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Truck platooning

An investigation into the enablers and barriers affecting its emergence

Master's thesis in Management and Economics of Innovation

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Cover: Visual of a truck platoon in relation to the promotion of the Truck Platooning Challenge (Aarts and Feddes, 2016).

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Abstract

With the increasing number of goods circulating in our economy, there is a significant amount of pressure being put on transport and logistics service providers to facilitate freight transport across the EU. In the interest of improving the current road freight transport conditions and meeting sustainable targets set by governments, truck platooning is a suggested solution which can reduce driver costs, improve fuel efficiency, and improve road safety. Although the technology provides solutions which benefit the economy as a whole, it has struggled to commercialise. In this paper, a Technological Innovation System (TIS) approach is taken to analyse the truck platooning system, to gain an understanding of the enablers and barriers for emergence in the EU. The analysis is based on a step by step TIS scheme, presented by Bergek et al. (2008), and uses data from a technical project, expert interviews, and secondary data analytic methods to identify and analyse system structures and functions. There is a general agreement amongst actors that truck platooning is a useful technology and that it can bring great economic, social, and environmental benefits. The emergence of truck platooning is heavily dependent on the entrance of governments and actors from supporting industries, along with changes in institutions to begin shaping the development and commercialisation. The results highlight three main barriers to the emergence of truck platooning; unaligned institutions, weak networks, and underdeveloped infrastructure. Comparing the results to studies from similar studies within other industries helped identify the effect and importance of the barriers, and allow for speculations to be made on the possible future steps in emerging truck platooning.

Keywords: Technological Innovation System (TIS), truck platooning, freight transport, innovation, enablers, barriers, commercialisation.

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1 Introduction

There is currently an increasing total volume of goods and services circulating in our economy (Eurostat, 2021). The transportation of these goods has therefore become increasingly important to sustain, manage, and optimise. A global trend of increasing freight traffic can be noticed and it is expected that this trend will continue in the following decades (Rodrigue et al., 2012). Currently, roughly 75% of all freight transportation is by means of road networks which results in excessive costs being experienced by logistics firms, the environment, and our economy (Veldhuizen et al., 2019; Eurostat, 2020). These costs present challenges due to ever-increasing fuel prices, the reduced greenhouse gas emissions targets, and increasing pressure from EU regulations. However, with the development of intelligent transportation systems (ITS), these challenges can be addressed (Alam et al., 2015).

One such growing cooperative method within ITS is known as truck platooning. The technology has been receiving a lot of interest from researchers in the past two decades due the aforementioned possibility of optimising logistics to find more efficient solutions. Truck platooning is a concept where multiple freight trucks drive behind each other in a close proximity, usually achieved by using some form of autonomous driving technology (Bhoopalam et al., 2018). Due to the continuous development of automated driving technologies coupled with the ever-growing demand for more sustainable freight transport (EC, 2020), large scale implementation of truck platooning has become an interesting research topic throughout the past 20 years. Therefore, I did a project where I further developed truck platooning software, and simulated the solution to find optimal formations (Appendix A).

Since the millennial shift, a significant number of tests have been carried out - with a large proportion of them being rendered in favour of truck platooning (Larson et al., 2014; Robinson et al., 2010). Results suggest that fuel costs and driver wages, the two outstanding operating costs in the road freight transport industry, can be significantly lower in comparison to single truck freight transportation. Generally in real-world experiments, 5-20% of fuel can be saved, depending upon the platoon setup (Veldhuizen et al., 2019; Alam et al., 2015). The dominant factor in these fuel savings is the reduction in aerodynamic drag – which is measured at around 48% across the platoon (Robertson et al., 2019). In addition to this, improvements to transport productivity, reduced highway congestion and reduced emissions have all shown to be benefits of truck platooning (Torrey IV and Murray, 2014; Levinson et al., 2005).

However, currently truck platooning is caught in a gap between remaining a technological invention and becoming a successful innovation. This, agreed upon by Carlson and Sullivan (2005), can be a cruel void to be lodged in. In order to bridge this gap, theoretical frameworks can be used to analyse the technological invention and gain an understanding of the problems its experiencing. This thesis will therefore use the Technological Innovation Systems (TIS) framework to analyse truck platooning, as an innovation system, and ultimately discuss its enablers and barriers for emergence. Due to the limited number of previous studies utilising the TIS framework to analyse how truck platooning can become a successful innovation, this investigation can help provide insight into the issues experienced by the truck platooning innovation system and hopefully aid the emergence and commercialisation of the technology.

Despite its limited use in truck platooning technology, the innovation systems approach has been used widely in the renewable energy sectors (**?**Wicki and Hansen, 2017). The framework has helped map the technology into a system, as well as aided in the identification of enablers and barriers. This has ultimately provided insight into the changes needed in TISs such as wind energy, photovoltaic cells, and alternative fuels. Hence the TIS framework is a viable option for attempting to reach similar results within the truck platooning technology. The goal is to provide research which can help truck platooning become an innovation - albeit in a small dose. This is because innovation is the most important aspect of economic development and growth. This statement is supported by the European Central Bank: "Innovation leads to higher productivity, meaning that the same input generates a greater output. As productivity rises, more goods and services are produced – in other words, the economy grows." (Bank, 2017). Therefore, not only can this research push truck platooning emergence in the correct direction, but also, should the technology prove to be beneficial, contribute to economic growth

Throughout the investigation the TIS framework and previous studies will be combined in order to identify and analyse the issues which currently occupy the truck platooning technology. This allows a multi-faced approach, where it will allow for mapping the truck platooning innovation system, while also allowing for enablers and barriers to be identified and measured.

1.1 Purpose

The purpose of this research is to introduce the invention of truck platooning and investigate which enablers and barriers exist in its progression towards becoming an innovation, which the logistics and transport sector can utilise. The findings from the project (Appendix A), along with a conceptual application of the TIS framework and comparisons with applications from previous works, will be used in the aforementioned investigation. It will subsequently be of interest to discuss the enablers and barriers and determine how truck platooning can emerge and commercialise.

In order to present thorough research and results in relation to the truck platooning technological innovation system, the main research question has therefore been formulated as the following:

What enablers and barriers are affecting the emergence of truck platooning?

1.2 Scope / Delimitation

The scope for this research is to illustrate enablers and barriers for truck platooning technology attempting to become an innovation through the use of the analytic TIS framework. However, the findings from this analysis should be able to influence other innovations in the transport and logistics industries. In achieving the purpose mentioned in the previous section, a key notation is that some delimitaions will be made in order to adhere to the scope. A number of areas that will not be considered throughout this research are explained below.

The research will remain within the premises of European Union markets as the regulations, actors, and institutions within this economy are fairly uniform. This further aids with discussing enablers and barriers relating to the theoretical frameworks as sectoral and geographical implications are paramount in innovative frameworks. Furthermore, the thesis will omit more technical research relating to truck platooning and its aerodynamic capabilities.

1.3 Thesis outline

The remainder of this paper is structured as follows: Chapter 2 provides an overview of the TIS framework and includes core concepts from adoption and diffusion of innovation theory. Chapter 3 presents the methodological details of the research, including how the project was designed and how accompanying research, frameworks, and applications aided in the analytic process. Chapter 4 follows the theoretical framework to analyse the truck platooning innovation system and investigate the enablers and barriers surrounding the TIS to ultimately provide suggested actions based on theory and findings from related research. Chapter 5 discusses results from the analysis and highlights implications, limitations, and future research. Finally, Chapter 6 derives conclusions from the research and rounds off the thesis.

2
Conceptual Framework

This section sets out the conceptual framework for identifying enablers and barriers in the emergence of truck platooning in Europe. Throughout this section, the conceptual framework will be supported with previous empirical studies utilising the framework. The innovation systems approach is used to analyse factors which can affect an inventions emergence in its market (Freeman, 1995). This process requires the assistance of multiple actors as well as corresponding functions. As this thesis investigates a technological invention, the TIS approach is suitable for identifying the issues that are preventing truck platooning from emerging as an innovation (Granstrand and Holgersson, 2020). Adoption of an innovation is widely spoken about as it is the significant step in an inventions life-cycle, which will allow it to enter the market (Rogers, 2003; Tidd et al., 2000; Van de Ven et al., 1999). However, as mention in Chapter 1, truck platooning has not yet reached the stages of adoption or diffusion. Hence, the theoretical framework in this thesis aims at identifying issues with the emergence of the technology to provide discussions on the severity of the issues. Throughout the remainder of this chapter, the TIS framework will be introduced along with empirical examples to lay the foundation of the coming analysis in Chapter 4.

2.1 Technological Innovation System

The concept of a Technological Innovation System was defined as a smaller aspect of the much larger parent approach, namely innovation systems. System of innovation had its debut in research papers in the mid 1980's with the framework based on Georg Friedrich List´s conception from as early as 1856 - "The National System of Political Economy" (Lundvall, 1985; List, 1856). Christopher Freeman, a British economist recognised as one of the founders of innovation studies, later revealed that this 1800's concept may as well have been called National Innovation Systems (NIS) - a term that he coined in 1988 before publishing a paper about it in 1995 (Freeman, 1995). Through technological advancements there has become a need for sub-categories within IS, with the relevant category for specific technologies attempting to emerge in the market being Technological Innovation Systems.

More recently, authors such as Carlsson et al. (2002); Bergek et al. (2005); Hekkert et al. (2007) and Jacobsson and Bergek (2011) have clarified and driven the use of the systems perspective. They motivate it as an important concept as it can lead to a better understanding of holistic and complex problems. In addition, adopting the systems approach helps create market-based incentives through the identification of enablers and barriers, while also informing policymakers on how to manage, influence, and accelerate technological evolution (Foxon and Pearson, 2008). Purely evaluating the technology is no longer considered enough due to the abundance of surrounding factors which enable or prevent a technology from becoming an innovation (Carlsson et al., 2002). According to Edquist (1997), the TIS approach analyses the entire "business ecosystem" of an innovation. This includes aspects such as analysing the interactions of the relationships between the various stakeholders, namely the firms, research institutes, and government, along with evaluating the flow of information, technology, and competence. Despite a technology perhaps being pushed by entrepreneurs, there is also a requirement for other actors to ensure that the invention can become a functioning product in the market - which is the target of a TIS approach (Edquist, 2004).

Defined as "network(s) of agents interacting in a specific technology area under a particular institutional infrastructure for the purpose of generating, diffusing, and utilising technology” (Carlsson and Stankiewicz, 1991), TIS analyses focus on two main dimensions; structural dimensions and systemic functions (Bergek et al., 2008). The former consists of a set of actors, institutions, network and - for the case of TIS - technology (Carlsson et al., 2002; Wieczorek et al., 2014). The latter is a slightly broader analysis as these functions are the key processes that are significant throughout the creation of a TIS. These are dynamic processes between the aforementioned structural dimensions which attempt to increase the chance of market success by accelerating the exposure or growth of the innovation system (Jacobsson and Bergek, 2011; Musiolik and Markard, 2011). Wieczorek and Hekkert (2012) showcased an example of this by suggesting that altering the structural elements allows policy makers to create circumstances in which functions can strengthen or weaken. The TIS framework in this thesis uses the structures as a method of mapping the TIS, while the functions serve the purpose of identifying the strengths and weaknesses of the TIS. Both the structural dimensions and systemic functions of a TIS analysis are explained in the following sections.

2.1.1 Structural dimensions

Innovation systems can be understood as containing four structural dimensions; the actor dimension, the institution dimension, the network dimension, and the infrastructure dimension (Wieczorek et al., 2014) that develop, diffuse and utilise the innovation (Carlsson and Stankiewicz, 1991; Edquist, 1997; Malerba, 2002). These elements are not specifically tied to one defined TIS, because actors within one TIS can often be active in other TISs - a university for example might be researching multiple technologies. In addition, both institutions and networks also exist for the purpose other than solely supporting one specific technology (Bergek et al., 2015). Therefore, identifying and showcasing their involvement in the specified TIS is important. In Table 2.1 it is shown how these structural dimensions can be classified into subcategories for the purpose of clarity and highlighting the different roles that are filled within a TIS (Wieczorek and Hekkert, 2012).

Table 2.1: Structural dimensions of innovation systems

Structural elements	**Subcategories**
Actors:	- Civil society - Companies: start-ups, SME's, large firms, MNC's - Knowledge institutes: universities, research centres, schools - Government - NGO's - Third parties: legal organisations, financial organisations, knowledge brokers
Networks:	- Nature: Informal, formal - Type: Academic, industry-academia, user-supplier
Institutions:	- Hard: rules, laws, regulations, instructions - Soft: culture, norms, routines, habits, traditions, expectations
Infrastructure: (Technology)	- Physical: artefacts, roads, machines, buildings, networks - Knowledge: knowledge, expertise, know-how, strategic information - Financial: subsidies, programs, grants, taxation

Source: based on Bergek et al. (2008); Wieczorek and Hekkert (2012)

Within innovation, actors can fulfil a large variety of roles which makes it difficult to determine whether they are considered users, producers, or support organisations (Smits and Kuhlmann, 2004). Wieczorek and Hekkert (2012) therefore suggest delineating and categorising the actors based on their economic functions. This leaves us with the following subcategories as shown in Table 2.1, where actors consist of a multitude of different organisations within the subcategories. The actors competencies are part of larger domain which helps shape the development of a technology. This domain includes, among other things, being part of the technology's value chain, being the end policymakers, or researching the technology. Carlsson et al. (2002) suggest that the competencies that the actors possess can be used to support the development of the innovation system.

Networks, in the context of structural dimensions of innovation systems, includes both the formal and informal interaction between the various actors. Networks emerge in a formal setting when actors structure their communication in a manner which achieves a common goal. A substantial amount of transfer of knowledge, technology, and competence occurs through the networks. Informal networks also exist in practice due to the need of collaboration among the consortia as the actors wish to ensure that a technology is enabled or barred from the industry. Jacobsson and Bergek (2011) suggest that networks serve different purposes for the emergence of a technology in an industry, but the goal of the actors in a network tends to be uniform.

Institutions, as defined by (North et al., 1990), "are humanly devised constraints that structure political, economic and social interaction". North further divides these institutions into formal (hard) and informal (soft), such as regulatory contexts and sociocultural norms, respectively. The former is considered a part of the hard institutions along with laws, instructions, and formal rules, and are created consciously due to their tangible nature (North, 1987). On the other hand there are the soft institutions, which refer to informal and implicit rules such as culture, established practices, and expectations among other things (Tripsas and Gavetti, 2000). These less tangible elements are much more varied and often evolve more spontaneously (Negro et al., 2012). The institutional context plays a major role in the emergence of a technology as actors will often attempt to shape these contexts to their advantage (Smink et al., 2015).

Infrastructure is split up into the physical, knowledge, and financial dimensions. Table 2.1 highlights what each of these dimensions of infrastructure refers to. However, within TIS the infrastructure as a whole is substituted for the technology (Jacobsson and Bergek, 2011). Technologies perhaps find themselves primarily in the knowledge dimension as they are normally centred around one primary knowledge area. In addition to this however, the technology is also composed of the other two dimensions in order to function properly. Technological knowledge is for example materialised in artefacts, which through financial means are applied in products (Jacobsson and Bergek, 2011). Due to this thesis using the TIS framework as opposed to a generic innovation systems framework, infrastructure as a structural element will not be analysed explicitly in Chapter 4.2, as this will be covered in Chapter 4.1.

