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Value Case Truck Platooning

an early exploration of the value of large-scale deployment of truck platooning

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Executive Summary

Sense of urgency for change in transport and logistics

In the Netherlands, the well-developed multi-mode accessible Rhein/Meuse/Scheldt delta region continues to flourish as the gateway to Europe. At the same time, severe congestion is threatening the quality of life. Adding to the challenges is a shortage of qualified truck drivers and the fact that no significant extensions to the physical road infrastructure are foreseen in the upcoming years, while traffic is forecasted to grow tremendously. Therefore, the search is on for innovations that utilize the existing infrastructure better and improve traffic flow, increase traffic safety, and decrease emissions from passenger and freight transport. Cooperative automation in transport and logistics is thought to bring about these promises, with one high-potential use case being Truck Platooning.

Truck platooning

Truck platooning – heavy-duty trucks driving in convoy formation with short gaps between them – has the potential for an attractive business case for fleet operators and shippers, as well as bringing many societal benefits such as improved traffic safety, using road infrastructure more efficiently, and reduced CO_2 emissions
The potential business and societal benefits of truck platooning are not clear yet. While technologically truck platooning has come a long way, it is not yet widely implemented so there is a need for estimating the potential value of the technology in order to assess its impact on society and validate large-scale public and/or private investments. Adding to the complexity is the uncertainty to what truck platooning systems will be capable of in the future, depending on strong market up-take and on-going investments in the technology, or alternatively market failure and divestment.

“Truck Platooning: cooperative automation in logistics to reduce traffic congestion, use infrastructure capacity better, increase traffic safety and reduce carbon emissions of heavy-duty transport”

Figure 1: EcoTwin Truck Platoon (photo credit: Johan van Uden)

Value Case of Truck platooning

To overcome this challenge, several parties in the Netherlands have joined forces to develop a Value Case of Truck Platooning. The Value Case Truck Platooning aims to provide (1) an identification and (2) initial/early quantification of the elements of truck platooning that create value for stakeholders involved, both public and private. Starting with a foresight definition of truck platooning system capabilities (initial, mid-term, and full operability capabilities are defined), the Value Case Truck Platooning is based on 5 categories of value: logistics business case, traffic safety, accessibility and traffic flow, environmental emissions, and economy. Specifically, and building upon previous studies, this Value Case report uncovers important nuances about the potential value elements, for instance with regard to fuel savings, the match-rate needed to drive in platoons, traffic safety, and accessibility.

"Aim of the Value Case Truck Platooning: identification and early quantification of potential value of truck platooning deployment for a key freight corridor in the Netherlands"

Scenarios in the Value Case Truck Platooning

In this study, a corridor approach is taken to estimate the potential value of truck platooning for a Rotterdam - Venlo transport corridor, using the A15 / A16 / A58 / A67 motorways. This is a freight corridor that sees dense traffic, serving European Hinterlands over a distance of 200 kilometers. Average traffic intensities are up to 2500 vehicles per hour, with heavy-duty trucks making up about 15%, or about 375 trucks per hour.
Two scenarios have been developed to assess the value of truck platooning on the corridor: a Natural Deployment scenario and a Stimulated Deployment scenario. The Natural Deployment illustrates the potential benefits and uptake of truck platooning based on increased system capabilities for 2020 – 2035. The Stimulated Deployment scenario is based on accelerated deployment of 100 truck platoons per day in 2020 (equal to 450 trucks outfitted with platooning technology, driving on the corridor per day).

Results from the Value Case Truck Platooning

The Value Case of the Natural Deployment scenario (Figure 2) shows the attractiveness of truck platooning, particularly in the long run. We find that truck platooning, at a Natural Deployment path, has a very positive and large total Value Case of almost 44 million EUR per year by 2030 – as part of a total corridor cost of 501 million EUR. The Net Present Value of this innovation – in the period of 2020 up to 2035 – approaches 305 million EUR (given an annual interest rate of 5%). Total society benefits are 46 million EUR, while the logistics savings are 259 million EUR (including the investment in technology costs of approximately 68 million EUR). It has to be noted that the Value Case only starts to become significantly positive near 2030. This is mainly due to the assumption that highly automated truck platoons (similar to SAE Level 4 automated driving platoons) may then become a reality, which really drives the business case. Excluding the labor benefits, there is still a positive Value Case in 2030 where fuel savings (almost 7.5 million EUR annually) and increased traffic safety (approx. 5 million EUR annually) provide the strongest impulses.

Annually, approximately 592.000 truck platoons will be formed, driving over 89 million kilometers in platoon formation on the selected Dutch corridor.

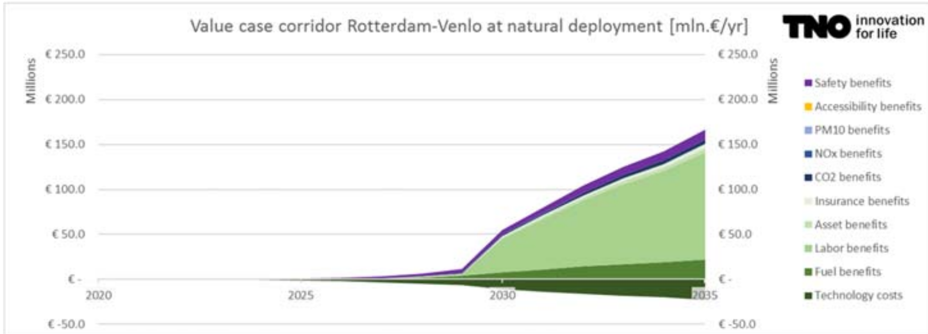


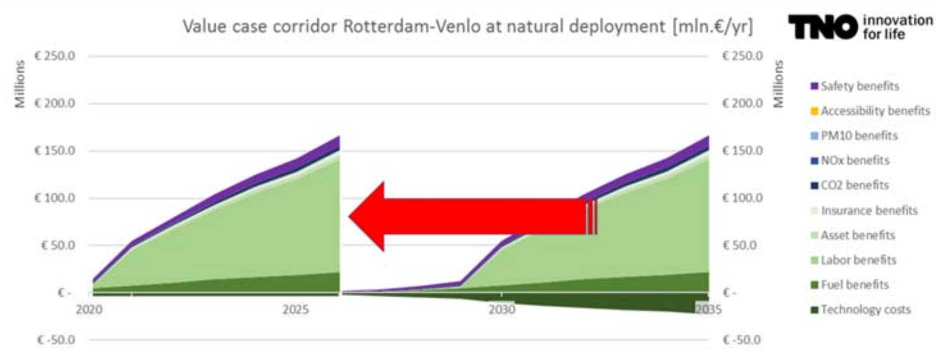
Figure 2: Value Case Truck Platooning - Natural Deployment 2020-2035*

(technology costs based on highly scaled up situation – no full business case evaluation performed)*

Pulling deployment timelines forward through Stimulated Deployment

In case of Natural Deployment, a positive Value Case is hardly existent in the short term (in 2020 or 2023). In our model, this implies that deployment of truck platooning has not taken off such that enough platoons are formed on the corridor and that benefits could eventually accrue.
In an effort to pull deployment timelines forward, a Stimulated Deployment Value Case is calculated, based on 450 platooning trucks deployed per day in 2020. In the Stimulated Deployment scenario, about 9.3 million platoon kilometers are driven by over 60.000 distinct platoons on the corridor in 2020. This annual Value Case is slightly negative (-/- 257k EUR); the estimated technology costs cannot be offset by business value and societal value. The most important drivers of the Value Case here are fuel economy improvements (194k EUR) and traffic safety improvements (208k EUR). Sensitivity analysis shows that only a very small increase in the number of platoons on the corridor steadily improves the Value Case.
To summarize, we find that truck platooning can have a really positive Value Case, with also societal benefits strengthening the Value Case. The main business case lies with parties in the logistics industry such as logistics service providers and shippers. These benefits mainly stem from labor productivity improvements and fuel savings. Society could benefit from reductions in CO_2 emissions and improvements in traffic safety due to the extensive use of advanced drivers assistance systems. Pulling deployment timelines forward appears to be feasible and financially rational. Further analysis should however develop a complete business case that is able to quantify the costs of pulling the timeline forward in time.

“Truck platooning at a Natural Deployment path is particularly attractive in the long-run with annual savings of 44 million EUR on the freight corridor in 2030. Active stimulation of deployment may pull traffic safety, emissions reductions and logistical benefits forward in time.”



Costs of stimulation to be determined:
- Platooning technology cost per truck at scale,
- Research and development for safety and efficiency assessments,
- PPP-based deployment program execution, financing arrangements,
- Physical infrastructure upkeep and adjustments,
- Enabling digital infrastructure, road-side technology.

Figure 3: Actively stimulate deployment of platooning by moving timelines forward

Decomposition: distinct drivers of the Value Case Truck Platooning

Next to the overall Value Case analysis, we also investigated which elements of the Value Case really drive total value creation.

Per value category (sorted by size), we find the following:
- Logistics business case: driver productivity improvements and fuel savings (between 4 – 16%) are key value drivers. Fuel savings already appear at lower platooning system capability levels and relatively large inter-vehicle gap distances (up to 20 meters / 1 second). Driver productivity improvement and reductions of labor costs (up to 90% for following vehicles) may be available in the long run, if continued development in system capabilities takes place. Of key interest here is also the match-rate: the number of kilometers driven as platoon as ratio of annual kilometers driven. The match-rate relies primarily on active coordination such that brand-neutral and fleet-interoperable platooning becomes feasible. We find match-rates of approx. 25% to be feasible, with future situations perhaps going even higher.
- Traffic safety: extensive use of Advanced Driver Assistance Systems (ADAS) can significantly improve traffic safety. Truck platooning systems increase safety for rear-endings, especially compared to non-instrumented 'tailgating', which happens frequently on Dutch highways. The main improvements found are based on compounding effects of Advanced Emergency Braking (AEB), Lane Keeping Assist Systems (LKAS), and the platooning-based vehicle-to-vehicle (V2V) wireless communication.
- Emissions: the fuel savings mentioned have a one-on-one relationship to CO_2 emissions, which therefore is the key value driver here. Other harmful emissions such as NO_x and particulate matter (PM) do not represent much financial value yet.
- Accessibility and traffic flow: truck platooning is expected to improve traffic flow due to smoothening this flow and vehicles taking up less space on the road. However, within the value case we have not been able to find conclusive evidence to state that truck platooning can have a positive effect on accessibility and traffic flow.

This is due to the fact that effects are expected for system adoption levels over 40%, whereas heavy-duty trucks account for maximum
20-25% of the total traffic, and even less on congested stretches of the corridor studied. Still, with full deployment already half of the estimated 40% required would already be achieved.
- Economy: truck platooning will influence various economic indicators. However more research is needed to be able to quantify such effects, for instance the costs of maintaining physical infrastructures (pavements, bridges, tunnels) under influence of truck platooning.

Recommendations based on the Value Case for truck platooning deployment

The Value Case Truck Platooning has led to proposing four courses of action.

1. *Actively stimulate/accelerate deployment of truck platooning*

Truck platooning deployment on its own and independent of other innovations is potentially very valuable in the long run, as evidenced by the Natural Deployment Value Case and Net Present Value. Also, truck platooning is considered an attractive technology with limited foreseen drawbacks. Though, the slow natural deployment path is an issue that needs to be addressed. Therefore, we propose to actively stimulate truck platooning so that potential benefits can accrue earlier in time. Even for a relatively small number of trucks (such as 450 trucks in this study) at limited truck platooning system capabilities, there would be potential for a positive Value Case. This warrants additional public funding in order to ‘cross the chasm’; meaning to take the edge of the difficult first steps of deployment, such that larger societal benefit can be captured in the future. Further analysis should however develop a complete business case that is able to quantify the costs of pulling the timeline forward in time.

2. *Labor savings and driver productivity improvements: long-term innovation perspective on Connected and Automated Driving*

The various Value Cases of Truck Platooning clearly emphasize when the largest benefits of truck platooning can be captured: if labor savings are part of the Value Case. Research should indicate whether drivers in following vehicles experience a relief in workload, such that valuation of driving and resting times can be considered. Policy-oriented action could be taken to be able to have some labor savings benefits accrue earlier in time, especially with regard to driving and resting time legislations. It creates additional financial incentives for the logistics industry to consider large-scale investments in platooning technology across fleets, reaching the needed high penetration rates to capture the full benefits of the technology, and urging truck manufacturers to keep investing in higher levels of platooning system capabilities (for instance SAE Level 3-4 systems). The professional drivers should be part of this discussion in order to keep their jobs attractive and value-adding in the long run, especially in combination with the current transition towards increased robotization and automation in transport and logistics.

3. *Digitization of data and extensive data sharing in the supply chain: Matchings platform for increased platoon match-rate, and also co-loading, backhauling and trailer swapping*

A slight increase in match-rate effectively improves the number of kilometers driven in platoon formation across the corridor and enables benefits from truck platooning technology to be captured.

The match-rate heavily relies on high numbers of vehicles outfitted with interoperable (multi-brand) platooning technology and the ability and willingness to exchange real-time operational data across fleets and act upon this information. Also, data access rights and encryption of proprietary data are important topics. In essence, truck platoon matching requires significant digitization of data and sharing of data across actors in the supply chain.
The value of this digital transformation extends benefits of truck platooning alone. Whereas matchmaking to form platoons is a useful application, this data exchange and data fusion has other highly attractive applications. For example jointly bundling cargo, arranging return trips or swapping even complete trailer loads might be possible applications.
We could see truck platooning as the breakthrough technology where logistics, vehicle and traffic data come together for the first time. The real impact develops if all services are used in an integrated way changing whole supply chains. Trucks, operating in an efficient multimodal system, filled to the brim by bundling loads, then drive as a semi-automated truck platoon to their destination, picking up an additional trailer on the way and minimizing empty running. Eventually, the benefits of these combined measures could make it so attractive that transport flows move to other times of the day, for instance to night times. Then, measurable impacts on accessibility and traffic flow could be expected. In fairness, strong (undesirable) stimulation of road transport could also be the case, which future research should investigate.

4. *Valuation of CO_2 emissions reduction from platooning*
The Value Case shows that fuel savings and corresponding CO_2 emissions can be reduced quite significantly over time. However, while the fuel savings hold quite some value for the logistics parties, it does not yield a lot of societal value yet. This is mainly due to the fairly low financial value of a ton of CO_2 at current price levels. The large-scale deployment of truck platooning, and thus releasing less CO_2 emissions into the atmosphere, can benefit from an increased valuation of CO_2. The key instrument towards that end on a European scale is through the VECTO tool (VECTO, 2017), as well as other incentivization schemes on national level.

“Active stimulation can pull deployment timelines forward for truck platooning. Driving- and resting times and driverless vehicle operation legislation amendments, improved digitization and platoon matchmaking, and valuation of CO_2 emissions may positively accelerate deployment”

Conclusions

The Value Case Truck Platooning is one of the first studies taking a multidisciplinary and integrated approach on identifying and estimating the societal and business value of large-scale truck platooning deployment, modelled for a freight corridor in the Netherlands. We find that truck platooning deployment on its own and independent of other innovations is potentially valuable in the long run. Stimulating deployment in the short term can bring about benefits for society ranging from decreased emissions and improved traffic safety, whereas businesses can enjoy positive return on investments.

Contents

1 Introduction

1.1 Background: need for a Value Case of truck platooning

Globalization, geopolitical shifts, digitization and automation, decarbonization, growing and ageing populations, and urbanization – just a few of the big developments that are happening in the world today. Especially automation and robotization will have far-reaching impacts on the global economy. In industrial production settings, robotization has already gained steady ground for years with advances in robot-based manufacturing and 3D printing. Now, the field of transport and logistics is seeing the first impacts of robotization as well, with the huge surge in interest in connected and automated driving, artificial intelligence and the Internet of Things. Simply put: in 2035 each and every individual physical process in the supply chain is going to be automated or robotized: deep-sea shipping, terminal operations, heavy-duty road transport operations, warehousing et cetera. Physical transport, storage and transshipment activities will be automated and robotized, just as the underlying information processes.

