’ lasting success. Also, the "service revolution" and "information revolution" highlight how technology is reshaping business and marketing. In the past, technology was built into products. Now, with the rise of the "Information Revolution," we see standalone information as a powerful tool. Even with tech becoming cheaper and faster, handling vast amounts of data can be overwhelming, underscoring the importance of managing information effectively.

Further, Lusch, Vargo, and O’Brien (2007) suggest some underlying forces of change. Firstly, it relies on open standards as catalysts for co-production and collaboration, paving the way for shared knowledge and innovation. On the other hand, presents specialization as the reason for expansive markets and increased interdependencies, creating an environment conducive to collaboration and fresh innovations. Also, connectivity promotes the seamless exchange of knowledge between market participants which amplifies market adaptability. Lastly, network ubiquity is crucial as the widespread connectivity among networks enhances collaboration and stimulates innovation.

Additionally, leveraging Information Technology (IT) is critical. Lusch, Vargo, and O’Brien (2007) emphasize how by mapping processes, entities can refine value creation, targeting both efficiency and elevating customer experiences. In fact, in digital infusion, IT acts as the key, enabling streamlined operations and driving value-centric strategies. In fact, at the heart of this transformation is the acknowledgment that value shall not be a static entity but emerges contextually, promoted by collaborative interactions and dynamic resource deployment. This increases intangible assets’ value like skills and relationships but also embraces technology's role, especially in handling vast data and optimizing information management. Overall, the narrative woven by the authors proposes a future where businesses prioritize service, collaboration, and knowledge. This way of thinking underscores that in our interconnected digital age, true competitive advantage lies not in hoarding resources but in accurately leveraging and co-creating value.

Regarding S-D logic applicability in transportation, Sérgio Pedro Duarte et al. (2021) explain that maintenance and management of these solutions pose challenges, as problems can be complex to identify and may originate from various sources. Companies often invest in complex information systems but may overlook valuable information from customer reports. In a digitalized world, customers can easily report issues affecting service quality, but service providers may not always prioritize these complaints. The authors emphasize the potential of customer participation through these reports to enhance mobility services and propose a methodology for leveraging customer engagement in the maintenance and management of smart city solutions, particularly in the context of urban mobility. The methodology aims to redesign the customer interaction process with service providers for improved efficiency and service experience, which can also be applied to TP and its ecosystem, as mentioned before. It is paramount that the success of technological solutions depends on user-centred design and the co-creation of value with stakeholders. The paper aligns with the intention to involve customers through participatory design to enhance experiences, emphasizing the importance of recognizing and encouraging stakeholders' contributions. The proposed methodology integrates Business Process Reengineering (BPR) for internal process efficiency and Service Design principles for customer experience improvement. For success, it is crucial to have a data-driven approach, categorizing reports and automating processes for efficient assignment to relevant teams. It emphasizes the need for feedback to customers and the importance of quick responses to urgent issues. This methodology can be expanded to other service processes and channels, and the authors suggest potential future developments, such as integrating chatbots and real-time assistance for customer-reported issues.

### 2.2.2 System Dynamics

System Dynamics (SD), as outlined by Schwaninger (2020), is a methodology and discipline, pioneered by MIT professor Jay W. Forrester which studies the modeling and understanding of dynamic systems, emphasizing the complex balance between system structures and their evolving behaviors. At its core, SD visualizes systems as networks connected with feedback loops, defined by stock and flow variables, which underline their inherent feedback mechanisms. This perspective, with its emphasis on continuous processes, sets SD apart from other modeling techniques like discrete event modeling and agent-based modeling.

In SD modeling, the fundamental structures are represented through loop diagrams comprised of positive and negative feedback loops. Ylén and Hölttä (2007) explain that these loops illustrate the interplay of variables within a system, often exemplified by population dynamics. For instance, considering a positive feedback loop such as population growth: as the population increases, so does the birth rate, leading to further population growth. Conversely, a negative feedback loop can be observed when factors such as limited food availability act as a constraint on population expansion. In this scenario, as the population grows, it consumes more resources, resulting in decreased food per capita, which then restricts population growth (see Figure 1).

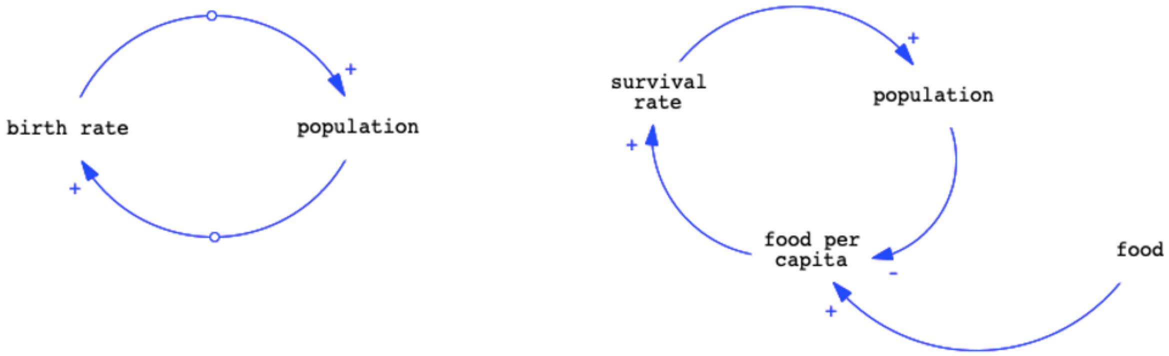


**Figure 1: Basic structures of SD models**

These feedback loops, in conjunction with flow and stock structures, form the basis of system dynamic models. For instance, the population is represented as a stock, while factors influencing population change, like birth and death rates, are captured as flow variables. The simplicity of these model structures hides their complexity in generating various system behaviors.

Depending on model parameters, outcomes can range from stability to instability, seeking equilibrium, or even oscillating between states. For example, a model where the birth rate is tied to population size and survival rate inversely relates to food availability can demonstrate how different levels of food supply led to varying population stability. By understanding these basic structures and their implications, SD modeling becomes a powerful tool for analyzing and predicting the behavior of diverse systems, from ecological ecosystems to socio-economic networks. Integrating such insights into literature revisions enriches the understanding of SD principles and their applications across disciplines.

While SD provides a robust framework for system analysis, Shepherd (2014) suggests its application in transportation showcasing its versatility. The methodology, enriched by its focus on causal loops and actors, extends beyond conventional modeling approaches. These causal loops represent the interplay among system components, delineating how they mutually influence outcomes, either reinforcing them (positive feedback) or regulating them (negative feedback). Such insights become pivotal for modeling complex system behaviors, defining potential challenges, and assessing various design implications.

Furthermore, the essence of SD goes beyond mere technical interrelations. It integrates the human dimension by acknowledging actors as vital entities within the system. While SD might not explicitly list these actors in organizational contexts, the underlying principles emphasize their pivotal roles and interactions, as pointed out by both Schwaninger (2020) and Shepherd (2014). Hence, a holistic SD analysis necessitates recognizing and understanding both technical and socio-human elements, ensuring comprehensive system evaluations. Abbas and Bell (1994) emphasize that to construct an SD model, it is essential to have a profound understanding of the subject being modeled. The authors point out the importance of multiple iterations and extensive study, suggesting that modeling is not just a result but also a method to deepen one's knowledge about the subject. The paper delineates crucial phases for studying this subject: problem identification, problem definition, variable generation, model development, system verbalization, system conceptualization, computer programming, and simulation and system analysis.

The rationale behind adopting the SD approach in transportation systems-related studies may be justified by their complexity and dynamism, distinguishing them as intricate and evolved systems. Ghaemi and Hadji Hosseinlou (2023) present arguments to emphasize that in the realm of transportation, understanding behaviors and designing effective solutions for optimal performance is challenging due to these features, which deviate from simple and linear relationships. Consequently, original, and creative approaches become imperative for their analysis. To address such challenges, it becomes essential to cultivate systemic thinking, establish the boundaries of mental models, and utilize compatible tools capable of comprehensively understanding the structure and behavior of complex urban freight transportation systems. On the other hand, SD offers a comprehensive framework for analyzing specific systems, encouraging confidence among researchers regarding the model's generalizability across diverse contexts and conditions. By encapsulating the dynamics of real-world events within a particular system, SD enables observation of how various variables interact to produce specific outcomes, thus facilitating cross-system comparisons. However, to ensure reliability, such models must undergo validation using real data specific to each system under consideration.

## 2.3 Identified Challenges and Barriers

### 2.3.1 Challenges related to Truck Platooning regulations, responsibilities, and driver regulations

TP represents a promising advancement in the transportation sector. Gwak, Shimono, and Suda (2022) hold the same position as some authors mentioned before, as they state that it holds the potential to revolutionize the way goods are transported by offering benefits such as reduced fuel consumption, decreased traffic congestion, and mitigation of driver shortages. Notably, the realization of unmanned platooning for the second and third trucks on a section of the Shin Tomei Expressway in Japan (Ministry of Economy 2021) marked a significant milestone, demonstrating considerable improvements in the safety of the TP system itself.

However, successful TP requires overcoming several technical and operational challenges. These include ensuring interoperability between different truck brands and fleets, improving vehicle and infrastructure communication, and addressing the safety and efficiency of road transport. Atasayar, Blass, and Kaiser (2022) remark that studies have shown that TP can enhance road safety by reducing human error, which is a major cause of road accidents. Nevertheless, it also presents new risks, such as potential issues at freeway entrances, requiring careful management and specific conditions for safe operation, both for users and peripheral drivers. Lourenço et al. (2024) systematic review of 35 studies shows that decision-makers are generally optimistic but concerned about implementation risks, the public worries about safety and traffic conflicts, and truck drivers see potential advantages but fear job loss, reliability issues, and added stress. Experience with platooning can improve perceptions, but broader work-related concerns remain underexplored, highlighting the need for further research on employment impacts, safety, and legal issues.

For instance, users are not fully satisfied with the upcoming solutions, which presents challenges. Neto et al. (2024) focus groups revealed drivers' dissatisfaction with their profession due to poor pay, lack of career progression, and time away from family, with new technologies requiring more skilled drivers. Drivers had mixed feelings about platooning, recognizing its potential benefits but highlighting safety and operational concerns, particularly regarding load weight and braking systems. They preferred leading positions in platoons for safety and freedom, and longer intervals between trucks to increase visual fields and reduce fatigue. Safety concerns and skepticism about automated systems, especially braking mechanisms, were prevalent, indicating the need for comprehensive training programs to foster behavioral adaptation and teamwork. The study's small sample size is a limitation, prompting the need for a larger-scale survey to gather more data on drivers' perceptions and experiences with platooning technology.

Regulatory frameworks play a crucial role in shaping the future of TP. The development and implementation of comprehensive regulations are essential to govern the operation of these systems, especially considering the involvement of unmanned trucks. Tobar et al. (2019) suggests that regulations must strike a balance between ensuring stringent safety standards and addressing concerns related to traffic flow, infrastructure compatibility, and potential conflicts with other road users. Furthermore, Calvert et al. (2018) alert for the determination of responsibility and liability in the event of accidents or malfunctions within a platoon remains a complex issue. Questions arise about accountability: Is it the leading driver, the operating company, or the technology manufacturer who bears the responsibility?

Dubljević et al. (2023) propose significant concerns and challenges related to TP regulations, responsibilities, and driver regulations within the realm of automated vehicles (AVs). The analysis of this qualitative study of the perceptions of professional drivers, especially those engaged in long-haul trucking (TR drivers), suggests apprehensions about the potential threats AVs pose to their income and safety. Also, a recurring theme is the predominant importance of safety. Drivers across the board highlighted concerns, with TR drivers particularly emphasizing issues related to adverse weather conditions and the decision-making capabilities of AVs. Additionally, urban, or local delivery drivers (UL drivers) lamented the impending loss of human interaction, emphasizing the value of intuition, conversation, and human knowledge inherent in their roles. A prevailing sentiment among TR drivers is a pervasive skepticism that their first-hand experiences and insights are inadequately considered in the formulation of policies and regulations concerning AVs. Consequently, while the advancements in TP and AVs technologies offer potential enhancements in efficiency and safety, integrating these innovations into the transportation landscape necessitates meticulous consideration of these voiced concerns and a collaborative approach involving all stakeholders.

Further, Gwak, Shimono, and Suda (2022), developed a study that aims to improve the safety and acceptability of TP by utilizing a human-machine interface (HMI) to communicate system information to peripheral drivers. The results emphasize the importance of timely and clear information transmission not only for platoon drivers but also for these peripheral drivers, highlighting the need for further research and standardization in HMI design. The safety and acceptability of peripheral drivers are also crucial for the successful implementation of TP and the integration with existing infrastructure and traffic management systems presents another layer of complexity. Ensuring compatibility and facilitating seamless interaction between TP systems and existing infrastructure may necessitate infrastructure upgrades. Moreover, the impact of varying traffic densities on the effectiveness of HMIs and overall platooning safety cannot be overlooked.

The study concluded that proper information transmission to peripheral drivers, along with adjustments for traffic density, can enhance the safety and acceptability of TP. Regulatory guidelines must account for diverse traffic conditions, establishing clear protocols for platoon operations under different density scenarios. Public acceptance and perception also play pivotal roles in the successful adoption of TP technologies. Addressing concerns related to safety, potential job displacement, and disruptions to traffic flow is essential to foster public trust and support. Furthermore, given the international nature of trucking operations, establishing international standards, and fostering collaboration among various stakeholders, including governments, industry players, and researchers, becomes crucial to ensure consistent regulations and interoperability across jurisdictions.

### 2.3.2 Challenges in applying System Dynamics to automated and electric vehicles in the transportation sector

SD models possess a distinct advantage, offering a transparent representation of interdependencies among submodules. Thaller, Clausen, and Kampmann (2016) comments that they outperform in elucidating non-linear cause-and-effect relationships, enabling the forecasting of medium- and long-term trends and the assessment of measure impacts. These models facilitate the analysis of evolving behaviors over time, thereby earning recognition as glass box modeling approaches, transparent and open, allowing for clear visibility into their inner workings.

However, despite their efficiency in operating with minimal data requirements at a high level of aggregation, they fall short in handling some results, such as traffic assignment and providing point-in-time forecasts. Thaller, Clausen, and Kampmann (2016) further hold the position that although economic and transport modeling algorithms can be integrated into SD models, overcoming the limitation of some findings remains a significant challenge.

Shepherd (2014) also observes that the application of System Dynamics (SD) in the transportation sector presents several challenges. Firstly, transportation systems exhibit inherent complexity, involving various stakeholders whose interactions produce feedback with diverse time lags, making them intricate to model and predict. Secondly, the accuracy and reliability of SD models depend on meticulous calibration and validation against real-world data, a process demanding significant resources. Additionally, as transportation models evolve to encompass complex spatial elements, the computational run times of SD models escalate, posing challenges when analyzing extensive zones.

While SD enriches our understanding of system behaviors, it is not tailored for pinpoint forecasts, emphasizing the need for broader mental models rather than exact predictions. Shepherd (2014) suggests that, moreover, the integration of SD with other modeling methodologies can yield disparate policy recommendations, underscoring the complexities of interdisciplinary approaches. Effective SD modeling in transportation necessitates the active involvement of stakeholders, leveraging qualitative models and CLDs for coherent communication. Lastly, adequately incorporating spatial nuances and accounting for temporal delays across different scales demand rigorous modeling and analytical strategies.

## 2.4 Gap Analysis

The analysis of the provided papers reveals common themes revolving around safety concerns in transportation and the introduction of TP as a transformative solution. However, there is a gap in the detailed discussion of the collaborative role of regulators and road operators in shaping the TP landscape. Also, the current perspectives of industry (OEMs) on the evolution of TP and its commercial viability are inadequately addressed. Additionally, the integration of S-D logic and SD in the context of TP is limited, presenting an opportunity for a more comprehensive exploration of these theories. Proposed additions include elaborating on the value co-creation by facilitators (regulators, road operators, and OEMs), integrating S-D logic to discuss an attractive proposition of "driving as a service," for the industry, and exploring how SD models can offer insights into regulatory challenges. Furthermore, societal concerns related to job displacement and public perceptions of the adoption of TP technologies should be addressed to provide a more holistic understanding of the challenges and opportunities in the evolving transportation landscape.