2.1.2 Systemic functions

The performance of a TIS can be assessed and compared by its functional activities (Bergek et al., 2005; Hekkert et al., 2007; Johnson, 2001; Negro et al., 2007). The analysis of systemic functions is based on these activities that take place in a TIS resulting in technological change. Seven functions have therefore been proposed by several authors relating to technological change (Bergek et al., 2008; Hekkert et al., 2007; Jacobsson and Bergek, 2011). Table 2.2 presents the definition of each of these functions along with minor remarks relating to each function.

Knowledge development and diffusion is normally placed at the heart of a TIS. According to the scheme presented by Bergek et al. (2008), this is because it is important to to understand how well the TIS performs within its knowledge base, how this knowledge base changes over time, as well as how the knowledge is diffused and combined. Several knowledge areas such as market, production, and technological knowledge can be distinguished between (Engholm et al., 2020). The function further distinguishes between different types of knowledge development processes - including R&D, imitation, and learning from experiences.

Influence on the direction of search is a function which combines incentives with varying forms of pressuring to induce actors to engage in the TIS. The purpose being that for a TIS to develop, a large number of actors would ideally have to enter the TIS and throughout their combined effort could influence the direction of

Table 2.2: Systemic functions of TIS

Functions	**Description**
F1: Knowledge development	The depth and breadth of the research and practice-based knowledge, and how actors develop, diffuse, and combine knowledge in the system **Indicators:** R&D projects, demonstration projects, patents, journal publications, reports, prototypes
F2: Influence of the direction of search	The extent to which actors are able to direct their research and investments in the TIS, along with how incentives to participate are created **Indicators:** Long-term targets, expressed visions, alignment of expectations, policy documents, demand articulation, belief in growth potential
F3: Entrepreneurial Experimentation	How new knowledge is turned into concrete entrepreneurial activities to generate, discover, or create new commercial opportunities **Indicators:** New entrants, experiments, start-ups, diversification activities, demonstrations, commercial projects
F4: Market formation	Articulation of demand and market development in terms of demonstration projects, nursing markets, bridging markets and, eventually, mass markets **Indicators:** The number of markets, market size, customer groups, actor strategy, demand profile, institutional stimuli, standards, purchasing process
F5: Legitimacy	How socially accepted, appropriate, and desirable the technology is to relevant actors, as well as how compliant relevant institutions are **Indicators:** Size and growth of interest, lobby activities, actions that legitimize technology, number of exhibitions, mental frames, advocacy coalitions
F6: Resource mobilisation	The extent to which the TIS is able to mobilize human, physical, and financial capital as well as complementary assets **Indicators:** Rising volume of capital, volume and quality of human resources, changes in complementary assets
F7: Development of positive externalities	The collective dynamics of the innovation and diffusion process. Externalities provide benefits and magnify the strength of the system **Indicators:** Quality of other functions, interest of new actors, alignment of institutions

Source: based on Bergek et al. (2008); Jacobsson and Bergek (2011)

development. This sum of pressures and incentives includes not only the external factors such as legislation and policies, but also the direction of search within the TIS such as business models, growth potential, and customer demand.

Entrepreneurial experimentation is a function to reduce the considerable uncertainty which exists within technological and industrial development throughout the evolution of a TIS (Rosenberg, 1998). The benefit of this function is the ability to test new technologies and applications, allowing a number of experiments to develop a social learning process upon their success. Bergek et al. (2008) is very adamant about the importance of this function, stating that "A TIS without vibrant experimentation will stagnate".

Market formation is the creation and development of a functional market allowing TISs to emerge or transform. Specifically for an emerging TIS, markets may either be underdeveloped or not exist at all, there may not be any customer demand, and there may be uncertainties regarding the technology (Carlsson and Stankiewicz, 1991). Market formation is defined as having three phases, where the first step requires a small nursing market evolve allowing the TIS to form within a learning space (Kemp et al., 1998). The second and third phases of market formation can take several decades by allowing the TIS to grow through a bridging market and a mass market, respectfully (Bergek et al., 2008). The markets in both the second and third phase are commonly distinguished by the volume of actors involved in the TIS.

Legitimisation is securing a form of compliance and social acceptance from the relevant actors and institutions. This is done by making the technology seem more appropriate and desirable allowing the resources to be mobilised and for demand to grow. Once legitimacy is initiated, expectations for the technology increase within the industry causing strategies to change creating implications for other functions such as direction of search and market formation.

Resource mobilisation is a necessary function to aid and allow a TIS to evolve (Carlsson and Stankiewicz, 1991). The main resources which need to be mobilised are human competence, financial capital, and complementary assets. Furthermore, it is important to gain an understanding of the extent to which the TIS can mobilise these resources as it will give indication on the prosperity of the technology.

Development of positive externalities is a key process in the formation and growth of a TIS due to the systemic nature of the innovation process (Porter, 2011). It is a function of generating positive externalities which aid in strengthening the other TIS functions - with (Hekkert et al., 2007) suggesting that it can therefore be seen as an indicator of the overall functional dynamics of the system.

2.1.3 Empirical studies using TIS framework

TIS has been researched and applied in an abundance of previous academic papers. The majority of TIS research has been used to analyse emerging technologies (Coenen, 2015; Hanson, 2018; Musiolik and Markard, 2011; Negro et al., 2008; Nevzorova and Karakaya, 2020; Sixt et al., 2018; Suurs et al., 2010) - where the purpose is to analyse and improve the conditions needed to facilitate an innovation (Farla et al., 2012). The renewable energy sector is a prime example of how the TIS perspective has been used to gain an understanding of why new technologies quickly emerged or failed to emerge. (Jacobsson and Johnson, 2000). Further strengthening the use of the TIS approach is its use within developing countries, clean-tech, and environmental sustainability (Gosens et al., 2015).

The previous study most similar to this research is perhaps Björkman and Joelsson (2019), a Master thesis which discussed self-driving vehicles in road freight transport in Sweden. Further, Engholm et al. (2020) uses this thesis to discuss the emerging TIS of driverless trucks. These studies follow the scheme presented by Bergek et al. (2008) and systematically go through the structures and functions to identify and analyse successes and failures. The results suggest that driverless trucks are in an early emerging phase in Sweden, and require more rigid structures, political support, and collaboration between actors. Furthermore, they identified key actors and driving forces behind the technology.

Studying the Engholm et al. (2020) case helps determine whether the TIS approach is a useful method for evaluating truck platooning as an emerging innovation. Although a driverless truck is not necessarily the same as truck platooning, a platoon will in almost all instances consist of one or more autonomous vehicles. Furthermore, as their investigation focuses on electrification of heavy-duty vehicles it is also strongly related to the core research by Bergek et al. (2007) within the renewable energy sector. The technology, industry, and theoretical framework from this case are similar to the investigation that has been brought forth in this thesis so far. Therefore, using the TIS approach will be an effective selection for the analysis of this topic as it will provide every opportunity to provide answers to the research question. Furthermore, it will be complemented by accompanying research from the renewable energy sector to gain a widened perspective on TIS's and their adoption.

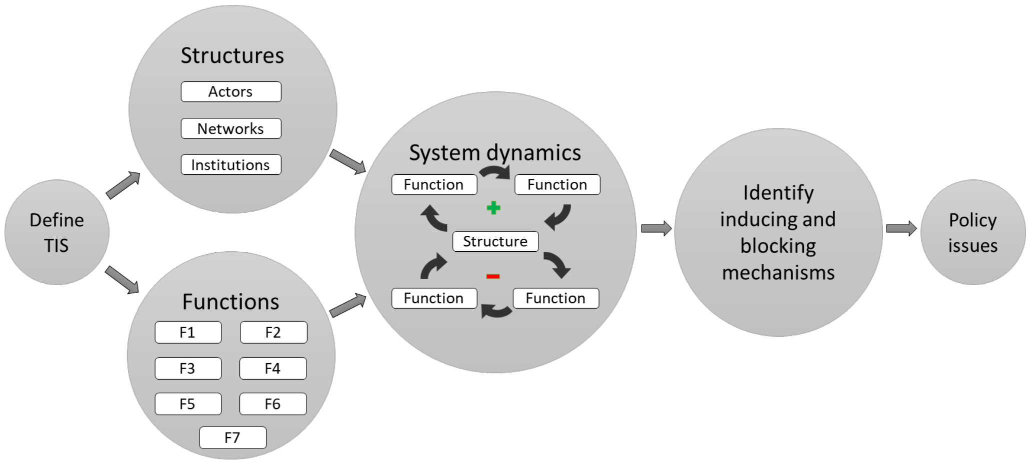
The conceptual framework shown by Bergek et al. (2008) is a pragmatic method which follows a precise step by step process. Previous works using this presentation of the framework therefore follow this process within the analyses. A couple examples of the use of the TIS framework is Hanson (2018); Strupeit (2017) and Vroon et al. (2021) within the photovoltaic TIS in Norway, Germany, and Netherlands respectively. From their methods it becomes clear that following the application of Bergek et al. (2008)'s scheme is rewarding and helps to identify struggling structures and functions within the system, which ultimately aid in identifying barriers and suggesting solutions. Hanson (2018) for example, identified the sector, defined the TIS, highlighted the existing structures, and subsequently realised the impacts of the various functions on the system. As a result, the author discussed 8 barriers which were found to be affecting the growth phase of the photovoltaic technology is Norway. These studies show that following the scheme, almost step by step, allows for useful results to be found relating to the enablers and barriers of the system.

These highlighted previous studies show results which are similar to what this thesis aims to discover - barriers and enablers for the TIS. Therefore, using the TIS framework is strongly motivated for this investigation as it will allow the mapping of structures, and also the use of functions to evaluate strengths and weakness of the system, which ultimately helps identify enablers and barriers to truck platooning emergence.

3
Methods

To answer the research question, an investigation was launched into the structural dimension and systemic functions related to truck platooning. The core TIS research conducted by Bergek et al. (2005) consists of multiple smaller processes - referred to as "steps" - to fulfil the function of a larger process. Using this theoretical lens of the TIS process aids to identify enablers and barriers for the adoption of the truck platooning TIS. The method used to execute the analysis is consistent with the framework for a TIS analysis presented in Chapter 2, and is represented in Figure 3.1.

Figure 3.1: The research process using TIS framework.



Source Bergek et al. (2008)

In order to effectively execute the aforementioned analysis, qualitative and quantitative data was first collected. Further, it is important to highlight that the TIS framework presented by Bergek et al. (2008) is a more iterative process than shown in Figure 3.1. However, for simplicity and clarity, the method will utilise the framework sequentially. Hence, the data collection supports the iterative process as each step uses the data collected to identify or analyse the structures and functions of the system. The sections below will discuss how this data collection was conducted, followed by how the data was used in the framework to analyse the truck platooning TIS.

3.1 Data collection

The data collection phase consisted of qualitative and quantitative primary data, which was also complemented with a host of secondary data. The primary data has been collected through semi-structured interviews, informal meetings, and empirical results from a technical project which I conducted. Secondary data collected for the study includes reports, papers, and scholarly literature. The importance of the secondary data is to both solidify and validate the primary data so that the subsequent analysis is thoroughly executed. While looking at previous empirical studies using the TIS framework, see section 2.1.3, it became apparent that to execute an effective TIS analysis, large amounts of data are needed. Furthermore, Engholm et al. (2020) and Björkman and Joelsson (2019) discussed how only using interviews as their data collection lead to limitations with the results - including bias. For this reasons, using secondary data is essential for executing the analysis in the steps that Bergek et al. (2008) suggests in their scheme. Both forms of data collection are explained in the subsections below.

3.1.1 Collection of primary data

A large source of primary data relating to the benefits and drawbacks of the truck platooning technology came from a technical project which I conducted at the University of Groningen (RUG) (Appendix A). This allowed for quantitative data on the economic and environmental performance of a truck platoon versus standard road freight trucking to be collected and interpreted. It is therefore an important factor in the data collection phase as it provides results from a scarcely researched niche, allowing the results to be injected in the analysis using the framework discussed in Chapter 2. Being at RUG, it also become possible to collect qualitative primary data from members of the Engineering and Technology Institute Groningen (ENTEG) through semi-structured interviews and informal meetings.

One integral ENTEG member, Dr. Bayu Jayawardhana - a well-recognised professor within Automation & Control Systems from RUG, provided a significant contribution to the data collection as he is one of the first researchers within the subject of truck platooning formations (Appendix B.1). This insight has aided in gaining an understanding of the logistics and transport industry, as well as research backing why technologies such as truck platooning can be a significant innovation. Although parts of the interviews and informal meetings focused on the technology, a portion of the quantitative primary data collection also focused on the economic benefits of this technology as well as its prospect as an innovation in the market. Table 3.1 highlights the interviews and informal meetings with members of the ENTEG group.

Table 3.1: Overview of primary data collection

Expert identifier	Role	Field	Relevant topics discussed
Me	Masters project	Automation and Control of Nonlinear Systems, IEM22, RUG	Economic & social benefits of truck platooning Optimisation of truck platooning technology Truck platooning tests on current infrastructure
Dr. Bayu Jayawardhana	Professor	Mechatronics and Control of Nonlinear Systems, ENTEG, RUG	Benefits of truck platooning Knowledge institution collaboration Logistics and transport industry
Expert #2	PhD	Distributed Control and Distributed Optimization, ENTEG, RUG	Benefits of truck platooning Cross border implementation of truck platooning EU involvement in the technology
Expert #3	PhD	Discrete Technology & Production Automation, ENTEG, RUG	Grants provided by the Netherlands government Formation of research groups and organisations Truck platooning challenge 2016
Expert #4	PhD	Distributed Control and Distributed Optimization, ENTEG, RUG	Effectivity of truck platooning in Netherlands The Amsterdam declaration and TNO Optimal truck platooning vs basic implementation
Expert #5	PhD	Automation & Control Systems, ENTEG, RUG	Localisation and mapping of automated vehicles Difficulty of V2V and V2I communication Cross industry collaboration

3.1.2 Collection of secondary data

A larger portion of the qualitative secondary data collection came from scholarly literature. For this method, the combined databases of Web of Science, university portals, and Google Scholar was used to retrieve literature specific to truck platooning or similar industries. An important factor was the use of references and forward citations as these helped find integral authors and similar evaluations from other academic papers. Quantitative data was also collected from scholarly literature as there are plenty of technical papers discussing the results from experiments, simulations, and research related to the logistics and transport industry. These empirical values were used in combination with the aforementioned technical project for comparisons and validation.

In addition, the use of reports, media, and newspapers were also used in the qualitative and quantitative secondary data collection. Reports and papers usually included published documents from governments, companies, knowledge institutes, or associations which covered topics such as truck platooning, innovation systems, and adoption within the EU. Media and press materials were utilised as data from news broadcasts, interviews, talks, and press conferences – with each of the aforementioned coming in the form of reports or recordings.

It is important to note that to execute an effective TIS analysis, a large variety of data sources are needed to gain insight on the structures, functions, and their subsequent dynamics (Bergek et al., 2008). For this reason the secondary data is the main source of information and is obtained through bibliometric and industry association analyses - see section 3.2 below for explanations on these. The expert interviews and the executed project from the collection of primary data is therefore complementary data which is used to gain specific insights that mass data might miss. This combination gives strength to the whole data collection process and avoids experiencing similar limitations that previous studies in section 2.1.3 discussed. Table 3.2 shows an overview of the data collected, the methods used, and how the information was obtained.