In the Netherlands, alongside a highly-skilled and creative workforce, a tradition of global trade, and excellent physical and digital infrastructures, we are fortunate to have the well-developed multi-mode accessible Rhein/Meuse/Scheldt delta region that continues to flourish as the gateway to Europe. At the same time, we have to deal with severe congestion on our roads, threatening the quality of life.
The Netherlands will come to a standstill with clogged up roads and economic damage if we do not act upon these developments now. Adding to the challenges is the fact that no significant extensions to the physical road infrastructure are foreseen in the upcoming years, while traffic is forecasted to grow tremendously. Therefore, the search is on for innovations that utilize the existing infrastructure better, increase traffic safety, and decrease emissions from passenger and freight transport. Essentially, cooperative automation in transport and logistics can bring about these promises and is considered the way to go to improve the liveability in our cities and improve the quality of life of our country while at the same time capturing the benefits of automation and robotization.

There are many potential technologies associated with automation and robotization in transport and logistics, such as fully autonomous trucks and AGVs in container ports, automated maneuvering and docking at distribution centers, and even cabinless long-haul trucks. A high potential application of cooperative automation in transport and logistics is truck platooning (Figure 4). Truck platooning – heavy-duty trucks driving in convoy formation with short gaps between them – has the potential for an attractive business case for fleet operators and shippers, as well as bringing along many societal benefits such as improved traffic safety, using road infrastructure more efficiently, and reduced CO_2 emissions (Janssen, 2015).

Figure 4: Truck platooning (photo credit: MAN Truck and Bus)

Truck platooning encompasses more than trucks driving very close together, bringing about a business case for fleet operators and shippers. It is also the all-important first step where vehicle automation goes hand in hand with vehicles being constantly connected to the cloud – highly digitized cyber-physical systems where traditionally separated systems of vehicle technology, logistics, traffic, road and digital infrastructure systems come together in an integrated way. Truck platooning, as a cooperative automation technology, also paves the way for further R&D investments in vehicle technology to reach higher automation levels, unlocking stronger business cases for businesses and societies from automation and robotization in transport and logistics.

In order to understand the potential value that truck platooning may bring, there is a need for assessing the potential business and societal benefits applied to the situation in the Netherlands. This assessment will yield insight in how attractive truck platooning will be in terms of societal impacts on emissions, traffic safety and traffic flow, which is the topic of this report.

1.2 Why and what: the Value Case

Truck platooning is believed to create value for logistics service providers (truck operators), shippers of cargo, national road operators and infrastructure managers, common road users, the liveability of cities, the environment, several sectors of industry, and the economy at large.
The potential business and societal benefits of truck platooning are not clear yet. While technologically truck platooning has come a long way, it is not yet widely implemented so there is a need for estimating the potential value of the technology in order to assess its impact on society and validate large-scale public and/or private investments.

Where a business case merely quantifies the (often direct) costs and benefits for a private stakeholder, a Value Case aims to quantify the value a phenomenon creates also for public. Some of this value is financial, some of it is environmental or societal. As such, a Value Case is an appropriate instrument when businesses, government and society need to work together towards a common goal.

This specific Value Case aims to quantify the value created by the introduction of truck platooning in the Netherlands. Some of this value is a direct benefit resulting from fuel savings, other benefits are indirect and caused by a reduction in emissions or an improvement in traffic safety. The direct benefits show the business case of platooning for industry considering to adopt platooning technology, whereas the indirect benefits aim to provide a rationale for governments to invest in and support the deployment of platooning technology. Governments play an important role by being able to legislate and change regulations, adapt infrastructure where needed, and support the transport and logistics industry by incentivizing initiatives such as truck platooning that make transport and logistics more efficient, safer, faster, greener and more reliable.

“Value Case Truck Platooning: identification and early quantification of potential value of truck platooning deployment based on a dense freight corridor in the Netherlands”

1.3 Corridor approach: freight corridor in the Netherlands

This report aims to describe and document the truck platooning Value Case on multiple abstraction levels. At a more detailed level we project and translate these elements towards the current and future situation in the Netherlands.
To that end, we have taken a corridor approach, that is, estimating the Value Case of truck platooning for a distinct motorway, being the heavily traversed Port of Rotterdam-Venlo corridor using the A15, A16, A58 and A67 motorways. The chosen corridor (shown in
Figure 5) is of high importance for the hinterland destinations from the Port of Rotterdam and vice versa. The corridor has a length of 205 kilometers. The main reason for choosing this specific corridor is the fact that its main alternative route (the A15, A50 and A73) is elaborated within an earlier research of TNO concerning the potential of ITS measures towards the eastern freight corridor in 2016 (Snelder, 2016), so findings may be corroborated.
In later stages of deployment, based on the input from this corridor analysis, the results can be applied to other corridors or scaled up for the whole of the Netherlands. This also implies that generalization of results in this study are only applicable to the corridor under investigation.

Figure 5: Rotterdam - Venlo freight corridor that is applied within the Value Case model.

More details on the current traffic and safety situation for the Rotterdam-Venlo corridor are respectively included in section 3.4, Appendix D and Appendix E.

1.4 Partners involved in the development of this Value Case

This Value Case was developed as a collaborative effort by various parties in the Netherlands (Figure 6). The actual report is written by TNO and funded by SmartPort Rotterdam, Rijkswaterstaat NOVA, and the SmartwayZ.NL program of the Province of North Brabant. Co-creators are the Netherlands Ministry of Infrastructure and Water Management, the Port of Rotterdam, *Innovatiecentrale*, TLN and Evofenedex, as well as the Roadmap Next Economy and TKI Dinalog.

Figure 6: Partners involved for delivery of this Value Case report

The following people have contributed to this report:

Organization	Name
Evofenedex	Jeroen de Veth
Ministry of Infrastructure and Water Management	Bart van der Westen
Ministry of Infrastructure and Water Management	Florien van der Windt
Ministry of Infrastructure and Water Management	Noor Pruijn
Port of Rotterdam Authority	Bob Dodemont
Port of Rotterdam Authority	Cees Deelen
Port of Rotterdam Authority	Michiel Nijdam
Rijkswaterstaat	Joris Cornelissen
Rijkswaterstaat / Innovatiecentrale	Dirk-Jan de Bruijn
SmartPort Rotterdam	Michiel Jak
SmartwayZ.NL	Theo Stevens
TLN	Leander Hepp
TLN	Wout van den Heuvel
TNO	Authors mentioned on frontpage

1.5 Reading guide

This report will provide many ins and outs regarding truck platooning, in order to get a thorough understanding of potential value creation from truck platooning. At first we will take the reader through the technical scoping of truck platooning for this Value Case. After that we will elaborate on the developmental paths for truck platooning.

Chapter 3 defines the scope of the research. It briefly discusses the identified value elements and organizes them in five categories: logistics business case, environment and liveability, accessibility and traffic flow, traffic safety and economy. The subsequent chapters 4 to 8 cover each of these categories in detail. The expected benefits (and costs) of each included value element are explained in these chapters.

Chapter 9 on Methodology explains the structure of the model, scenario calculation, and interaction effects. This Value Case targets The Netherlands specifically. Although most of the notions from the literature review could be applied worldwide the actual business case calculation includes assumptions such as the Dutch GDP growth, fuel price development, legislation and governmental policies around modal shift and electrification. These are included in chapter 9.

Chapter 10 on Results discusses the output of the model. It includes the results of the Value Case, the impact on stakeholders and upscaling to the Netherlands.
The discussion in chapter 11 includes all topics that need more research or extension beyond the scope of this study. Truck platooning has not yet reached operational capability, and many of these unanswered questions will be addressed when the time of implementation comes.

Finally, the Appendices A - L include additional information, sources, and relevant research that contextualizes this study.

2 Scoping Truck Platooning for the Value Case

This chapter scopes truck platooning for the Value Case. Truck platooning, as a term, has been very loosely interpreted and defined so far, so in order to distinguish between various levels of technical capabilities, to the best of our knowledge we scope initial, midterm and full operating capabilities. These various technical capabilities will arrive at various timeframes. Along with these various timeframes, also the potential benefits derived of truck platooning will be different. In that sense, the various improvements in technical capabilities and potential benefits incurred per level of capability outline an innovation rhythm.

2.1 What is truck platooning

A truck platoon (see
Figure 7) may be defined as trucks that travel together in convoy formation at a fixed gap distance (Janssen, 2015) typically less than 1 second apart up to 0.3 seconds. The vehicles closely follow each other using wireless vehicle-to-vehicle (V2V) communication and advanced driver assistance systems (Verhaart, 2016). The truck at the head of the platoon acts as the leader, with the following vehicles behind reacting and adapting to changes in its movement. For example, when the platoon leader brakes, all other trucks in the platoon will brake nearly simultaneously. At higher adoption levels, there is also a potential need for long distance cellular connectivity (LTE+).

Truck platooning is a technology geared towards motorways and highway driving. In the upcoming years the drivers are responsible for system controls at all times. However, part of the promise of truck platooning technology is that vehicles may be able to drive themselves in the next decade or so. Truck platooning holds great potential to make road transport safer, more efficient and cleaner by improving fuel consumption, reducing CO_2 emissions, braking automatically with virtually zero reaction time compared to typical human reaction times, and by using roads more effectively, helping deliver goods faster and reducing traffic jams.

Figure 7: Truck platooning: trucks driving in convoy formation at short inter-vehicle distances using radar, cameras, GPS, and wireless connection

2.2 Truck platooning development stages

In order to describe the technical capabilities of truck platooning for use in the Value Case, one would expect to apply SAE Levels of Automation (SAE International, 2014). The SAE Levels of Automation (see Appendix B), however, cannot easily be applied to truck platooning because platooning is a connected and automated driving technology with multiple vehicles *being* a platoon.

A widely accepted definition of truck platooning is still lacking. Some people refer to truck platooning as CACC (Cooperative Adaptive Cruise Control), whereas others imply that truck platooning at the very least involves lateral control (steering) of the vehicle (Nowakowski, 2015). Generally speaking, vehicle-to-vehicle (V2V) communication and a constant distance gap strategy are considered to be minimum requirements. One could argue that driving closely together is already a form of platooning, even without longitudinal control. In such a scenario V2V communication serves to identify the platoon and indicates which drivers are part of a platoon. This is essentially a form of connected – not yet cooperative – ACC.

To provide some clarity to the former discussion, we have identified four stages of development for truck platooning. The stages differ in roles assigned to the vehicles following the platoon leader, with the current situation designated as Stage 0:

Stage	Capability	Intuitive explanation
Stage 0	Adaptive cruise control	Current driver assistance systems
Stage 1	Adaptive cruise control + V2V communication for connected driving	Hands on, feet off, eyes on the road
Stage 2	Adaptive cruise control + V2V communication for cooperative longitudinal control	Hands on, feet off, eyes on the road
Stage 3	Adaptive cruise control + V2V communication for cooperative longitudinal + lateral control	Hands off, feet off, eyes (partially) off the road
Stage 4	Fully automated platoons (“robot-followers”)	Hands off, feet off, eyes off in following vehicles

These stages do not correspond perfectly to the SAE levels. Ignoring important nuances, stage 1 and 2 match to SAE level 1, and stage 3 and 4 range from SAE levels 2 to 4 depending on the capability of the system.

“Defining truck platooning: vehicle-to-vehicle (V2V) communication and a constant distance gap strategy are often considered to be minimum requirements.”

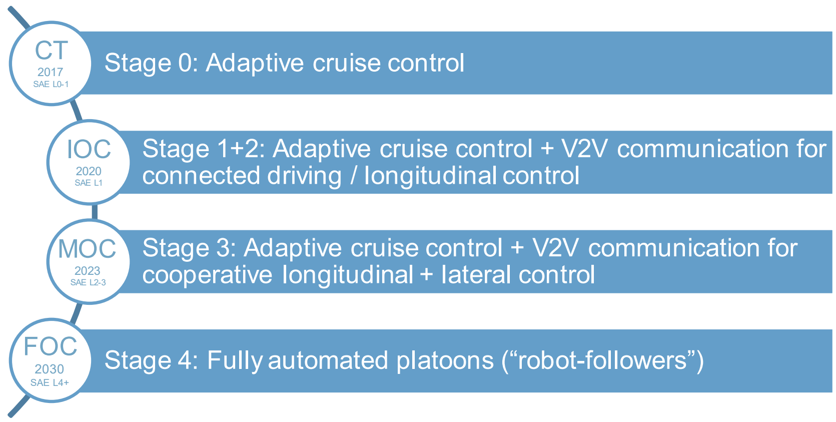


Figure 8: Truck platooning development stages

2.3 Initial to full operating capability of truck platooning

With the former discussion on platooning development stages in mind, we have opted to define three operational capability levels: initial, mid-term and full operating capability (
Table 1) .

At Initial Operating Capability (IOC) the leading vehicle of this platoon will be manually driven while the following vehicles are just using a CACC for longitudinal control. The drivers will need to steer and closely monitor the system. At the Full Operating Capability (FOC), the following vehicles could be driven driverless on motorway sections. The Mid-term Operation Capability (MOC) is somewhere in between: drivers in following vehicles may be able to go 'out of the loop' (hands off, feet off, eyes off) but only for limited/specified amounts of time.

The table summarizes some important assumptions that are partially based on the ACEA roadmap (ACEA, 2017) for truck platooning and the literature found. We are listing the aspects that differentiate current trucks from trucks at initial-, mid-term, and full operation capability of truck platooning. For brevity, we assume that the following technical IOC, MOC, and FOC descriptions will also be legally compliant by the time of introduction.

Table 1: Truck platooning: initial, mid-term and full operating capabilities

Aspect	Current trucks	Initial Operating Capability (IOC)	Mid-term Operating Capability (MOC)	Full Operating Capability (FOC)
SAE level	SAE level 0-1	SAE level 1-2	SAE Level 2-3	SAE level 4+
Stage	Stage 0	Stage 1 + 2	Stage 3	Stage 4
Estimated year of commercial introduction	Established	2020	2023 (ACEA, 2017)	2030 (ERTRAC, 2015)
Advanced Emergency Braking (AEB)	✔	✔	✔	✔
Forward Collision Warning (FCW)	✔	✔	✔	✔
Lane Keeping Assist (LKA)	✔	✔	✔	✔
Adaptive Cruise Control (ACC)	✔	✔	✔	✔
Cooperative Adaptive Cruise Control (CACC)		(✔)	✔	✔
V2V communication		✔	✔	✔
Human machine interface		✔	✔	✔
Lane Change Assist (LCA)			✔	✔
Full lateral control			✔	✔
Brand interoperability	Mono-brand	Mono-brand	Multi-brand	Multi-brand
Inter-vehicle distance	>1 seconds	1.0s / 22 meters	0.6s / 13 meters	0.3s / 6.7 meters

3 The Value Elements and the Value Case model

Truck platooning has potential benefits from various point of views and for various stakeholders. This chapter details which value elements are jointly making up the Value Case of truck platooning and how they are defined and quantified in the Value Case model.

3.1 Value elements identified

The potential of truck platooning does not only lie in in monetary benefits for Logistics Service Providers (LSPs), but extends itself to society. In this report and its underlying model we will investigate direct and indirect effects. Direct effects of truck platooning include fuel savings, reduction in CO_2, and labor cost savings. Indirect effects include benefits from data sharing, an increased competitive advantage, and a better business climate. We aim to quantify all direct effects and some of the indirect effects.

Figure 9 shows the value elements of truck platooning that have been identified from our literature review, expert judgement from the authors, colleagues within TNO and input from others.