## 2.5 Summary

This chapter explores the evolving landscape of freight transport in the EU, with a focus on strategic roadmaps, SD, and S-D logic. Here are the key takeaways:

- **EU's strategic roadmap:** The EU roadmap envisions a sustainable and efficient freight transport system, emphasizing decarbonization, automation, and inter-modality.
- **Challenges identified:** The roadmap acknowledges challenges such as business model adaptations, achieving comprehensive connectivity, and ensuring seamless data exchange.
- **Role of S-D Logic:** S-D Logic emphasizes value co-creation between stakeholders (regulators, road operators, etc.) for effective technology deployment and a balanced transport ecosystem.
- **SD:** SD is a methodology for understanding complex systems through feedback loops and causal relationships. It can be used to model and analyze the dynamics of freight transport systems.
- **Gap Analysis:**
  - Limited discussion on the role of regulators and road operators in shaping TP
  - Lack of industry perspective on TP's commercial viability
  - Limited integration of S-D logic and SD in the context of TP

This research focuses on developing an SD model within the framework of S-D logic principles to enhance the understanding of TP acceptance factors and their interdependencies. Current SD models in transport technology primarily simulate market penetration rather than user acceptance, thus this study proposes an SD model informed by focus groups and literature review findings to assess TP levels based on technology and regulatory developments.

# 3 Methodological Framework

The research aims to map key stakeholders in an actor-to-actor network, treating requirements as objective functions and regulatory aspects as decision variables. Expected outcomes include actor networks, causal loop diagrams (CLDs), and policies guiding stakeholder actions. By applying SD's systemic approach, the study seeks to improve decision-making in TP regulation, addressing safety, infrastructure standards, and operational guidelines.

This work underscores the integration of S-D logic principles to foster policy co-creation and develop SD scenarios that explore the complex dynamics between technological progress and regulatory frameworks, ultimately advancing understanding and decision-making in the TP ecosystem beyond traditional technology acceptance models.

This chapter delves into the research methodology employed to analyze TP acceptance. A qualitative approach, encompassing industry insights, focus groups, and industry reviews, is used to understand stakeholder perspectives and challenges.

Furthermore, an SD model is developed to map interactions and decision-making processes within the TP ecosystem. This model incorporates stakeholder relationships, causal relationships, and real-world data to explore the impact of regulations and technology on TP acceptance.

This methodological framework provides a comprehensive approach to analyzing TP acceptance and its related complexities.

## 3.1 Methodology Selection

Research designs outline the plan and methods for research, from initial assumptions to detailed data collection and analysis approaches. Creswell and Creswell (2018)'s book illustrates that these decisions do not necessarily follow a linear order. The selection of a research design is influenced by the researcher's worldview assumptions, inquiry strategies, methods of data collection, analysis, and interpretation, as well as the nature of the research problem and audience.

There are three primary types of designs: qualitative, quantitative, and mixed methods. While these approaches may seem distinct, they exist on a continuum rather than as absolute distinct categories. Creswell and Creswell (2018) additionally explain that mixed methods research integrates elements from both qualitative and quantitative approaches, positioning itself between the two extremes. Traditionally, the differentiation between qualitative and quantitative research is simplified as utilizing words versus numbers or open-ended versus closed-ended questions. However, a more nuanced understanding considers philosophical assumptions, research strategies, and specific methods employed. Quantitative research tests objective theories through statistical analysis, while qualitative research explores the meaning individuals or groups attribute to social or human problems. Mixed methods research combines both approaches, aiming for a comprehensive understanding that exceeds the strengths of either approach alone. Each approach involves philosophical assumptions and distinct methods. Research design, essentially the plan for conducting research, involves the interplay of philosophical worldview, inquiry strategy, and specific research methods. This interaction is crucial in crafting a coherent and effective research study.

Business and Technology is a field where a diverse range of methodologies are suitable, demanding careful selection to construct effective research. Basias and Pollalis (2018) present arguments to emphasize that this matter captures the interest of researchers and involves navigating through various methods, approaches, and techniques to address the interdisciplinary nature of Economics, Business, and Information and Communication Technology (ICT). Additionally, the authors explain that research, as a systematic initiative to advance knowledge and address challenges, revolves around two primary design categories: qualitative and quantitative. Researchers opt for specific methods based on factors such as research aims, objectives, topic nature, and questions posed. The research journey typically involves defining questions, gathering data, processing it, deriving answers, and presenting findings to enhance understanding of the subject matter.

The choice between quantitative and qualitative methods is not merely dictated by data availability; rather, it relies on aligning with the specific goals of a study. Goertz and Mahoney (2013) advocate for recognizing the suitability of both quantitative and qualitative techniques for diverse research objectives, each tailored to distinct research aims. Quantitative methods may be suitable in certain contexts, while qualitative techniques may better serve other research inquiries. Indeed, there are instances where a combination of both methodologies, through mixed-method research, becomes imperative, particularly in complex projects necessitating the amalgamation of diverse analytical approaches to fully address research goals.

In addition, methodological fit in management field research promotes the alignment between methodology and research objectives, fostering the cultivation of robust and convincing field research. In this context, Edmondson and McManus (2007) explain that different patterns of methodological alignment in field research are outlined, where three stages of prior work (early stage, established, and transitional) correspond to three distinct methodological approaches (qualitative, quantitative, and hybrid). The authors share how theory development stages influence methodological choices critically, highlighting the importance of fit alongside other research elements.

Design Science Research (DSR) embraces a pragmatic worldview, delving into the understanding of organizational phenomena within their contexts. Hevner et al. (2004) explain that DSR advances research by creating artifacts and evaluating solutions to organizational challenges, while also expanding the knowledge base of the field. These artifacts take various forms, including constructs, models, methods, instantiations, and design theories. In this approach, contributions extend beyond the field of academia, making tangible impacts in the real world, while simultaneously enriching scholarly research works.

Conversely, the behavioral-science research paradigm adopts a more reactive approach, accepting technology as given and concentrating on developing theories that elucidate and predict events related to technology adoption, implementation, management, and usage. Hevner et al. (2004) argue that, however, both paradigms carry inherent risks. The excess of technological artifacts in design-science research may lead to well-designed solutions that prove ineffective in real-world organizational settings, while an excessive focus on contextual theories in behavioral-science research may result in outdated or inadequate principles. Thus, the authors advocate for a balanced approach that embraces both proactive design-science and reactive behavioral-science methodologies to foster innovation while grounding research in practical applicability.

Regarding the choice of the methodology in this dissertation, a qualitative approach was selected, since qualitative methodologies are more advantageous when considering both the information that has been shared in the focus groups and the information that exists in the literature regarding the industry. A qualitative approach offers a comprehensive understanding of the complex research problem, better fitting the results that are aimed to achieve in this work. In the need to generalize findings, bringing together engineering, services, and policy, this method approach becomes particularly advantageous. By integrating qualitative data, the dissertation development can achieve a deeper understanding and produce richer insights on policies, guidelines, and further steps to take.

To address RQ1 (What are the primary challenges associated with TP from a regulatory perspective?), the study focuses on qualitative methods to explore and understand the regulatory challenges as perceived by various stakeholders involved in TP. Also, to address RQ2 (How can an SD model, through its CLDs, offer insights and solutions to the regulatory challenges posed by TP?), the study uses qualitative insights to inform the development of the CLDs, capturing the dynamic interactions and feedback loops among stakeholders.

## 3.2 Methodology Description

This study seeks to analyze the complexities of TP, guided by key theories such as S-D logic, decision-making, and SD. These theoretical frameworks play a pivotal role in shaping our understanding of the research questions and influencing methodological choices.

By exploring the dynamic interaction between technology and regulations, the study aims to uncover factors that influence the acceptance of TP. The goal is to provide practical insights for well-informed decisions in the realms of regulation and technology. To achieve a comprehensive investigation into TP, our methodology unfolds in two main umbrella steps:

### 3.2.1 Qualitative Data Collection and Analysis: Delving into Stakeholder Perspectives and Desired Outcomes

The initial phase involves data collection within the dynamic landscape of transportation planning (TP). Under Project TRAIN, which aims to tackle the challenges and risks linked to implementing partially automated TP on public roads, an analysis of previously conducted focus groups involved facilitators, including regulators (REG1 and REG2) and road operators (RO1, RO2, and RO3) is made. The purpose of these focus groups is to support the development of safe and attractive conditions for implementation by identifying requirements regarding the different dimensions of the truck platooning ecosystem. These focus groups included three road operators operating in Portugal and two interviews with Portuguese regulators. Insights from these groups are extracted and variables identified, aligned with existing literature. This manual analysis forms the basis before transitioning to digital methods.

Using *NVivo,* transcriptions from focus groups are categorized by stakeholders and subjected to coding. Codes are created for variables like number of drivers, shift duration, and fuel savings, with relevant excerpts allocated accordingly. Additionally, a word frequency study identifies key terms prevalent in focus group discussions, aiding in the creation of a word cloud that highlights common variables across groups and supports the development of CLDs in SD.

An essential aspect of the intended investigation involved conducting a scoping review on leading industry manufacturers (OEMs) such as Volvo, DAF, Daimler, Iveco, MAN, Scania, and Ford Otosan. This review aims to analyze reliable sources such as press releases, corporate websites, and news articles to ascertain their stance on investment in TP, despite its technical feasibility. Understanding the perspectives of these manufacturers is crucial in determining the likelihood of servitization taking place in the industry. Furthermore, the technical feasibility of TP is assessed by examining information related to ongoing projects like Ensemble, Sweden 4

Platooning, European Truck Platooning Challenge, and the Electronic Drawbar – Digital Innovation (EDDI) project.

After the preliminary analysis, variables were grouped based both on stakeholders (regulators, road operators, and OEMs) and on objectives (lower number of accidents, higher fuel savings, lower operational costs, and better working conditions) to create a structured framework for further analysis. This involved categorizing variables according to stakeholders' perspectives and desired outcomes. In this interconnected and strategic approach to data collection, analysis, interpretation, and validation each step seamlessly feeds into the next, contributing to a holistic and nuanced exploration of the TP ecosystem.

To address RQ1, the focus groups provided in-depth perspectives on the regulatory challenges faced by TP. These insights allow the identification of the primary challenges, such as unclear liability frameworks and the need for adaptable regulations.

### 3.2.2 System Dynamics Model Development: Mapping Interactions and Decision-Making Processes

Moving through the SD model development stage in this individual master's thesis involves a series of interconnected steps that collectively shed light on the challenges of the TP ecosystem. Commencing with the mapping of actor-to-actor networks, the aim is to visually analyze stakeholder relationships. This mapping process provides a comprehensive understanding of the dynamic interactions, dependencies, and SD within the TP landscape.

Subsequently, the creation of CLDs is crucial in this model development. These visual representations serve as narrative tools, articulating the interdependencies inherent in the TP ecosystem. Through the lens of causal relationships, a clean image emerges, revealing how various components within the system influence one another and contribute to the overall dynamics. A crucial facet of the SD model development is the incorporation of objective functions and decision variables. These elements serve as the support, outlining specific requirements as objective goals and elucidating the variables influencing regulatory and technological decision-making within the TP domain.

Furthermore, this phase is enriched through the assimilation of insights garnered from interviews and focus group data. This qualitative data infusion not only strengthens the objective functions and decision variables but also establishes a meaningful bridge between theoretical constructs and the pragmatic considerations of stakeholders. It introduces a layer of real-world perspectives into the model, enhancing its applicability and relevance within the context of TP dynamics.

Moving forward, these objective functions and decision variables are informed by requirements elucidated in the discussions, including considerations such as the required distance between vehicles on the road, the presence of dedicated or non-dedicated lanes, and their necessity.

The decision variables, identified during the discussion groups and including parameters like distance and signage, play a crucial role in shaping the decision support systems problem. This strategic integration ensures a comprehensive alignment of theoretical underpinnings with practical considerations, providing a robust foundation for addressing challenges within the TP ecosystem.

In essence, the SD model development phase in this master's thesis is a dynamic and interconnected process. It encompasses the visual mapping of actor-to-actor networks, the creation of CLDs, first drawn in the paper and later produced using the software *Vensim PLE*, and the integration of real-world data. Additionally, the use of SD allows to derive a list of steps, roadmaps, and guidelines to conduct stakeholders' actions. Together, these elements construct a comprehensive model that captures the essence of the TP ecosystem, providing a nuanced understanding of its behavior and influencing factors. Moreover, the methodology, notation, and artifacts related to SD were validated by an expert in the field, ensuring their accuracy and reliability.

To address RQ2, the SD model development used insights from the literature review, industry insights, focus groups, and interviews to create CLDs that mapped the interactions among stakeholders. These diagrams revealed areas for collaboration and potential bottlenecks, offering solutions to the regulatory challenges identified in RQ1.

In summary, this methodology establishes a foundation for a thorough and methodical investigation into TP, a pivotal aspect of modern transportation. Through the delineation of study boundaries, incorporation of pertinent theoretical frameworks, and utilization of robust data collection and modeling methods, the research seeks to provide a comprehensive understanding of the dynamic interaction between technology and regulation within the TP ecosystem. Progressing through data collection and model development, the study aims to undo complexities, offering valuable insights for well-informed decision-making in both regulatory and technological areas. This methodological approach, emphasizing transparency and precision, means a dedication to advancing knowledge and contributing to the effective integration of TP in contemporary transport systems.

### 3.3 Summary

This chapter outlines the research methods used to explore complexities surrounding Truck Platooning (TP) acceptance.

1. **Qualitative Approach:** The study employs a qualitative approach to gain an in-depth understanding of stakeholder perspectives and desired outcomes. This involves:
    - Analyzing focus groups with regulators and road operators;
    - Conducting a scoping review of industry leaders' stances on TP investment;
    - Categorizing variables based on stakeholders and objectives.

2. **SD Model Development**

An SD model is developed to map interactions and decision-making processes within the TP ecosystem. This includes:

- Mapping actor-to-actor networks to visualize stakeholder relationships;
- CLDs to picture causal relationships between system components;
- Integrating objective functions, decision variables, and qualitative data to inform the model.

This methodology provides a comprehensive framework for analyzing TP acceptance and its impact on regulations and technology.

# 4 Collaborative Projects and Industry Insights in Truck Platooning

## 4.1 Evolution of Collaborative Projects in Truck Platooning

The Government of the Netherlands (2016) remarks that over the last years, the biggest European truck manufacturers (DAF Trucks, Daimler, IVECO, MAN, Scania AB, and Volvo) collectively demonstrated the technical feasibility of TP. European Truck Platooning Challenge in 2016 was one of the events that made this evident, a project aimed to advance the implementation of TP in Europe, utilizing key ITS corridors. Later, the ENSEMBLE project, launched in 2018, brought together manufacturers the project gathered the same manufacturers, as explained by Connected Automated Driving (2022). This transitioned from individual technology development to collaborative automation systems across multiple brands. The project incorporates V2V and Vehicle-to-everything (V2X) communications, alongside long-range back-office systems, with the manufacturers aiming for greater harmony.

In 2017, a Swedish research project on TP had already begun to take shape. Known as Sweden4Platooning (S4P), this three-year project involved the collaboration of key industry players, such as Scania and Volvo, (Scania 2017). Together, these entities took the first industry steps in the exploration of multi-brand platoons on public roads, driven by the shared vision of reducing carbon emissions and optimizing goods transportation efficiency. Bishop (2020) explained that this project had collaborative efforts with ENSEMBLE, existing considerable motivation to establish a standardized inter-vehicle data protocol for platooning, particularly on the EU scale. Nevertheless, there remains ambiguity regarding the potential obligation for providers to comply with this standard, as well as the timeline for its implementation.