Table 3.2: Overview of data collection methods

Data	Data type	Analysis method	Source(s)
Benefits of truck platooning:	Primary	Technical project	Simulations using control law Simulations using optimisation models
	Primary	Expert interviews	Members of ENTEG Members of RUG
	Secondary	Industry association analysis	Actor documents, broadcasts, interviews, etc Publications of truck platooning tests/simulations
Involved structures:	Primary	Expert interviews	Members of ENTEG Members of RUG
	Secondary	Bibliometric analysis	Volume of actor publications and forward citations Volume of actor participation in publications - from Web of Science and Google Scholar
	Secondary	Industry association analysis	Market analysis: Market share, investments, growth Actor reports: Changes, adjustments, testing relating to involvement in TIS
Activity of functions:	Primary	Expert interviews	Members of ENTEG Members of RUG
	Primary	Structural analysis	Results from the structural identification and analysis
	Secondary	Bibliometric analysis	Volume and results of publications Changes in volume, results, direction of publications - from Web of Science and Google Scholar
	Secondary	Industry association analysis	Market analysis: Changes in the market

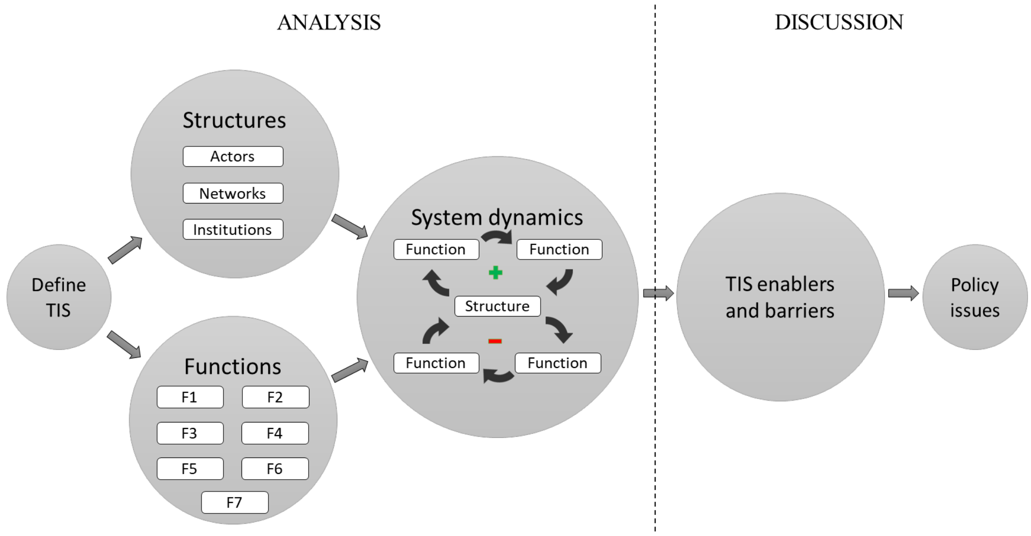
3.2 Data analysis

The data analysis follows the step-by-step scheme that Bergek et al. (2008) published based on her application from a few years earlier (Bergek et al., 2005). The scheme suggests a method for analysing innovation systems through iterative steps. Furthermore, previous studies using the TIS framework have also to a large extend followed the scheme, making minor adjustments to suit their research. This thesis has therefore adopted this method and adjusted it slightly so that it suits the truck platooning TIS, while also serving the purpose identified in Section 1.1. As shown in Figure 3.2, these steps are conducted as follows:

1. Define the TIS in focus
2. Identify and analyse the structural components
3. Mapping the functional patterns
4. Assessing the functionality of the TIS
5. Identifying the TIS enablers and barriers
6. Policies and their implications

Steps 1-4 were executed in Chapter 4 as they serve the purpose of analysing the technology using a systems perspective. Furthermore, the dynamics between the structures and functions analyses the system and helps identify possible reasons for system failure. These reasons allowed for enablers and barriers to be identified. Hence, to serve the purpose of the thesis, steps 5 carried over into the discussion and was elaborated on. Step 6 was removed from the analysis and shifted to a subsection in the discussion due to policy issues being considered of low relevance in this research. Despite the steps above suggesting that the analysis is structured in a linear matter, this is not necessarily the case. Instead each of the steps contain a significant amount of iterations throughout the analysis. However, for the purpose of clarity, the analysis is expressed sequentially in Chapter 4.

Figure 3.2: Method of analysis using the TIS framework



Source: adopted from Bergek et al. (2008)

The first subsection determined the focus and constraints of the analysis within an innovation system, which is not always straightforward. Throughout the first step of the conceptual framework proposed in Chapter 2 it is important to set the prerequisites for the analysis and make deliberate and appropriate choices (Bergek et al., 2008). The predefined choices were re-evaluated throughout the analysis and allowed for conclusions to be drawn based on the context of the starting point. As per directive from (Bergek et al., 2008), the following 3 choices were highlighted and motivated:

1. Is the technology in focus defined as a product or a knowledge field?
2. Will the analysis focus on depth or breadth?
3. What is the spatial domain for the analysis?

The following subsection of the analysis focused on identifying and analysing the components of the TIS structure. This included which relevant actors are present, whether they have positive or negative mindsets about the technology, and if they have the capacity to innovate Rickne (2000). Furthermore, determining whether the institutions and networks were present aiding the TIS in development was crucial to gain an understanding of potential barriers and enablers (North, 1994). Finally, analysing the technology infrastructure and determining whether they were sufficiently developed to support the systems innovation or whether they were missing important dimensions, in combination with the previous, laid the foundation for the core analysis of the TIS in functional terms (Bergek et al., 2008).

In order to identify the presence of structures, Bergek et al. (2008) suggests a couple methods which are required to aid the analysis of the actors' effects; industry association analysis, patent analysis, bilbiometric analysis, and expert interviews/discussions. All four of these methods are considered effective in their own right, however, patent analysis was excluded as an identification method throughout this thesis because truck platooning is still in its early phases of development Bakermans (2016). Furthermore, patent analysis is considered inconclusive due to difficulties in finding clear links between knowledge fields and patents (Bergek et al., 2004). Bilbliometric analysis is the act of quantifying the volume of publications, citation analysis, or similar to identify the most active actors in terms of publications. An industry association analysis as used by (Bergek et al., 2008), is similar to how a market analysis would be conducted. Therefore, in this thesis, the truck platooning market was analysed in terms of the actors presence through market shares, business strategies, and so forth. Finally, expert interviews were conducted by the method expressed in subsection 3.1.1.

In continuation, subsections 4.3.1-4.3.7 consist of critical steps where the majority of the empirical analysis based on the TIS functions and subsequent dynamics were applied. In addition, the functionality of the TIS was concurrently analysed providing insight on benefits and drawbacks of each function to the TIS. This stage is where the quantitative data collection from section 3.1 shows its significance. Furthermore, the presence of the functions were indicated, allowing for their effects to be dissected and analysed, which helped provide an indication whether the function is strong or weak and subsequently, whether it was at a risk of function failure. Finally, in section 4.4, the analysis helped to extract enablers and barriers which are currently affecting the truck platooning TIS, which ultimately assesses the risk of system failure.

It is important to note that the analysis will only identify the enablers and barriers, leaving the discussion to take over and discuss the barriers and their impact on the system. Therefore, upon identifying and understanding functional patterns, along with the identification of enablers and barriers within the system, discussions can be held around the results allowing for implications, limitations, and future application to highlighted, and finally, conclusions to be drawn.

4

Analysis

The analysis throughout this chapter follows the adaption of Bergek et al. (2008)'s scheme as depicted in Figure 3.2.

4.1 Defining the TIS

Technology in general is defined by Layton Jr (1974) and Das and Van de Ven (2000) as having the interrelated meanings of artefact and knowledge, meaning that defining truck platooning as either a product or knowledge field can be motivated. However, based on the nature of questions typically raised within truck platooning research, the definition and focus of this analysis will be the *technological knowledge field of truck platooning* due to its various methods of application. Previous studies from institutes in the Netherlands such as Bakermans (2016) and Kagenaar and Mingardo (2016) have different applications of truck platooning, with the former identifying the technology as a multi-vehicle freight transport and the latter discussing how the technology is better defined as communication between entities. In addition, the project I conducted at RUG treated truck platooning as a driving formation (Appendix A.2). Here the concept of truck platooning is not necessarily a product related to the vehicles, but rather a separate optimisation program that a collection of vehicles in close proximity can implement.

Having looked at previous research using one specific knowledge field (Holmén and Jacobsson, 2000) compared to Rickne (2000) which uses a set of related knowledge fields, the definition of this TIS is best considered a narrow knowledge field. Although the analysis of structure and functions must take into account aggregate knowledge fields such as autonomous drive or communication networks, the focus will remain on the truck platooning knowledge field. An issue with increasing the having a broader knowledge field, such as driverless trucks, is that the results from the analysis can be skewed due to the defined knowledge fields incorporating more dominant structures in the analysis (Carlsson et al., 2002). Continuing with this example, should this TIS be defined within the driverless truck knowledge field, structures and functions relating to trucks underground, inside production plants, or on private roads would be analysed. Broader aggregations such as this would then leave the analysis in a less specific knowledge field, potentially ending up with enablers and barriers unspecific to commercialised truck platooning.

In addition, the range of application for truck platooning solutions currently remains narrow as it is solely the transport and logistics industries which will utilise the technology. As the truck platooning technology in this paper is based on the collaboration and positioning of vehicles in close proximity, wider ranges of application exist. One such example could perhaps be the privatised or shared automotive industry, but leading researchers within this field (Liu et al., 2019, 2022) conclude that current infrastructure is not advanced enough for full driving autonomy. Due to other wider applications also taking many other actors into account, the TIS in this analysis is defined as a narrow knowledge field which contains the range of applications related to the freight transport industry.

There is an argument made that a TIS analysis needs to have an international spatial domain as the system cannot be understood or assessed without a larger context (Bergek et al., 2008). For the truck platooning TIS this is accurate in many cases, but it is challenging to motivate the use of a global context due to the significant differences in freight transport regulations between countries (Belzer and Thörnquist, 2020; Savy and Burnham, 2013). However, the structures, specifically institutions, within the EU are fairly coherent, meaning that the truck platooning TIS can remain within this geographic domain. Furthermore, regimes within freight transport in the EU are also consistent (Eurostat, 2020), hence the spacial domain for this TIS analysis will be confined to the European Union.

4.2 Truck platooning TIS structures

As expressed in Chapter 3, the three analysis methods that are used to identify structures in the truck platooning TIS are bibliometric analysis, industry association analysis, and expert interviews. Further, the omission of patent analysis has been expressed due to noted instances where new technology development patents, such as the Holmén and Jacobsson (2000) microwave antenna case, do no highlight any deep knowledge related to the TIS. Throughout the remainder of the analysis, these three methods will be used interchangeably and in collectively within the constraints of the truck platooning TIS.

4.2.1 Actors

Present actors play a large role in the innovation process of a technology as they are responsible for aiding the technology in its bid to be adopted or prevent the technology from being further developed. The combination of bibliometric analysis and industry association are useful in identifying which actors are present in the TIS due their involvement in academia and industry. In addition, the complement of the primary expert interviews from RUG ENTEG are beneficial as it can help to gain a further understanding of actors that are linked to the TIS (Rickne, 2000).

The bibliometric analysis makes use of Web of Science, Scopus, and Google Scholar as these are statistically the three largest citation databases available online (UVA, 2022). Using these three databases, publications related to specific topics, location, and time-frame can be searched to reveal which affiliations have produced the most work within the predefined query. As described in the method from Chapter 3 and the first section above (Probable ref this later), this TIS is confined to the freight transport and logistics sector within the EU. Tables 4.1 and 4.2 show the summation of results based on the following constraints:

1. Topics related to:
    - Road Freight Transport
    - Truck Transport
    - Logistics and Transport
    - Truck Platooning
2. Research regions:
    - EU-28
    - EU-17
3. Publication Years:
    - 2000 - Present

Despite research relating to automated transportation systems began as early as the 1970's (Tsugawa et al., 2016), more in depth research, simulations, and tests first began in the 1990's (Zabat et al., 1995). For this reason, along with the immense technological changes that have occurred since the millennial shift, it seems reasonable to only use publications from the 21st century in the identification of the various actors.

Table 4.1: Bibliometric analysis - Total publications by leading countries

Country / Region	**Number of publications**
Germany:	448
Netherlands:	437
Sweden:	353
France:	257
Italy:	218

Source: adopted from Web of Science, Scopus, and Google Scholar

Evident in the results from Table 4.2, the most active actors based on the bibliometric analysis are the various knowledge institutes - which is expected due to universities typically being actors who publish the most research. The majority of university publications come from Dutch, Swedish, or French universities, while the most involved research centres and NGO's are based in Germany, Netherlands, and France. This is consistent with results in Table 4.1 which has the total number of

Table 4.2: Bibliometric analysis - Actors with most publications

Actors	**Specification**	**Number of publications**
Knowledge Institutes:	**Universities**	
	- League of European Research Universities (LERU)	368
	- Delft University of Technology (TU Delft)	188
	- Chalmers University of Technology	112
	- University of Zilina	102
	- Maritime University of Szczecin	81
	- Royal Institute of Technology (KTH)	67
	- Vrije Universiteit Brussels (VUB)	61
	- Universite Gustave Eiffel	49
	- Eindhoven University of Technology (TUe)	33
	Research centres	
	- Helmholtz Association	62
	- Centre national de la researche scientifique	41
	- Institute of transport economics	36
	- DLR Germany	35
	- UDICE France	25
Companies: (Firms)	- Volvo Group	24
	- Scania	14
	- Deutsche Bahn	8
	- Applus+ IDIADA	4
	- Vodaphone Group	3
NGO's:	- The Netherlands Organisation for applied scientific research (TNO)	40
Governments:	- European Commission Joint Research Centre (JRC)	17

Source: adopted from Web of Science, Scopus, and Google Scholar

publications produced from each of the countries within the EU-28. The benefit of the EU is that a lot of governments and knowledge institutes from various countries work in tandem and are run centrally by an EU body (EU, 2022). Therefore, the bibliometric analysis also shows that LERU - a collection of 23 leading research universities spread across the EU - along with EU JRC - a joint research centre for the European Commission - are also present actors in the truck platooning TIS.

The dominance of the knowledge institutes is perhaps expected based on the TIS still being in its infancy and the majority of new knowledge creation occurs within knowledge institutes or innovative teams (Von Krogh, 1998). So where are the innovative teams working on the truck platooning TIS? Well, they almost certainly exist within the logistics, heavy-duty vehicle, and transport firms, as the results attempt to suggest. However, a bibliometric analysis will not provide all the information regarding which companies are involved as their research is not commonly published, instead it is kept internally or presented at exhibitions, catalogues, and company documents.

Therefore, in order to complement the results from the bibliometric analysis and get a broader perspective, an industry association analysis is a better method of finding companies active in a TIS. In this analysis, data from Eurostat and Orbis is used as they contain majority of the data related to European companies and their presence is markets. Table 4.3 shows the results from this analysis and identifies the leading firms within the truck platooning TIS.