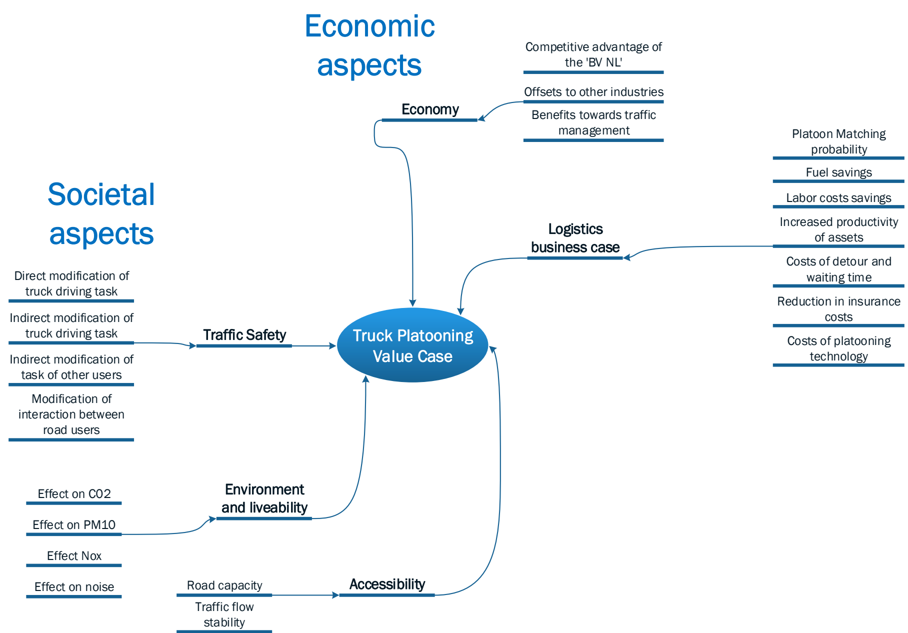


Figure 9: Value elements of truck platooning identified

These value elements can be categorized in two major groups. Firstly the *economic aspects*, the value elements within this group mainly describe the added value of truck platooning in terms of the competitiveness of corporate ‘BV Nederland’, other industries and the logistical sector. The second group, *societal aspects*, mainly focusses on the societal benefits, such as reduction in emission, improvements in accessibility and road utilization and traffic safety. These two groups can be subdivided into five categories of value elements (see 3.2).

3.2 Brief overview on the five categories of value elements

3.2.1 Logistics business case

Truck platooning has been shown to decrease fuel consumption of trucks. In later stages of development, also drivers can become more productive reducing labor costs. From earlier work (Janssen, 2015), we expect the adoption (i.e. development and fitting of equipment, and replacing vehicles) and the mileage (how many kilometers are platooned) are important aspects within the Value Case for the logistics business case. The logistics business case is discussed in detail in chapter 4.

3.2.2 Environment and liveability

Based on earlier works (Janssen, 2015; Ligterink, 2016) we know that most negative impacts of mobility towards the liveability are a derivative of the combustion process that powers the vehicles. Chapter 5 will further research this subject.

3.2.3 Accessibility and traffic flow

Truck platooning reduces the space that vehicles take up on the road. This could lead to improved accessibility due to reduced spatial footprint of platoons and the effect that the cooperative technology could induce in terms of the stability and robustness of the traffic stream. Based on earlier works (i.e. see (Muller, 2012)) we expect this subject to be a little more complex due to the many influential factors such as the road design, the composition of the traffic flow and moreover the mixing of platooning and non-platooning vehicles. Chapter 6 goes into detail about this subject.

3.2.4 Traffic safety

The relation between truck platooning technology and the traffic safety is quite uncultivated. On the one hand the task of the driver will change significantly and could reduce the change of human errors. On the other hand the behavior of other users may also be influenced, for example at intersections and on- and offramps. Moreover the current situation in terms of traffic (un)safety is a very important aspect since that ultimately describes the ‘room’ for improvement.

3.2.5 Economy

The introduction of truck platooning may have a significant effect on the economy as a whole. Possible effects could be an offset to other industries, increased competitive advantage, and benefits for infrastructure managers. Many of these effects are the result of digitization and are considered out of scope for this study. Therefore, these effects were not quantified and taken into account in our modelling. However, we will describe several opportunities in chapter 8.

3.3 Value Case model development

This section details how the underlying model for the Value Case works, based on the inputs of the value elements. It also shows two important assumptions regarding the scenarios in which we developed our model for the Value Case: the GDP growth of the Netherlands and the fuel price development.

3.3.1 Value Case model explanation and structure

The Value Case model that has been created for this study is an extensive Microsoft Excel spreadsheet. It allows to model the impact of truck platooning on a range of indicators, such as decreases in emissions, changes in traffic safety and accessibility and also logistics business case parameters.
Principally, the Value Case model calculates the quantitative business and societal value to be expected from truck platooning in a certain year.

Figure 10 summarizes the structure of our model. The model we used is based on several *inputs*, these are fixed values based on our literature review. These inputs are used in the *throughput* to calculate the effects of our value elements per platooned kilometer. What follows are two upscaling states: (1) to an output per *corridor* and an output for *(2) the Netherlands,* for which our main interest in this study is the output per corridor.

Table 2 lists some key model inputs that are used in the calculations.

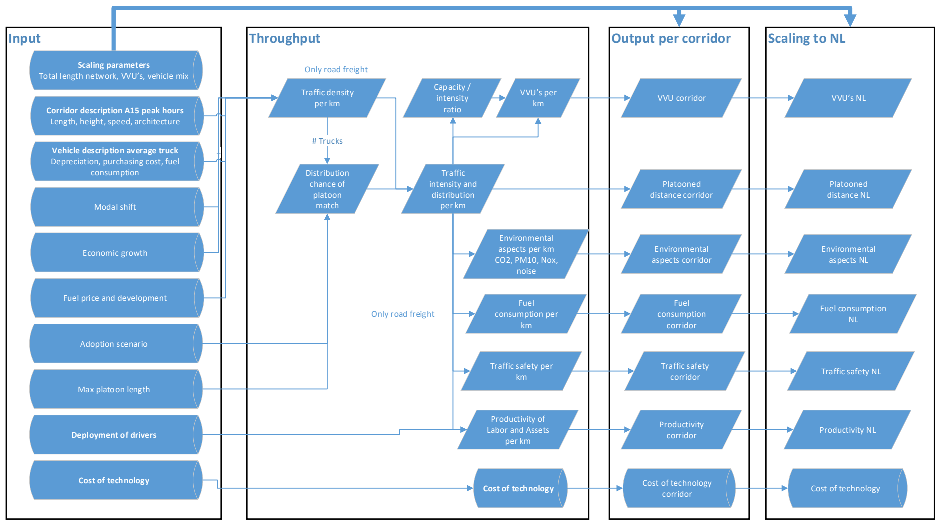


Figure 10: Model structure for the Value Case

Table 2: Assumptions and model input.

Variable	Value for 2017	unit	Increase/decrease	Used for
Average kilometers per truck per year	77731	[km]	Fixed	Calculation of insurance and technology costs per km.
Current fuel price	1.08	[€/l]	+1.3% per year	Calculation of fuel savings
Labor price	25	[€/h]	+2% per year	Calculation of labor savings
Cost of a truck	75.000	[€]	+2% per year	Calculation of asset savings
Value of time trucks	45	[€/h]	+1% per year	Calculation of accessibility savings (derived from WLO High scenario) (Kennisinstituut voor Mobiliteitsbeleid, 2013)
Value of time passenger cars	9	[€/h]	+1% per year	Calculation of accessibility savings (derived from WLO High scenario) (Kennisinstituut voor Mobiliteitsbeleid, 2013)
Maximum gap distance to platoon	1	[km]	Fixed	Calculation of platooning chance
Truck speed	80	[km/h]	Fixed	Various calculations
Economic lifetime of a truck	7	[years]	Fixed	Calculation of technology costs and asset savings
Percentage spent on motorways for heavy trucks	73	[%]	Fixed	Calculation of safety savings

3.3.2 GDP growth

The Centraal Planbureau (CPB) and the Planbureau voor de Leefomgeving (PBL) (Centraal Planbureau, 2015) jointly developed a high and a low scenario for the future of welfare and liveability in the Netherlands (see Figure 11). The scenarios for 2030 and 2050 are compared to the statistics of 2013. With respect to macro-economic changes the following statistics are presented.
The high scenario predicts an average GDP growth of 2% per year, partially caused by a stronger population growth. The low scenario predicts an average GDP growth of 1% per year.

Ontwikkeling bbp, arbeidsproductiviteit en werkgelegenheid in 2030 en 2050

		Scenario Hoog		Scenario Laag	
	2013	2030	2050	2030	2050
	(niveaus)	(2013=100)			
BBP (in mrd, marktprijzen 2010)	644	140	205	120	145
Arbeidsproductiviteit		130	180	115	150
Werkgelegenheid (in mln)	8,3	110	115	100	95

Figure 11: CPB/PBL economic scenarios for The Netherlands

For our model we will adopt the high scenario which also matches with the more detailed GDP growth forecast of the CPB (Centraal Planbureau, 2016) which estimated an annual growth of 1.8% per year over the period 2018-2021.

The GDP growth has a direct relation to the growth in tons of freight transported and the number of kilometers transported by road. Figure 12 below shows that the number of kilometers for trucks will have increased with 25% by 2050. This is an annual increase of 0,6% until 2030 and 0,5% continuing to 2050 (CPL/PBL, 2016).

Governmental policies possibly are aiming to shift a considerable amount of freight kilometers from trucking to other modalities. This was quantified in the *Voorjaarsnota Infrastructuur en Milieu 2015* (Ministery of Infrastructure and the Environment, 2015) as a yearly reduction of 85 million truck kilometers per year. That equals a relative reduction of 1,2% on the total of 6.8 billion kilometers driven in 2015 (CBS StatLine, 2016). Although not explicitly stated in the high scenario of the CPB we assume in our model that this policy aim is deducted from the increase in truck kilometers.

Vrachtauto's en trekkers	2010	2030	2050
Hoog			
Voertuigkilometers (mld)	7,2	8,1	9,0
Energiefactor (MJ/km)	10,8	10,8	9,1
Brandstofverbruik op Nederlands grondgebied (PJ)	77	87	82
CO2-emissies op Nederlands grondgebied (Mton)	5,7	5,8	4,9

Figure 12: Increase in road transport kilometers

3.3.3 *Fuel price development*

Evofenedex (Evofenedex, 2017) monitors the development of the price for a liter of diesel in the Netherlands. Figure 13 shows the development of the diesel price in cents per liter over the last 14 years. Over this time period the fuel price increased on average with ~3% per year.

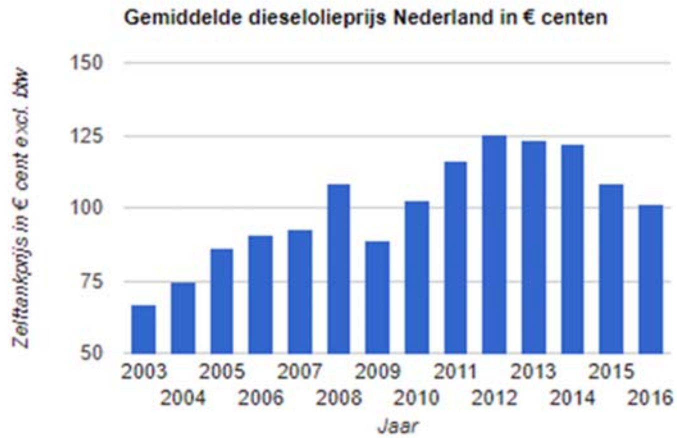


Figure 13: Average diesel price per year

The graph above was drawn based on data from TLN (TLN, 2017). It shows the daily diesel price development over the last 9,5 years. We may conclude that there is considerable price fluctuation.

3.4 Corridor information

We have taken a corridor approach estimating the Value Case of truck platooning for a distinct motorway, being the Port of Rotterdam-Venlo corridor using the A15, A16, A58 and A67 motorways. The chosen corridor (shown in Figure 14) is of high importance for the hinterland destinations from the Port of Rotterdam and vice versa. The corridor has a length of 205 kilometers. Table 3 highlights some traffic characteristics of the freight corridor.

Figure 14: Rotterdam - Venlo freight corridor for the Value Case.

Characteristics of the corridor:

- Motorways included in this corridor (205km length): N15 / A15 / A16 / A58 / A2 / A67
- Key corridor for Port of Rotterdam – European hinterland traffic
- Mix of 2-lane and 3-lane motorways
- Dense traffic volumes, sometimes highly congested
- Traffic with high truck shares (number of trucks / all traffic)

- Lots of heavy duty transport (tractor-trailer container transport towards 50t/60t)
- Potential border-crossings with Belgium (A4 towards Antwerp) and Germany (Motorway 40)
- Part of TEN-T Rhine Alpine Corridor and ITS Corridor projects

Table 3: Corridor information (weighted averages across corridor)

Scope	Corridor indicator	Weighted average across corridor	Unit
Overall	Length	205	km
	Avg. number of lanes	2,3	lanes
	VVU-weighted total	24.807.515	total vehicle-loss hours
Rush hour	Flow all traffic	2.958	per hour
	Flow heavy-duty trucks	322	per hour
	Truck share	11%	percentage of all vehicles
Non-rush hour	Flow all traffic	2.209	per hour
	Flow heavy-duty trucks	403	per hour
	Truck share	18%	percentage of all vehicles

More information about the corridor is in Appendix D and Appendix E.

4 Value Element: Logistics Business Case

This chapter will investigate the direct costs and benefits attributed to truck platooning in order justify its introduction on the basis of expected commercial benefit.

4.1 Value Case formulation

In a simple mathematical equation, that captures most of the direct costs and benefits, we may formulate the net result for a transport firm or logistics service provider as follows:

$$R = \underbrace{C}_{1} \cdot \underbrace{(F + L + A + W) \cdot N}_{2} \underbrace{+ I + T + D}_{3}$$

R = Net result in EUR per year
C = Chance of a successful platoon match in percentage
F = Fuel savings in EUR per kilometer
L = Labor cost savings in EUR per kilometer
A = Increased productivity of driving assets in EUR per kilometer
W= Cost of detour/waiting time to form a platoon in EUR per kilometer
N = Number of platooned kilometers per year
I = Reduction in insurance cost in EUR per year
T = Costs of platooning technology in EUR per year
D = Cost of driver instruction in EUR per year

Within the following sections we will describe the elements that are relevant to this equation. What will become apparent is that the Value Case for the logistics sector is quite applicable within a model due to the three main components. This is depicted underneath the formula and represented by the three multiplications within the equation. This chapter will describe the individual elements in terms of the expected application and the range of values in which an effect is expected. In addition, Appendix K gives an overview of how the costs of operating a current truck are built up.

4.2 Chance of a successful platoon match: platoon match rate

Expected application and effect
In general, benefits of platooning only accrue when trucks have actually driven in platoon formation at short gap distances where aerodynamic improvements occur. Therefore, we define the so-called platoon match rate as the number of kilometers driven in platoon formation as percentage of all eligible kilometers. This is an important indicator for the potential value of truck platooning, as other benefits are dependent on this match rate.

The platoon match rate is also one of the most difficult factors to estimate. Earlier research has estimated an upper-bound for the match rate to be about 70% based on the number of kilometers driven on regular cruise control in the Netherlands (Janssen, 2015).

Bhoopalam and colleagues (Bhoopalam, 2016) also studied potential match rates based on a macro-analysis of point estimations of freight traffic intensities across the A15 motorway. Their analysis showed that up to 20-25% of all trucks on the A15 motorway could travel as platoon during most of the day, with acceptable waiting times. A drawback in using freight traffic intensities (detector loop data) is that no inferences on the distance for which platoons stay intact may be made.