## 4.2 Industry Insights: Pioneers, Perspectives, and Paradigm Shifts

According to Janssen et al. (2015), DAF, Volvo, and Scania were the truck manufacturers, as known as Original Equipment Manufacturers (OEMs), pioneers in TP, which offers significant advantages, allowing them to capture a larger market share. OEMs are pivotal players in integrating technological advancements into their trucks, as they facilitate innovations like Cooperative Adaptive Cruise Control (CACC), which enables platooning. By being pioneers, they also gain valuable insights into test requirements and type approval, while enhancing their brand image and marketing efforts. However, for the overall industry, standardization, and compatibility of platooning technology across various makers and brands are essential. The technology roadmap for platooning also unveils opportunities for additional features like Automated Docking and Parking, as well as cooperative functions such as low-speed Stop-and-Go and Cooperative Autonomous Emergency Braking (C-AEB).

Additionally, Janssen et al. (2015), explain that TP's business value was, initially, in less fuel consumption, since aerodynamic drag reduction results in decreased fuel consumption for both trucks in a platoon, surpassing the benchmark of regular cruise control driving. On the other hand, there were also expectations of asset utilization optimization, impacted by decreased idle time for trucks which leads to improved efficiency. Lastly, there was the advantage of decreasing labor with the implementation of platooning due to optimized driver capacity utilization. As platooning technology advances and regulations evolve, scenarios may arise where the driver of the Following Vehicle could potentially be eliminated, or allowed to rest while the truck is still in motion, thus minimizing idle time.

By 2017, Gunnar Tornmalm, head of Predevelopment, Systems Development at Scania, addressed the significant role of drag in a truck's fuel consumption, noting that it constitutes 25% of the total (Scania 2017). He explained that when trucks closely follow one another, fuel efficiency improves due to reduced drag, with fuel savings ranging from 3-7% at an 80km/h speed in early tests. In addition, the transformative potential of platooning technology was emphasized, highlighting societal factors such as the ability to enhance traffic flow on highways and mitigate the environmental impact of transportation, underscoring the necessity for multi-brand compatibility to ensure widespread adoption of the technology.

In 2018, the same manufacturer highlights a notable shift in the discourse surrounding platooning, emphasizing its broader potential and contribution to sustainable transport systems (Scania 2018). This evolution in perspective is attributed to the quick advancements in connectivity, sensors, and digitalization within the transport industry. The transformative impact of these developments is underscored, particularly in facilitating not only V2V communication within platoons but also connectivity to a broader digital V2I system. This integration opens avenues for enhancing traffic flows and optimizing overall transport system efficiency. In addition, Volvo (2018), also shared great excitement about TP’s state of the art and its evolution, showing experimental results on how both staged and spontaneous vehicle cut-ins were utilized to showcase that the technology adeptly manages typical traffic scenarios. Also, it emphasized the importance of studying faster responses to hard braking while maintaining safety and fuel efficiency. It was underscored that the advanced technology is intended to supplement rather than replace skilled professional truck drivers. In this context, it is explained these technologies are poised to shape the future; however, their precise integration hinges on several factors, including regulatory frameworks, infrastructure development, adherence to safety standards, and market demand. Daimler Truck (Daimler 2018), maintains to develop the technology with Freightliner on public roads in the US. Also, Japan is identified as a key market for the company, actively promoting and embracing new technologies. They are actively engaged in the Japanese government's initiative to advance platooning in Asia, aiming to retain their leadership position in the technology's development.

However, according to Scania (2019), TP, previously seen as a transitional phase toward automated vehicles, now appears to have lost some appeal following the European Commission's recent choice to refrain from revising driving and rest period regulations. Considering recent regulatory decisions, the company shifted focus from platooning to more ambitious trials, advocating for hub-to-hub transports on dedicated motorway lanes, stressing the need for collaboration among truck manufacturers and other stakeholders to fully explore the implications of this technology. Accordingly, Daimler (2019) is reevaluating its stance on TP, which has undergone extensive testing for several years, particularly in the US In fact, results have shown that the anticipated fuel savings, even under optimal platooning conditions, are not as significant as initially estimated. Additionally, when platoons disconnect, requiring trucks to accelerate to reconnect, these savings are further diminished. Based on current analysis, there appears to be no viable business case for customers utilizing platooning with new, highly aerodynamic trucks in US long-distance applications. Instead, the company is shifting its focus on automated vehicles and is hiring 200 new engineers and robotics specialists with IT and programming skills.

Nevertheless, Daimler Trucks remains committed to existing partner projects in this area, and, Bishop (2020) states that it is unlikely they will ignore the growing trend of automated convoying. Contrarily to Daimler, the same author additionally points out that in the same year, Ford Otosan, which is a partnership between Ford and Koç Holding, joined TP’s industry.

Collaborating with AVL, Ford Otosan demonstrated a pre-commercial platooning system on a test track in Turkey. Burak Gökçelik, Assistant General Manager at Ford Otosan, highlighted the company's aim to develop SAE-Level 4 automation technology in the long run.

IVECO (2022), as an active member of the ENSEMBLE consortium, has contributed to the successful development and deployment of a multi-brand platooning technology, jointly agreed upon by leading European truck manufacturers, in real traffic conditions. Over the course of the 46-month project, co-funded by the EU, ENSEMBLE has showcased the potential of platooning to significantly enhance sustainable transport objectives. By facilitating multi-brand platooning and automated driving, this technology has demonstrated promising improvements in fuel economy, reduction of $CO_2$ emissions, enhancement of road safety, and optimization of traffic efficiency.

## 4.3 Key Findings and Future Directions in Truck Platooning

The exploration of industry perspectives and projects within the TP domain presents a multifaceted landscape influenced by technological advancements, regulatory dynamics, and shifting market demands.

Initially, collaborative projects such as the European Truck Platooning Challenge in 2016 and the subsequent ENSEMBLE project in 2018, in collaboration with S4P, highlighted the concerted efforts of major truck manufacturers towards advancing TP technology. These initiatives underscored the transition from individual technology development to collaborative automation systems, emphasizing the importance of standardized protocols for interoperability across brands.

Industry perspectives have evolved, with early pioneers like DAF, Volvo, and Scania recognizing the potential of TP to optimize fuel consumption, enhance traffic flow, and mitigate environmental impacts. However, recent regulatory decisions and market analyses have prompted a re-evaluation of TP's business case in many OEMs, such as Scania and Daimler, as anticipated fuel savings have not materialized as expected.

Despite challenges, there is still a commitment to advancing automation technology, as evidenced by Ford Otosan's entry into the TP industry and Daimler Trucks' continued engagement in partner projects. The pursuit of SAE-Level 4 automation technology underscores the industry's long-term vision for enhancing transport efficiency and safety.

Furthermore, collaborative efforts such as the ENSEMBLE project and IVECO's contributions highlight the potential of multi-brand platooning to significantly enhance sustainable transport objectives, including fuel economy, $CO_2$ emissions reduction, road safety, and traffic efficiency.

In conclusion, while TP faces regulatory and commercial challenges, ongoing technological advancements and collaborative initiatives signal a continued commitment to innovation within the trucking industry. The journey towards fully realizing the potential of TP technology requires continued collaboration, regulatory support, and market adaptation to address evolving industry dynamics and societal needs. Figure 2 illustrates the timeline of key developments and collaborative projects in TP from 2015 to 2022. This timeline captures significant milestones and insights, highlighting the progression from individual technical demonstrations to broader collaborative efforts and regulatory engagements. This timeline uses color-coding to distinguish between different types of milestones:

- Green Boxes: Indicate significant advancements and demonstrations in the technical feasibility and efficiency of TP, where OEMs demonstrated will to invest in the technology and belief in its commercial viability.
- Red Boxes: Represent notable shifts or reassessments in industry perspectives regarding the commercial viability and regulatory impact of TP.
- Black Boxes: Highlight the launch and objectives of collaborative projects focused on multi-brand and regulatory aspects of TP and indicate advancements in the sustainability and practical applications of TP technologies.

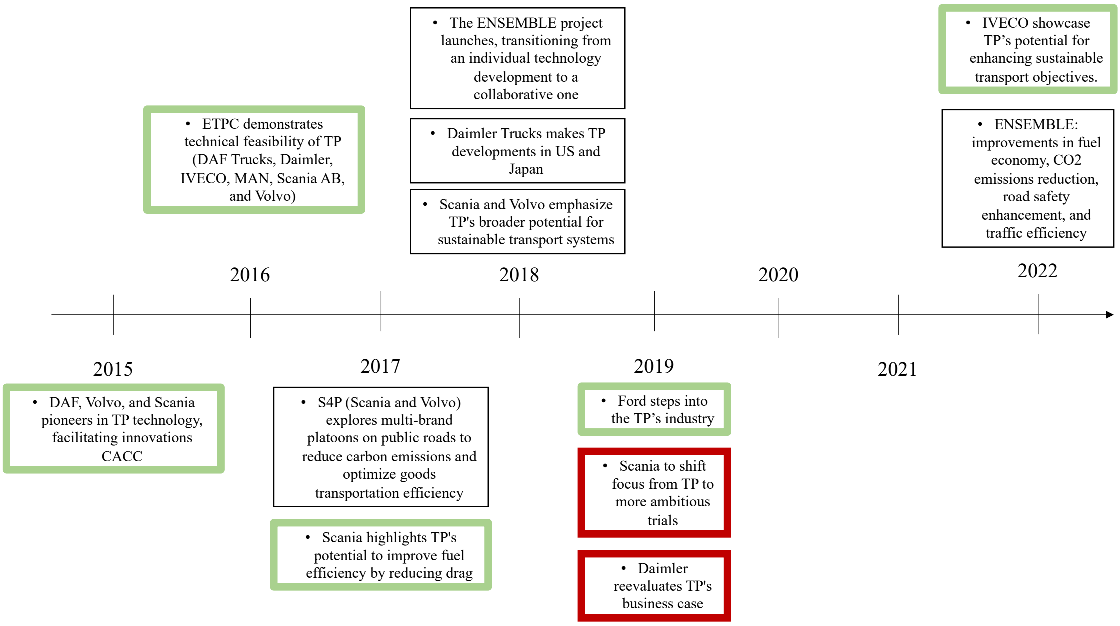


**Figure 2: Timeline of Key Developments in Truck Platooning between 2015 and 2022 (own elaboration)**

## 4.4 Summary

To complement the existing data from the FGs with logistics companies, road operators and regulators of the road freight transport sector, through a scoping literature review, this chapter explores collaborative projects and industry perspectives on TP. It highlights the evolution of the technology development to date, key findings, and future directions in the field:

1. **Collaborative Projects:** Major TP projects, such as the European Truck Platooning Challenge (2016) and ENSEMBLE (2018), showcasing industry collaboration and progress in multi-brand technology.
2. **Industry Insights:** Early pioneers like DAF, Volvo, and Scania saw TP's potential for efficiency and sustainability. However, recent challenges like regulations and fuel savings reevaluations led some OEMs to reassess its business case.
3. **Timeline:** Fig. 2 depicts key developments and collaborative projects in TP from 2015 to 2022, highlighting milestones and industry perspectives.

4. **Future Directions:** Despite challenges, advancements like Ford Otosan's entry into TP and the ENSEMBLE project's success indicate continued industry commitment to automation and multi-brand compatibility.
5. **Conclusion:** While facing hurdles, ongoing advancements and collaborations signal a focus on innovation. Realizing TP's potential requires continued collaboration, regulatory support, and market adaptation.

## 5 Results

In this chapter, the dynamics of the TP ecosystem are studied, by examining the interactions between key stakeholders and their impact on four critical objectives:

1. Higher fuel savings (a modification of the original objective of lower emissions from lower fuel consumption).
2. Lower number of accidents.
3. Better working conditions.
4. Lower operational costs.

The four boundaries proposed by Duarte et al. (2023) suffered a slight modification to the first objective, emphasizing higher fuel savings (quantified in percentage) as a critical factor influencing TP acceptance among all stakeholders. CLDs are utilized to map out these interactions to uncover the feedback loops and leverage points that drive system behavior. This approach not only elucidates the complex relationships within the ecosystem but also highlights potential areas for strategic intervention. By integrating insights from focus group discussions, existing literature, and recent industry scoping reviews, the research aims to provide comprehensive policy recommendations for regulators, road operators, and OEMs to collaboratively enhance public acceptance and expedite the deployment of TP technology.

To understand the interactions within the TP ecosystem, it is essential to identify the key stakeholders and their value exchanges. A well-functioning ecosystem aims for efficiency, safety, and economic growth within the transportation sector.

From both the literature industry insights and the focus groups, the stakeholders can be categorized into four groups (see Table 1):

- Facilitators: These entities create the enabling environment for TP. They include regulators who establish safety standards and operational guidelines, road operators who manage infrastructure compatibility, and OEMs who develop the necessary vehicle technology.
- Adopters: Organizations that adopt and integrate TP technology into their operations. Logistic service providers and carriers fall under this category.
- Users: Drivers are the individuals directly operating TP systems. Their expertise and feedback are crucial for successful implementation.

- Non-users: Stakeholders who may not directly participate but can influence adoption. Peripheral drivers who share the road with platoons fall under this category. Their comfort level and understanding of TP can impact wider acceptance.

**Table 1: Actors in the TP ecosystem**

| Tier 1 | Tier 2 | Tier 3 |
|---|---|---|
| Facilitators | Regulators | National policy makers |
| | | Safety authorities |
| | | European Commission |
| | Road Operators | Private concessionaires |
| | | State-owned road operators |
| | OEMs | Vehicle manufacturers |
| | | Vehicle component manufacturers |
| Adopters | Logistic service providers | |
| | Carriers | |
| Users | Drivers | |
| Non-users | Peripheral drivers | |

The stakeholders in the TP ecosystem interact through a continuous exchange of value. This exchange ensures that the technology is implemented effectively and meets the needs of all involved parties (see Figure 3). This interaction manifests in several keyways:

- Facilitators provide an operational framework that outlines the regulations, infrastructure requirements, technology available, and safety protocols for TP. This framework helps adopters plan for implementation and ensures a smooth transition.
- Adopters end up defining the operational requirements to facilitators. This feedback loop allows regulators and road operators to refine regulations and infrastructure to better suit the needs of the technology developed by the OEMs.
- Facilitators and adopters work together to create favorable work conditions for users (drivers). This includes training, clear communication protocols, and appropriate compensation for operating this new technology.
- Adopters provide labor opportunities for users (drivers) who contribute their expertise and experience to the successful operation of TP systems.