Table 4.3: Industry association analysis - Most involved companies

Industry	**Company/Firm**
Truck Manufacturing:	- Daimler AG - Volvo Group - DAF Trucks - Scania AB
Logistics providers:	- Deutsche post DHL - Deutsche Bahn - Maersk Denmark - DSV Denmark - La Poste Group France - UPS Europe

Source: data adopted from Eurostat and Orbis

From this industry association analysis it is shown that truck manufacturing companies in Europe are involved in the truck platooning technology and have performed a host of coordinated tests with universities, research centres, and NGO's identified earlier (TNO, 2021). Furthermore, the large logistics and transport companies are also praising the truck platooning technology, with DHL stating that they are at the forefront and intensively look at the TIS (Terbrüggen, 2021). The fact that these large actors are present, have a positive mindset, and, based on their revenue, a clear capacity to innovate means that there are not many barriers put up by these actors.

Although the major actors in the truck platooning TIS have perhaps been identified from the previous analyses, questions remain whether NGO's and governments were also active actors in the system and are therefore missing from the data-set. Through the project work I conducted at RUG ENTEG, I was put in contact with a host of industry experts whom I interviewed - see Table 3.1 for an overview of these. Throughout these unstructured interviews they also expressed groups they had worked with, tests they had been a part of, and organisations in the Netherlands that push for truck platooning. Their information provided the foundation to find other actors involved in the TIS, which are shown in Table 4.4.

By the end of the project that I conducted at RUG, names such as TNO, Ensemble, and Amsterdam Declaration became very familiar. These organisations have been funded by EU governments to perform large scale tests, such as the truck platooning challenge (Hogg, 2016), where the results are then shared at major European Union conferences (Ensemble, 2022). Having actors such as Arbeit de Chalendar

Table 4.4: Expert interview analysis - Involved actors

Type of actor	**Actor name**
Government:	- European Union - European Commission - Netherlands Government
NGO's:	- Ensemble EU - ERTICO - International Road transport Union (IRU) - ACEA - Amsterdam declaration - TNO

Source: data adopted from Appendix B

and Daems (2020), who are funded by the European Commission, and have partnered with some of the transport and logistics industries major firms, organisations, and universities is a real positive for the truck platooning TIS.

Based on the various analytic methods used, the actors most present in the truck platooning TIS have been identified in Table 4.5. The method used to determine the most relevant actors is one suggested by Woolthuis et al. (2005), where the important actors in a system are those that have the ability to prevent system failure. For this reason, actors who have the generalised largest presence, capacity to innovate, and have positive mindset to the TIS have been extracted. For example, it could be seen that the majority of innovation within truck platooning occurred within Germany, Netherlands, Sweden, and France due to the largest truck manufacturers, logistics firms, and organisations being present in these countries. Therefore, they are considered more present actors in the truck platooning TIS.

Another set of actors noted in Table 4.5 are the truck drivers. In line with Smits and Kuhlmann (2004)'s suggestion, these actors can be seen as users of the truck platooning technology and therefore have great influence on the implementation of the TIS. As per Adam (2022), there is a large shortage of drivers within the logistics industry, which could naturally lead to an accelerated need for solutions utilising less drivers. Hence, despite these actors neither being viewed as actors with a capacity to innovate, their presence, or in this case lack of presence, in the TIS can have major implications (Bakermans, 2016).

4.2.2 Networks

Knowledge is exchanged in academic, industry-academic, and user-supplier networks (Jacobsson and Bergek, 2011). Within this TIS there are not a large number of user-supplier networks due to the technology still being widely researched. Furthermore, truck platooning has for the majority of its technology life-cycle been a technology-push (Bakermans, 2016). Hence, there has been a history of less orchestrated formal networks such as standardisation, requested solutions and formal partnerships

Table 4.5: Structural analysis - Most involved actors

Actors	**Specification**
Civil Society:	- Truck drivers - Commuters
Knowledge Institutes:	**Universities** - League of European Research Universities (LERU) - Delft University of Technology (TU Delft) - Chalmers University of Technology - Royal Institute of Technology (KTH) - Eindhoven University of Technology (TUe) **Research centres** - Helmholtz Association - Centre national de la researche scientifique - Institute of transport economics
Companies: (Firms)	- Daimler AG - Volvo Group - DAF Trucks - Scania AB - Deutsche post DHL - Deutsche Bahn - Maersk Denmark
NGO's:	- Ensemble EU - TNO - International Road transport Union (IRU) - ACEA
Governments:	- European Commission Joint Research Centre (JRC) - European Union - European governments (Specifically Germany, Netherlands, Sweden, France)

Source: summarised from tables above

(Wieczorek and Hekkert, 2012). However, in more recent years, a large number of formal industry-academic links have appeared - adding to the formal collaborations within academia which has been present for longer periods.

In academic networks, Dutch, Swedish and French universities, to name the most prominent ones, have collaborated extensively to drive the development of the truck platooning TIS within their respective economies. A primary example is the project and study that I conducted at RUG, where our ENTEG collaborated with departments from TU Delft and TU Eindhoven to develop ground-breaking technical solutions for truck platooning. Furthermore, the previously mentioned Ensemble (2022); TNO (2021); Hogg (2016) collaborations are prime examples of the existence of formal networks between academia, industry, and even government.

Despite formal networks being available and visible, the informal network for the truck platooning TIS is significantly larger due to the infancy of the technology Bergek et al. (2008). Through both the bibliometric analysis and primary data collection methods mentioned in subsection 4.2.1 and Chapter 3 respectively, informal networks were identified and briefly mentioned. These include the co-publications and collaborations between universities, leading firms, and organisations respectively. In contrast to the publicly funded projects mentioned above, there is the example of informal networks between the truck drivers on European roads, as they have been known to test the knowledge field by placing themselves in a platoon (Kagenaar and Mingardo, 2016).

Networks within the truck platooning TIS have primarily been oriented around technological tasks and market formation as highlighted above. Furthermore, these aforementioned networks have showed to be strong in relation to academia and industry - with government networks also growing in strength. These growing networks primarily have a political agenda, which aim to influence the institutional set-up in a similar manner to previously successful innovation systems (Rao, 2004; Sabatier, 1998; Suchman, 1995).

4.2.3 Institutions

Concerning institutions, the truck platooning TIS is present in the automotive, truck manufacturing, and logistics sectors. Implementing driverless vehicles as part of a platoon will demand European law institutions to re-align central components of the current traffic legislations (Vellinga, 2017). Challenges with these laws include the inability for logistics firms to reduce their wage bills due to the requirement of a driver being present in each truck. However, it could still allow for drivers to perform alternate task while sitting in the driver's seat (Bakermans, 2016). Additional hard institutions have begun to align more with the technological requirements over the past decade. Sweden and Netherlands are prime examples of legislation and laws being changed to enable truck platoon testing. The Swedish Transport agency has since 2017 granted permits to allow driverless trucks to run tests on public roads under certain stipulations (SOU, 2016). Additionally, Netherlands's "Vision Truck Platooning 2025" has led to changes in Dutch legislation to allow innovative solutions relating to truck platoons to be tested on public roads (Ministerie, 2020). Hard institutional changes have since begun to take effect in the rest of Europe as well, showing positive implications for the TIS.

As for the soft institutions; habits, routines, and shared concepts used by humans can in some cases be more detrimental to a TIS than laws and regulations (Crawford and Ostrom, 1995). Current norms and culture surrounding freight trucks commonly results is a state of discontent as other commuters do not enjoy driving in a close proximity to trucks (Lumsden, 2014). This is mainly due to their inconvenient size, low speed, and enhanced sense of danger. Therefore, to attempt to change this norm and convince the general public that the future consists of driving past a platoon of freight trucks as opposed to a single one is a challenge. Other cultures and norms such as

Institutions are not in all cases in favour of truck platooning either. The increasing demand for safety requirements and emission regulations has made it difficult for heavy duty vehicles, specifically in the autonomous sector, to diffuse (EC, 2020).

Furthermore, bureaucracy is a common method of barricading a TIS when the technology seeks to replace a labour force - specifically when unemployment rates begin to rise (Eurostat, 2022). The unfortunate circumstances of the Covid-19 pandemic have further prevented technological innovations from replacing human labour due to the rise of unemployment rates. Although institutions might provide some resistance for the truck platooning TIS, the general shift in laws, regulations, and culture seems to be favourable.

4.3 Truck platooning TIS functions

Both the primary and secondary data collection phases show conflicting results regarding the positives and negatives of truck platooning as a technology. The following analysis of the TIS functions therefore focuses on extracting the benefits and drawbacks which are present in each of the functions. Amid the identification of function strengths and weaknesses, the goal is to extract enablers and barriers which are currently affecting the truck platooning TIS in its attempt to emerge.

4.3.1 Function 1: Knowledge development

Knowledge development within "driverless" technologies has existed ever since vehicles were invented (Sentinel, 1926). The dream of taking a driver out of the vehicle began in the 1920's and the knowledge field developed extensively until the 1980's through university and car manufacturer collaboration. As with many knowledge fields, it eventually begins to spill over into other technologies and industries - which is how truck platooning knowledge development commenced around the 1990's Fritz (2004). Since the turn of the century, knowledge development within truck platooning has intensified due to technological advancements, increases in demand of goods, and increased highway congestion. During these stages, the development of driverless trucks came from the leading truck manufacturers as they saw a potential to benefit from first mover advantage (Bakermans, 2016). Furthermore, the term "autonomous drive" became a buzzword meaning that truck manufacturers felt they could develop this knowledge field as well and implement it in their products.

The knowledge regarding truck platooning was isolated and only thought about as individual driverless trucks. However, once the logistics and transport firms began entering the TIS, the knowledge began to diffuse as it was combined between firms in the industry (Terbrüggen, 2021). A large part of the knowledge development occurred at various universities and research centres where the software aspects of truck platooning were optimised, simulated and tested in order to be suitable for the mechanical R&D executed at the firms. A member from RUG ENTEG who had been working on truck platooning solutions discussed how knowledge development within the truck platooning TIS has become a digital development as opposed to mechanical (Appendix B.6). The belief is that truck platooning goes beyond the scope of building new trucks, but instead focuses on the digitisation of freight transport due to majority of the vehicle technology being controlled by computers. This shift in the knowledge development is something that has slowed the emergence of the TIS due to moral and ethical implications which are connected to computer-controlled entities (Johnson, 1985).

The above is the development of the technological and scientific knowledge base through R&D. However, the knowledge base was broadened as the truck platooning TIS began to encapsulate the entire value chain. Despite the truck manufacturers and logistics sectors being confident in their technical solutions (Ensemble, 2022), the knowledge development within digital security, business aspects, and road infrastructure in severely underdeveloped within the TIS. As seen from Table 4.2, Vodafone are actors currently present in the truck platooning TIS. Telecom actors, including Vodafone, are some of the later entrants into the system and they stress the need for knowledge development regarding the connectivity requirements for truck platooning (Alvarez et al., 2020). Issues such as the digital infrastructure, cyber security, and ethical implications cannot be solved with the current state of the knowledge base. Therefore, regardless of the impressive size of the knowledge field within certain sectors, an acceleration in the cross-sectoral knowledge development is required to strengthen the TIS.

4.3.2 Function 2: Influence of the direction of search

In order to influence the direction of search towards the truck platooning TIS there needs to be incentives for actors to aid the development of the TIS. Hence, factors such as belief in growth potential, articulation of interest by leading actors, and financial/regulatory benefits become critical. Governments within the EU have already made it clear that they support the TIS by offering funding for a multitude of projects (TNO, 2021; Arbeit de Chalendar and Daems, 2020; Hogg, 2016). Furthermore, the incentives provided by lower carbon emission targets as well as tax breaks for firms that aim for sustainable development (EU, 2021) has shifted the direction of search in favour of systems that naturally obey these regulations (Bergek et al., 2008). Governments have further promoted the TIS by explicitly stating local visions and aims relating to truck platooning which the European Union has since evaluated and promoted themselves (EU, 2022). Two examples are the Dutch and Swedish governments, who developed a "truck platooning vision 2025" (TNO, 2021), and an aim of sustainable driving automation (Näringsdepartementet, 2018), respectively. These various actions from governments increase the expectations and beliefs in growth potential while making it clear to actors that they are willing to support them.

When discussing with members of RUG ENTEG, it has become evident that they strongly believe in this technology and expect the market to grow. Despite their bias, the argument that there are significant economic benefits of implementing truck platooning as opposed to single freight trucking is supported by the results from my project simulations (Appendix A.1; Appendix B.1; Appendix B.3). Additionally, several analyses of the truck platooning market forecast Compound Annual Growth Rates of 32% over the next 5 years, while also suggesting that Europe is the fastest growing market (Intelligence, 2021). Google, one of the world's most recognisable names, has shown its support for the autonomous drive technology which is used in truck platooning, stating in 2014 that the technology was ready for use, but the infrastructure was not, and they could not guarantee the safety and security of all drivers (Gibbs, 2014). Results such as these give a clear indication that future of the truck platooning market is attractive for firms which means they are more likely to direct their own search towards the TIS.

Leading logistics and truck manufacturer firms are perhaps the technical bottleneck in relation to the direction of search due to the spread across the industry. On one hand, moving towards the TIS can be seen as a major business opportunity due to possibility of reducing operational costs. The road freight logistics market is highly competitive and is notorious for its low margins (Torrey IV and Murray, 2014). In addition, one of the largest variable operational costs is wages for the truck drivers. Hence, given the opportunity to eliminate this cost, a firm can gain a clear competitive advantage over other firms in the market. Furthermore, the current driver shortage is a crisis in the current business which is aided by shifting the direction of search towards truck platooning (Adam, 2022). However, it is important to note that a significant investment is required to completely restructure the logistics of road freight transport, as well as replace all existing truck with new vehicles. This is something that is preventing firms from committing until other sectors have made infrastructural changes which create additional incentive and belief in the truck platooning TIS.

4.3.3 Function 3: Entrepreneurial experimentation

From subsections above, it is already clear that firms, universities, and organisations are already heavily engaged in experimentation surrounding the technology and its applications. The benefits of these experiments have already become evident; given that each of Europe's five largest truck manufacturers have entered truck platooning R&D and testing (Arbeit de Chalendar and Daems, 2020). University research, including the project I conducted, have primarily experimented with platooning formations and optimisations through calculations and simulations (Appendix A.1; Appendix A.3). Despite there being countless simulations being conducted at universities all over Europe, legislation prevent the experiments from taking effect in the physical form. Although a few physical experiments have been conducted under controlled conditions (Hogg, 2016; TNO, 2021), there has not been enough physical tests under real conditions. One interesting solution to the European legislation demanding a driver always be present behind the wheel is remotely driving the car via a connected simulator (T-Systems, 2021). These are interesting experiments which not only benefit the TIS through diversifying its entrants with established firms, namely leading Telecom firms, but it also gives the TIS a possibility to advance in the market - albeit in smaller steps.

Due to the difficulties of safely and cost-effectively executing physical testing, it is difficult for entrepreneurial experimentation to accelerate without significant funding or infrastructural changes. Unfortunately, the infrastructural changes will most likely not come quick enough causing actors to believe that their truck platooning system needs to be adapted to existing infrastructure instead. The fear is that the truck platooning TIS will stagnate without changes to driving legislation and regulations which would enable extensive experimentation. Furthermore, the barriers for testing are high due to real life testing requiring extensive resources leading to high uncertainties. Therefore, the use of alternate forms of entrepreneurial experimentation, such as remote operations, is important to lower both the barriers for testing and the uncertainties.