In 2017, TNO-ers Van Ark and colleagues (Van Ark, 2017) therefore developed micro-simulations on a dataset consisting of approx. 250 trucks, from 4 different transport companies, for which very detailed geo-coordinates, times and travel intensions were known. Using an on-the-fly platooning algorithm 6% match-rate was achieved, even at this fairly small total number of vehicles in the data set. This means that for these 250 vehicles, on average about 6% of all kilometers were driven as platoon, without additional coordination imposed on them. If additional coordination was imposed, the match rate grew to approximately 13%. Additional analyses also showed that the platoon match rate was increasing nearly exponentially with fleet-size.

Currently, we are in the process of developing a multi-agent based simulation that uses Maasvlakte Plaza – a new truck stop in the Port of Rotterdam port area – as premier departure (matchmaking) location for platoons bound for the Dutch and European hinterland. Simulations will focus on 2-truck and 3-truck platoon matchings, and results will be available in 2018, as part of the TKI Dinalog funded "Smart Data Factory Innovations" program.

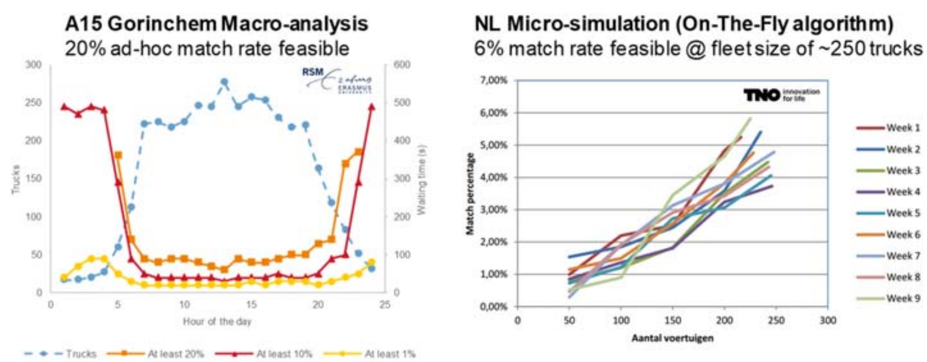


Figure 15: Match rate findings in earlier studies (Bhoophalam et al. 2016; Van Ark et al., 2017).

The platoon match-rate: the number of kilometers driven in platoon formation as part of all driven kilometers is a key indicator

Range of values

In sum, we could argue that match rate ranges in values between lower-bound estimates of 6% towards upper-bound estimates of 70%, with a conservative median of 20-25% can be used for this study.

For this Value Case, we calculate the actual chance of a successful match based on the density of trucks on the road (on the corridor) and the number of trucks that are outfitted with platooning technology. Furthermore we estimate the rate of change in the adoption degree over time.

In our model we are expecting the introduction of multi-brand platooning technology in 2023 (in accordance with the ACEA (ACEA, 2017)). This will be an important barrier to push the adoption rate which we expect to reach 50% in 2030 (see Appendix A). In addition we expect the technology to reach full adoption in 2035 either because of legal requirements or because of standardization of automated driving technology.

Another important factor for finding a successful match is the average distance between two random trucks. This can be calculated when the number of outfitted trucks per kilometer is known. It is assumed that the following distance is Poisson distributed with an average headway of the distance (1000 meter) divided by the number of vehicles at that specific road section (vehicles per 1000 meter). From the Poisson distribution and the average headway we subsequently are able to determine the change of finding another outfitted truck within a certain maximum distance. A Poisson distribution lends itself well to studies of vehicle spacing and has been used to analyze traffic problems throughout the 20th century (Gerlough, 1955).

4.3 Fuel savings

Expected application and effect
The reduction in fuel consumption can be achieved by truck platooning because of a reduction in air resistance and aerodynamic drag. The resulting fuel savings in EUR depend on the development of the fuel price, the reduction in fuel consumption attributed to truck platooning and the general efficiency of truck engines.

Range of values
The development of the fuel price over the years 2017-2022 is estimated to be 1,3% annually by *Kennisinstituut voor Mobiliteitsbeleid* (Kennisinstituut voor Mobiliteitsbeleid, 2017). This value has been adopted in our model. Read section 9.1.2. for more details on the fuel price development.

The general annual fuel efficiency improvement of trucks was studied by Todts (2015) (Appendix G). In our model we are adopting his EU-realistic reduction percentage of 0,5% starting in 2015 at 29 liters per 100 kilometer.
On top of that, we expect savings based on platooning technology and driving at short inter-vehicle distances. Various studies on fuel reduction achieved with truck platooning yield different results (see Figure 16 and Appendix F). This can be explained by variations in gap distance, speed, location and vehicle used. However, we can conclude that fuel will be reduced for all trucks platooning; both leading and following trucks. It should be noted that these savings are not the same for all vehicles.

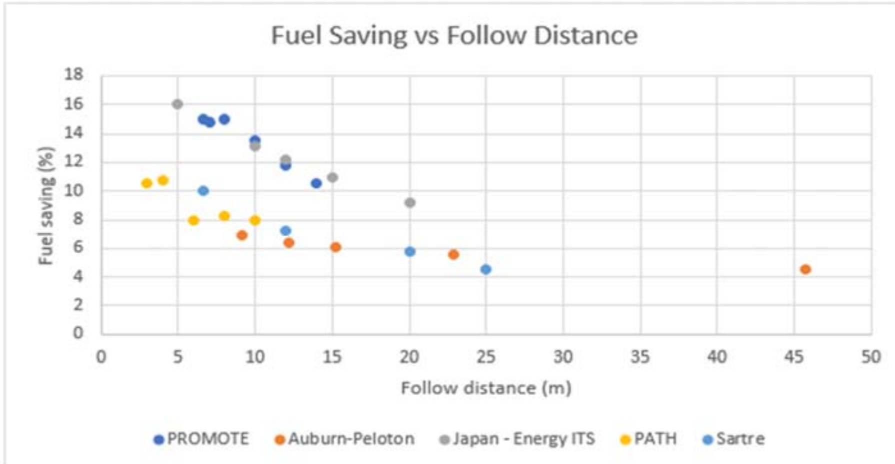


Figure 16: Fuel savings vs. following distances - compared across studies

Throughout this report, we will refer to team savings: the average savings of all vehicles in the platoon, expressed as a percentage of the baseline motorway-driving fuel consumption. Todts (2015) quotes an average European diesel consumption of 35L / 100km. This seems a little high for The Netherlands with its predominantly flat surface, so we'll adopt a fuel efficiency of 29L / 100km, based on research by TNO (Ligterink, 2016) into the CO_2 emissions of heavy-duty trucks on motorways. With the Dutch heavy-duty speed limit of 80km/h we chose to adopt an average (team) reduction in fuel consumption of 10% per vehicle for a two-truck platoon (consistent with SARTRE (Dávila, 2013)) and an average reduction of 14% per vehicle for a three truck platoon (consistent with Energy ITS (Tsugawa S. K., 2011)). The gap distance adopted for calculation is 0,5 seconds or 11,1 meters. Early technology demonstrations have shown that shorter gap distances, for instance 0,3s (6,6 meters) are possible, whereas first implementations on the public road will have larger (perhaps >1s) gap distances.

"Fuel savings potential of truck platooning depend on how close vehicles are driving together."

The numbers reported here are mainly based on experimental test-track studies such as SARTRE. That typically implies that relative fuel savings are determined based on driving in platooning modus at a short inter-vehicle distance, and setting a baseline at a very large inter-vehicle distance of multiple 100s of meters. The latter is typically not very representative of real-world conditions where vehicles regularly at shorter inter-vehicle distances (without platooning systems) of 1 to 2 seconds (22 – 44 meters @ 80km/h) in busy traffic. Actual real-world fuel savings could be much lower, with preliminary results showing only 0.5L/100km savings for slipstream driving between 10 m (0.4s gap @ 85km/h) and 70m (3s gap @ 85k/h) (Van Raemdonck, 2017). The net effect of experimental platooning versus real-world platooning operations is something that needs to be established, based on distribution of inter-vehicle distances across the day for transport operations in the Netherlands.

All in all, we use the following average fuel savings (Table 4) in the Value Case based on the findings of Figure 16.

Table 4: Estimated fuel savings per platooning capability.

Stage	Operating capacity	Estimated inter-vehicle distance @ 80km/h	Avg. fuel savings – 2-truck platoon	Avg. fuel savings – 3-truck platoon
1+2	IOC	1.0s – 22m	6%	9%
3	MOC	0.6s – 13m	8%	12%
4	FOC	0.3s – 6.7m	10%	14%

4.4 Labor cost savings

Expected application and effect

Labor cost savings will depend for a large part on legislation and the level of automation, such that the driver can go ‘out of the loop’ with regard to this dynamic driving task. These two factors are intricately linked, the higher the level of automation, the more we can save on labor cost, provided that the legislation allows for less driver interaction.

Range of values

Currently each truck driver has to rest for 45 minutes after 4,5 hours as legislated by the EU (UK Government, 2017). Taking the various stages of truck platooning into account we make the assumptions as summarized in Table 5. Truck platooning will be introduced commercially in 2020. Legislation around resting while being a platooning follower is likely to be absent. Once truck platooning reaches 50% adoption we assume that both automation and legislation will allow drivers to take breaks or perform administrative tasks while driving. Finally, at full automation no following drivers will be required for the automated parts of the trip. In our model we are adopting a hourly wage for a truck driver of € 25,=.

Table 5: Driver productivity improvements potential.

Stage	Operating capacity	Responsibility driver of following vehicles	Year	Reduction in labor costs of *following* vehicles
1+2	IOC	Human driver will respond to a request to intervene at any time	2020	0%
3	MOC	Driver has no responsibility during automated modus	2023	8% (Janssen, 2015)
4	FOC	No human driver required	2030	90% (Roland Berger, 2016)

4.5 Increased productivity of assets

Expected application and effect
The productivity of assets, trucks, can be improved by (partial) elimination of the need for an attentive driver, optimization of driving times, and minimization of truck idling time, that is, an improvement in productivity of assets.

Range of values
Tavasszy (Working paper) showed the effect on asset productivity under the assumptions of a two-truck platoon, driving 80km/h, where the second driver gets a 50% task relief. The extra distance two trucks are able to cover is estimated to be 30%. This benefit can either be calculated as an increase in daily range or a reduction in costs for co-drivers. This is explained in more detail in Appendix I.

In theory the number of Dutch road freight kilometers may, under these circumstances, be driven with two-thirds of the trucks. In practice this will be impossible to achieve (due to differences in schedules, destinations, et cetera). Until further study we will assume a savings on asset costs of 8% for Stage 3 (MOC), in line with and constrained by driver productivity improvements. However, this advantage will be lost when Stage 4 truck platooning is introduced. When there are no drivers in the following vehicles, there is no opportunity to alternate leads.

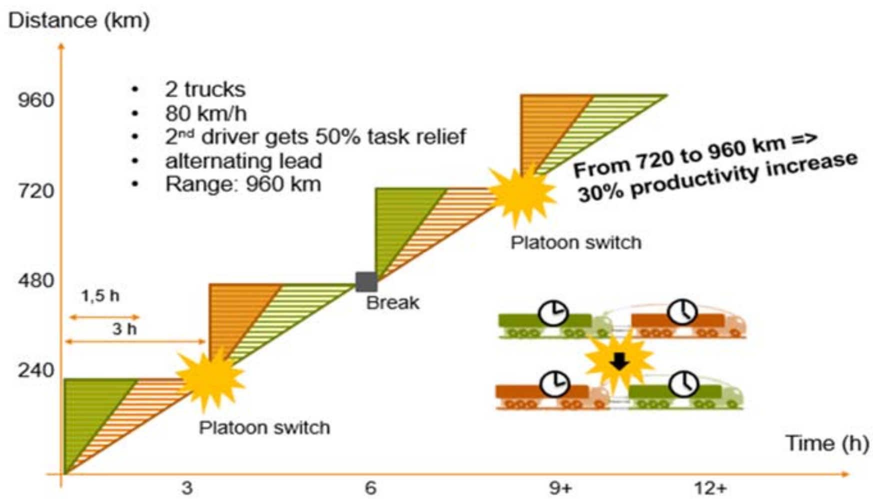


Figure 17: Increased asset productivity when driving as platoons (source: Tavasszy, 2016)

Table 6: Asset productivity improvements potential.

Stage	Operating capacity	Responsibility driver of follow vehicles	Year	Increased asset productivity of *following* vehicles
1+2	IOC	Regular break schedules need to be observed	2020	0%
3	MOC	Additional driving time and switching leads yields increased driving range	2023	8%
4	FOC	Driverless vehicles inhibit additional range	2030	0%

4.6 Cost of detour or waiting time

Expected application and effect
What is the acceptable amount of waiting time or size of a detour to still benefit from platooning? Zhang (2016) developed an extensive model that calculates the cost in relation to the deviation in minutes from the scheduled travel time.
The cost involves additional driving cost, fuel cost and a penalty for missing the schedule (Appendix H).

Liang (2016) conducted an experiment in Sweden to find how much time trucks need to merge if their speed differs 10 kilometers per hour, and found that:
- If the gap size increases over 1 kilometer it becomes very difficult to merge on an 11 kilometer stretch of highway.
- Highly congested traffic makes it difficult for the follow vehicle to catch up to the lead vehicle.

Range of values
In our model we are focusing on corridors with a relatively high density of freight traffic. For the sake of simplicity we choose to adopt on-the-fly platooning as opposed to scheduled platooning, meaning trucks will form platoons on the road while driving rather than forming platoons in truck plannings. We are adopting the maximum gap distance of 1 kilometer found by Liang (2016). This means that if 2 equipped trucks find each other within a 1 kilometer range, the lead vehicle would slow down to 75km/h and the following vehicle would speed up to 85km/h.
The trucks would merge within 10 minutes and without travelling more than 10 kilometers. As such, the leading vehicle would lose around 30 seconds, even in a heavy traffic scenario. We are assuming that the cost of a 30 second delay is negligible and moreover we are not factoring in the cost of potential disturbances in the traffic flow.

4.7 Reduction in insurance cost

Expected application and effect
Bishop (2015) lists four factors that will impact insurance cost: Accident reduction, shift of liability, increased hours of service and enforcement.

The Insurance Information Institute (Insurance Information Institute, 2016) writes that the impact of automated driving on insurance cost is currently unclear. When the technology becomes more mainstream insurers will be able to determine to what extend accidents will be reduced and whether the accidents that do occur lead to a higher percentage of product liability claims (Appendix L).

Range of values
We assume that insurance cost will not be reduced until we reach 50% adoption. Roland Berger (Roland Berger, 2016) estimated a 2% cost reduction for vehicles with a SAE Level 3 automation, increasing to 30% reduction for further stages.
We estimate the cost of insuring a truck to be EUR 3.000,-.

4.8 Cost of platooning technology

As there are no official commercial price lists for platooning technology available, we have to rely on estimations.

Various estimations of the cost of platooning technology exists, for example by Roland Berger (2016) and Litman (2017). The cost consist of modifications to the truck, such as an automatic transmission, various sensors, automated steering column, testing and maintenance.

Range of values
We will make use of an average between the various estimations found in the literature mentioned above (Appendix J). In addition, we will assume that the cost of training the drivers is included in the cost of technology, as well as some costs for instance associated with platoon matchmaking (platoon formation based on coordination or a dedicated third-party service provider), increase maintenance costs et cetera.

Note that we employ costs per vehicle on the basis of large-scale deployment here. Current platooning-able vehicles are still much more expensive because it involves prototypes and R&D-originated vehicles. In our model, we assume cost levels compatible with highly matured and large-scale deployed technology, thus EUR 12.000,- for stage 1 and 2. Later stages increase in cost because of additional functionalities, but the same argument holds.