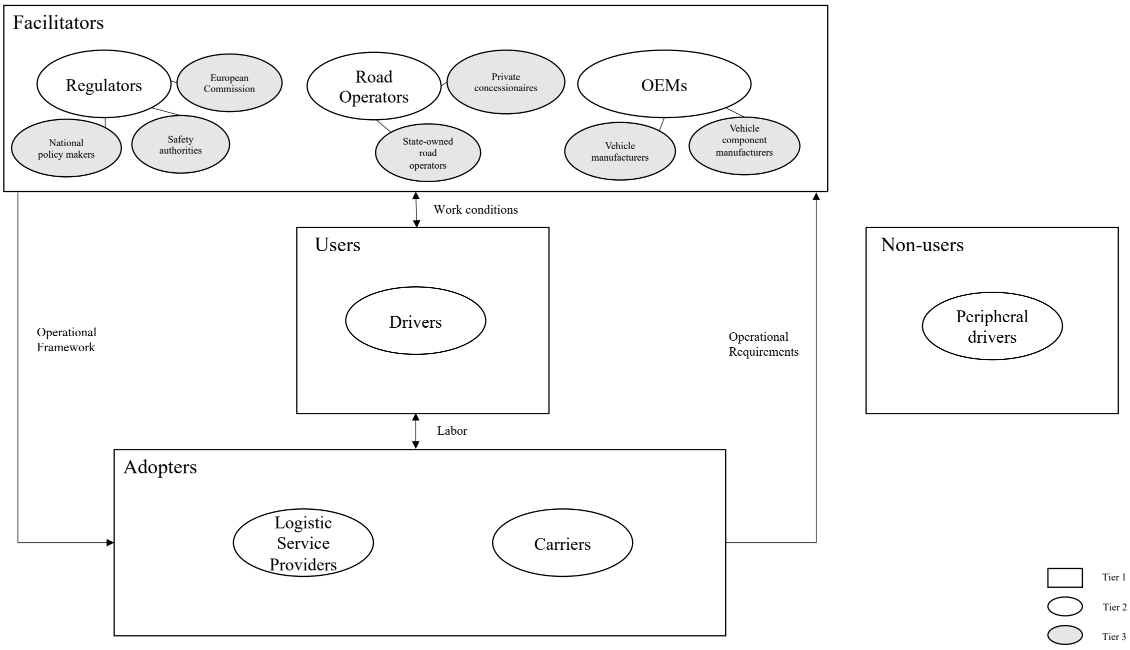


**Figure 3: Actors and their value exchanges in TP ecosystem**

The "Facilitators" category plays a critical role in establishing the groundwork for TP adoption. They interact with each other in specific ways to ensure the technology is safe, efficient, and well-integrated into the existing infrastructure (see Figure 4).

1. Regulators (National policy makers, Safety authorities, European Commission):
    - They set the overall direction by revising and changing regulations based on safety assessments and technological advancements.
2. OEMs (Vehicle manufacturers, Vehicle component manufacturers):
    - They implement these new technologies into their vehicle designs.
    - They provide guidance to road operators on adapting their infrastructure for smooth implementation.
    - They work together to develop innovative solutions for infrastructure compatibility with TP technology.
3. Road Operators (Private concessionaires, State-owned Road operators):
    - They collaborate with regulators to ensure their infrastructure (e.g., lane markings, communication systems) complies with the regulations.

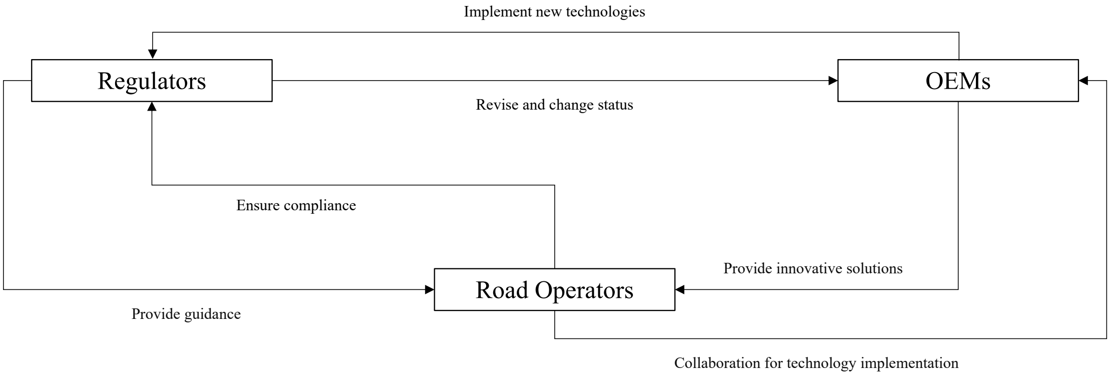


**Figure 4: Facilitators and their roles in the TP ecosystem**

### 5.1 Variable Identification and Analysis

Before exploring the interactions within the TP ecosystem, it is essential to present the analysis conducted to identify the key variables and themes. This section details the process of analyzing focus group discussions and *NVivo* data, reflecting the foundational work that informs the subsequent chapters.

#### 5.1.1 Focus Group Discussion

The analysis began with transcribing the five focus group discussions, which were then imported into *NVivo* for qualitative data analysis. These focus groups were categorized into two main groups: regulators (REG1 and REG2) and road operators (RO1, RO2, and RO3). The *NVivo* software facilitated a systematic coding process, associating relevant data provided by the entities with variables previously identified, both in literature and in the industry analysis, as potentially interesting attributes:

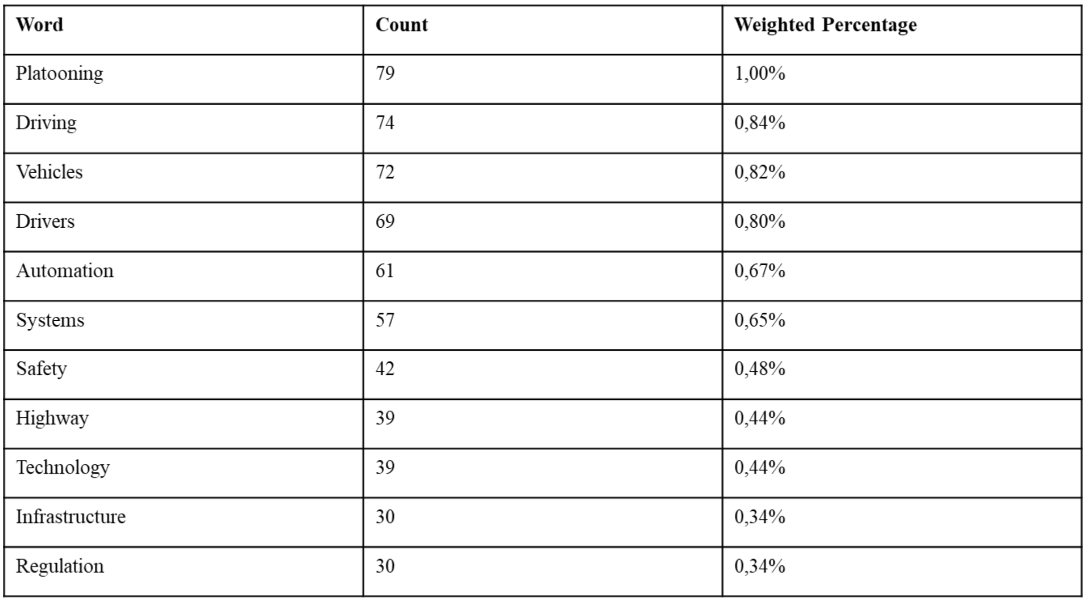
1. Vehicle automation level
2. Vehicles per platoon
3. Platoon length
4. Distance between platooning vehicles
5. Number of drivers
6. Drivers' training level
7. Shift duration
8. Mandatory resting periods
9. Time restriction
10. Dedicated lanes
11. Distance between highways exits
12. Number of lanes

13. V2V communications
14. V2X communications
15. V2I communications
16. Fuel savings

### 5.1.2 Word Frequency Analysis

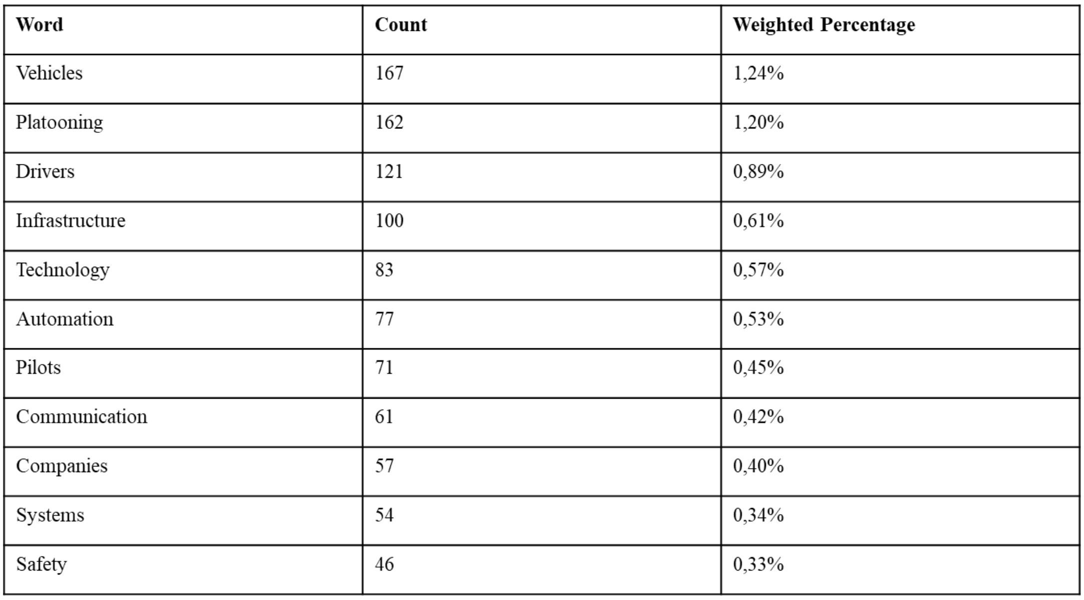
Subsequently, it was crucial to identify the most frequently mentioned variable groups by the regulators and road operators. *NVivo* was used to assess the most frequently mentioned words by both stakeholder groups, focusing on terms mentioned more than 25 times and excluding common stop words. This allowed for the creation of a word query highlighting key “kick-off” variables common across various groups, facilitating the creation of causal loops in System Dynamics (see Table 2 and Table 3):

**Table 2: Regulators' word query**



| Word | Count | Weighted Percentage |
|---|---|---|
| Platooning | 79 | 1,00% |
| Driving | 74 | 0,84% |
| Vehicles | 72 | 0,82% |
| Drivers | 69 | 0,80% |
| Automation | 61 | 0,67% |
| Systems | 57 | 0,65% |
| Safety | 42 | 0,48% |
| Highway | 39 | 0,44% |
| Technology | 39 | 0,44% |
| Infrastructure | 30 | 0,34% |
| Regulation | 30 | 0,34% |

Table 3: Road Operators' word query



| Word | Count | Weighted Percentage |
|---|---|---|
| Vehicles | 167 | 1,24% |
| Platooning | 162 | 1,20% |
| Drivers | 121 | 0,89% |
| Infrastructure | 100 | 0,61% |
| Technology | 83 | 0,57% |
| Automation | 77 | 0,53% |
| Pilots | 71 | 0,45% |
| Communication | 61 | 0,42% |
| Companies | 57 | 0,40% |
| Systems | 54 | 0,34% |
| Safety | 46 | 0,33% |

The word frequency query emphasized key terms such as "platooning," "vehicles," "drivers," "automation," "technology," "infrastructure," "safety," "highway," "project," "companies," "systems," and "regulation."

### 5.1.3 Synthesis of Focus Group Insights

The synthesis of insights from the focus groups provided a comprehensive understanding of stakeholder perspectives, which informed the subsequent analysis of the TP ecosystem. This work consolidates how stakeholders influence the deployment of this technology and goes deeper into their interactions, as discussed in the following sections.

### 5.1.4 Additional Variables and Grouping

A review of the obtained data allowed the incorporation of new variables suggested by other authors, potentially enhancing technical rigor (e.g., platoon uptime). This groundwork laid the foundation for the development of CLDs. Variables were grouped by stakeholders and boundaries as follows:

1. Grouping by Stakeholders:
    - Regulators:
        - Number of drivers
        - Shift duration
        - Fuel savings
        - Platoon length
        - Vehicles per platoon
        - Vehicle automation level

        - Dedicated lanes
        - Distance between highway exits
        - V2V communications
    - Road Operators:
        - Vehicle automation level
        - Vehicles per platoon
        - Distance between platooning vehicles
        - Dedicated lanes
        - Number of lanes
        - Time restriction
        - Mandatory resting periods
        - V2V communications
        - V2X communications
        - V2I communications
        - Fuel savings
    - OEMs:
        - V2V communications
        - Distance between platooning vehicles
        - Vehicle automation level
        - Fuel savings
        - Dedicated lanes

2. Grouping by Boundaries:
    - Lower number of accidents:
        - Vehicle automation level
        - Vehicles per platoon
        - Platoon length
        - Distance between platooning vehicles
        - Drivers training level
        - V2V communications
        - V2X communications
    - Lower fuel emissions:
        - Vehicle automation level
        - Vehicles per platoon
        - Platoon length

        - Distance between platooning vehicles
        - V2X communications
        - Fuel savings
    - Lower operational costs:
        - Vehicles per platoon
        - Shift duration
        - Mandatory resting periods
        - Time restriction
        - Dedicated lanes
        - Distance between highway exits
        - Number of lanes
    - Better working conditions:
        - Number of drivers
        - Shift duration
        - Mandatory resting periods

## 5.2 How Stakeholders Influence TP Implementation

CLDs are used in this study to analyze how each facilitator impacts the abovementioned four objectives of TP. These diagrams help visualize the complex dynamics and feedback loops between various factors, carefully constructed based on information provided by focus groups with regulators and road operators, and a scoping review that included literature and press releases from OEMs. Some CLDs use color-coding to assist the reader in following different causal paths that a single variable may influence. This color-coding is necessary when a variable can lead to different outcomes based on its input, providing clarity on the distinct paths and their implications: (i) the blue arrows indicate one path within the causal loop where specific variables interact in a particular sequence; (ii) the red arrows indicate another path within the causal loop, helping to distinguish it from the path indicated by blue arrows, especially when the same pair of variables is involved in different loops.

Key elements and paths illustrate the interconnected dynamics within the system. These elements are crucial for understanding the directional influence between variables, as shown in Figures 5 and 6:

- Variable interaction: The arrows illustrate the direction of influence between variables. Example: During the focus group, REG2 underscored the relationship between platoon uptime and fuel savings. As platoons have infrastructure conditions to operate during extended periods without interruptions, they can achieve substantial reductions in fuel consumption. From there, it is established in Figure 5 that “Platoon uptime” influences positively “Fuel savings”.
- Following paths:
    - Identify the starting variable: Taking the same example, where “Platoon uptime” influences positively “Fuel savings”.

  - Trace the arrows: There is a direct relation between “Fuel savings” and the investment the truck industry makes. So, it is established in Figure 5 that “Fuel savings” influences positively “Investment by OEMs”. The investment OEMs make is reflected in technology developments, which leads to a more efficient and higher “Platoon uptime”, closing the loop.
- Other Examples:
  - Starting from "Technology developments", Figure 6 is showing a positive feedback loop where improved technology facilitates greater V2V communication, as concluded in the industry review. Tsugawa, Jeschke, and Shladover (2016) present arguments to emphasize that improved V2V communication reduces the risk of accidents. So, it is established in Figure 6 that “V2V communication” influences negatively “Risk of accidents”, which impacts positively “Acceptance by Regulators”. A higher “Acceptance by Regulators” impacts positively the “Technology developments”, closing the loop.
  - Conversely, starting from "Vehicle automation level" (VAL), Figure 6 is illustrating a negative feedback loop where a higher VAL leads to a higher “Passive fatigue”, as concluded from RO2’s focus group, which impacts positively the “Risk of accidents”. A higher “Risk of accidents” implies a lower level of “Safety”, which, when compensated with “Changes in regulation” will slow down the “Vehicle Automation Level”, closing the loop.

### 5.2.1 Higher Fuel Savings

The first model emphasizes the intricate dynamics involved in achieving higher fuel savings within the TP ecosystem (see Figure 5). This objective necessitates the concerted efforts of regulators, road operators, and OEMs. Each stakeholder plays a pivotal role in facilitating the acceptance and implementation of technologies that contribute to fuel efficiency.

**Regulators** are instrumental in shaping the landscape through changes in regulations that promote fuel-efficient technologies. By developing and enforcing policies that encourage the adoption of platooning, regulators can create an environment conducive to technological advancements. Their acceptance of new regulations further legitimizes and accelerates these innovations, paving the way for a smoother implementation. As the scoping review of the industry perspective reveals, some OEMs’ decision to shift focus from platooning underscores the impact of regulatory decisions on technological development. In this case, the European Commission's choice not to revise driving and rest period regulations appears to have influenced Scania's strategic direction. This emphasizes the need for a multifaceted approach that considers not only technology development but also the regulatory framework and collaboration among stakeholders. In addition, platoon uptime is critical to regulators’ positioning about this technology deployment, since REG2 shared during the focus groups that platooning needs to be sustained over substantial distances, rather than being limited to short ranges.