Entrepreneurial experimentation is however remaining strong as there has been a significant increase in the number of physical test, despite the difficulties of planning such an operation. The number of publications discussing simulations of truck platooning have increased significantly within Swedish and Dutch universities since the announcement of the truck platooning challenge 2016 (Aarts and Feddes, 2016). Local tests in Sweden, Germany, and Netherlands have also increased in recent times, albeit on closed roads under controlled conditions (Liang et al., 2016). Both the bibliometric and industry association analyses seem to show an increase in testing different applications of the technology, which suggests positive effects on the entrepreneurial experimentation function.

4.3.4 Function 4: Market formation

According to a study done on the truck platooning market it is currently moving towards a consolidated market which is dominated by 1-5 major players (Intelligence, 2021). Furthermore, the estimated total market valuation in 2017 was just shy of 500 million EUR, with this number growing to 1,400 million EUR by 2021 (Katare and Sonpimple, 2019). This growth shows that the market is not necessarily in a nursing market anymore, but has arguable broken into the bridging market (Bergek et al., 2008). However, the local markets within the various EU countries vary, in countries like the Netherlands, Germany, Sweden, and France the TIS has an active number of actors and is therefore in the bridging market. On the other hand, the majority of the EU-27 markets are still in the nursing market and require knowledge diffusion from the leading countries. The largest presence of actors in the TIS are the truck platooning component suppliers making up 50% of the markets firms, followed by the logistics providers and truck manufacturers with 30% and 20% of the market respectively (Marketsandmarkets, 2021).

Despite the market size looking healthy, there are still uncertainties which act as barriers to market formation. Truck manufacturers and logistics providers have a hard time projecting the infrastructure changes that will occur over the next decade. Hence, it is difficult to pinpoint and articulate the drivers of market formation as it could be any combination of institutions, leading firms, or infrastructure. As expressed by Wieczorek and Hekkert (2012), uncertainties regarding leading actors, potential users, and purchasing processes is an indicator that market formation is disrupted, regardless of actor strategies. Therefore, the actions taken by truck manufacturers, logistics firms, and the government is not sufficient for achieving market maturity without clarity on future infrastructure and customer demand. Additionally, it is expected that new partnerships will form, under new business models, to make changes to the logistics operations and begin developing the required digital infrastructure (Engholm et al., 2020).

Speaking to experts on the technological side of the truck platooning TIS, they are adamant that logistics firms and truck manufacturers need to step in and take lead in the market formation (Appendix B.5; Appendix B.6). Currently, the majority of research and development is still taking place at universities and research institutes, which makes it difficult for the truck platooning TIS to expand and diffuse. TNO agree with this and have produced a report highlighting how to drive truck platooning to become the future of transport (Janssen et al., 2015). In this report, it becomes clear that the truck manufacturers need to be the suppliers of the technology, and the logistics firms need to be the users and set demands on the manufacturers, government, and institutions to ensure that their operations can remain effective in the midst of a transforming industry. They continue to express how various regulators throughout Europe will provide either support or resistance to the market formation, but generally an increase in innovation is a common target.

4.3.5 Function 5: Legitimisation

Legitimisation of the truck platooning TIS is closely tied-in to the legitimacy of autonomous vehicles as it is perceived as the underlying technology which could enable truck platooning. Firstly, the technology needs to be developed to an extend where it is proven to be safe and reliable for public acceptance, while also providing a marketable value for both consumers and producers. Legitimacy relies heavily on relevant actors considering the TIS to be appropriate and desirable, while also complying with institutions (Bergek et al., 2008). Autonomous driving within passenger vehicles has experienced a lot of resistance from the general public. Not only because of the scepticism tied to allowing a machine to control a vehicle, but they also believe it takes away from the driving lifestyle (Litman, 2020). The exact same argument can perhaps not be made by truck drivers as it is perhaps considered less fun to drive 18 hours through Europe in a heavy-duty vehicle than taking a sports car for a spin. But the scepticism is enhanced within truck drivers as the vehicle is much more challenging to handle and control (Boeijinga et al., 2016).

In addition to resistance from general public and drivers, current actors in the logistics sector who do not wish to experience industrial change will make themselves heard. One member of ENTEG who had run tests with a Dutch local freight carrier insisted that they were scared of the shift towards platoons and relaxed regulations on the size of freight trucks (Appendix B.5). Their reasons being that the current regulations allow smaller couriers a competing chance, and if platoons were to begin driving their routes then their businesses would be devoured by large European conglomerates who could offer significantly lower prices. These competition dilemmas appeal to regulators within the EU who strive for fair competition, forcing them to either intervene with subsidies to aid local businesses, or they set up institutional barriers to protect fair competition Janssen et al. (2015). As soon as resistance to change is created or begins to manifest, the legitimacy of the technology comes into question, which harms the development and diffusion of the TIS (Wieczorek and Hekkert, 2012).

On the other hand, the prospective spending on R&D, organisation of large-scale tests, and pressure put on governments to improve infrastructure is proof that legitimisation activities are taking place with the truck platooning TIS. Other resistance potentials such as the risk of unemployment for truck drivers due to automation is naturally being counteracted due to the driver shortages emerging (Adam, 2022). Furthermore, the most powerful actors within the TIS, such as the large truck manufacturers, major logistics companies, and leading governments, are actively promoting and investing in truck platooning. This does not only speak to the legitimacy of the technology on a societal level, but the acts of promotion and investment themselves hold a legitimising effect.

4.3.6 Function 6: Resource mobilisation

Truck platooning falls primarily under the development of software development in combination with engineering and manufacturing. Within these fields, the mobilisation of human resources is found to be strong due to a combined 900 thousand university graduates within the European Union obtaining degrees relevant to the TIS in 2019 (Clark, 2022). These graduates will have the ability to aid the system in its development as they will have become part of the human resource in various industries by now. Countries, such as Sweden and Germany, which naturally manufacture trucks are more likely to have graduates join their firms and aid in the development of the truck platooning TIS. In addition, there has been a gradual development of internal competencies within truck manufacturing firms to support the shift towards driving automation (Engholm et al., 2020).

In terms of financial resources, it seems to be a strength due to the constant increasing value of venture capital funds in Europe throughout the last decade (Statista, 2022). Furthermore, major firms including Peloton, Volvo Group, Intel Capital, and BP Ventures to name a few, have raised capital and invested in truck platooning safety suggesting that there is a rise in the volume of capital within the TIS (Sawers, 2017). However, logistics service providers, the firms who will end up using the technology, highlight the difficulties of financing the shift towards truck platooning. The margins within the freight transport sector are low meaning the high associated costs with the technology will be a challenge to fund without external support.

The factor that significantly weakens the resource mobilisation function is the lack of complementary assets within the truck platooning TIS. A large amount of infrastructural changes will be needed to complement the development, but unfortunately there is still a lack of clarity as to what exact changes will be required. The organisers of the 2016 truck platooning challenge estimate that increased mobile networks covering the entire road network, charging stations, and better vehicle batteries will all be necessary complementary assets to the TIS for it to emerge in the market (Aarts and Feddes, 2016). This uncertainty regarding infrastructure and complementary assets, along with the limited financial resources of the logistics firms, creates barriers for the market formation and diffusion.

4.3.7 Function 7: Development of positive externalities

The creation of positive externalities is important in any system as it allows for a third party to enjoy a benefit as a result of an action (Ayres and Levitt, 1998). Within TIS, the other six functions can therefore experience positive externalities based on actions taken which influence one of the other functions. As an example, the knowledge which is being acquired throughout testing for truck platooning is equally as useful in other existing technologies such as autonomous drive, vehicle-to-vehicle (V2V) communication, and sustainable logistics - strengthening knowledge development. Furthermore, the entrance of new financially powerful actors brought R&D, competence, and funding to the TIS stimulating resource mobilisation and further strengthening knowledge development. The actors relating to manufacturing and logistics further demonstrated its use as a technology and thereby influenced the direction of search, while governing actors created positive externalities by increasing the legitimacy of the technology - thus stimulating the legitimacy function.

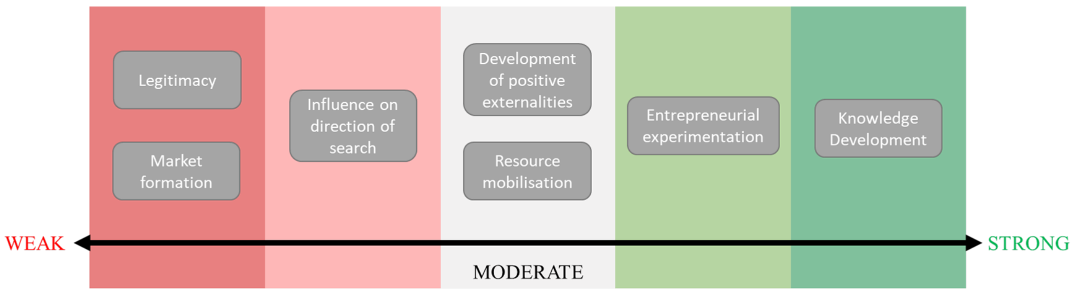
The development of truck platooning is not creating any new labour markets however, due to the nature of the automation involved in the solutions. Instead there is an argument that through digital industrialisation, the human work force will be replaced by machines and technology. Effects of these are weakening the legitimisation of truck platooning and slowing the entrepreneurial experimentation and market formation. Additionally, the uncertainty expressed, specifically by logistics firms, regarding the future development of infrastructure remains high, which in turn weakens functions such as resource mobilisation, direction of search, and legitimacy. Suurs et al. (2010) states that this is a common characteristic of emerging innovations which can possess dragged out development phases. However, a small spark by an increase in any of the functions can quickly accelerate the development of the TIS.

The general consensus within the TIS seems to be that there are efforts being made to align the institutions with the emerging technology. The more developed European economies, and the EU itself, have a culture of collaboration between government, public authorities, and industry which motivates the emergence and diffusion of new innovations that form a sustainable future. This willingness for major actors to set goals, fund research, and facilitate testing is further evidence that the truck platooning TIS is receiving the support it requires through the strengthening of market formation, direction of search and legitimisation.

4.3.8 Summary of functions

The identification and analysis of the individual functions present in the truck platooning TIS has showcased that some are having a stronger effect on the system than others. More critically however, there are a host of functions which are at a risk of function failure, which can ultimately cause system failure (Woolthuis et al., 2005). Avoiding system failure is important, quantifying the results from the analysis is therefore a method to produce clarity on the systemic problems. An indication of the strength of each function has been given in subsections 4.3.1 - 4.3.7 through the analysis of the functional dynamics. Figure 4.1 provides an overview of the strength of the functions present in the system in a more quantitative manner.

Figure 4.1: Evaluation of the systemic functions



Source: grading method adopted from Wieczorek and Hekkert (2012)

According to Wieczorek and Hekkert (2012), it is important to focus on the weakest or absent functions and identify what is hindering them. This is what sets up the identification of the main barriers to the emergence of truck platooning, and subsequently leads the discussion on the effects of these barriers. From Figure 4.1 it is shown that market formation and legitimacy are by far the weakest, with direction of search being affected by high uncertainties. Although highlighting the benefits of strong knowledge development and positive indication of the entrepreneurial experimentation aids in the identification of enablers, the risk of function failure is far more prominent and therefore engulf the discussion surrounding strong functions. Hence, both section 4.4 and chapter 5 focus on the destructive nature of the weaker functions and the resulting barriers for emergence that they cause.

4.4 Identifying enablers and barriers

This section uses the discovery from the structure and function dynamics to identify enablers and barriers in the TIS. Below, the enablers are first highlighted based on the current and potential of the TIS, before the barriers are expressed allowing for discussions to take place in Chapter 5 based on these results.

4.4.1 Enablers

Based on the identification and analysis of structural components, along with the identification of functions and the subsequent analysis of system dynamics have provided insight on the enablers with regards to the truck platooning TIS. Table 4.6 shows an overview of these enablers and their relation to the respective TIS functions.

Table 4.6: Truck platooning TIS enablers

Enabler	**Function(s) benefitted**
Common belief in technology:	- Market formation (F4) - Entrepreneurial experimentation (F3) - Influence on direction of search (F2)
Major actors investing:	- Resource mobilisation (F6) - Influence on direction of search (F2) - Legitimacy (F5)
Industry moving towards crisis:	- Knowledge development (F1) - Influence on direction of search (F2) - Entrepreneurial experimentation (F3)
Growth potential:	- Market formation (F4) - Entrepreneurial experimentation (F3)
Long-term institutions aligned:	- Legitimacy (F5) - Market formation (F4)

It became clear throughout the analysis that leading actors within the truck platooning TIS are investing and funding the development and testing of the technology. The four truck manufacturers most active in developing truck platooning technology; Volvo, Daimler, Scania, and DAF, accounted for over 60% of the market share in 2018 (ACEA, 2018), and are investing in R&D. This only takes into account the four *largest actors within the truck platooning TIS* - with other actors comprising of significant market shares also investing in the technology. Other actors, including leading European governments and non-government organisations, are further investing in truck platooning knowledge field by providing funding for research and testing of the technology and its development.

An enabler which speaks highly to the future of truck platooning is the common belief in the technology and its growth potential. As aforementioned, the investments shows that there is both a belief and a long-term vision for truck platooning. However, universities and research centres show their belief in the growth potential by performing an increasing number of publications related to the knowledge field - as shown in section 4.2.1. Further belief in the truck platooning TIS is shown in the collaborative efforts between knowledge institutes to develop and optimise the technical aspects of truck platooning. The belief in growth is clearly stronger in certain European economies, but the Dutch, German, French, and Swedish economies are currently leaders within the EU and therefore influence the development and induce the TIS.

An industry which is in "crisis" can act as a powerful enabler (Bergek et al., 2008). Saying that one of the industries involved in the truck platooning TIS is experiencing a crisis is perhaps a stretch, but the truck driver shortage within the logistics sector is an indication that the industry is slowly depleting should it remain static. As current road freight trucking requires one person to drive one vehicle, the market is unable to expand if there is a downward trend in the number of actively employable truck drivers. This, coupled with a consistent increase in the consumption of goods leading to an increase in the road freight transport (Eurostat, 2021), suggests that the logistics sector could fail to meet the demand of their services. In this case, it becomes evident that it is an enabler as truck platooning technology, and its implementation in logistics, requires at most half as many truck drivers to supply the demand.

An important step in the emergence of a technology is aligning institutions with the TIS. In this case, the fact that some institutions within Europe are already aligned is a rather strong enabler. One of the largest goals set by local European governing bodies and the EU commission is related to sustainable development, climate preservation, and carbon emissions (EU, 2021). Although all institutions are most definitely not in-line with the requirements of the TIS, it is evident that changes are being made, albeit at a slow pace, within the European economic powerhouses to enable the development and emergence of truck platooning.

4.4.2 Barriers

On the flip side, the barriers are important to understand so that correct suggestions can be made and so that eventual solutions can be found to help a technology emerge (Bergek et al., 2008). Additionally, some barriers can be so powerful that they prevent a TIS of a certain nature from developing. Table 4.7 therefore shows the barriers extracted from the structural and functional analysis.