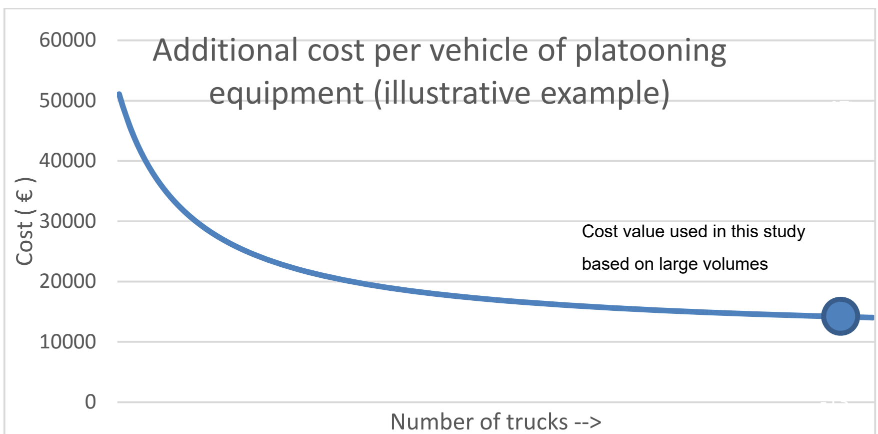


Figure 18: Additional cost per vehicle of platooning equipment – illustrative example

Table 7: Costs of platooning technology

Stage	Cost per vehicle at scaled up situation (Roland Berger, 2016)
1+2	EUR 12.000,-
3	EUR 16.000,-
4	EUR 20.000,-

5 Value element: Environment and liveability

Road transport affects both the logistics sector and society as a whole. The effects on society are amongst others harmful emissions (including noise), congestion and traffic safety. Monetizing these externalities is needed in order to calculate the societal Value Case. In this section the expected effects from platooning on harmful emissions are described.

5.1 Value Case formulation

Societal costs of road traffic emissions consist of CO_2, NO_x, PM_{10} and noise (KiM, 2017). Following the logic from the previous section, the net societal result on environment and liveability can be calculated as follows:

$$R = TP \cdot (CO + NO + P + No)$$

R = Net result in EUR per year
TP = Total platooned km per year
CO = CO_2 savings in EUR per kilometer
NO = NO_x savings in EUR per kilometer
P = PM_{10} savings in EUR per kilometer
No = Noise savings in EUR per kilometers

Within the following sections the individual components will be further described. Due to the ample availability of literature on this subject, it has been chosen to structure this chapter by references to the scientific literature that provide the cornerstones in this research field and to describe the expected application and effects concisely.

5.2 Kilometers per year

The environmental platoon benefits are calculated per kilometer and therefore the total platooned kilometers per year need to be known.

For each road section the total platooned kilometers shall be calculated by multiplying the chance of a successful platoon match (as described in section 4.2) with the length of the road section and the number of trucks that traverse the section each year.

5.3 CO_2 savings in EUR per kilometer

CO_2 or carbon dioxide emissions are harmful to the environment mainly due to their contribution to global warming. In order to meet international regulations from the Paris Agreement, the Dutch government is forced to halve CO_2 emissions by 2030 (Planbureau voor de leefomgeving, 2016).
In fact, the transport industry needs to work on a so-called Factor 6 carbon productivity improvement in 2050: transporting 2.5 times more goods 2.5 times more efficiently (Smokers, Wilkins, Kok, Van Zyl, & Spreen, 2017).

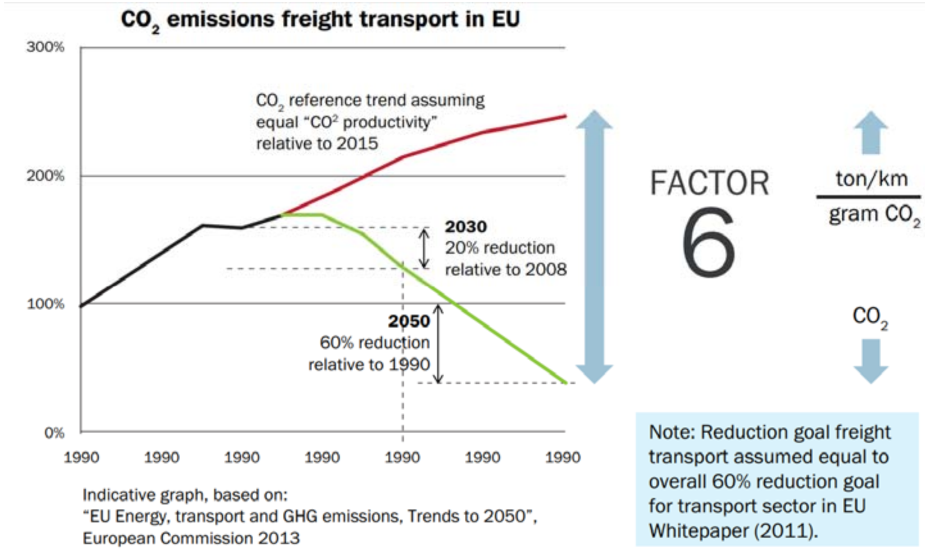


Figure 19: Six-fold increase in CO_2 productivity is needed to achieve CO_2 reductions targets in EU members (Smokers, Wilkins, Kok, Van Zyl, & Spreen, 2017)

"The transport industry needs to work on a so-called Factor 6 carbon productivity improvement in 2050: transporting 2.5 times more goods 2.5 times more efficiently"

Expected application and effect
In order to calculate the CO_2 savings the difference in CO_2 emissions (in grams/km) between platooning and non-platooning vehicles is estimated. Then, the result is multiplied with the societal costs per gram CO_2.

Range of values
According to Tsugawa (2011) the effect of truck platooning on emission reduction is twofold. First of all, trucks driving closer together experience less aerodynamic drag. Second of all, truck platooning can increase road capacity and thus provide more room or surrounding traffic and smoother flow.

According to Scora and Barth (Scora, 2006) there is a linear relation between fuel consumption on the one hand and CO_2 and NO_x emissions on the other hand. In our Value Case model, the reduction of CO_2 emissions is therefore equal to fuel savings, i.e. 10 % per vehicle for a two-truck platoon and 14 % per vehicle for a three-truck platoon (see section 4.3).

TNO has measured the emissions per kilometer for different road- and vehicle types (Heijne V. L., 2016). The CO_2 emission for new (EURO VI (European Commission, 2016)) heavy trucks is 898 grams per kilometer on highways. The average for heavy duty vehicles on Dutch motorways is 768 grams per kilometer (Ligterink, 2016). Due to a changing composition of the vehicle fleet this is estimated to increase to 792 grams per kilometer in 2030 (Ligterink, 2016).
The societal costs are € 78,- per tonne CO_2 according the Dutch Ministry for Infrastructure and the Environment (Ministery of Infrastructure and the Environment, 2016).

In summary, each platooned km. saves society € 0,007 for two-truck platoons and € 0,010 for three-truck platoons due to reduction of CO_2 emissions.

5.4 NOx savings in EUR per kilometer

NO_x is a collective name for pollutant nitrogen oxides produced during combustion of fuels. These gasses are harmful to the environment because of their contribution to smog and acid rain.

Expected application and effect
Since NO_x emissions are also linear to fuel use (diesel in this case), NO_x emissions are calculated similar to CO_2.

Range of values
The NO_x emission for new heavy trucks is 0,195 gram per kilometer (Heijne V. L., 2016) and societal costs are € 10,60 per ton NO_x emitted (Ministery of Infrastructure and the Environment, 2016).

In summary, each platooned km saves society € 0,0002 for two-truck platoons and € 0,0003 for three-truck platoons due to reduction of NO_x emissions.

5.5 PM_{10} savings in EUR per kilometer

PM_{10} stands for Particulate Matter 10 micrometers or less in diameter. These dust emissions are harmful for humans. PM_{10} emissions are caused by wear of moving parts of the vehicle (e.g. tyres, brakes, clutch) and road deck and by tailpipe emissions. Since platooning does not stop the trucks from moving, effects are only expected on the latter.

Expected application and effect
In the model PM_{10} exhaust emissions are calculated similar to CO_2 and NO_x.

Range of values
Modern trucks are all equipped with closed diesel particulate filters. These filter reduced particulate emissions that are exhausted via the tailpipe significantly to less than 0,05 g/km for modern trucks (Kadijk, 2015).

PM_{10} exhaust emissions cost society EUR 109,30 per ton (Ministery of Infrastructure and the Environment, 2016).

In summary, each platooned kilometer saves society EUR 0,0005 for two-truck platoons and EUR 0,0008 for three-truck platoons due to reduction of PM_{10} emissions.

5.6 Noise

Noise pollution by trucks costs society € 28,- per 1000 km, compared to € 5,- for person cars and € 115,- for busses (Ministery of Infrastructure and the Environment, 2016).

One might reason that the effect of truck platooning on noise emissions is twofold. First of all, trucks driving on close proximity produce more noise (decibels) than a single truck.

On the other hand, clustering of trucks in platoons means that there are less peaks in the noise level. However, there is no research available on noise emissions of truck platoons and therefore noise is not included in the model.

5.7 Conclusion

In Table 8 the effects of platooning on environment and liveability are summarized. Altogether, emission reduction of platooning save society between EUR 7,94 and EUR 11,11 per 1000 kilometers, depending on the size of the platoon (2-truck or 3-truck).

Table 8: Effects truck platooning environment and liveability (based on maximum fuel reduction 2030)

	Platoon	Societal costs/1000 units	Reduction	Default units/ km	Cost savings / 1000 km
CO_2	2 truck	EUR 0,08	10%	898	EUR 7,18
	3 truck	EUR 0,08	14%	898	EUR 10,06
NO_x	2 truck	EUR 10,60	10%	0,195	EUR 0,21
	3 truck	EUR 10,60	14%	0,195	EUR 0,29
PM_{10}	2 truck	EUR 109,30	10%	0,05	EUR 0,55
	3 truck	EUR 109,30	14%	0,05	EUR 0,77
Total	2 truck				EUR 7,94
	3 truck				EUR 11,11

6 Value element: Accessibility and Traffic Flow

Traffic congestion is an inescapable condition in large and growing urban areas and an inherent result of the way our society operates (Downs, 2004).
Building roads and highways to expand the road capacity is no longer regarded as a feasible solution. Expanding the infrastructure is often not practical due to the high costs and most cities, given their spatial setup have already reached their maximum road capacity.

Policy emphasis has turned to the improved utilization of the existing road-capacity by deploying telematics technology, integrated with Advanced Driver Assistance Systems, of which truck platooning is part. This chapter explores the impact of truck platooning on traffic flow and accessibility.

6.1 Value Case formulation

When we look at the fundamentals of the traffic flow we see that congestion often starts as shockwaves in which drivers are forced to decelerate. These shockwaves may grow in length and width and are referred to as unstable traffic (Schakel, van Arem, & Netten, 2010). Shockwaves have many drawbacks related to fuel consumption, the environment, travel time and traffic safety.

The performance of the traffic flow is often described the total delay (or ‘hours lost in traffic’) which is the number of hours spent in traffic beyond what normally would occur in conditions without congestion.

This chapter will research the expected effect of truck platooning on the traffic flow or accessibility. In comparison with the previous value elements, accessibility has not yet been researched as extensively as the previous value elements. Due to this difference this chapter will first provide a general literature study and apply this knowledge to the Dutch situation.

6.2 Literature review

6.2.1 Primary effects

Truck Platooning strongly resembles Cooperative Adaptive Cruise Control (CACC) for which the effects are studied in multiple studies. The main difference between CACC and TP is the addition of lateral control (lane keeping/vehicle following) where CACC only controls the longitudinal distance of the vehicle to its predecessor. In respect to the effects of TP towards the accessibility the advantage lies mainly in two factors:

1. The physical capacity of a road section can be increased due to the fact that vehicles are driving at smaller gap distances,
2. The traffic flow becomes more stable because the differences in speed between the platooning vehicles are reduced.

With respect to the physical capacity it is fairly easy to determine the difference: a group of three trucks (tractor-trailers with a length of 16,50m each) driving at a road section with a speed of 80km/h at a following distance of 1,2s will occupy a total footprint of 129,50m. If these three vehicles platoon with a gap distance of 0,5s the total overall length becomes 98,40m (a difference of 24%).

Regarding the stability of the traffic flow the difference lies mainly in the fact that the 'human' factor is removed from the equation. V2V-communication equipped vehicles can look 'further ahead' and anticipate accordingly. Moreover the technology can estimate speed differences, distances and accelerations more precisely and with a lower response time. Within mixed traffic of equipped and non-equipped vehicles it is found that CACC, and thus truck platooning, can quickly damp shockwaves and have shockwaves move faster (Schakel, van Arem, & Netten, 2010).

With respect to the road capacity, the effect is achieved instantaneous when two vehicles are coupled and decrease their inter-vehicle distance. In contrast, the effect towards the traffic flow stability only becomes apparent if a significant group of *all vehicles* – that is passenger cars and/or heavy-duty freight transport – is equipped with the technology and able to platoon (40% according to the research of Schakel et al. (2010)).

6.2.2 Mitigating factors

Theoretically, there should be a clear significant positive effect, when the gap distance between (heavy) vehicles becomes smaller (higher density of traffic), the throughput of the highway becomes higher, and the flow is more stable due to the automated longitudinal behavior. This effect is especially visible at high truck shares – high proportion of heavy duty vehicles versus total vehicles – and optimal when no other traffic is mixed within the traffic flow.

However, there are mitigating factors that could adversely affect the benefits of truck platooning in regard to the traffic flow. One of these factors might be 'mixed' traffic operations', such as in the Netherlands. Within a mixed traffic scenario, light vehicles should move through or around the truck platoons. Especially weaving, entering or diverging behavior can destabilize the traffic flow. For example, the simulation study of Kuijpers (Kuijpers, 2017) showed that the performance of lane changing is difficult and fluctuations in the overall speed appeared which increased the amount of traffic conflicts, traffic jams and spill backs.

Not only the amount of onramps, offramps and connecting roads is relevant but also the design of the road itself; that is, the amount of lanes and the potential (dynamic) availability of a dedicated lane for platooning vehicles. Within the German EFAS-project a simulation study explored these factors and concluded that in a two lane-scenario the effects of truck platooning were overcompensated by the formation/dissolution process of the platoons. For a three-lane scenario a different outcome was determined and resulted in a speed increase of 14**%** and a more stable traffic flow. Finally, modelling a separate lane for truck platooning could decrease the travel time on that lane by 20**%** (RWTH Aachen, 2002) (thus for platooning vehicles) however the effect on the other (non-platooning) vehicles depends on share of equipped trucks (Van Arem, 2006).

We should note that, while the direct effect of Truck Platooning on road capacity is limited, this limited effect could already be very influential on the total hours lost in traffic. One of the reasons behind this is the so-called 'traffic breakdown' and 'capacity-drop' phenomenon which can be explained by the three 'states' in which the traffic is able to flow (May, 1968):

- Free traffic at high speeds and low traffic volumes and densities,
- Partially constricted traffic, stable, up to the range of maximum traffic volumes, optimal speed and traffic density,
- Constricted traffic with high traffic densities, unstable, low traffic volumes and speeds.

There is no exact value when the flow changes between the stable and unstable state, but when traffic breakdown occurs the speed and volume suddenly drops significantly. Later on the traffic flow can recover but the maximum traffic volume (capacity) will not become as high as before the breakdown. This is caused by the fact that the driver, in keeping a greater distance when leaving the downstream traffic-jam front, maintains a greater distance than before (Friedrich, 2016).

In practice this means that if the capacity of a road segment is increased by only a small percentage and a traffic breakdown is prevented, the overall result in terms of the prevented hours lost in traffic can be significant. In 2010 it was seen that, due to the economic situation in the Netherlands, the traffic demand reduced with 1% which resulted in 10% less congestion (Kennisinstituut voor Mobiliteitsbeleid, 2010).