**Road Operators** have a significant impact on operational costs and the overall feasibility of platooning. Their acceptance and support of platooning technologies are crucial, as they manage the infrastructure and ensure that the roadways can accommodate such advancements. According to the focus groups with the three road operators, the distance between vehicles, a critical factor in fuel savings, is influenced by the operational strategies and guidelines set forth by road operators. Additionally, their engagement with non-user acceptance can help mitigate resistance from the public and other road users. Furthermore, the infrastructure managed by road operators can greatly impact V2V communication. Well-maintained roads and the integration of supportive technologies, such as road sensors and communication relays, can enhance the reliability and efficiency of V2V systems, thus contributing to better fuel savings.

**OEMs** are at the forefront of technological developments that drive fuel efficiency. Their investment in research and development leads to innovations in V2V communication, data sharing, and optimal speed and gap distances between vehicles. By prioritizing fuel savings in their design and engineering processes, OEMs can enhance platoon uptime and reduce emissions, contributing significantly to the overall goal of higher fuel efficiency.

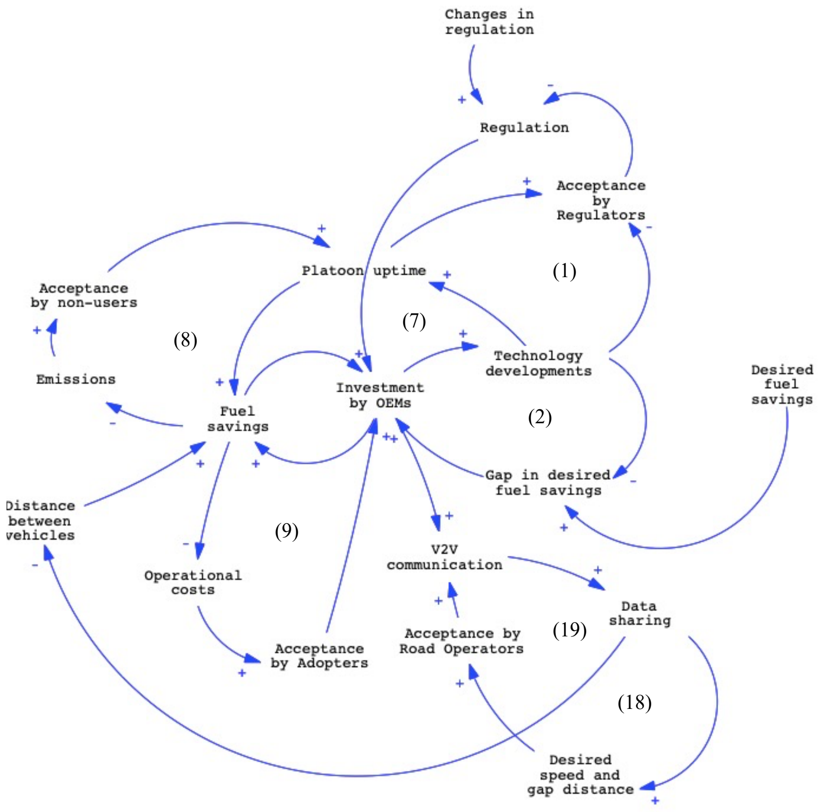


**Figure 5: Fuel Savings Dynamics**

Through the synergy of these stakeholders, the system can achieve substantial fuel savings, demonstrating how collaborative efforts and strategic investments can lead to meaningful advancements in TP.

### 5.2.2 Lower Number of Accidents

The second model focuses on the dynamics associated with reducing the number of accidents, highlighting the safety aspect of TP (see Figure 6). Here, the roles of regulators, road operators, and OEMs intersect to create a safer driving environment through regulation, education, and technological innovation.

**Regulators** play a critical role in establishing safety standards and mandatory education programs that ensure drivers are well-prepared to operate within a platooning system. Based on the focus groups with both regulators by setting strict safety regulations and overseeing their enforcement, regulators help mitigate the risk of accidents. Their acceptance and promotion of advanced safety measures promotes a culture of safety within the industry.

**Road Operators** contribute to safety by facilitating pilot programs that allow for the testing and refinement of platooning technologies in real-world conditions. Their oversight ensures that the infrastructure supports safe platooning operations. By accumulating experience from these pilots, road operators can make informed decisions that enhance overall safety. Additionally, their efforts in gaining acceptance from drivers and other stakeholders help build trust in the system's safety. Road operators also play a crucial role in supporting V2V communication, which is essential for real-time data sharing and coordination between platooning vehicles. By ensuring that the infrastructure supports robust communication networks, road operators can significantly enhance the safety and reliability of V2V interactions.

**OEMs** are pivotal in developing the technologies that underpin safe platooning. Their focus on V2V communication, data sharing, and vehicle automation levels directly impacts the safety of platooning operations. By addressing passive fatigue through advanced automation features and designing systems that minimize human error, OEMs contribute to a significant reduction in the risk of accidents. Their investments in safety-centric innovations ensure that platooning can be both efficient and secure.

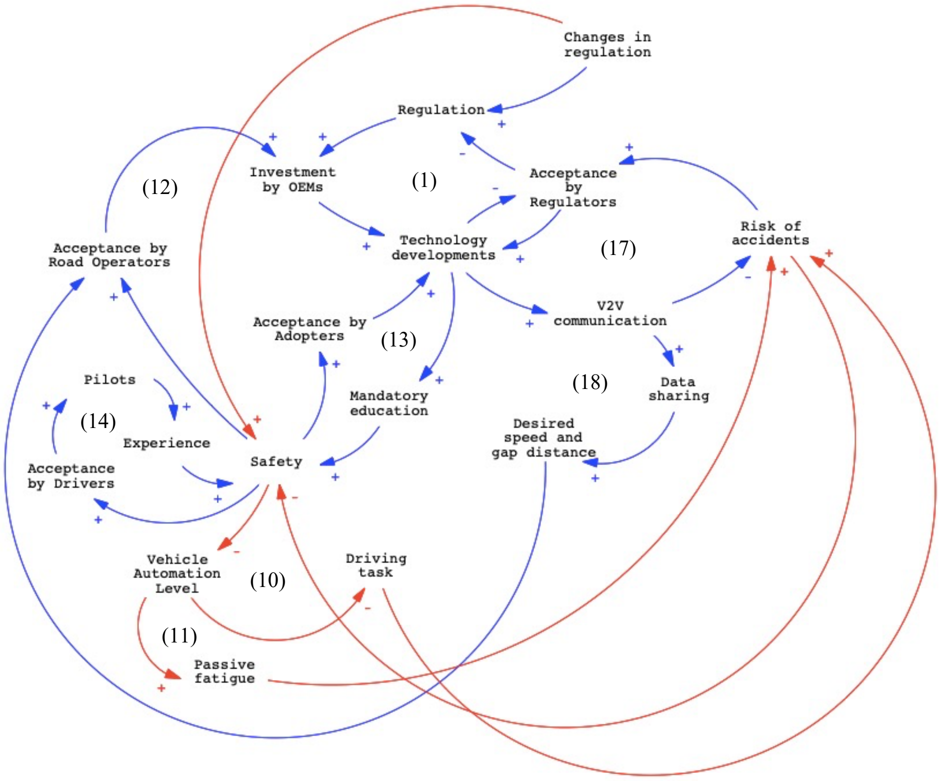


**Figure 6: Safety Dynamics**

The collaborative efforts of these stakeholders, each addressing different sides of safety, illustrate how a multifaceted approach can lead to a substantial reduction in accidents. This model underscores the importance of regulatory support, operational oversight, and technological advancement in creating a safer TP ecosystem.

### 5.2.3 Better Working Conditions

The third model explores the dynamics involved in achieving better working conditions within the TP ecosystem (see Figure 7). This goal is critical for enhancing driver satisfaction, safety, and overall system efficiency. The roles of regulators, road operators, and OEMs are crucial in fostering an environment that supports these objectives.

**Regulators** play a fundamental role in setting the standards and policies that ensure better working conditions for drivers. By implementing changes in regulation, they can enforce rules that promote safer and more comfortable working environments. Regulations around mandatory education ensure that drivers are well-informed and prepared for platooning operations, which enhances safety and reduces the risk of accidents. How regulators classify resting periods under TP is crucial for acceptance by drivers. For instance, RO2 explains drivers' rest could be simplified if it were legally considered rest time while the driver is in a platoon without driving. Additionally, the analysis of security and border-related issues will significantly impact the technology's implementation.

**Road Operators** contribute by ensuring that the infrastructure supports smooth and efficient V2V communication, which is essential for the effective operation of platoons. Their acceptance and support of these technologies are crucial for seamless integration and operation. Effective V2V communication not only enhances safety but also reduces the mental strain on drivers by providing real-time information and support.

**OEMs** are pivotal in developing the technologies that make platooning a viable and attractive option for drivers. Their investments in technological developments lead to innovations that enhance driving pleasure. By improving automated driving systems towards higher automation levels, OEMs ensure that platooning is both efficient and comfortable for drivers. The development of advanced vehicle automation levels reduces the cognitive load on drivers, allowing them to focus more on monitoring and less on manual driving, thereby contributing to better working conditions.

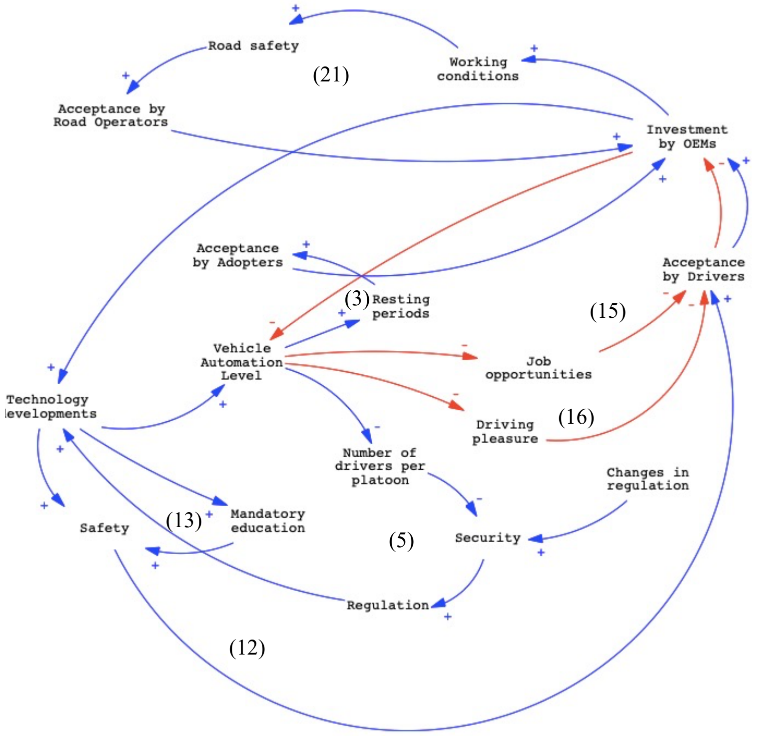


Figure 7: Working Conditions Dynamics

Through the collaborative efforts of these stakeholders, significant improvements in working conditions can be achieved, demonstrating how strategic investments and supportive policies can lead to a more sustainable and driver-friendly platooning ecosystem.

### 5.2.4 Lower Operational Costs

The fourth model examines the dynamics associated with reducing operational costs, a key factor for the widespread adoption and commercial viability of TP (see Figure 8). Achieving this objective requires the combined efforts of regulators, road operators, and OEMs.

**Regulators** influence operational costs through the establishment of regulations that streamline operations. By setting guidelines on shift duration and travel distance without resting stops, they help optimize driver schedules and reduce unnecessary downtime. Additionally, by promoting and overseeing advancements in vehicle automation levels, regulators can facilitate the adoption of technologies that lower operational costs by enhancing efficiency and reducing labor costs.

**Road Operators** play a crucial role by ensuring transparency in infrastructure costs. By providing clear and predictable cost structures for the use of roadways and associated services, they enable more accurate budgeting and cost management for platooning operations. This transparency helps companies plan more effectively and reduces unforeseen expenses, contributing to lower overall operational costs.

**OEMs** are at the forefront of technological advancements that directly impact operational costs. Their focus on fuel savings through efficient vehicle design and engineering significantly reduces one of the major cost components for trucking operations. By advancing vehicle automation levels, OEMs reduce the reliance on human drivers, which can lower labor costs and increase operational efficiency. Additionally, continuous technology developments lead to more reliable and efficient platooning systems, further driving down costs.

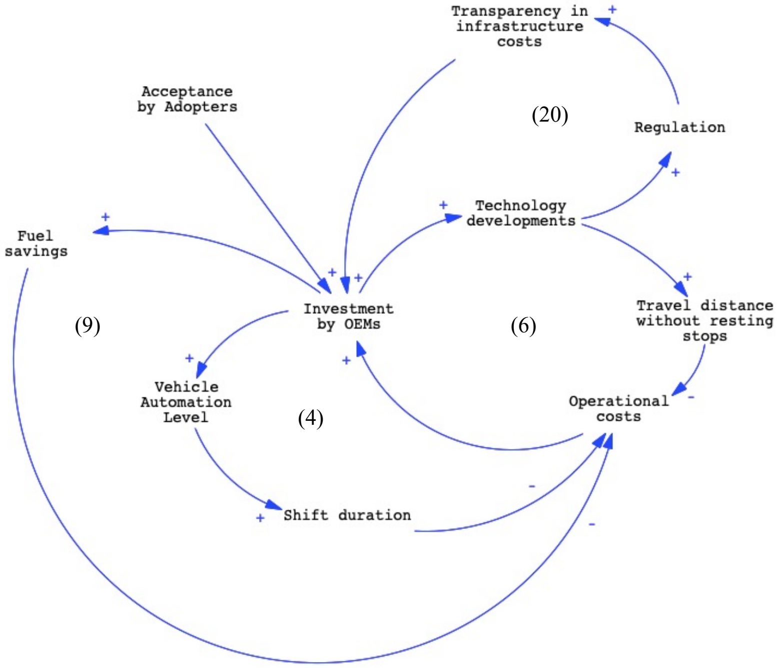


Figure 8: Costs Dynamics

The combined efforts of these stakeholders create a robust framework for reducing operational costs, demonstrating how regulatory support, transparent infrastructure management, and technological innovation can collectively enhance the economic sustainability of TP.

In conclusion, the successful deployment of TP hinges on the dynamic interplay between regulators, road operators, and OEMs across four critical boundaries: higher fuel savings, lower number of accidents, better working conditions, and lower operational costs. Each stakeholder has unique contributions that, when combined, facilitate the achievement of these goals.

**Regulators** are essential in shaping the framework within which TP operates. By implementing changes in regulation, setting mandatory education standards, enforcing safety protocols, and managing shift durations and resting periods, regulators ensure that the platooning environment is safe, efficient, and favourable to driver well-being. Their efforts directly influence the reduction of accidents, enhancement of working conditions, and optimization of operational costs.

**Road Operators** play a pivotal role in the practical implementation and acceptance of platooning technologies. Their responsibility for maintaining and enhancing infrastructure, supporting V2V communication, and ensuring transparency in infrastructure costs is critical for the seamless operation of platooning systems. By facilitating pilot programs and accumulating operational experience, road operators contribute to both the safety and economic viability of TP.

**OEMs** are at the forefront of technological innovation. Their investments in research and development lead to advancements in vehicle automation, V2V communication, fuel efficiency, and driver comfort. By focusing on technology developments that optimize speed and gap distances, reduce fuel consumption, and enhance the driving experience, OEMs play a crucial role in achieving higher fuel savings, improving safety, enhancing working conditions, and lowering operational costs.