During the structural analysis it became apparent that despite the presence of a significant number of large actors, their ability to form strong relevant networks is weak. The only exception is the academic and industry-academic networks which have strength and continue to grow. However, a market is not created by having volumes academic studies, instead user-supplier networks are needed (Jacobsson and Bergek, 2011; Wieczorek and Hekkert, 2012). Truck platooning is a collective effort between at least three industries; truck manufacturing, logistics, and software. As their networks remain weak and underdeveloped, the technology is unable to emerge in a correct manner, blocking the development of functions within the TIS. A barrier is also that various industries are developing at different rates creating

Table 4.7: Truck platooning TIS barriers

Barrier	**Function(s) affected**
Weak networks:	- Market formation (F4) - Entrepreneurial experimentation (F3) - Influence on direction of search (F2)
Lacking common knowledge about the TIS:	- Market formation (F4)
High uncertainty amongst leading actors:	- Legitimacy (F5) - Market formation (F4)
Poor articulation of demand:	- Market formation (F4) - Entrepreneurial experimentation (F3)
Weak advocacy coalition:	- Legitimacy (F5)
Lack of complementary assets:	- Legitimacy (F5) - Resource mobilisation (F6)
Asynchronous developments of industries:	- Influence on direction of search (F2) - Resource mobilisation (F6)
Underdeveloped infrastructure:	- All functions (F2 – F6) - Negligible in knowledge development (F1)

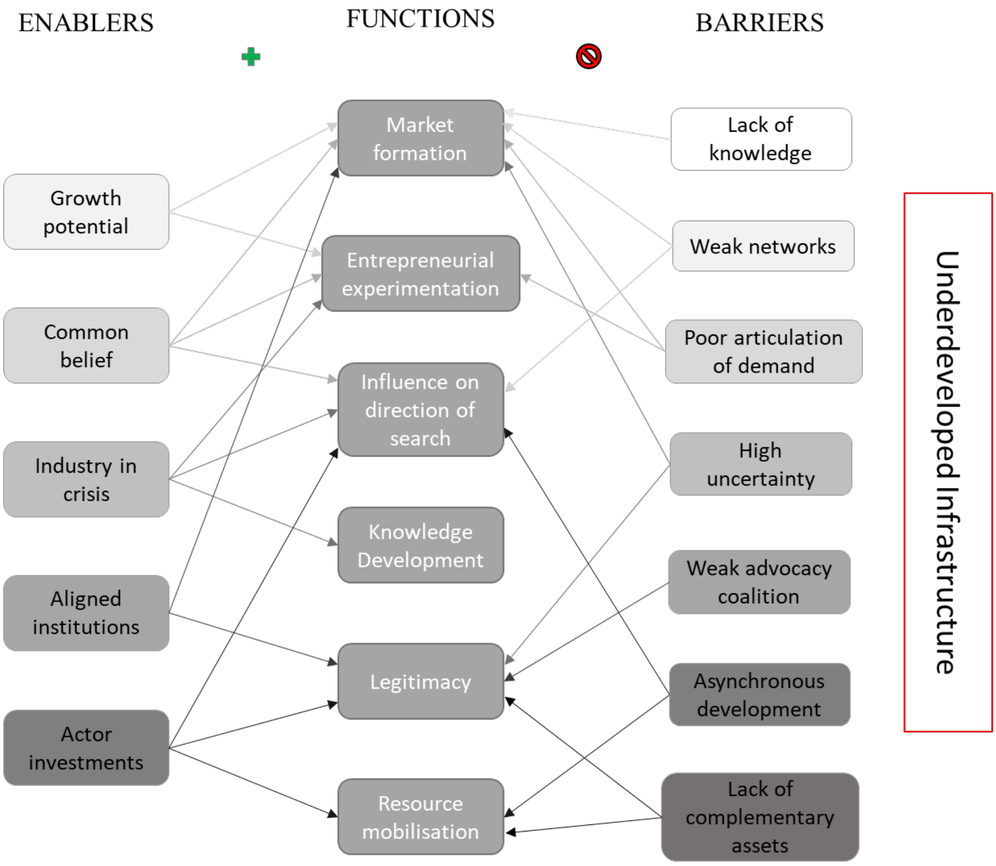
asynchronous advancements within the truck platooning TIS. This prevents lock-in effects and collaborative work which harms the entrepreneurial experimentation, direction of search, and market formation.

The lack of complementary assets surrounding truck platooning are significant in acting as barriers. As previously mentioned, truck platooning requires the combined efforts from multiple actors in varying industries, and as long as they are unable to produce results which go in tandem with the technological side, the whole TIS will suffer. Examples of this include batteries not being advanced enough for freight transport, vehicle safety being hindered by ethics discussions, and infrastructure being severely underdeveloped - all of which need to make progress in order to explore the full effects of the truck platooning TIS. The lack of infrastructure is by far the main barrier as truck platooning is almost certainly unable to be used throughout Europe without changes relating to road networks and V2V communication.

In addition, the general uncertainties surrounding the TIS creates a strong barrier for the emergence of truck platooning. These uncertainties stem the whole way through the value chain and essentially concerns all the stakeholders. Governments are uncertain over the benefits, logistics providers are uncertain over the future infrastructure, truck manufacturers are uncertain over the vehicle requirements, and the general public is subsequently uncertain over its functionality in our current ecosystem. Another contribution to the barriers is that there is not enough lobbying or pressure placed on governments, organisations, or the public to align institutions or demand infrastructural changes. The result of this is a lack of legitimacy, experimentation, and market formation.

Figure 4.2 summarises the enablers and barriers identified throughout the TIS analysis. As showcased, underdeveloped infrastructure has been a common identifiable

Figure 4.2: Truck platooning TIS enablers and barriers



Source: TIS analysis

barrier which is affecting each of the TIS functions and their respective dynamics. The topic of infrastructures will be discuss in length in the following chapter. It is apparent from the figure that the majority of barriers attack the market formation and legitimacy functions. Furthermore, the knowledge development and entrepreneurial experimentation functions are hardly affected at all by the identified barriers. This is consistent with the current state of the truck platooning TIS, which is in its formative stages and is therefore driven by knowledge development and experimentation by universities, research centres, and early company R&D. Additionally, it is further consistent as the technology has not yet reached a suitable level of acceptance and is therefore unable to legitimise and form a market - resulting in the gap between invention and innovation as suggested in Chapter 1.

5
Discussion

As the purpose of the analysis was to highlight the enablers and barriers to entry for the truck platooning TIS, it is now important to discuss the barriers to give an indication if they can be overcome allowing the enablers to thrive. Within innovations systems, being faced with high barriers enhances the chance of experiencing system failure (Woolthuis et al., 2005). This something that needs to be avoided in order to give truck platooning the ability to emerge in the European economies. System failure can come in various forms; Infrastructural, institutional, interaction, and capabilities to name a few which will be discussed in greater depth throughout this chapter (Woolthuis et al., 2005). Policies and suggestions will then briefly be discussed which serve the purpose of allowing future research to attempt to guide it to a healthier state.

Being confident that the thorough research, structured methodology supported by conceptual and empirical framework applications, and in-depth analysis has served the purpose, the three largest barriers have been identified as follows:

1. Unaligned institutions
2. Weak networks
3. Underdeveloped infrastructure

Although these barriers are individual and are harmful to the truck platooning TIS on their own, its their relation and unavoidable connection that is pushing towards system failure. A commonality between the three identified barriers is that they are partly based on high uncertainties within the industry, which ultimately causes market formations to fail, and the legitimacy of the technology to be questioned. The results show why the uncertainty remains so high, amongst others is the lack of clarity on the institutional and infrastructural requirements. Lack of clarity in itself is a communicative error which highlights the weak networks. The results therefore show that these three barriers are not only a hindrance on their own, but combine effortlessly to bring detriment to the truck platooning TIS.

From the analysis it became apparent that the majority of the barriers can be tied back to a lacking supporting infrastructure. It is therefore interesting to discuss the links between the strongest barriers with the infrastructure as a central component. It is clear that governments control infrastructural changes, and as they have not yet specified a target or set clear visions to support truck platooning, a few possible actions must occur:

1. Current actors must ensure governments are informed about truck platooning allowing infrastructural changes to occur naturally
2. Current actors must lobby and pressure government to further align institutions and begin developing infrastructure
3. New actors must enter and grow the TIS so that new knowledge can naturally or actively induce infrastructural changes

Weak networking is affecting various functions and does not allow for infrastructural changes to be enforced. There is a lack of entrepreneurial experimentation, unstructured direction of search, and hence slow market formation due to the poor communication between leading actors. Should these actors improve on their resource mobilisation, enable strong and uniform networks, and align their targets, it would become much easier to pressure the government or use lobbying to ensure changes to the infrastructure. On the other hand, if governments, who are also major actors in the TIS, have access to information regarding the benefits of truck platooning and its specific alignment with sustainability targets, then they need to take action themselves and push for change. However, should they lack information of the knowledge field, then governments need to poll for knowledge within the truck platooning TIS from academia and industry. Currently however, the knowledge dissipates within universities and research centres without important details reaching the actors which are able to put changes into effect. Hence, it is suggested that if the governments had more knowledge on the benefits of truck platooning then they would be able to put changes of the infrastructure in motion.

Poor articulation of demand is both a cause and effect of uncertainty surrounding users needs. Governments are unable to make definitive changes due to uncertainties, causing actors to be uncertain on the future requirements and are therefore unable to articulate their demands from other relevant actors. Concurrently, major actors project their uncertainty by not clearly articulating the demand, which then affects other relevant actors' certainty and subsequently the government. The vicious cycle can be seen between the logistics providers, truck manufacturers, and the government; with neither overcoming their uncertainties to demand specifications in relation to trucks, infrastructure, or knowledge, respectively. These issues prevent market formation and entrepreneurial experimentation, while also causing the legitimacy of the technology to be question. A lack of knowledge on supporting industries is the detrimental factor for the firms involved, while weak advocacy coalition is the factor which is hindering governments. To improve this new clusters need to be formed, networking needs to be increased, or unified organisations must be created to collectively form a plan of action for the future of the technology.

Asynchronous development of components within the TIS is an issue that clearly disrupts the emergence of truck platooning. Truck platooning software is already advanced enough to work within vehicles - with the exception of perhaps ethical and security risks . Despite this, collaborative components such as vehicle specifications, telecommunication channels controlling V2V and V2I communication, and infrastructure are either lagging behind or unaligned with the technical applications of the software. This causes immense uncertainty within the unified development of the truck platooning TIS due to poor resource mobilisation, direction of search, and questions surrounding legitimacy. This development ties into the dilemma surrounding a lack of complementary assets which is a well known barrier for market formation (Bergek et al., 2008). Furthermore, the lack of developed complementary assets makes it difficult for the truck platooning TIS to pressure or lobby against the governments to force institutional or infrastructural change. Instead a larger base with industries penetrating from different angles is required to increase pressure and substantiate lobbying attempts. Policies such as cooperative research programs, technology promotion programmes, or perhaps collaboration and mobility schemes need to be put in place to ensure government facilitation with infrastructure.

It is important to note that current institutions are still a big barrier to the emergence of truck platooning. Despite some regulations, instructions, and expectations being aligned with the requirements of the TIS, numerous larger adjustments need to be made to allow driverless vehicles on European roads. Hard institutions prevent the technology from being used at an optimal level due to the requirement of a qualified person, in this case holding a European category C driver license (Union, 2022), sitting behind the wheel. Institutions such as these, demotivate actors, such as logistics firms, from investing in the technology as it provides them with very little financial benefit - with the exception of fuel cost reduction (Appendix A.7). The issue of institutions heavily ties back to the infrastructure, as laws and regulations regarding the safety of vehicles on public roads cannot be guaranteed without infrastructural changes to the road networks and V2V/V2I communication. In addition, soft institutions are both hindering and being hindered by the infrastructure. With current infrastructure, norms and culture cause the average driver to become uncomfortable when they are alongside a heavy-duty vehicle without a driver in it. Sometimes, older generations must expire as it can be difficult to change soft institutions while undergoing a paradigm shift - a prime example of this is the use of legacy systems within the health care industry (Iroju et al., 2013).

5.1 Implications of related studies

The unaligned soft institutions were shown to be important in the analysis of the truck platooning TIS as it showed why it wasn't emerging. A couple studies into photovoltaic TISs support the importance of soft institutions and highlight how quickly emergence can occur after these institutions align (Palm, 2015; Traverse et al., 2017; Vroon et al., 2021). According to the research, the actors within the TIS pay attention to government spending and their targets, which resulted in the interests of the actors to shift towards the use of photovoltaic cells when the push came from a governing body. Comparatively, the importance of aligned hard institutions has been seen in various renewable energy TISs, where the environmental tax breaks provided incentive for actors to reduce carbon emissions or transition to sustainable development (Jacobsson and Bergek, 2004; Wicki and Hansen, 2017; Edsand, 2017). Providing similar alignments for soft and hard institutions within the truck platooning TIS would ultimately motivate logistics providers and truck manufacturers to collectively focus on bridging the gap between invention and innovation.

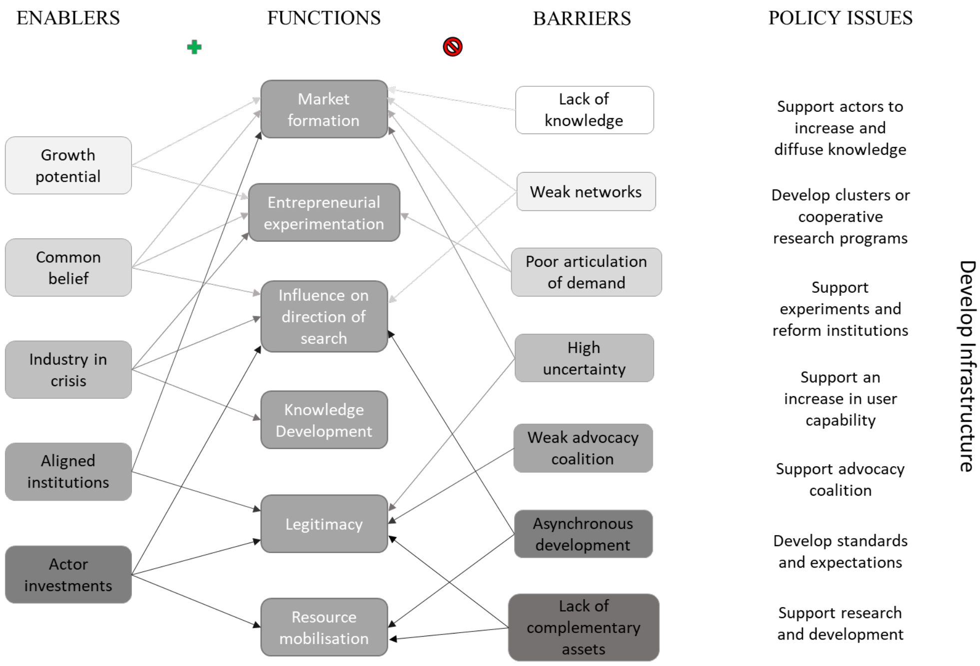
Malerba (2009) discusses the concept of dynamic complementarity failure, which is another argument for describing that weak networks lead to failure. The weak networks fail to identify and establish "complementarity" which causes the truck platooning TIS to suffer. The automotive industry in Germany is a notable TIS which has shown the importance of establishing complementarity (Scheuplein, 2021). Supporting infotainment and sound systems built strong networks with the German automotive sector giving their respective firms improved market shares. Furthermore, previous studies on the innovation systems within Silicon Valley have shown the significance of strong networks. Specifically the connectivity TISs, showing that once mobile phones had the ability to connect to the internet, telecommunication, graphics design, and operative systems firms all relocated and acted as complementary assets, which strengthened the networks (Breschi and Malerba, 2005; Tripsas, 1997; Zander and Anderson, 2008). The strong networks ultimately lead to the emergence and diffusion of the dominant design that we use as phones today. Complementary assets and supporting industries are therefore important to aid truck platooning in developing strong relevant networks which ultimately will enable the TIS to emerge into the European market.