Figure 20 shows, for the A15 motorway based on Weigh-in-Motion systems, that three traffic states are observed and the cumulative probability of occurrence ρ_{veh}:

- Free flow traffic: $\rho_{veh} < 20$ vehicles/km/lane
- Traffic jam (partially constricted): $20 < \rho_{veh} < 30$ vehicles/km/lane
- Stationary (constricted) traffic: $\rho_{veh} > 30$ vehicles/km/lane

On the A15 motorway, and part of the corridor in this study, 93% of the time traffic is free-flowing, 5% of the time traffic is partially constricted and about 2% of the time traffic is stationary (Vervuurt, et al., 2015).

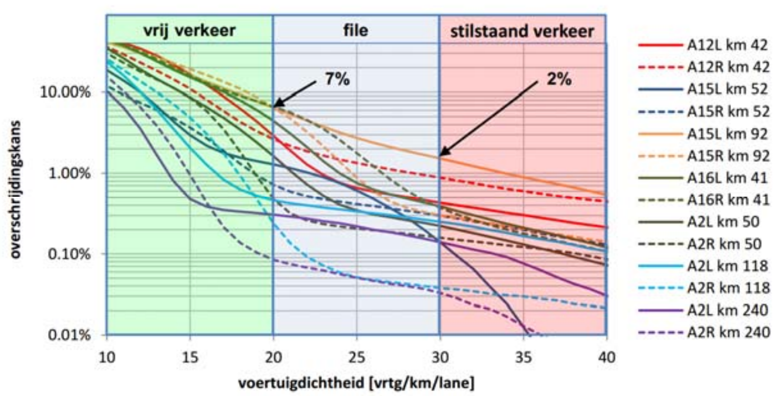


Figure 20: Free-flow traffic, traffic jams and stationary traffic at key Dutch motorways: vehicle density of vehicles/km/lane versus number of exceedances (Vervuurt, et al., 2015)

If we bring together the most relevant literature on the effect of truck platooning on the traffic flow the research of Muller (2012) provides an overview of the studies that focused on the impact of CACC on traffic flow. If we couple the more recent studies with this overview it becomes apparent that the effects of truck platooning on the traffic flow has been a focus of numerous studies. There are very different results but in general most researches show a positive relationship between the implementation of truck platooning technology and the road efficiency (as in capacity and flow stability). It is however difficult to fully compare all the studies due to varying traffic densities, equipment, the simulation model qualities and constraints of very different conditions are present in the investigations.

6.3 Application to the Netherlands

Having studied the general effect of truck platooning on traffic performance we can now relate these findings to the current situation in the Netherlands as input for the Value Case. The main aim is to determine whether the effect of truck platooning on the traffic flow can (directly) be influenced by policy or regulatory choices within the model or if the effect is a result of choices in other fields (that is, the logistics value elements).

Expected application and effect
Based on the traffic literature review it becomes apparent that in an optimal scenario (in terms of adoption level, truck share and infrastructure design) and while disregarding dynamic factors an increase in terms of road capacity and traffic flow stability is to be expected. This finding comes from simulation studies that model fairly optimal scenarios, that is, with straight roads, no on- and offramps, limited weavings et cetera. On the other hand, the literature also shows that the interaction with other traffic could have an adverse effect, this interaction is mainly triggered by merging/exiting maneuvers, which very much mitigates any potential positive effects of truck platooning on traffic flow (Calvert, Under review).

“On the freight corridor, the number of trucks is not high enough to see improvements of truck platooning technology on the accessibility and traffic flow”

One other main factor is the adoption rate (or penetration level) that determines the overall effect in relation to the traffic flow. Looking at the existing literature, it becomes apparent that a penetration level of 40% is required as a lower bound in which an ‘effect’ is measurable or apparent (Schakel, van Arem, & Netten, 2010). Figure 21 shows one of the most important long-haul freight corridors, the A15 motorway that runs across the Netherlands from the Rotterdam port towards Germany. We see that this minimum percentage is only reached locally or at road sections where the other (non-freight) intensities are low (in example the road sections close to the border). Given the lower limit of 40% and the current situation we would expect none to negligible effects.

Figure 21: Freight percentages at the A15 corridor from Rotterdam towards Venlo.

Furthermore, if we combine the truck percentages at the A15 (Figure 21) with the actual hours lost in traffic at this corridor, as can be seen in Figure 22, we can see that the hours lost in traffic are mainly incurred at sections where the freight percentage is less than 20%.

Figure 22: Vehicle hours lost in traffic at the A15 freight corridor from Rotterdam to Venlo.

Of course one could argue that due to the yearly growth of the GDP the truck percentage could increase and eventually exceed the limit of 40% trucks in total traffic. However due to the reinforcing effect of both truck share and adoption rate we assume that the chances that the lower boundary threshold of 40% platooning-capable trucks on the whole traffic flow is met, are going to be low. And, if this boundary is eventually exceeded, it is expected to be located at road sections that have none to negligible hours lost in traffic.

To conclude in relation to the Value Case model; we expect that truck platooning will have a positive effect on both the traffic flow stability and road capacity, however given the lower limit of 40% in terms of the truck share the effects will be very limited and very locally. If we look at the potential of reducing the hours lost in traffic we note that the truck share is likely to be too low to generate a measurable effect.

Range of values
Based on the analysis above we assume an effect between **0 and 0.5%** reduction of the yearly vehicle hours lost in traffic in the Netherlands **at two lane highways** until a platooning truck share of 40%. For **three lane highways** an effect is expected between **0.5 and 0.75%** towards a platooning truck share of 40%. These figures both respect the notion that a truck platooning effect will only be seen while the truck share is higher than 40% and the assumption that a higher effect is expected on three lane highways. Further research is required to determine the effect of platooning in circumstances in which the truck share is higher than 40%. Due to the lack of scientific literature we (for the time being) assume an effect of 8% when all the vehicles are equipped (100% share of the total vehicle fleet) for two-lane highways and an effect of 13% for a three lane highway when all vehicles are equipped.

7 Value element: Traffic Safety

Road accidents are undesired and unpleasant events that lead to human and economic losses (injuries or fatalities) (Sadauskas, 2003). These deaths and injuries result in significant social and economic costs (European Transport Safety Council, 2011). Although the number of fatalities on the roads has decreased in the past few years, over a million people are still involved in road accidents in Europe. About 26,000 people died in road accidents in Europe (EU-28) in 2014. More than half of road fatalities involve people inside motor vehicles; the rest are either pedestrians, cyclists or motorcyclists (European Commission, 2017).

Deaths and injuries due to traffic accidents result in social and economic costs, these costs could be direct (i.e. medical, mental, material, handling costs and hours lost in traffic due to traffic jams) but also indirect such as the loss in productivity when a victim of an accident temporarily or permanently cannot contribute to the national GDP.

Often road safety is quantified by the total cost of society. Also, within the traffic performance often a distinction is made in the hours lost in traffic due to (regular) capacity congestion and the hours lost in traffic due to incidents and accidents.

7.1 Literature review

One of the expected benefits of truck platooning is that platooning will increase traffic safety. The following trucks are able to brake almost immediately and faster than a human driver can, made possible by the V2V wireless connection between the vehicles. Moreover, platooning technology can take over the lateral driving task from the driver and prevent or mitigate accidents on the flanks of the vehicle or with the road shoulder.

7.1.1 Truck-related accidents in the Netherlands

The Dutch Safety Board (*Onderzoeksraad voor Veiligheid*) carried out an analysis of truck accidents in the Netherlands using the Dutch accident database “BRON” (Dutch Safety Board, 2012). It identified four areas of analysis related to the most frequent situations for truck accidents with a serious outcome. The four areas are: alertness, rear-end collisions / traffic-queue collisions, tire blowouts and accidents related to shoulder lane use. Of these four areas, rear-end collisions / traffic-queue collisions and accidents related to lane use are the ones relevant to the application of truck platooning and the possible safety effects.

Based on historic accident data from the Netherlands rear-end collisions are the most frequent type of accident registered among serious accidents on motorways. More than half of all serious accidents with trucks on motorways involve rear-end collisions in the period 2005-2009 (Dutch Safety Board, 2012).

Up until 2015, traffic safety improved in the Netherlands. Since then, the number of fatalities in the Netherlands has increased slightly and safety has also been improved on motorways. However accidents in which truck were involved account for a relatively large number of victims.

On average, truck accidents on motorways resulted in approximately 23 fatalities and 105 seriously injured annually in the period 2006-2010 (Dutch Safety Board, 2012).

7.1.2 Differentiating a net effect of truck platooning on traffic safety compared to other active safety systems

A challenge in researching the effects of truck platooning on the safety-related aspects of traffic is the precise definition of ‘truck platooning’ in relation to other safety systems that are used in the vehicles or that are part of the platooning technology suite. For example radar, one of the components of Advanced Emergency Braking systems (AEB), is also part of the technological architecture of truck platooning. As such it is challenging to differentiate a net effect of truck platooning on traffic safety compared to other active safety systems such as AEB.

Since November 2013, the European Commission requires the fitment of AEB and Lane Departure Warning (LDW) systems in trucks and buses over 3.5t, with 100% fitment for new trucks by the end of 2015 (Automotive World, 2017). AEB alone is thought to be able to decrease accidents by up to 27 percent according to the European Commission (Telegraph.co.uk, 2017). AEB is a factory-fitted system, meaning that the equipment rate of trucks in the Netherlands depends on the purchase rate of new trucks. It becomes a challenge then to distill a net effect of the truck platooning systems from the already legally mandatory active safety systems such as AEB. Especially since there are no studies that detail empirical findings on the effects of AEB on its own over a longer period, for instance from 2015 until today.

In contrast to AEB and LDW, truck platooning technology is aimed towards improving the frequently occurring ‘tailgating’ of trucks. This phenomenon revolves around trucks tending to cluster together and drive at very short inter-vehicle distances (often significantly shorter than typically advised or legally mandatory inter-vehicles distances of 2s). Essentially, trucks are forming platoons already, however they do not rely on advanced activity safety systems yet. Even while some transport companies actively discourage this practice from their drivers, the phenomenon can be observed especially at motorways with dense traffic and where truck overtaking is not permitted. Truck platooning systems will at least have the potential to improve the safety of these situations, with the wireless V2V connection able to lower braking response times compared to the human drivers and/or stand-alone AEB-based radar braking.

For our analysis, therefore, in order to fairly discuss the effects of truck platooning in respect to the baseline situation we will discuss the effects within the context of two scenarios; one in which we compare the effects of truck platooning towards ‘old’ generation’ trucks without AEB and LDW systems and the other in which we compare the effects towards the ‘new’ generation trucks that include these systems. We assume that the share of non-equipped vehicles will decrease over time in favor of the trucks that include both systems.

7.1.3 Expected safety effects under the influence of Truck Platooning?

Although there are high expectations for the safety impacts of truck platooning, there are no empirical results yet from on-road deployment. To reason through the possible safety impacts of truck platooning, this analysis takes a structured approach based on Kumala (2010).

The approach is a comprehensive framework for the safety assessment of Intelligent Transport Systems (ITS). It covers all three dimensions of road safety: exposure, crash risk and consequence, the effects due to both the engineering and behavioral adaptation effects. This is compatible with state-of-the art safety theory. The framework is based on nine ITS mechanisms, taking into account direct and indirect, and intended and unintended effects.

Table 9: Expected safety effects of ITS Mechanisms

No.	ITS mechanism	Relevant or not relevant for Truck Platooning
1	Direct in-vehicle modification of the driving task:	Relevant
2	Direct influence by roadside systems	Not relevant
3	Indirect modification of user behavior	Relevant
4	Indirect modification of non-user behavior	Relevant
5	Modification of interaction between road users	Relevant
6	Modification of exposure	Not taken into account
7	Modification of modal choice	Not taken into account
8	Modification of route choice	Not taken into account
9	Modification of accident consequences only	Not relevant

Truck Platooning will significantly affect the direct task of the (platoon) driver within the vehicle. When platooning the following vehicle(s) will assume primary control of the vehicle in terms of its lateral and longitudinal position and this will influence the workload of the driver. This workload can change in any way; both a decrease or increase is possible, for example in case of sudden emergency situations.

The exact degree of change in the driving task depends on the future role of the vehicle driver, that is, can the driver rest when the vehicle is platooning as a following vehicle? Or can the driver be completely absent when the vehicle is platooning? This topic also has a link with legislation and liability.

In terms of the safety improvement that truck platooning can induce it is important to look at the absence or presence of technologies in trucks on the road. As mentioned earlier there are two important vehicle scenario's which include the old or new generation trucks. In comparison with the first group of vehicles we can reason that platooning trucks will be safer than vehicles without AEB, due to synchronized and cooperative braking. The safety improvement for the second group of more modern vehicles is less apparent for truck platooning specifically, since these vehicles already have AEB technology available so most of the 'traditional' rear-ending collisions will already be mitigated. One could, however, argue that, especially in a mixed environment of various vehicle types, the platooning technology could benefit from the fact that the platooning vehicles communicate in unity (that is, the third vehicle brakes immediately when the first vehicle brakes while within traditional radar-based AEB systems the brake maneuver propagates through the vehicles, an phenomenon known as string instability (Ploeg, 2014)).

There are also secondary safety aspects that are relevant. For example, if the lead driver in a platoon makes an error, such as speeding in a curve resulting in an accident, the following trucks in the platoon will most likely also crash.

If the following vehicles do have drivers while platooning, the drivers will probably not have enough time to react in a way to prevent or mitigate the consequences of the accident. Compared to both the situations above, the truck platoon has a higher risk (and possible severity) of an accident, in comparison when the lead driver of 2-3 individually functioning trucks loses control.

The presence of new technologies can lead to situations in which platoon-truck drivers decide to drive longer, in spite of being tired, than they would have without the technology which is an example for indirect modification of user behavior.
The drivers depend on and trust the technology, which could result in overreliance. It is not known how effective the rest periods are for in-active drivers in the following trucks, if the following time counts as a 'full' break; they may overestimate their overall fitness level when taking over the driving task again.

In relation to the indirect modification of non-user behavior it could be that drivers of trucks that are not platoon-capable may exhibit copycat behavior. Although not equipped, these 'copycats' may mimic the shorter headways maintained by the platoon which (could) result in a small negative impact on safety due to the absence of TP technology which results in an increased risk of accidents.

The last relevant aspect is the 'modification of interaction between road users', while trucks usually maintain a following distance which allows other users to access or egress the highway the reduced headway while platooning can result in a perceived barrier by other road-users. It is expected that there will be problems between other road users (passenger car drivers) and platooning in different road situations (motorway entry and exit, platoon overtaking by light vehicles). Cut-ins rarely occur between two trucks which are following at a distance of 40 m or less (=time headway of 1,8 s or less at 80 km/hour) (Kumala, 2010). If cars want to exit the motorway, but cannot due to the barrier formed by a platoon, the behavior of these drivers will become unpredictable and this can result in unexpected and unsafe maneuvers. Relevance of this challenge resides in how platooning will eventually be implemented – already it is foreseen that the platoons will be able to dynamically increase the gap between the vehicles to allow for merging/cutting behavior which should alleviate this concern.

Kuipers (2017) carried out traffic microsimulations of truck platooning using data from the A15, examining peak and off-peak periods. Focusing on the safety analysis, the effects of large-scale truck platooning on weaving, merging and diverging (exiting) were analyzed.
The results showed that:

- Performing lane changes becomes more difficult when platoons drive on the road especially for cars within the merging area;
- Lane change performance is optimized at the beginning of the weaving area and decreased at the end of the weaving area. A 'snowball' effect occurs to the other lanes;
- Minimum traffic intensity of platoons is beneficial for traffic efficiency and partially for the safety in every traffic location;
- Maximum traffic intensity of platoons increases traffic conflicts and the queue delay on the road due to the number of platoons and the small inter-vehicle distance;
- Platooning affects the merging and diverging behavior of other platoons.

All these results showed that platooning with a mean and maximum traffic intensity is not beneficial for the efficiency and safety. A small-inter vehicle distance of platooning has a large impact on traffic behavior within weaving, merging and diverging areas.