The combined efforts of these stakeholders create a comprehensive and integrated approach to TP. Regulators set the stage with supportive policies and safety standards, road operators ensure the infrastructure is conducive to platooning, and OEMs provide the technological advancements needed to make platooning viable. This study underscores the importance of collaborative efforts and strategic investments guided by S-D logic to address the complex and dynamic nature of TP deployment strategies, promoting value co-creation (see Table 4). By working together, these stakeholders can create a sustainable, efficient, and safe TP ecosystem that meets the needs of all parties involved.

**Table 4: Stakeholders' impact in each boundary**

| | Higher fuel savings | Lower number of accidents | Better working conditions | Lower operational costs |
|---|---|---|---|---|
| Regulators | Shape landscape through regulations promoting fuel-efficient technologies.<br>Enforce policies encouraging platooning adoption. | Establish safety standards and mandatory education programs.<br>Mitigate accident risk by enforcing stringent safety regulations. | Implement and enforce regulations to promote safer and more comfortable working environments.<br>Ensure mandatory education and proper classification of resting periods for drivers. | Streamline operations through regulatory guidelines.<br>Promote advancements in vehicle automation to enhance efficiency. |
| Road Operators | Influence vehicle distance through operational strategies.<br>Supportive infrastructure enhances V2V communication, improving fuel savings. | Facilitate pilot programs for testing platooning technologies.<br>Ensure infrastructure supports safe platooning operations. | Support smooth V2V communication for safer platooning.<br>Provide real-time information and support to reduce mental strain on drivers. | Provide clear, predictable cost structures for roadway use.<br>Enable accurate budgeting and cost management for platooning operations. |
| OEMs | Drive fuel efficiency through technological developments.<br>Innovate V2V communication, data sharing, and optimal speed/gap distances. | Develop technologies supporting safe platooning.<br>Address passive fatigue through automation features. | Invest in technological developments to enhance vehicle automation and driving comfort.<br>Develop advanced vehicle automation levels to reduce cognitive load on drivers. | Improve fuel savings and efficient vehicle design for lower cost components in trucking operations<br>Enhancing platooning systems to drive down labor costs |

## 5.3 Power *versus* Interest

In the deployment of TP, the Power-Interest Grid serves as a relevant tool for understanding the roles and influences of various stakeholders. The Power-Interest Grid is a fundamental tool for stakeholder identification and analysis, helping to categorize stakeholders based on their level of power and interest regarding a particular issue or project. Bryson (2004) explains that this tool is particularly useful in strategic planning, policy development, and organizational change efforts, where understanding the dynamics between different stakeholders is crucial. According to Eden and Ackermann (1998), the grid arrays stakeholders on a two-by-two matrix, with the dimensions being the stakeholder's power to influence the organization's future and their interest in the organization or issue. Stakeholders are then categorized into four groups:

players, who have both high interest and high power; subjects, who have high interest but low power; context setters, who have high power but low interest; and the crowd, who have low interest and low power. An adapted version is utilized, featuring key stakeholders, those to be kept satisfied, those to be kept informed, and those requiring minimum effort.

Each stakeholder group occupies a distinct position within this grid (see Figure 9), determined by their level of power and interest in the successful implementation of TP. This section will outline how facilitators (regulators, road operators, and OEMs) are positioned in the Power-Interest Grid and the implications of their positions for the overall deployment strategy. In addition, the other stakeholders that were mentioned before, adopters, drivers, and non-drivers are positioned to help consider relative perspectives:

1. **Regulators: High Power, High Interest**

Regulators are critical in shaping the legal and operational framework for TP. Their high-power is related to their ability to approve and enforce regulations, set mandatory safety and education standards, and manage operational guidelines such as shift durations and rest periods. Regulators also have a high interest in ensuring that TP reduces accidents to accomplish increasingly demanding safety targets, while enhancing driver working conditions, and promoting environmental sustainability. Their strategic positioning in the grid means they are key players whose decisions directly influence the feasibility and safety of TP.

2. **Road Operators: Moderate Power, High Interest**

Road operators hold a crucial role in maintaining and upgrading infrastructure to support platooning technologies. They possess moderate power due to their control over road networks and the implementation of Vehicle-to-Infrastructure (V2I) communication systems. Their high interest in TP is driven by the potential for improved road safety, reduced traffic congestion, and cost efficiencies in infrastructure usage. Road operators facilitate pilot programs and gather operational data, which are essential for refining and scaling up platooning initiatives.

3. **OEMs: High Power, High Interest**

OEMs drive the technological advancements necessary for TP. Their high power comes from their role in developing and supplying the vehicles and systems that make platooning possible, including automation, V2V communication, and fuel efficiency technologies. While their primary interest may lie in market expansion and innovation, the successful deployment of TP directly benefits their business by creating demand for advanced trucking technologies.

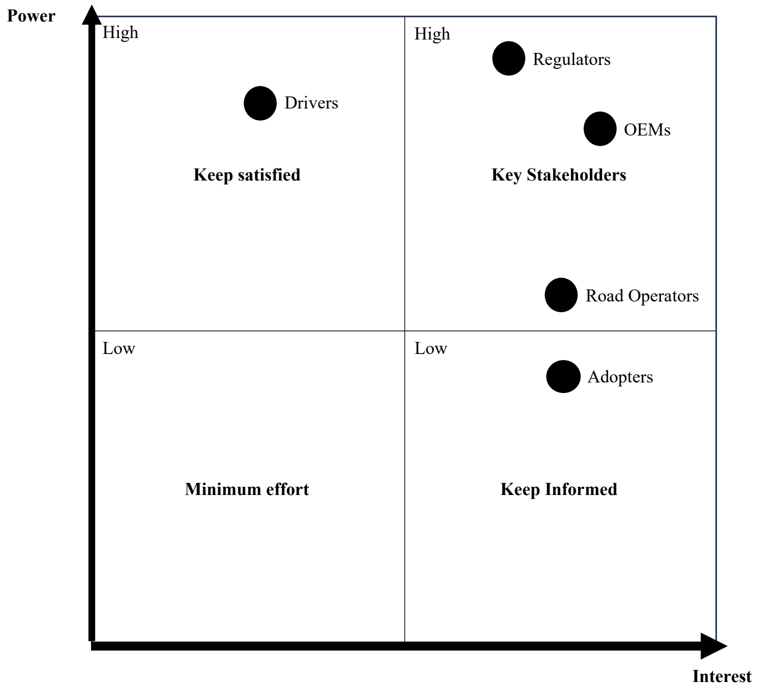


**Figure 9: Power-interest grid analysis**

Other stakeholders outside the scope of this research are also included in the matrix, considering their importance as adopters and users, and based on the results of previous analyses under the project TRAIN (Neto et al. 2024) (Lourenço et al. 2024). In this respect, it is important to highlight the perceptions of drivers, who recognize the role that technology has had to improve driving and working conditions, but still have some relevant concerns regarding the maturity of automated driving systems. Additionally, logistics companies, as adopters, assume a positive but expectant stance towards TP technology, demanding for more knowledge and demonstration about real-world benefits.

## 5.4 A Roadmap to TP Deployment

The general adoption of TP faces several significant obstacles. A critical challenge is the current level of investment in automation technologies. Without a substantial increase in funding, the development and deployment of TP systems will be delayed. Additionally, conducting a rigorous cost-benefit analysis is essential to assess the trade-off between fuel efficiency gains and safety considerations. While TP promises considerable fuel cost reductions, ensuring the highest safety standards remains paramount. Achieving these fuel savings without compromising safety necessitates a high level of technological maturity.

Furthermore, the role of regulatory bodies in facilitating TP implementation is crucial. While worker safety is a justified regulatory priority, regulators must also be willing to adapt and innovate labor regulations to accommodate the unique operational requirements of TP. This includes embracing legislative reforms that enable TP adoption while protecting worker rights. The current regulatory status, characterized by a lack of proactive measures and critical thinking, impedes progress. Similarly, infrastructure providers must adopt a more forward-thinking approach to support TP.

Moreover, OEMs face concerns regarding potential liability issues associated with Level 3 automation systems. The fear of legal repercussions for accidents involving these systems discourages OEMs from introducing TP solutions to the market. To address this, regulators must actively collaborate with OEMs to establish clear liability frameworks and risk-sharing mechanisms.

To overcome these challenges and pave the way for TP implementation, a comprehensive framework is proposed (see Table 5). This framework outlines a ten-step process, with each step accompanied by a responsibility matrix identifying the key stakeholders – regulators, road operators, and OEMs – involved in its successful execution. The ten steps encompass:

1. **Achieving Level 4 technology:** Establishing clear definitions and classifications for different automation levels and ensuring significant investment in research and development.
2. **Enabling regulatory-approved testing:** Developing efficient processes for approving testing on public roads and ensuring collaboration with road operators and OEMs.
3. **Ensuring market readiness:** Establishing regulations for commercial deployment and developing operational guidelines and protocols.
4. **Establishing V2V and V2N communication protocols:** Defining standardized communication protocols to ensure seamless and secure data exchange and coordinated operations.
5. **Develop and implement training programs:** Setting mandatory training requirements and curriculum standards, supported by adequate facilities and resources.
6. **Pilot testing and data collection:** Overseeing compliance with safety regulations and ethical data collection practices during pilot testing.
7. **Develop business models and revenue streams:** Creating regulatory frameworks to incentivize investment and exploring potential taxation models.
8. **Secure public and industry acceptance:** Addressing public concerns about safety and job displacement through effective communication and awareness campaigns.
9. **Standardization and interoperability:** Enforcing technical standards to ensure interoperability between different platooning systems and infrastructure compatibility.
10. **Long-term infrastructure investment:** Allocating funding for necessary infrastructure upgrades and planning improvements based on pilot testing results. By addressing these challenges and implementing the proposed framework, the transition towards a viable and sustainable TP solution can be accelerated. Collaborative efforts from all stakeholders, guided by a shared vision for TP's potential benefits, can unlock a future where TP contributes to improve transportation efficiency and safety, and to reduce environmental impacts.

## Table 5: Responsability Matrix

| | Regulators | Road Operators | OEMs |
|---|---|---|---|
| Achieving Level 4 technology | Establish clear definitions and classifications for different automation levels, particularly focusing on Level 4. Define the operational boundaries and responsibilities for Level 4 systems. | Assess infrastructure readiness for Level 4 operations, identifying potential limitations and areas for improvement. | Invest in research and development to achieve Level 4 automation. |
| Enabling regulatory-approved testing | Develop a clear and efficient process for approving platooning technology testing on public roads. Define safety protocols and data collection requirements for testing. | Collaborate with regulators to identify suitable test routes and infrastructure modifications needed to support safe testing. | Work with regulators to obtain approvals for testing their platooning technology on designated routes. Ensure compliance with established safety protocols and data collection requirements. |
| Ensuring market readiness | Establish regulations for the commercial deployment of platooning technology, addressing issues like insurance, liability, and data privacy. | Develop operational guidelines and protocols for platooning on their infrastructure. This may include designated lanes, signage, and communication protocols. | Ensure their platooning systems meet all regulatory requirements and are commercially viable for fleet operators. This includes factors like cost, reliability, and ease of integration with existing fleet management systems. |
| Establishing V2V and V2N communication protocols | Define mandatory communication protocols for V2V and V2N interaction between platooning vehicles and roadside infrastructure. This ensures seamless data exchange and coordinated operations. | Upgrade infrastructure to support established V2V and V2N communication protocols. This may involve installing roadside communication units and providing reliable network connectivity. | Design their platooning systems to comply with the established V2V and V2N communication protocols. This ensures vehicles can seamlessly exchange data and coordinate maneuvers with other platoons and infrastructure elements. |
| Develop and Implement Training Programs | Establish mandatory training requirements and curriculum standards for drivers operating in platoons. Define proficiency levels for different automation levels. | Offer training facilities and infrastructure resources to support training programs. | Develop training programs specific to their platooning systems, ensuring drivers understand operational procedures and emergency protocols. |
| Pilot Testing and Data Collection | Oversee testing to ensure compliance with safety regulations and ethical data collection practices. Define data collection protocols and anonymization procedures. | Provide designated test routes with appropriate signage and infrastructure to support safe and efficient testing. | Deploy platooning technology for testing, gather data on performance, safety, and user experience. Collaborate with regulators on data collection and analysis. |
| Develop Business Models and Revenue Streams | Define regulatory frameworks that incentivize investment in platooning technology and infrastructure. Explore potential taxation models for platooning operations. | Develop pricing models for using platooning-specific infrastructure, such as dedicated lanes or congestion pricing for non-platooning vehicles. | Develop pricing strategies for platooning technology (purchase, leasing, subscription models) and related services (maintenance, software updates). |
| Secure Public and Industry Acceptance | Address public concerns about safety and potential job displacement. Communicate the regulatory framework and safety protocols established for platooning. | Engage with communities to address concerns about potential disruptions caused by platooning on roadways. | Implement public awareness campaigns highlighting the benefits of platooning for safety, fuel efficiency, and environmental impact. |
| Standardization and Interoperability | Develop and enforce technical standards for communication protocols (V2V, V2N), data formats, and safety features to ensure interoperability between different platooning systems from various OEMs. | Ensure infrastructure is compatible with standardized communication protocols for seamless operation of platooning systems from different manufacturers. | Design their platooning systems to comply with established standards, ensuring seamless interoperability and data exchange between platoons. |
| Long-Term Infrastructure Investment | Allocate funding for infrastructure upgrades to support platooning needs. This may include dedicated lanes, improved signage with dynamic information displays, and roadside communication infrastructure for data exchange. | Plan and implement infrastructure improvements based on pilot testing results and long-term vision for platooning adoption. | Collaborate with infrastructure providers to develop in-vehicle systems that can leverage new infrastructure features (e.g., smart roads, roadside sensors) to further enhance platooning efficiency and safety. |

## 6 Conclusions

This research examined the multifaceted environment of TP and its potential to revolutionize the transportation sector. Key findings highlighted the significant benefits of TP, including improved fuel efficiency, which leads to reduced $CO_2$ emissions, lower operational costs, enhanced road safety, and better working conditions for truck drivers. Despite these advantages, the study also identified critical challenges, such as regulatory challenges, technological limitations, market readiness, and commercial viability.

### 6.1 Key findings and Takeaways

The work addressed a gap in the current understanding of the collaborative role of regulators and road operators in shaping the TP landscape. By employing S-D logic, the study underscored the importance of collaboration between facilitators (regulators, road operators, and OEMs), adopters (logistic service providers and carriers), and drivers, in creating value. Here, the research explores the concept of "driving as a service" (Sérgio P. Duarte et al. 2024), promoting a collaborative ecosystem. Building on focus groups with Portuguese road operators and regulators, key requirements for a safe and attractive TP environment were identified. These discussions highlighted the interdependence between the different facilitators emphasizing the need for co-creation to overcome uncertainties and drive acceptance. Regulators can co-create value by establishing clear and adaptable regulations that encourage OEMs investment while ensuring safety, and promoting regulatory innovation. Road operators can collaborate by investing in infrastructure upgrades and providing dedicated lanes for platoons, optimizing traffic flow, and enhancing TP efficiency.

Furthermore, the research integrated S-D logic with SD models to offer a comprehensive systems approach to TP. SD models provided valuable insights into the dynamic interplay between stakeholders, including regulators, road operators, OEMs, and truck drivers. By analyzing feedback loops and potential bottlenecks, CLDs identified areas for collaboration and value co-creation. For instance, the model revealed that unclear liability frameworks hinder OEMs investment in TP technology. This insight can be used to encourage collaboration between regulators and OEMs to develop clear liability frameworks, fostering innovation and accelerating TP deployment. The study also recognized the importance of addressing societal concerns related to job displacement and public perceptions in the adoption of TP technologies

A critical challenge identified was the current level of investment in automation technologies. Without substantial increases in funding, the development and deployment of TP systems will be delayed. Conducting rigorous cost-benefit analyses is essential to assess the trade-offs between fuel efficiency gains and safety considerations. Achieving these fuel savings without compromising safety necessitates a high level of technological maturity.