The importance of infrastructure in innovation and development has been emphasised in a host of previous literature. Looking at functioning innovative technologies in Europe, such as 4G telecommunications, and comparing it to various countries in Africa, the vital influence of infrastructure becomes apparent (Ridley et al., 2006). By developing infrastructure in Africa, it would enable the emergence of a technology that Europe has had for over 20 years. On the other hand, the significant publications based on European innovation systems have commonly stemmed around the renewable energy sector (Bergek and Jacobsson, 2003; Bergek et al., 2007; Jacobsson and Bergek, 2004, 2011). The wind energy sector overcame barriers and emerged more successful in Germany than Sweden and Netherlands due to the improved infrastructure which allowed the emergence and diffusion of the technology (Bergek and Jacobsson, 2003; Jacobsson and Bergek, 2004). Based on these previous TIS studies, its worth arguing that if truck platooning technology received the same amount infrastructural support that the renewable energy sectors have received, then a similar emergence should be possible.

5.2 Implications for policy issuers

The effects of these barriers leads to various functions being affected which ultimately creates the potential for system failure. The functions experiencing the highest toll are market formation, influence of direction of search, and legitimacy. This means that the priority for policy makers should be to enable these functions so that the system has a better chance to avoid failure. Figure 5.1 suggests a number of potential policy issues and their connection to the identified barriers.

Figure 5.1: Truck platooning TIS policy issues



Source: based on theory from Bergek et al. (2008)

From the "Policy Issues" column in Figure 5.1, the suggestions can be split up into three main purposes:

1. The first two aim at resolving the issues relating to communication and understanding of the technology
2. The following three serve the purpose of providing clarity on demands set or required by actors in the TIS
3. The final two aim to ensure development of products and services surrounding the technology
4. In addition to these, a larger aim focuses on building infrastructure to enable the use of truck platooning

Policy support for the truck platooning TIS has to date not been technology specific enough, which is not sufficient to aid the emergence (Jacobsson and Bergek, 2011). General policies surrounding environmental criteria or sustainable technology are in effect, but they do not specifically enable truck platooning TIS functions. Further, policies aimed at developing standards for liability and security of the technology has been used within the passenger vehicle autonomous drive sector (Fagnant and Kockelman, 2015; Long et al., 2019; Winkelhake et al., 2018; Teece, 2018), and have shown to alter the previous suspicions on the technology to one of the most sought-after prospective transitions within the transport sector. Incorporating the heavy-duty vehicle and logistics sectors within the policies will help the alignment of institutions and the development of supporting infrastructure.

However, creating policies with the sole purpose of benefiting one technology can lead to complications (Alkemade and Suurs, 2012). The dangers involve becoming too locked-in to a technology that is not optimal, which ultimately prevents better technologies from emerging and diffusing. This research does not specify the policies that need to be issued in order to commercialise truck platooning as policies need to take a view broader than defined TIS in this research. Therefore, the results above should enable policy makers to understand the issues relating to the emergence of the truck platooning TIS and subsequently evaluate the best method to form policies to help counteract them.

5.3 Limitations

In innovation systems research a common limitation is the decisions made on the definition of the TIS (Featherston et al., 2012). Perhaps the analysis of enablers and barriers related to truck platooning could be best served by expanding the TIS to include a larger geographical area, wider range of industries, and including structures along an elongated value chain. However, time and resource constraints prevent this from being possible in this research. Additionally, a systems based analysis on similar industries or technologies would help provide context benefiting the complexity of the research. Lastly, the simplification and altering of the framework can make it subject to inaccuracies as each mutation of the original framework follows its own tangent.

Bias is another limitation of this research which manifested in the methodology. The primary data is subjective and in all instances points in favour of truck platooning as opposed to traditional road freight trucking. Due to the interviewees working on this topic as their primary research also leaves their data highly bias towards their goals and successes - with little mention of potential setbacks or issues relating to the technology. Subsequently, the secondary data collection can therefore be affected by confirmation bias, which could cause the identification of enablers and barriers to be inaccurate.

5.4 Future research

As this study has focused on the identification of enablers and barriers relating to a defined truck platooning innovation system, it is possible to use this research to get an overview of the difficulties with the emerging knowledge field. Furthermore, future research should perhaps dive deeper into the structures and analyse them from a different perspective. This research primarily used the structures to map the TIS and gain an understanding of their involvement in the TIS functions. However, future research could evaluate the actors mindset, growth, and ambitions in relation to truck platooning, which could cause the identification of barriers to be more accurate.

Future research should also attempt to create a linkage between the defined TIS and other related industries. An example of this would be researching the impact of the autonomous, electric, and cyber-security industries to further understand the roles regarding responsibility and liability of the technology. Gaining understanding of this broader perspective could help single out the most important factors in enabling the emergence and diffusion of truck platooning.

Finally, the policy suggestions is critical research for the next steps relating to truck platooning. Gaining an understanding of the legal and political side of the technology can be of interest when attempting to decide direction for the truck platooning emergence. Policies will need to be put in place and changes will need to be made to support the existing technology. But researching specific policies and motivating their use is a large future requirement which will help provide clarity for the emergence of truck platooning.

6
Conclusion

Truck platooning is still in an early and emerging phase within the European Union. Despite simulations and tests showing the vast benefits of the technology in comparison to its predecessor, barriers within the innovation system which hinder its emergence and commercialisation. Values such as 10% reduced costs on fuel, halving the cost of truck drivers, and reducing the road congestion has not been able to convince relevant actors to push for the technology - suggesting that they perhaps don't know about the benefits. This knowledge exists primarily in academia and in academic-industry settings, which shows that the knowledge needs to diffuse to governing bodies and other influential actors to overcome this barrier.

Knowledge development and entrepreneurial experimentation have shown to be strong within the truck platooning TIS which further showcases the infancy of its emergence. Factors stagnating this are related to the weaknesses of market formation and legitimacy, which have thus far failed to convince structural dimensions to change and support the technology. From this, it became evident that the three largest barriers to truck platooning emergence is the unaligned institutions, the weak networks, and the underdeveloped infrastructure. Governing bodies are the force which are most suited to aligning institutions and developing infrastructure, suggesting that securing their involvement in the TIS is critical to the success of truck platooning. New actors therefore need to enter the TIS. Alternatively, existing actors need to improve their access to information or increase pressure and lobbying on the governments.

Results from the conceptual framework, along with previous research using the framework, highlight the importance of infrastructure supporting the TIS. This was shown to be the most significant barrier for truck platooning. The requirement of developing the infrastructure to incorporate truck platooning is therefore the most important takeaway from this research. Other factors such as aligned institutions and stronger networks will fall more naturally once the infrastructural dimensions improve to the correspondence of truck platooning requirements.

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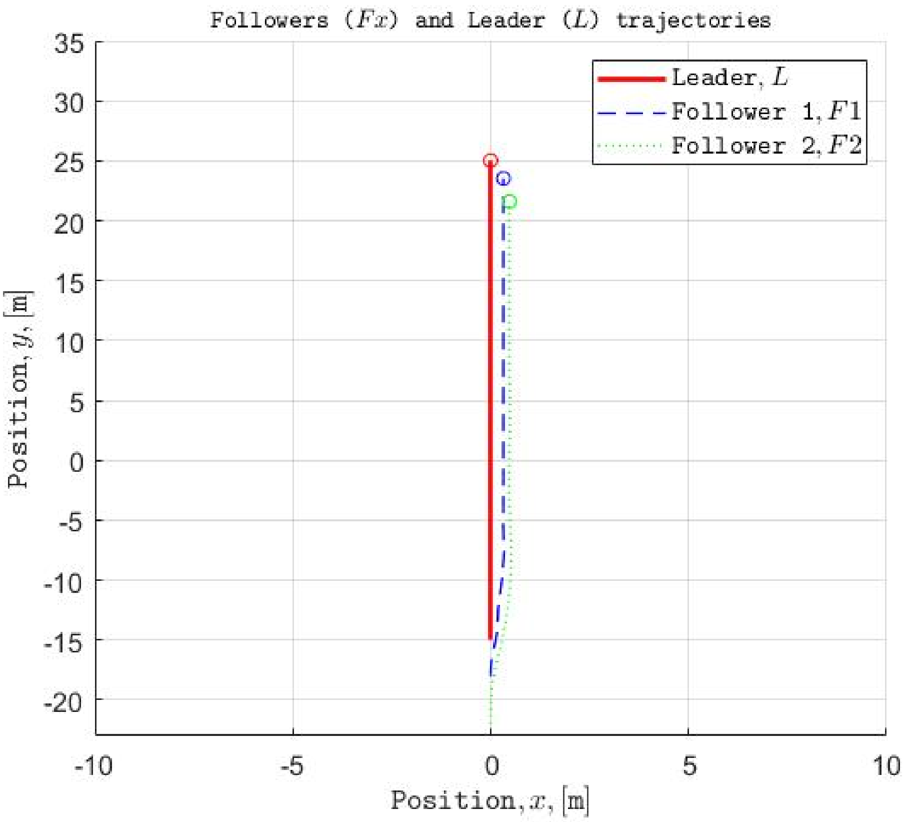
A
Project work

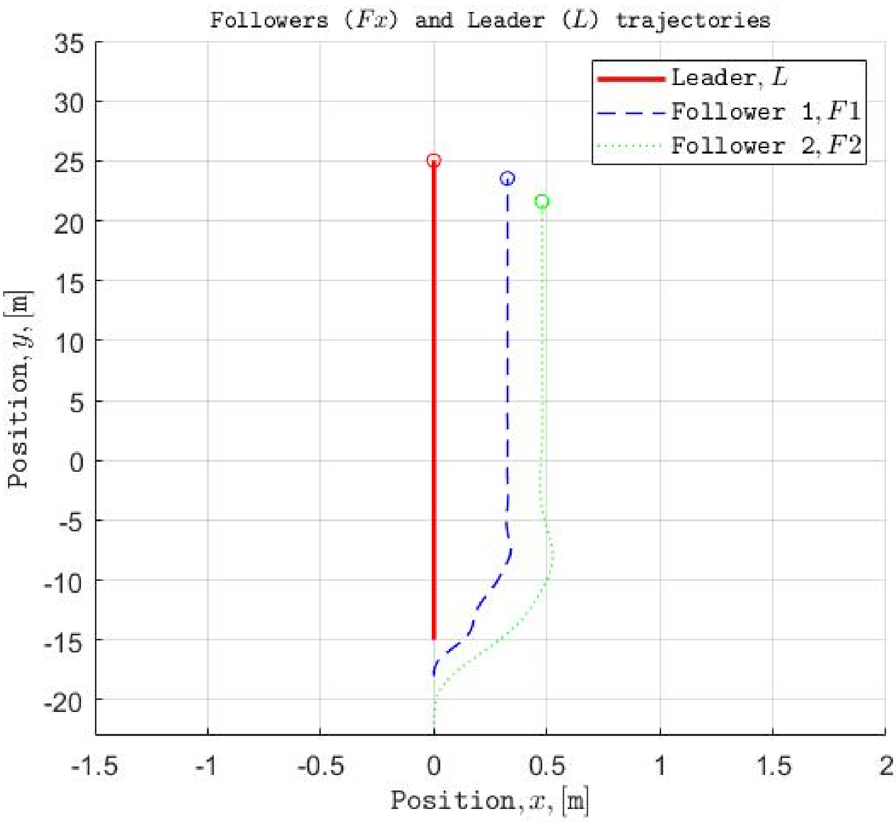
A.1 Truck platoon simulations

Figure A.1: Simulating a three-truck platoon in 15 degree crosswinds



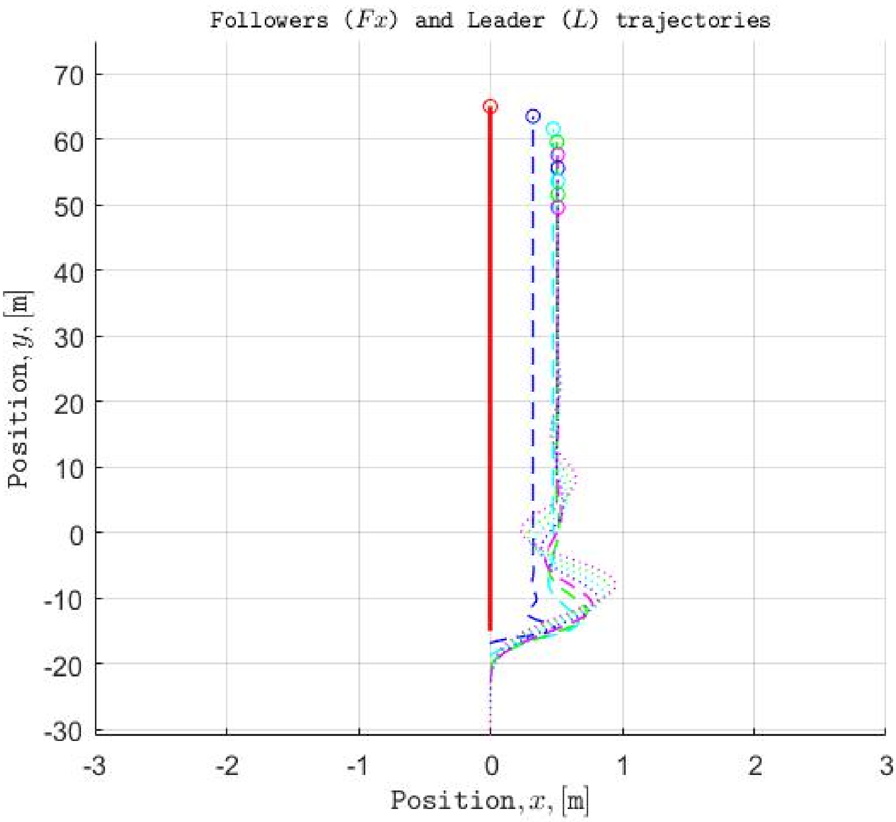
Source: simulations in Matlab via RUG

Figure A.2: Simulating a three-truck platoon in 15 degree crosswinds - road view



Source: simulations in Matlab via RUG

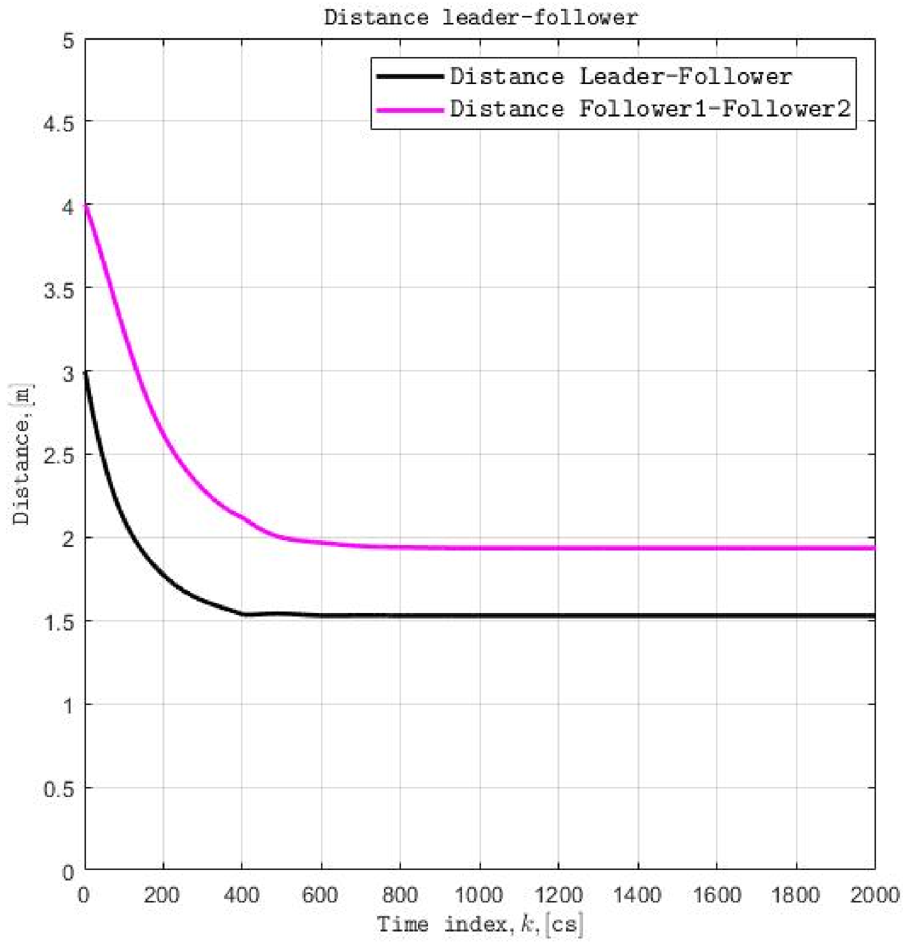
Figure A.3: Simulating a nine-truck platoon in 15 degree crosswinds