Conclusion based on the literature review
It is difficult to precisely appreciate the effect of truck platooning technology towards road safety in a specific value or percentage. Moreover we see that the effect of truck platooning towards road safety is strongly related to the compulsory safety systems such as AEB and LDW active safety and advanced driver assistance systems; therefore determining the net individual benefits of each technology is challenging. The main but unknown factor is the interaction with other users, that is, how will car users react on the platoons while maneuvering on the highways? This is a research field that is uncultivated due to the lack of real-life field tests and very influential for the ultimate effect of truck platooning technology on traffic safety.

7.2 Application to the Netherlands

Instead of looking at the predicted effects we could also look at the ‘maximum’ effect that could be reached when implementing the platooning technology by examining the historic accidents to gain insight in the range in which the availability and utilization of truck platooning technology could have affected the traffic safety.

Within appendix E) a detailed analysis is described that has been conducted on an extensive database that included the accidents and incidents between 2007 and 2009 at the Rotterdam-Venlo freight corridor. We subsequently apply this information to see whether truck platooning, in combination with AEB and LDW, could have played a possible role in terms of mitigating or avoiding accidents at the corridor.

Based on the analysis in appendix E) we have seen that, from a total number 31078 incidents 5471 were related to freight traffic at the Rotterdam-Venlo corridor for which both directions have been summed. From these freight incidents we have detected 1297 accidents from which 80% of the freight related accidents are caused either by head/tail (rear-ending) or flank collisions. Given the combined technology of LDW, AEB and truck platooning and by assuming that all vehicles have been equipped this could result in a significant improvement since the technology could mitigate the accident risk in these circumstances.

To determine the number of injury of deadly accidents that could have been mitigated (or prevented) we apply the statistics of the accident severity from the earlier described traffic safety analysis of the Rotterdam Venlo corridor. From this analysis we learned that 2% of the freight accidents resulted in fatal injury, 17% of the accidents resulted in injuries and that over 80% of the freight related accidents resulted in only material damage.

Table 10. Total costs for (un)safety

Total costs for (un)safety in EUR	
Only material damage	3520,00
Injury accident	22902,80
Deadly accident	2.900.000,00

The last step would be to translate these statistics towards a monetary value which is applicable for the Excel model. The Dutch Institute for Road Safety Research (SWOV) has been researching the direct and indirect costs related to traffic safety and these statistics are applied within the report of *Rijkswaterstaat* (RWS, 2012). Based on the results of this study we have been able to deduct the cost for the three accident categories, these costs are depicted in Table 10.

Based on the accident data and the cost for each individual accident we have determined that the total societal cost for (un)safety at this corridor between 2007 and 2009 was. This cost equaled EUR 57.439.634 of which EUR 19.509.666 was related to freight traffic in this period (of 3 years). Based on the fact that 80% of the truck related accidents could be mitigated when applying truck platooning (in combination with AEB and LDW) we could argue that the best-case safety effect is equal to EUR 15.607.732 based on the accidents registration from 2007 to 2009 (thus approximately EUR 5.000.000 per year) .

To see the effect over multiple years, it is also important to research the safety prognoses on a larger timeline. The KiM Netherlands Institute for transport Policy Analysis states that, within the recent years, the total cost of traffic unsafety for the Netherlands was equal to 2% of the GDP. Within the model we have used this estimation to model the costs of traffic (un)safety for the period between 2020 and 2035.

“The Value Case Truck Platooning considers the joint effects of mandatory AEB and LDW systems together with truck platooning technology on traffic safety.”

Conclusions

It is difficult to model or predict the safety effect of Truck Platooning. Especially since determining the individual (net) effect of ‘only’ truck platooning is nearly impossible given the obligatory AEB and LDW systems for new trucks produced from 2015 an onwards.

On the other hand, given the historic accident data, we are able to determine the compound effect for the applying the three technologies together as an indicating for the ‘best-case’ result. As a quick-scan we have investigated the accident-data between 2007 and 2009 for the relevant logistic corridor that is applied within the value-case model. Based on this analysis we see that potentially 80% of 1297 truck related accidents could have been mitigated or prevented by applying TP in combination with AEB and LDW systems. For the total amount of accidents (for all vehicle categories) this results in a potential improvement of **17,9%**, if we translate this effect towards a monetary value this results in a **yearly cost reduction of 5.000.000 EUR.**

Based on the accident data from 2007 towards 2009 and the assumptions for monetarizing and propagation of the traffic safety aspects have been implemented in the Value Case model.

We should however note that there are limitations to the analysis as elaborated earlier. We for instance assume that for each truck involved in an accident the truck itself could have mitigated or prevented the accident. In practice this is often not the case since the truck is only one of two (or perhaps more) involved parties; i.e. the truck platooning technology is not able to affect the accidents when a passenger car hits the rear of the truck. Moreover the results from this analysis touches upon parts of the traffic safety subject. While this analysis mainly focused on the direct effect on equipped users other important elements (i.e. interaction between equipped and non-equipped users and copycat behavior) have not been taken into account. Lastly the applicability of the results from this specific corridor on the other roads in the Netherlands should be further validated.

8 Value element: Economy

This chapter describes several value elements that are categorized under *Economy.* It is import to note that this list is not exhaustive and far from complete. Truck platooning, in its broad technological sense, may provide benefits for various stakeholders in the supply chain. We aim to give some examples of indirect effects of truck platooning.

8.1 Offset to other industries

The technology needed for truck platooning will have an offset to other industries in the sensor- and software industries. Truck platooning also allows for increased data collection, which will need analyzing. These analyses could lead to very accurate Estimated Time of Arrival (ETA) predictions, which in turn could help container terminals reduce their handlings (Tavasszy, Working paper). A platoon service provider might arise to organize matchmaking for platoons, or provide additional services such as redistribution of benefits from platoons across the vehicles. Lastly, trainers will be needed to educate drivers of the new reality. The improved quality of service has an impact on the reputation of the Netherlands as a logistic hub, which might attract new companies to establish a presence in the country. Overall, we assume that the introduction of truck platooning technology will have a positive effect on the Dutch economy, however we do not attempt to quantify this in the Value Case model.

8.2 Competitive advantage

Logistic Service Providers (LSPs) can gain competitive advantage by the formerly mentioned ETA predictions, which is highly desired by their customers. In addition, the increased the productivity of their assets allows them to transport more freight within the same time. Finally, the reduction in fuel and labor cost allows firms to decrease costs and offer their transportation services at a better rate.

Accenture (2015) identified four key areas where data analytics may provide value and increase competitive advantage:

1. Operational efficiency and planning: Data analytics can help in capacity planning, and building a predictive network that includes route optimization.
2. Customer experience: On-demand or even real-time data creates a visibility for the customers of an LSP.
3. Supply chain risk management: Analytics can synthesize data about local weather and traffic conditions. With this insight LSPs can evaluate risks and shape resilience plans.
4. Business model innovation: Real-time local intelligence can aid last mile delivery, data and insights allow for further collaboration with other parties or may be sold off.

8.3 Benefits for infrastructure managers

Truck platooning technology may provide a lot of insight to infrastructure managers. Data on the density of traffic on roads might improve their management on the infrastructure.

Better insight in the behavior of trucks on the road might aid to design policies around modal shifts and reductions in CO_2. In addition, the technology in the trucks is able to do more than connect to each other. The same technology could function as pothole detection (if allowed by privacy law), informing the infrastructure manager earlier when a stretch of highway needs some maintenance (Jaguar Land Rover, 2017). There might also be some drawbacks to platooning for infrastructure managers. TNO colleagues have described the effect of truck platooning on structural reliability of bridges and tunnels and also on asphalt quality (tracking/rutting). Results so far are mainly indications of potential risks yet cannot be quantified at this point in time (Vervuurt & Bigaj-van Vliet, 2017). For instance, there would be the potential of having a 2-truck platoon, weighing in at 100 metric tons, simultaneous on the span part of a bridge. It needs to be investigated what the odds and consequences are of such traffic passages. Also, technically the vehicles could just create additional space before the bridge, using geo-fending, to pass as regular vehicles. Additional research and measurements is therefore need to assess the real-life impacts of platooning on pavements, tunnels, bridges and viaducts is necessary before more quantified information can be given.

“The impact of truck platooning on physical infrastructure (bridges, pavements, etc) cannot be quantified at this point in time”

8.4 Application to the Netherlands

The former three paragraphs give an indication of the broad scope of economic benefits that may be triggered by truck platooning. It is clear that these effects are of a second order, resulting from the digitization of trucks outfitted with platooning technology. The Value Case for the sharing and utilization of data is, however, outside of the scope of this research. This is an area that has tremendous potential, but also requires further study. In this particular study we have not quantified these effects, and therefore they are not taken into account in our model.

9 Results of the Value Case Truck Platooning

This chapter details the results from the Value Case for two scenarios: a Natural Deployment and a Stimulated Deployment approach. We aim here to show the extent of the Value Cases, as well as to pinpoint what the pivotal variables are in the Value Case. That is, what are the ‘knobs’ that can be turned, that really have a profound effect in the Value Case.

9.1 Scenarios: natural and stimulated deployment of truck platooning

Principally, we have defined two key scenarios for assessing the Value Case. The first is a scenario in which truck platooning follows a fairly Natural Deployment path. In this scenario, timelines for deployment are derived from official automotive roadmaps such as the ACEA and ERTRAC roadmaps and assessments of subject-matter experts. Second, we refer to a scenario of Stimulated Deployment in which platooning uptake by the industry and market is actively encouraged. In the stimulated deployment scenario potential benefits are moved forward in time, that is, they are incurred earlier than typically anticipated in official roadmaps. Within this stimulated deployment scenario, we model the truck platooning ambition of the Roadmap Next Economy (RNE) of the Rotterdam–The Hague Metropolitan area. The ambition of the large-scale RNE program is to have 100 platoons driven daily on public roads, that is on the corridor in 2020.

The following sections and sub scenarios are of primary importance and are reported on in this chapter:

Natural Deployment 2020-2035
- 2020 | Start year natural deployment (IOC)
- 2023 | Focal year ACEA roadmap, multi-brand commercially available, minor driving/resting time benefits included (MOC)
- 2030 | Full labor productivity improvements incorporated (FOC)

Stimulated deployment 2020-2035
- 2020-I | Start year stimulated deployment: RNE ambition ~100 platoons / ~450 trucks deployed (IOC)
- 2020-II | Start year stimulated deployment: RNE ambition ~100 platoons / ~450 trucks deployed (IOC) and increased platoon match-rate.
- 2020-III | With benefits similar to 2023 timeframe captured in 2020 with minor driving/resting time benefits included (MOC)
- 2030 | Full labor productivity improvements incorporated (FOC) at RNE ambition ~100 platoons / ~450 trucks deployed

For ease of reading,

Table 11 provides all results in one overview. Within the following sections, we present both cross sections of that overview table and individual tables. Note that for each scenario, we report findings across the corridor, per kilometer and per truck. For more information about IOC, MOC and FOC, refer back to section 2.3.

Table 11. Value Case Truck Platooning - combined results[1][2][3]

Value Case Truck Platooning	**Natural Deployment scenario**				**Stimulated deployment scenario**				
	2020	2023	2029	2030	2020	2020	2020	2030	
Operating Capability	IOC	MOC	MOC	FOC	IOC	IOC	MOC	FOC	
Value case result	**Total [€/yr]**	**Total [€/yr]**	**Total [€/yr]**	**Total [€/yr]**	**Total [€/yr]**	**Total [€/yr]**	**Total [€/yr]**	**Total [€/yr]**	**Avg. Effect**
L1: Technology costs	-25.000	-371.000	-6.735.000	-10.970.000	-771.000	-771.000	-771.000	-1.286.000	
L2: Fuel savings	-	1.000	3.616.000	7.429.000	194.000	299.000	194.000	345.000	24%
L3: Labor savings	-	1.000	1.961.000	37.830.000	-	-	130.000	1.789.000	84%
L4: Asset savings	-	-	865.000	1.483.000	65.000	99.000	65.000	79.000	5%
L5: Insurance savings	-	-	50.000	1.261.000	-	-	27.000	405.000	4%
Total-Logistic case	**-25.000**	**-369.000**	**-243.000**	**37.033.000**	**-512.000**	**-374.000**	**-355.000**	**1.332.000**	**74%**
S1: CO2 savings	-	-	735.000	1.499.000	42.000	65.000	42.000	70.000	5%
S2: NOx savings	-	-	22.000	44.000	1.000	2.000	1.000	2.000	0%
S3: PM10 savings	-	-	57.000	117.000	3.000	5.000	3.000	5.000	0%
S4: Accessibility	-	-	1.000	1.000	-	-	-	-	0%
S5: Safety	19.000	210.000	3.957.000	5.188.000	208.000	312.000	208.000	222.000	21%
Total-Society	**19.000**	**210.000**	**4.773.000**	**6.849.000**	**255.000**	**384.000**	**255.000**	**299.000**	**26%**
Total	**-7.000**	**-159.000**	**4.529.000**	**43.882.000**	**-257.000**	**10.000**	**-100.000**	**1.631.000**	
	-	-	-	-	-	-	-	-	
Platoon km's	-	1.000	42.096.000	88.812.000	9.315.000	13.973.000	9.315.000	9.315.000	
Platoons (average length = 150 km)	7	7	281.000	592.000	62.000	93.000	62.000	62.000	
Match-rate (2-truck platoon)	Dynamic	Dynamic	Dynamic	Dynamic	25%	**35%**	25%	25%	
Match-rate (3-truck platoon)	Dynamic	Dynamic	Dynamic	Dynamic	5%	**10%**	5%	5%	

[1] Please note that the traffic safety improvement is high due to the fact that this is the combined result of AEB, LK and truck platoon technology, as already mentioned in chapter 7.
[2] The 2029 figures are included for comparison purposes with the 2030 figures, highlighting Stage 4 (SAE L4) platooning potential.
[3] Years chosen for the Value Cases correspond with developments in technology (IOC, MOC or FOC stages) or official roadmap timelines.

9.2 Results of the Value Case: Natural Deployment 2020-2035

Figure 23 shows the Value Case for the Natural Deployment scenario from 2020-2035[4]. Table 12 shows the Value Case for the individual year 2023, and Table 13 displays the Value Case for the upscaled situation in the year 2030.

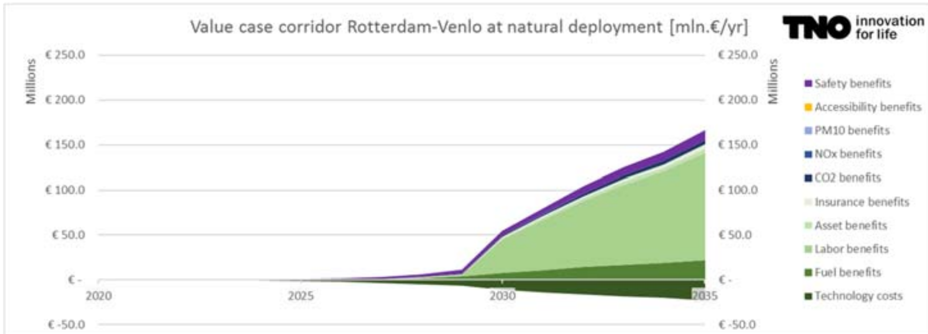


Figure 23: Value Case Truck Platooning: Natural Deployment 2020-2035*

(technology costs based on highly scaled up situation – no full business case evaluation performed)*

First, we find that truck platooning, at a Natural Deployment path, has a very positive and large total Value Case of almost 44 million EUR per year from 2029 and onwards – a total saving which constitutes a little almost 9% of the total corridor costs at 501 million EUR. However, it has to be noted that, based on the assumptions made, the Value Case only starts to become really big near 2030. This is mainly due to the assumption that that highly automated truck platoons (Stage 4, FOC platoons) are then becoming a reality, which really drives the business case. To emphasize this argument, we have included the Value Case for year 2029 in Table 11, which shows just how big the effect is moving from Mid-Term to Full Operating Capability platoons. The labor savings increase from about 2 million EUR in 2029 to over 38 million EUR in 2030. In the 2030 case with FOC, about 89 million platoon kilometers are then driven each year on the corridor by about 592.000 platoons that were formed on the corridor.