The role of regulatory bodies is crucial in facilitating TP implementation. While worker safety is a justified priority, regulators must adapt and innovate labor regulations to accommodate TP's unique operational requirements. This includes legislative reforms to enable TP adoption while protecting worker rights. The current regulatory status, characterized by a lack of proactive measures and critical thinking, impedes progress. Similarly, infrastructure providers must adopt a forward-thinking approach to support TP.

Moreover, OEMs face concerns regarding potential liability issues associated with Level 3 automation systems. The fear of legal repercussions for accidents involving these systems discourages OEMs from introducing TP solutions to the market. Regulators must actively collaborate with OEMs to establish clear liability frameworks and risk-sharing mechanisms.

To overcome these challenges and pave the way for TP implementation, a comprehensive ten-step framework is proposed, with each step accompanied by a responsibility matrix identifying key stakeholders - regulators, road operators, and OEMs - required for successful execution. These steps include achieving Level 4 technology, enabling regulatory-approved testing, ensuring market readiness, establishing V2V and V2N communication protocols, developing and implementing training programs, pilot testing, and data collection, developing business models and revenue streams, securing public and industry acceptance, standardization and interoperability, and long-term infrastructure investment.

The primary contribution of this research lies in the development of a group of CLDs tailored to the TP ecosystem. Unlike traditional transport SD models that focus only on market penetration, this model assesses user acceptance and interdependencies, informed by S-D logic principles. By examining the interconnectedness of diverse societal groups and their influence on each other, this systemic approach offers a deeper understanding of the TP ecosystem, leading to more informed regulatory decisions.

In comparison to the existing literature reviewed in Chapter 2, this study extends the understanding of TP by providing a comprehensive framework that integrates S-D logic with SD models. This approach not only addresses the technological and regulatory aspects of TP but also emphasizes the collaborative efforts needed among various stakeholders, underlining the different responsibilities each stakeholder represents in this technology’s deployment. The research contributes to the literature by demonstrating how a systems-oriented approach can effectively address the complexities and uncertainties associated with TP implementation.

This research successfully responded to the research questions, by understanding and facilitating TP adoption. The findings are structured around the two central research questions, providing detailed insights into the regulatory challenges and the potential of SD models to address these challenges:

**Key Findings for RQ1: Regulatory Challenges in TP**

1. **Regulatory Challenges:** The study identified several critical regulatory challenges, such as:
    - **Unclear Liability Frameworks:** The need for clear liability frameworks to address accidents and incidents involving TP.
    - **Adaptable Regulations:** The necessity for regulations that can adapt to the rapid advancements in TP technology.
    - **Stakeholder Collaboration:** The importance of collaboration between regulators, road operators, and OEMs to develop effective regulatory frameworks.
2. **Technological Limitations:** Current automation technologies require significant advancements and increased funding to meet regulatory standards and ensure safe TP operations.
3. **Market Readiness and Commercial Viability:** The market readiness and commercial viability of TP are hindered by regulatory uncertainties and the lack of proactive measures to encourage investment from OEMs and other stakeholders.

**Key Findings for RQ2: SD's Role in Addressing Regulatory Challenges**

1. **Insights from SD Models:** The integration of S-D logic with SD models provided valuable insights into the dynamic interactions among stakeholders. CLDs identified feedback loops and potential bottlenecks, suggesting collaboration between regulators and OEMs to develop clear liability frameworks.
2. **CLDs:** The CLDs revealed key areas for improvement and collaboration, such as:
   - **Liability and Safety Regulations:** Addressing the need for clear and adaptable regulations to ensure safety and liability.
   - **Technological Advancements:** Highlighting the importance of continuous investment in TP technology to meet regulatory requirements.
   - **Market Incentives:** Identifying incentives for OEMs to invest in TP technology despite regulatory challenges.
3. **Collaborative Efforts:** The study underscored the importance of collaborative efforts between facilitators (regulators, road operators, OEMs), adopters (logistic service providers, and carriers), and drivers to create value and overcome regulatory challenges.

By addressing RQ1 and RQ2, this research contributes significantly to the literature on TP, offering a framework that underscores the importance of stakeholder collaboration and systemic thinking in advancing TP technology and its adoption. In conclusion, by employing a collaborative, systems-oriented approach, the study provided valuable insights into the roles of regulators, road operators, and OEMs in creating a sustainable, efficient, and safe TP ecosystem. These findings contribute significantly to the literature on TP, offering a framework that underscores the importance of stakeholder collaboration and systemic thinking in advancing TP technology and its adoption.

## 6.2 Guidelines for Future Research

Future research should explore deeper into several areas to advance TP adoption and optimize its benefits:

1. **Technological Advancements:** Investigate advancements in automation technologies to enhance the safety, reliability, and cost-effectiveness of TP systems. Research should focus on overcoming current technological limitations and accelerating innovation in V2V communication and automated driving capabilities.
2. **Regulatory Innovation:** Explore innovative regulatory frameworks that can adapt to rapid TP technological advancements while ensuring safety and liability clarity. Future studies should emphasize proactive regulatory measures that encourage OEMs investment and foster regulatory agility.
3. **Socio-Economic Impacts:** Conduct comprehensive studies on the socio-economic impacts of TP adoption, including job displacement and workforce transitions. Develop strategies such as retraining programs and job creation initiatives to mitigate potential negative impacts and maximize societal benefits.
4. **Public Perception and Acceptance:** Investigate public perceptions and attitudes towards TP technologies through extensive surveys and qualitative studies. Develop targeted public awareness campaigns to address safety concerns, environmental benefits, and overall societal implications of TP.

5. **International Collaboration:** Foster international collaboration and knowledge-sharing initiatives to harmonize regulatory standards, promote interoperability and facilitate global TP deployment. Comparative studies across different regions can provide valuable insights into regulatory best practices and technological adaptation strategies.

By addressing these future research directions, scholars and industry stakeholders can contribute to advancing TP technology, enhancing its societal acceptance, and realizing its transformative potential in the transportation sector.

## References

Abbas, Khaled A., and Michael G. H. Bell. 1994. "System dynamics applicability to transportation modeling." *Transportation Research Part A: Policy and Practice* 28 (5): 373-390. https://doi.org/https://doi.org/10.1016/0965-8564(94)90022-1. https://www.sciencedirect.com/science/article/pii/0965856494900221.

Atasayar, Hatun, Philipp Blass, and Susanne Kaiser. 2022. "Truck Platooning Worldwide." In *Energy-Efficient and Semi-automated Truck Platooning: Research and Evaluation*, edited by Alexander Schirrer, Alexander L. Gratzer, Sebastian Thormann, Stefan Jakubek, Matthias Neubauer and Wolfgang Schildorfer, 13-19. Cham: Springer International Publishing.

Basias, Nikolaos, and Yannis Pollalis. 2018. "Quantitative and qualitative research in business & technology: Justifying a suitable research methodology." *Review of Integrative Business and Economics Research* 7: 91-105.

Bishop, Richard. 2020. "U.S. States Are Allowing Automated Follower Truck Platooning While The Swedes May Lead In Europe." Forbes. https://www.forbes.com/sites/richardbishop1/2020/05/02/us-states-are-allowing-automated-follower-truck-platooning-while-the-swedes-may-lead-in-europe/.

Bryson, John M. 2004. "What to do when Stakeholders matter." *Public Management Review* 6 (1): 21-53. https://doi.org/10.1080/14719030410001675722. https://doi.org/10.1080/14719030410001675722.

Calvert, Simeon, Giulio Mecacci, Daniel Heikoop, and Filippo Santoni de Sio. 2018. *Full platoon control in Truck Platooning: A Meaningful Human Control perspective*.

Castritius, Sarah-Maria, Christoph Johannes Dietz, Patric Schubert, Johanna Moeller, Simone Morvilius, Sabine Hammer, Chung Anh Tran, and Christian T. Haas. 2021. "Truck Platooning Under Real Traffic Conditions: First Insights on Behavioral Adaptations and Gap Preference of Professional Drivers." *Human Factors* 63 (6): 1033-1045. https://doi.org/10.1177/0018720820908481. https://journals.sagepub.com/doi/abs/10.1177/0018720820908481.

Connected Automated Driving, The Knowledge Base on. 2022. "Platooning becomes a reality in Europe." https://www.connectedautomateddriving.eu/blog/platooning-becomes-a-reality-in-europe/.

Creswell, John W., and J. David Creswell. 2018. *Research Design: Qualitative, Quantitative, and Mixed Methods Approaches*. 3rd ed. Journal of Chemical Information and Modeling: SAGE Publications, Inc.

Daimler, 2018, "Daimler now testing platooning technology for more truck efficiency also in Japan," https://www.daimlertruck.com/en/newsroom/pressrelease/daimler-now-testing-platooning-technology-for-more-truck-efficiency-also-in-japan-32920883.

---, 2019, "Daimler Trucks invests half a billion Euros in highly automated trucks," https://www.daimlertruck.com/en/newsroom/pressrelease/daimler-trucks-invests-half-a-billion-euros-in-highly-automated-trucks-42188247.

Duarte, Sérgio P., António Lobo, Sara Ferreira, and António Couto. 2024. Driving as a Service: Promoting a Sustainable Transition to Automated Driving. *Sustainability* 16 (7). https://doi.org/10.3390/su16072809.

Duarte, Sérgio Pedro, Marta Campos Ferreira, Jorge Pinho De Sousa, Jorge Freire De Sousa, and Teresa Galvão. 2021. "Improving Mobility Services through Customer Participation." 654-663. Springer International Publishing.

Duarte, Sérgio Pedro, Liliana Cunha, Sara Ferreira, and António Lobo. 2023. "Understanding interdependencies of success factors for truck platooning implementation: a facilitators' perspective." ICDSST 2023-9th International Conference on Decision Support System

Technology: Decision Support System in an Uncertain World: the Contribution of Digital Twins.

Duarte, Sérgio Pedro, António Lobo, Joana Ribeiro, João Valente Neves, António Couto, and Sara Ferreira. 2023. "A multilevel decision-making approach for road infrastructure management." *Journal of Decision Systems*: 1-23. https://doi.org/10.1080/12460125.2023.2263675. https://doi.org/10.1080/12460125.2023.2263675.

Dubljević, Veljko, Sean Douglas, Jovan Milojevich, Nirav Ajmeri, William A. Bauer, George List, and Munindar P. Singh. 2023. "Moral and social ramifications of autonomous vehicles: a qualitative study of the perceptions of professional drivers." *Behaviour & Information Technology* 42 (9): 1271-1278. https://doi.org/10.1080/0144929X.2022.2070078. https://doi.org/10.1080/0144929X.2022.2070078.

Eden, C., and F. Ackermann. 1998. *Making Strategy: The Journey of Strategic Management*. SAGE Publications.

Edmondson, Amy C, and Stacy E McManus. 2007. "Methodological fit in management field research." *Academy of management review* 32 (4): 1246-1264.

Frow, Pennie, and Adrian Payne. 2011. "A stakeholder perspective of the value proposition concept." *European Journal of Marketing* 45 (1/2): 223-240. https://doi.org/10.1108/03090561111095676. https://dx.doi.org/10.1108/03090561111095676.

Galvagno, Marco, and Daniele Dalli. 2014. "Theory of value co-creation: a systematic literature review." *Managing Service Quality* 24 (6): 643-683. https://doi.org/10.1108/MSQ-09-2013-0187. https://doi.org/10.1108/MSQ-09-2013-0187.

Ghaemi, Seyed Ali, and Mansour Hadji Hosseinlou. 2023. "Modeling the Urban Freight-Transportation System Using the System Dynamics Approach." *Systems* 11 (8): 409. https://www.mdpi.com/2079-8954/11/8/409.

Goertz, Gary, and James Mahoney. 2013. *A Tale of Two Cultures*. Princeton: Princeton University Press.

Government of the Netherlands, Government of the Netherlands. 2016. *European Truck Platooning Challenge 2016.* https://www.government.nl/binaries/government/documenten/leaflets/2015/10/06/leaflet-european-truck-platooning-challenge-2016/brochure-european-truck-platooning-challenge-2016.pdf.

Gräter, A, M Harrer, M Rosenquist, and E Steiger. 2022. Connected, Cooperative and Automated Mobility Roadmap. European Road Transport Reserach Advisory Council.

Guerrero-ibanez, J. A., S. Zeadally, and J. Contreras-Castillo. 2015. "Integration challenges of intelligent transportation systems with connected vehicle, cloud computing, and internet of things technologies." *IEEE Wireless Communications* 22 (6): 122-128. https://doi.org/10.1109/MWC.2015.7368833.

Gwak, Jongseong, Keisuke Shimono, and Yoshihiro Suda. 2022. "Effects of Traffic-related Environmental Factors on Acceptability and Safety of Truck Platooning for Peripheral Drivers: A Simulator Study." *International Journal of Automotive Engineering* 13 (2): 54-59. https://doi.org/10.20485/jsaeijae.13.2_54.

Hevner, Alan R, Salvatore T March, Jinsoo Park, and Sudha Ram. 2004. "Design science in information systems research." *MIS quarterly*: 75-105.

IVECO, 2022, "IVECO takes further step towards connected and autonomous driving with successful conclusion of ENSEMBLE project," https://iveco.com/en-us/press-room/release/Pages/IVECO-takes-further-step-towards-connected-and-autonomous-driving-with-successful-conclusion-of-ENSEMBLE-project.aspx.

Janssen, Robbert, Han Zwijnenberg, Iris Blankers, and Janiek de Kruijff. 2015. "Truck platooning: driving the future of transportation." TNO. https://publications.tno.nl/janssen-2015-truck.

Kirkwood, Craig W. 1998. *System dynamics methods: A quick introduction.College of Business, Arizona State University*.

Lourenço, Vladimiro, Sérgio Pedro Duarte, António Lobo, Sara Ferreira, and Liliana Cunha. 2024. "Representations of truck platooning acceptance of truck drivers, decision-makers, and general public: A systematic review." *Transportation Research Part F: Traffic Psychology and Behaviour* 104: 359-373. https://doi.org/https://doi.org/10.1016/j.trf.2024.06.008. https://www.sciencedirect.com/science/article/pii/S1369847824001414.

Lusch, Robert, and Stephen Vargo. 2004. "Evolving to a New Dominant Logic for Marketing." *Journal of Marketing* 68 (1): 1-17. https://doi.org/10.1509/jmkg.68.1.1.24036. https://journals.sagepub.com/doi/abs/10.1509/jmkg.68.1.1.24036.

---. 2006. "Service-Dominant Logic as a Foundation for a General Theory." 406-420.

Lusch, Robert, Stephen Vargo, and Matthew O'Brien. 2007. "Competing through service: Insights from service-dominant logic." *Journal of Retailing* 83 (1): 5-18. https://doi.org/https://doi.org/10.1016/j.jretai.2006.10.002. https://www.sciencedirect.com/science/article/pii/S0022435906000649.

Ministry of Economy, Trade and Industry in Japan. 2021. "Successful Autonomous Driving Technology Tests for Truck Platooning." Accessed January 2, 2024. https://www.meti.go.jp/english/press/2021/0305_003.html.

Neto, Catarina, Anabela Simoes, Liliana Cunha, Sérgio Pedro Duarte, and António Lobo. 2024. "Qualitative data collection to identify truck drivers' attitudes toward a transition to platooning systems." *Accident Analysis & Prevention* 195: 107405. https://doi.org/https://doi.org/10.1016/j.aap.2023.107405. https://www.sciencedirect.com/science/article/pii/S0001457523004529.