Source: simulations in Matlab via RUG

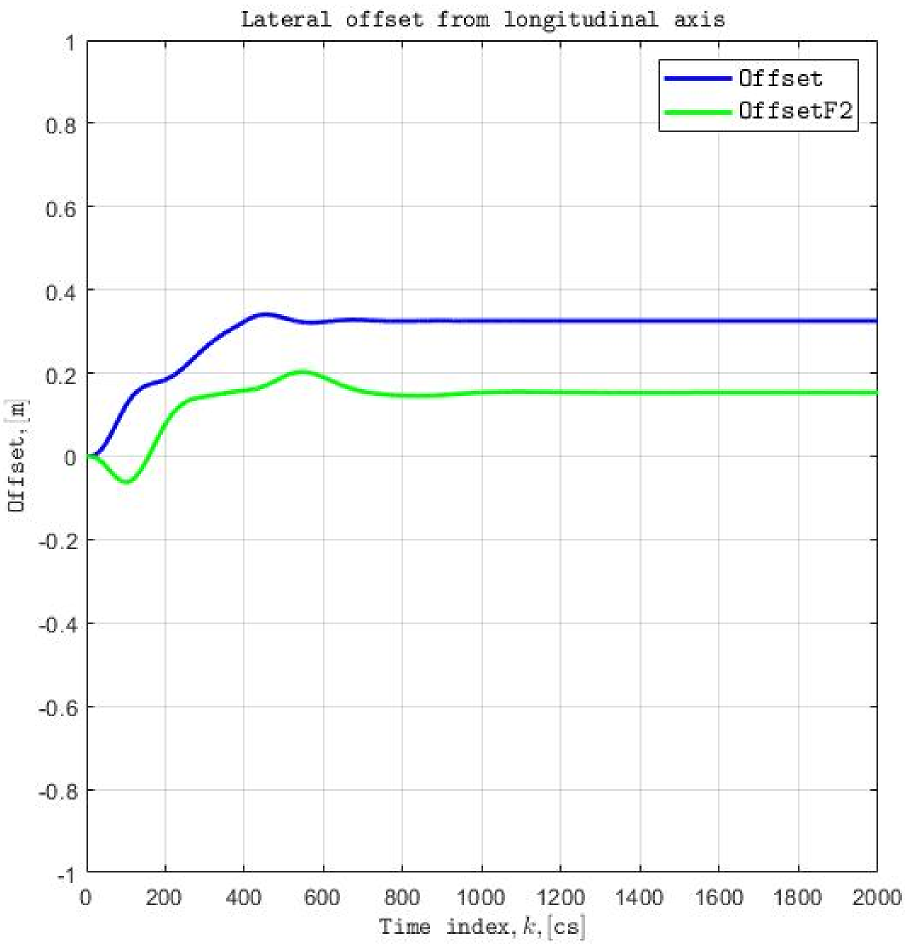
A.2 Simulation results

Figure A.4: Vertical distance between trucks in 3-truck platoon simulation



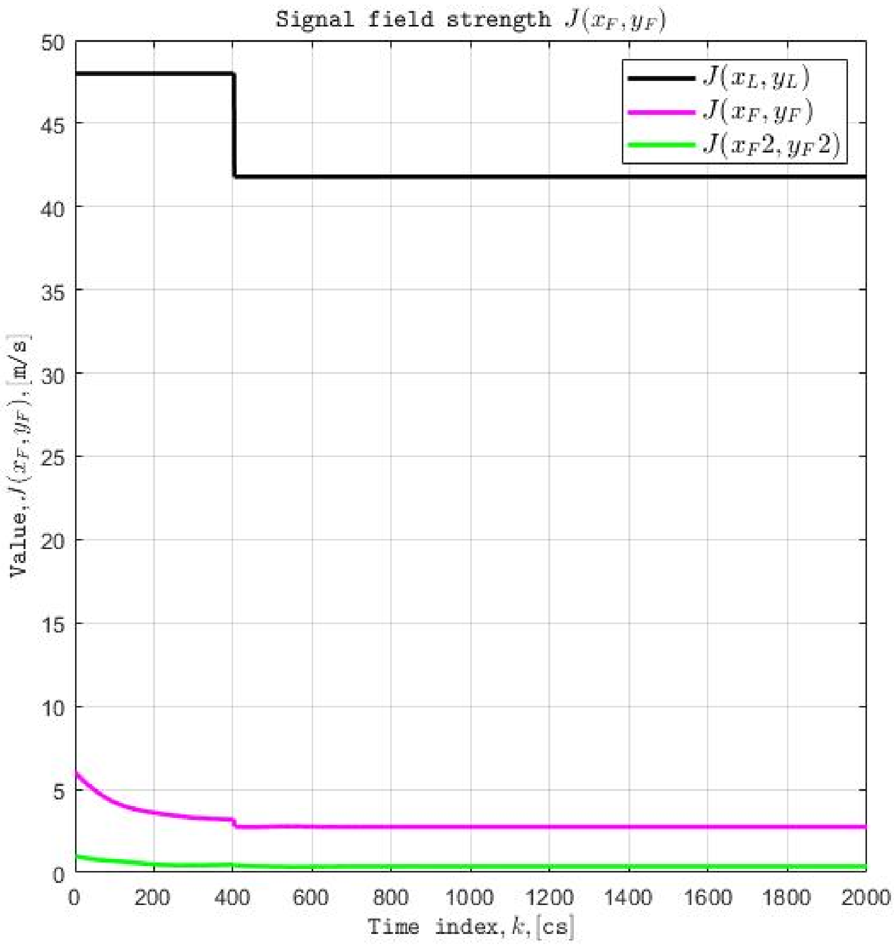
Source: simulations in Matlab via RUG

Figure A.5: Lateral offsets between trucks in 3-truck platoon simulation



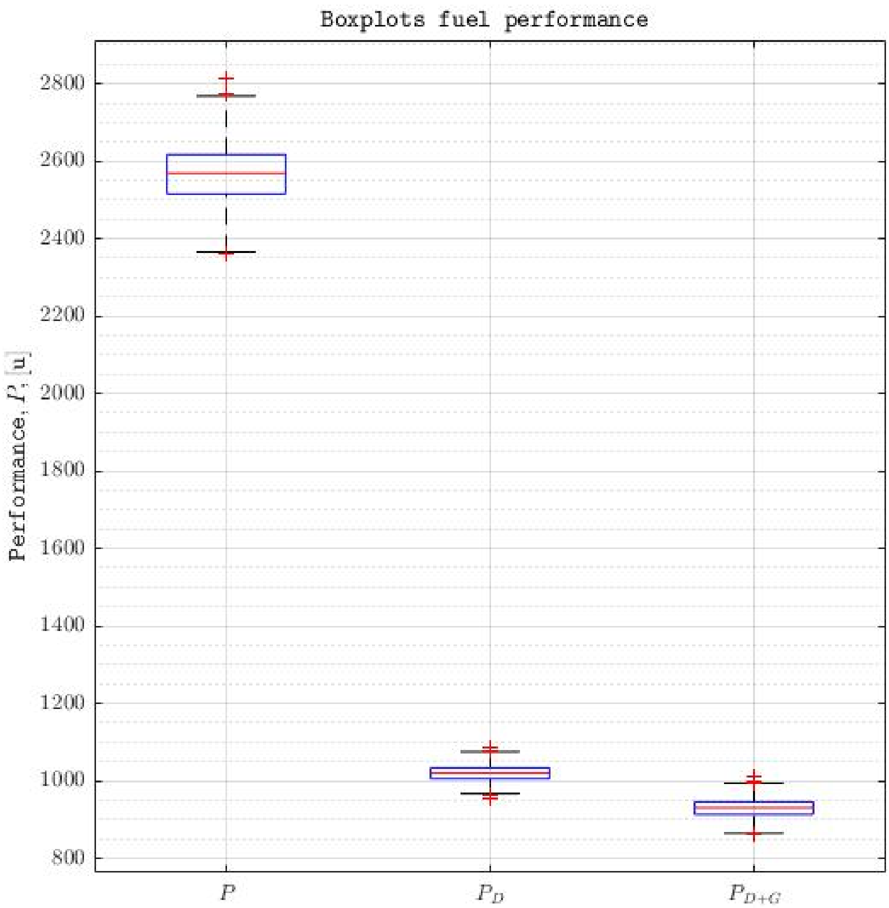
Source: simulations in Matlab via RUG

Figure A.6: Wind resistance by trucks in 3-truck platoon simulation



Source: simulations in Matlab via RUG

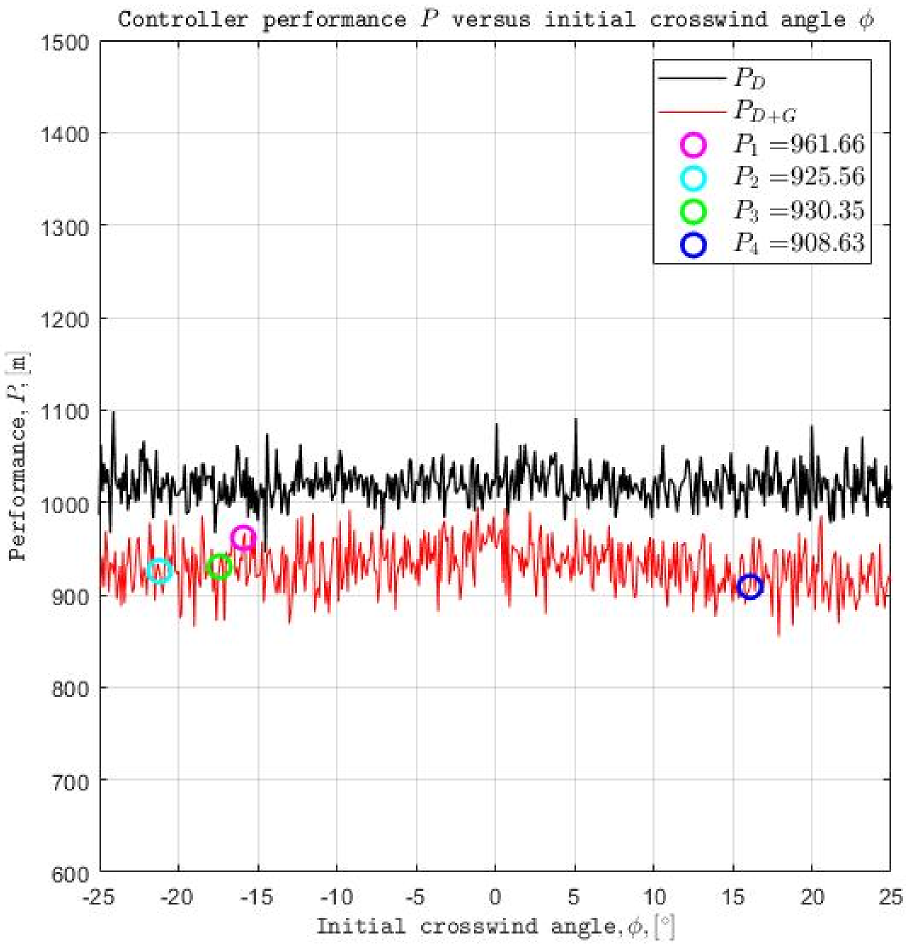
Figure A.7: Fuel performance by platoon types in simulation



Source: simulations in Matlab via RUG

A.3 Optimisation results

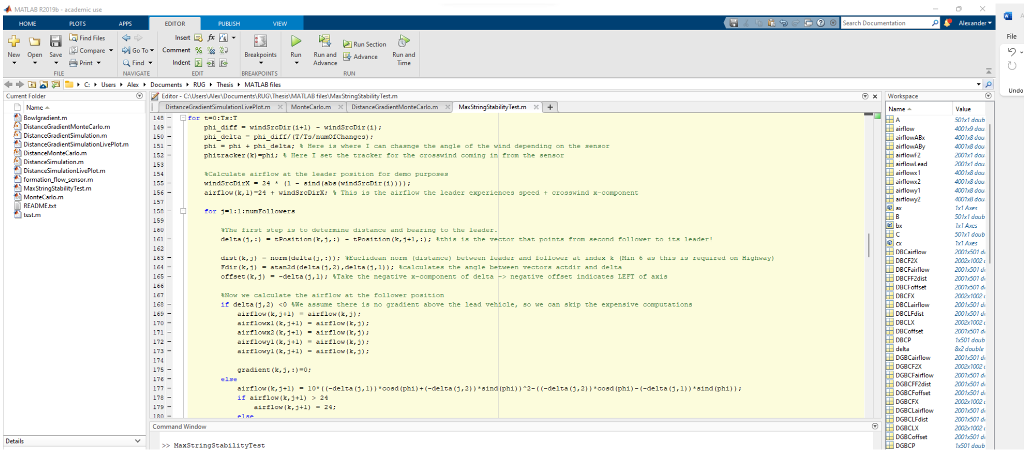
Figure A.8: Best performing platoon formations in crosswind conditions



Source: simulations in Matlab via RUG

A.4 Truck platoon simulation code extract

Figure A.9: Extract of project code and working environment*



Source: code belonging to RUG ENTEG

*For intellectual property purposes it is not possible to share more about the code than this extract.

B

Expert interviews

Figure B.1: Unstructured zoom interview 1: Dr. Bayu

MP4 Dr. Bayu zoom video recording1

Figure B.2: Unstructured zoom interview 2: Dr. Bayu

MP4 Dr. Bayu zoom video recording2

Figure B.3: Unstructured zoom interview: Expert 2

MP4 Expert 2 zoom video recording

Figure B.4: Unstructured zoom interview: Expert 3

MP4 Expert 3 zoom video recording

Figure B.5: Unstructured zoom interview: Expert 4

MP4 Expert 4 zoom video recording

Figure B.6: Unstructured zoom interview: Expert 5

MP4 Expert 5 zoom video recording

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