Nowakowska-Grunt, Joanna, and Monika Strzelczyk. 2019. "The current situation and the directions of changes in road freight transport in the European Union." *Transportation Research Procedia* 39: 350-359. https://doi.org/https://doi.org/10.1016/j.trpro.2019.06.037. https://www.sciencedirect.com/science/article/pii/S2352146519301255.

Scania, 2017, "Scania takes part in multi-brand platooning project," https://www.scania.com/group/en/home/newsroom/news/2017/scania-takes-part-in-multi-brand-platooning-project.html.

---, 2018, "Automated platooning – step by step," https://www.scania.com/group/en/home/newsroom/news/2018/automated-platooning-step-by-step.html.

---. 2019. "More real-life autonomous vehicle trials needed." https://www.scania.com/group/en/home/newsroom/news/2019/more-real-life-autonomous-vehicle-trials-needed.html.

Schnell-Lortet, I, and B Jacob. 2019. Long Distance Freight Transport—A Roadmap for System Integration of Road Transport. ERTRAC: Brussels, Belgium: ERTRAC.

Schwaninger, Markus. 2020. "System dynamics in the evolution of the systems approach." *System Dynamics: Theory and Applications*: 21-39.

Shepherd, Simon. 2014. "A review of system dynamics models applied in transportation." *Transportmetrica B: Transport Dynamics* 2. https://doi.org/10.1080/21680566.2014.916236.

Thaller, Carina, Uwe Clausen, and Raymond Kampmann. 2016. "System Dynamics Based, Microscopic Freight Transport Simulation for Urban Areas." Commercial Transport, Cham, 2016//.

Tobar, Marta, Bernard Jacob, Odile Arbeit de Chalendar, and Frank Daems. 2019. ENSEMBLE regulatory framework – state of the art.

Tsugawa, S. 2014. "Results and issues of an automated truck platoon within the energy ITS project." 2014 IEEE Intelligent Vehicles Symposium Proceedings, 8-11 June 2014.

Tsugawa, S., S. Jeschke, and S. E. Shladover. 2016. "A Review of Truck Platooning Projects for Energy Savings." *IEEE Transactions on Intelligent Vehicles* 1 (1): 68-77. https://doi.org/10.1109/TIV.2016.2577499.

Vargo, Stephen L. 2011. "Market systems, stakeholders and value propositions." *European Journal of Marketing* 45 (1/2): 217-222. https://doi.org/10.1108/03090561111095667. https://dx.doi.org/10.1108/03090561111095667.

Volvo, AB, 2018, "Volvo Trucks and FedEx demonstrate Truck Platooning," https://www.volvogroup.com/en/news-and-media/news/2018/jun/news-2971141.html.

Ylén, Jean-Peter, and Vesa Hölttä. 2007. "System Dynamics—A Tool for Designing and Analysing Complex Processes." *Simul. News Eur* 17: 27-31.

## APPENDIX A: SDGs Reflection

This table outlines the alignment of my dissertation project with the Sustainable Development Goals (SDGs) set forth by the United Nations. The project focuses primarily on SDG 9, aiming to advance resilient infrastructure, promote inclusive and sustainable industrialization, and foster innovation through the development of an SD model for truck platooning technology. This model supports regulatory and technological decisions by assessing adoption, reducing CO2 emissions per ton-kilometer transported, and identifying economic benefits such as cost savings. Additionally, the dissertation contributes to SDG 11 by exploring how integrating truck platooning in urban areas can potentially alleviate congestion and reduce local emissions, thereby enhancing urban sustainability. Table 6 categorizes these contributions alongside relevant performance indicators and metrics to quantify the project's impact on sustainable development:

**Table 6: Sustainable Development Goals (SDGs)**

| SDG | Target | Project Contribution | Performance Indicators and Metrics |
|---|---|---|---|
| 9 | Advance resilient infrastructure, promote inclusive and sustainable industrialization, and foster innovation | Development of a system dynamics model to simulate the adoption of truck platooning technology, supporting regulatory and technological decisions | Adoption rate of truck platooning technology; Reduction in CO2 emissions per ton-kilometer transported; Economic benefits in terms of cost savings; Social impacts such as improved road safety and reduced congestion |
| 11 | Make cities and human settlements inclusive, safe, resilient, and sustainable | Potential reduction in urban congestion and local emissions by integrating truck platooning in urban areas | Reduction in average urban travel time; Improvement in urban air quality; Reduction in urban traffic accidents |

## APPENDIX B: Individual Causal Loops

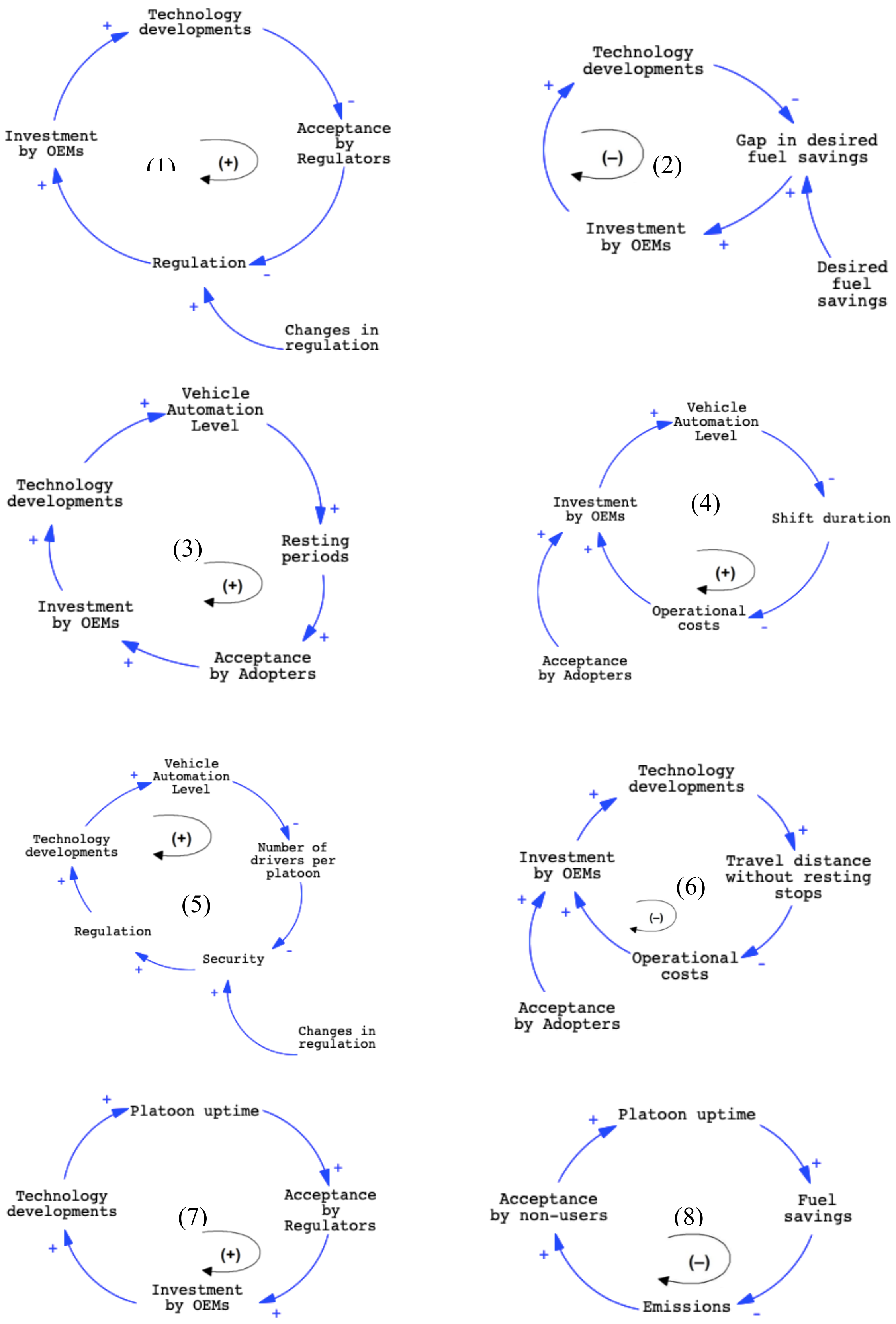


**Figure 10: Individual causal loops (Part 1)**

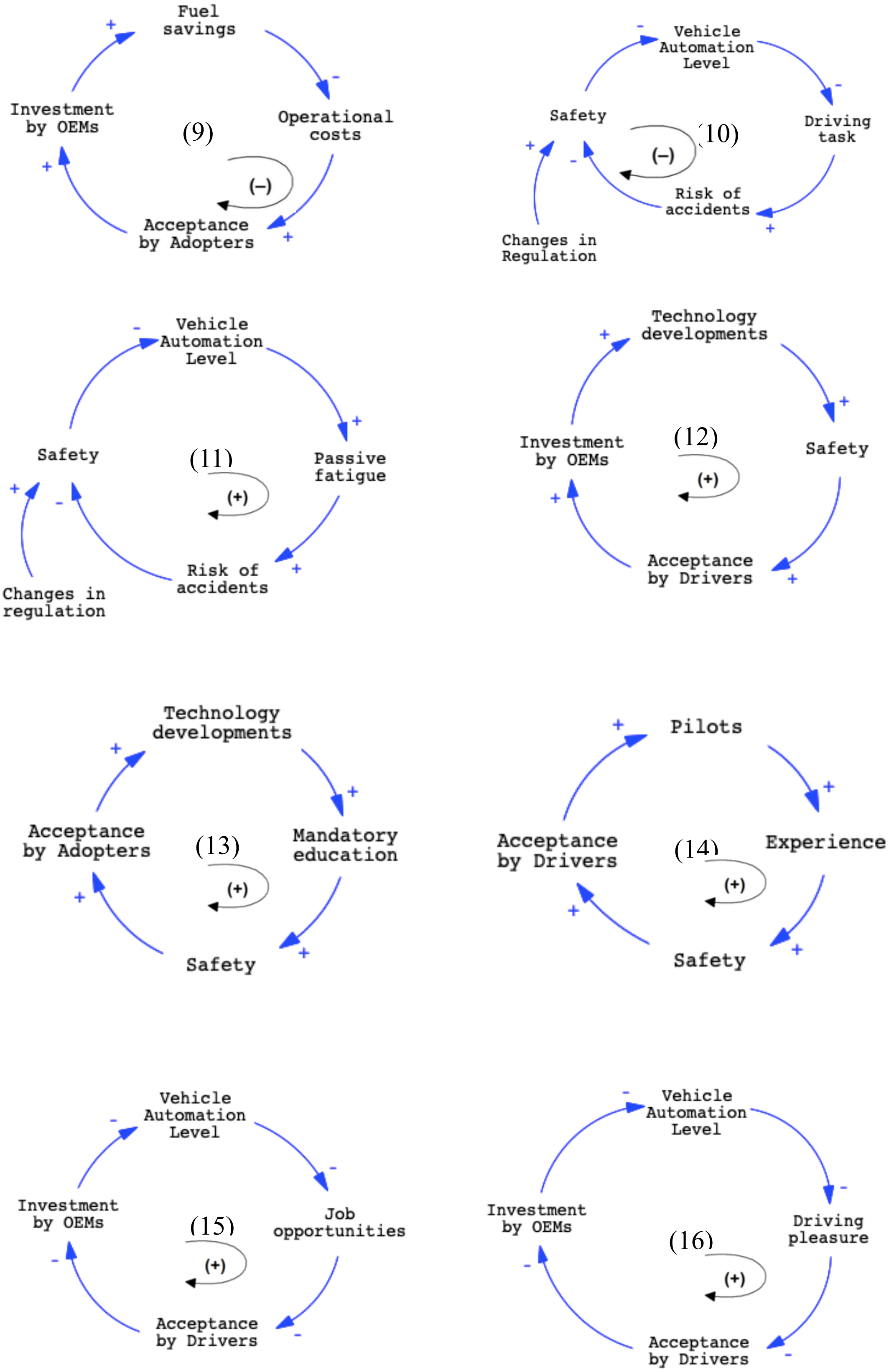


**Figure 11: Individual causal loops (Part 2)**

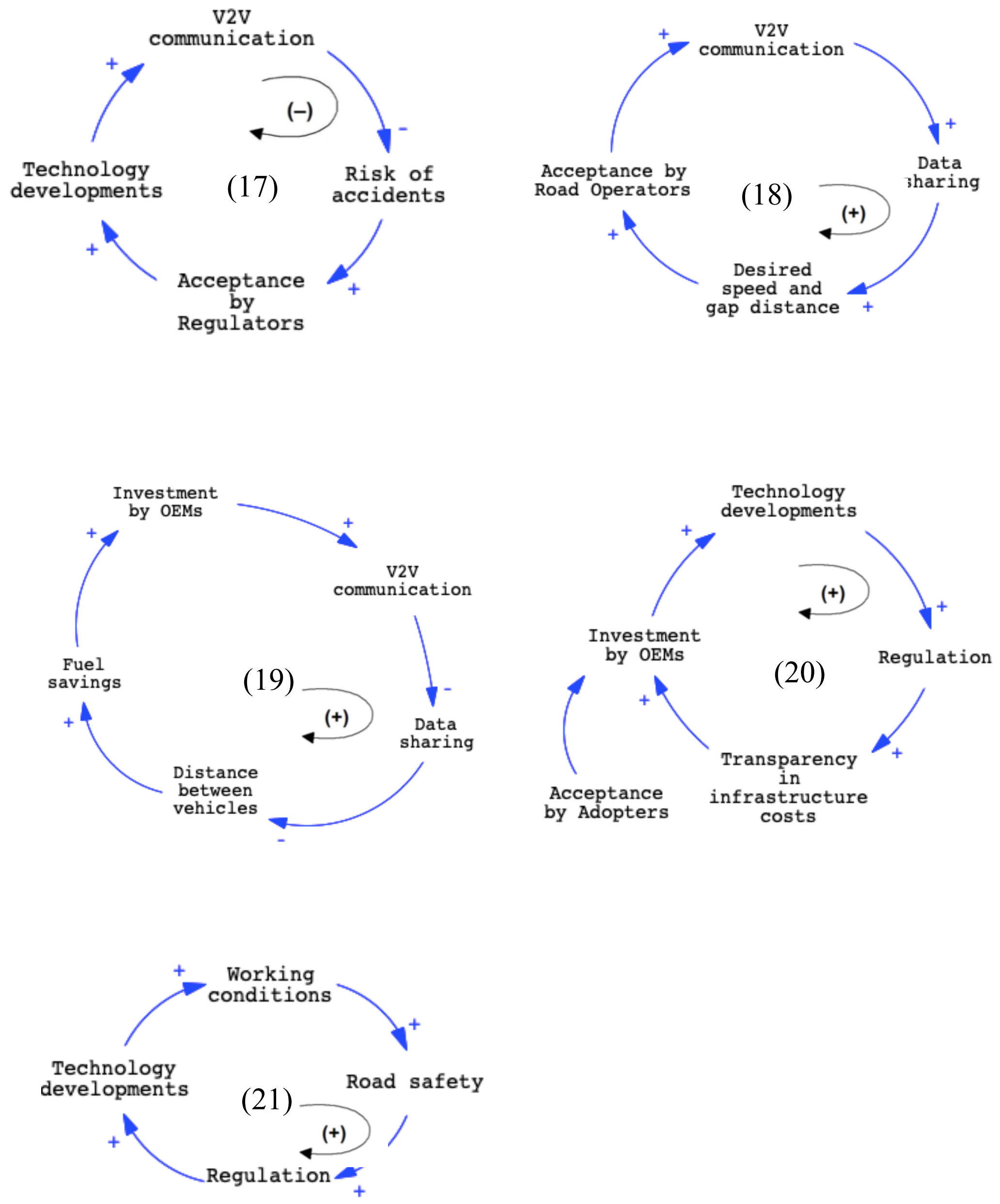


Figure 12: Individual causal loops (Part 3)