“In 2030, we estimate that 89 million platoon kilometers are driven each year on the corridor by about 592.000 platoons.”

That also implies that benefits from other sources such as fuel savings, CO_2 savings, NO_x savings, decreases in particulate emissions and insurance benefits do provide some value to the overall model, but it are the labor productivity improvements that really drive the business case to a positive state. Excluding the labor benefits, there is still a positive Value Case in 2030 where fuel savings (almost 7.5 million EUR annually) and increased traffic safety (approx. 5.1 million EUR annually) provide the strongest impulses. The aspect of accessibility and traffic throughput does not provide much value, which is a logical result from our reasoning in chapter 6 in which we stated that truck traffic intensities do not meet threshold values for any effect to be found anywhere along the whole corridor.

[4] Because we deal with many assumptions and estimations, corridor-level values cases are rounded to the nearest 000s. Kilometer-level values are rounded to two digits after the decimal, and truck-level values are rounded to the nearest whole number.

Also, apparent from Table 12, a positive Value Case is hardly existent in 2020. In our model, this implies that deployment of truck platooning has not taken off such that enough platoons are formed on the corridor and that benefits could eventually accrue. For the same reason, this also signals that the Initial Operating Capability (IOC) does not have a viable Value Case in 2023.

In sum, truck platooning can have a really positive Value Case, with also societal benefits driving the Value Case, but the main business case lies with parties in the logistics industry such as logistics service providers and shippers. These benefits mainly stem from labor productivity improvements and fuel savings, while society could benefit from reductions in CO_2 emissions and improvements in traffic safety due to the extensive use of advanced drivers assistance systems.

Table 12: Value Case Truck Platooning: Natural Deployment 2023 (MOC)[5]

Value Case result	Total [€/yr]	Per km [€/km]	Per truck [€/truck]
L1: Technology costs	-371.000	-0,04	-2.286
L2: Fuel savings	1.000	0,00	7
L3: Labor savings	1.000	0,00	4
L4: Asset savings	-	0,00	2
L5: Insurance savings	-	0,00	1
Total-Logistic case	**-369.000**	**-0,04**	**-2.272**
S1: CO_2 savings	-	0,00	2
S2: NO_x savings	-	0,00	-
S3: PM_{10} savings	-	0,00	-
S4: Accessibility	-	0,00	-
S5: Safety	210.000	0,02	1.293
Total-Society	**210.000**	**0,02**	**1.295**
Total	**-159.000**	**-0,02**	**-977**
	-		-
Platoon km's	1.000	0,00	6
Platoons (average length = 150 km)	7		-

[5] Safety has a positive result of 210k EUR, while the platoon km's is still low. This is due to the fact that all trucks with TP technology on board, are assumed to improve safety (and not all these trucks will drive in a platoon in this year).

Table 13: Value Case Truck Platooning: Natural Deployment 2030 (FOC)

Value Case result	Total [€/yr]	Per km [€/km]	Per truck [€/truck]
L1: Technology costs	-10.970.000	-0,05	-2.857
L2: Fuel savings	7.429.000	0,03	1.935
L3: Labor savings	37.830.000	0,17	9.853
L4: Asset savings	1.483.000	0,01	386
L5: Insurance savings	1.261.000	0,01	329
Total-Logistic case	**37.033.000**	**0,17**	**9.645**
S1: CO_2 savings	1.499.000	0,01	390
S2: NO_x savings	44.000	0,00	12
S3: PM_{10} savings	117.000	0,00	30
S4: Accessibility	1.000	0,00	-
S5: Safety	5.188.000	0,02	1.351
Total-Society	**6.849.000**	**0,03**	**1.784**
Total	**43.882.000**	**0,20**	**11.429**
	-		-
Platoon km's	88.812.000	0,41	23.131
Platoons (average length = 150 km)	592.000		154

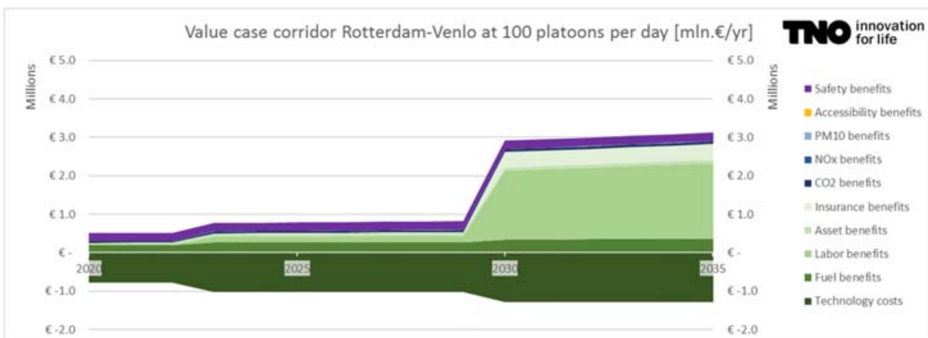
Table 14: Total Platooning Value Case for 2030 compared against total corridor cost in 2030

Natural deployment scenario			
Value case result	**2030 Truck Platooning savings**	**2030 Total Corridor Cost**	**TP savings / total corridor**
L2: Fuel savings	7.429.000	161.426.000	5%
L3: Labor savings	37.830.000	176.150.000	21%
L4: Asset savings	1.483.000	73.803.000	2%
L5: Insurance savings	1.261.000	18.945.000	7%
Total-Logistic case	**37.033.000**	**428.326.000**	**9%**
S1: CO2 savings	1.499.000	30.521.000	5%
S2: NOx savings	44.000	900.000	5%
S3: PM10 savings	117.000	2.381.000	5%
S4: Accessibility	1.000	26.825.000	0%
S5: Safety	5.188.000	12.969.000	40%
Total-Society	**6.849.000**	**73.596.000**	**9%**
Total	**43.882.000**	**501.922.000**	**9%**
	-		
Platoon km's	88.812.000		
Platoons (average length = 150 km)	592.000		

9.3 Results on the Value Case: Stimulated Deployment

The Roadmap Next Economy (RNE) of the Rotterdam–The Hague Metropolitan Area (MRDH) has stated the ambition to have 100 platoons driven daily on its public roads by 2020. In a way, this ambition can be thought of as a way of stimulating deployment of truck platooning as it could significantly pull deployment timelines forward. To that end, we calculated a Stimulated Deployment Value Case, which is specially geared towards the RNE ambition. Figure 24 shows the Value Case for the Stimulated Deployment scenario from 2020-2035[6]. Table 15 shows the Value Case for the individual year 2020 based on the Initial Operating Capability (IOC) and Table 16 displays the Value Case for a Mid-term Operating Capability occurring in 2020. Note that this scenario works completely differently than the one for the Natural Deployment scenario. That is because we model the effect of 100 platoons, calculated to be approximately equal to 450 outfitted trucks, on the chosen corridor. That means that the number of trucks is fixed to 100 platoons / 450 outfitted trucks, and the Value Case is calculated from Initial (IOC) to Full Operating Capabilities (FOC).

“The Stimulated Deployment scenario is based on accelerated deployment of 100 platoons or 450 trucks on the freight corridor.”



Costs of stimulation to be determined:
- Platooning technology cost per truck at scale
- Research and development for safety and efficiency assessments
- PPP-based deployment program execution, financing arrangements
- Physical infrastructure maintenance and adjustments
- Enabling digital infrastructure, road-side technology

Figure 24: Value Case Truck Platooning: Stimulated Deployment (RNE Ambition, 100 truck platoons, ~450 trucks)

Figure 24 shows the Value Case of stimulated deployment across the years, if the number of trucks remains fixed at 450 trucks. In 2030, for instance, the total Value Case for 450 trucks has benefits of about 3 million EUR and technology costs of about 1.2 million EUR. However, it is more interesting to analyze what stimulated deployment can do for the uptake of truck platooning in the shorter term.

[6] Because we deal with many assumptions and estimations, corridor-level values cases are rounded to the nearest 000s. Kilometer-level values are rounded to two digits after the decimal, and truck-level values are rounded to the nearest whole number.

Table 15 therefore, shows the Value Case for the stimulated deployment scenario at Initial Operating Conditions in 2020. The match rate in this case is set at 25% for 2-truck platoons and 5% for 3-truck platoons, which are match rates that we can expect at a local penetration degree of 450 trucks, based on the match rate discussion in section 4.2.

In the stimulated deployment scenario, about 9.3 million platoon kilometers are driven by over 60.000 distinct platoons on the corridor in 2020. As can be seen, this annual Value Case is slightly negative (-/- 257k EUR); the estimated high technology costs cannot be offset by business and societal value. The most important drivers of the Value Case here are fuel economy improvements (194k EUR) and traffic safety improvements (208k EUR). Also, as part of a sensitivity analysis, if we increase the match rate to 35% for 2-truck platoons and 10% for 3-truck platoons, the Value Case already moves into positive territory (10k EUR – see Table 11), based on over 13.9 million platoon kilometers driven on the corridor by over 93.000 platoons.

Note that no comments can be made about the cost of pulling deployment timelines forward as of yet, which would be an important factor to include in future studies. Therefore, it should be noted this is a not a complete business case. Costs associated with physical infrastructure, enabling digital infrastructure, accelerating deployment program et cetera have to be factored in for a full business case analysis.

“Future studies should establish a full business case analysis, including costs for pulling deployment timelines forward.”

Table 15: Value Case Truck Platooning: Stimulated Deployment 2020 (IOC)

Value Case result	Total [€/yr]	Per km [€/km]	Per truck [€/truck]
L1: Technology costs	-771.000	-0,02	-1.714
L2: Fuel savings	194.000	0,01	432
L3: Labor savings	-	-	-
L4: Asset savings	65.000	0,00	144
L5: Insurance savings	-	-	-
Total-Logistic case	**-512.000**	**-0,02**	**-1.139**
S1: CO_2 savings	42.000	0,00	94
S2: NO_x savings	1.000	0,00	3
S3: PM_{10} savings	3.000	0,00	7
S4: Accessibility	-	0,00	-
S5: Safety	208.000	0,01	462
Total-Society	**255.000**	**0,01**	**567**
Total	**-257.000**	**-0,01**	**-572**
	-		-
Platoon km's	9.315.000	0,30	20.700
Platoons (average length = 150 km)	62.000		138

Table 16 then shows the Value Case the Mid-term Operating Capability in 2020 (whereas Table 15 showed the IOC in 2020). This entails the same stimulation in uptake of platooning, however we add the potential driver productivity increases due to ability to take some breaks in driving vehicles. Essentially, this converts some working time into driving over the legally allowed 9 hours per day. Based on our conservative estimates of the actual amount of labor savings possible (see section 4.4), we see that changes to driving and resting time do add some additional value (130k EUR) to the annual Value Case. However the overall effect of this fairly far-reaching policy and legislative change is fairly limited. Still, labor savings then already are the third most important factor in the Value Case, after fuel savings and increased traffic safety. Also, it helps to bring the business case for the logistics industry closer to a break-event situation.

In sum, stimulating deployment of truck platooning can help to pull the business and societal values earlier in time. Stimulating can happen through amending legislations (to capture value from driving and resting times) and financing the initial negative case of deployment. Technically it will still take some years before SAE Level 3 systems will be available on the market, for which driving and resting time discussions will be the first viable application. Still, even for a relatively small number of truck such as 450 trucks in this study, at Initial Operating Capabilities, there would be potential for a positive Value Case if the platoon match rate is high enough, however within the first years the Value Case is negative. Also, no costs are included for pulling deployment timelines forward, which would make Value Case even more strongly negative. Still, This warrants additional public funding in order to ‘cross the chasm’, meaning to take the edge of the difficult first steps of deployment, such that larger societal benefit can be captured in the future.

Table 16: Value Case Truck Platooning: Stimulated Deployment 2020 (MOC)

Value Case result	Total [€/yr]	Per km [€/km]	Per truck [€/truck]
L1: Technology costs	-771.000	-0,02	-1.714
L2: Fuel savings	194.000	0,01	432
L3: Labor savings	130.000	0,00	290
L4: Asset savings	65.000	0,00	144
L5: Insurance savings	27.000	0,00	60
Total-Logistic case	**-355.000**	**-0,01**	**-789**
S1: CO_2 savings	42.000	0,00	94
S2: NO_x savings	1.000	0,00	3
S3: PM_{10} savings	3.000	0,00	7
S4: Accessibility	-	0,00	-
S5: Safety	208.000	0,01	462
Total-Society	**255.000**	**0,01**	**567**
Total	**-100.000**	**-0,00**	**-222**
Platoon km's	9.315.000	0,30	20.700
Platoons (average length = 150 km)	62.000		138

9.4 Net Present Value of Natural Deployment 2020-2035 scenario

When looking at the Net Present Value (NPV) of the Natural Deployment scenario in the period of 2020 up to 2035 we see a total NPV of 305m EUR (given an annual interest rate of 5%). Total society benefits are 46m EUR, while the logistic savings are 259m EUR (including the investment in technology costs of approximately 68m EUR).

Table 17: Value Case Truck Platooning; Net Present Value (2020): Natural Deployment

Value Case result	Total [mln €]	
L1: Technology costs	€	-68,37
L2: Fuel savings	€	53,27
L3: Labor savings	€	254,10
L4: Asset savings	€	10,87
L5: Insurance savings	€	9,77
Total-Logistic case	€	**259,63**
S1: CO_2 savings	€	10,54
S2: NO_x savings	€	0,31
S3: PM_{10} savings	€	0,82
S4: Accessibility	€	0,01
S5: Safety	€	34,01
Total-Society	**€**	**45,69**
Total	**€**	**305,33**

9.5 Limitations of the Value Case

The current setup of this Value Case of truck platooning has some limitations, most of them already mentioned earlier in the text. Table 18 provides an overview of the most important limitations, and recommendations how to address these limitations in later endeavors.

Table 18: Limitations of the Value Case and recommendations to address the limitations

Aspect	Limitation	Recommendation how to address limitation
A priori analysis	The Value Case is based on current (a priori) state-of-the-art knowledge about the potential value of truck platooning. Some values are well established in the literature such as fuel savings based on test-track studies in European projects such as SARTRE. For other value elements such as accessibility and traffic safety, this Value Case is a first attempt to quantify potential effects based on a thorough and detailed analysis. This means that this Value Case is based on	Pilot studies or field trials can provide empirical data for the value elements. Research to gather this data should follow the deployment path, that is, research should not be put on the critical path, but should happen in parallel with the deployment process that puts vehicles on the road.

	estimations to the best of our knowledge, and without the benefit of a long track record of empirical and real-life data collection and analysis for some value elements.	
Limited cost information included	This Value Case only includes costs factors of deployment to a limited extent. Not much is currently known and only costs directly associated to platooning technology in the vehicle are included in the analysis. Additional digital or physical infrastructure, such as road-side units or LTE V+ types of cellular communications infrastructure may be required at higher penetration levels of truck platooning but are not included in the cost estimations.	Execute full business case analysis with all parties in the value chain that have a direct or indirect interest in the large-scale deployment of truck platooning such as truck OEMs, shippers, logistics service providers, insurers, mobile network operators, road operators et cetera.
Indirect compounding and collateral effects	Truck platooning may benefit from positive compounding or collateral effects such as additional uptake of C-ACC for passenger cars having a strong influence on accessibility and traffic throughput. We have not modeled these to keep the focus on the value of truck platooning.	Regional and national authorities should aim to execute integrated/inclusive studies that model the (interactive) benefits of Smart Mobility and ITS innovations for a road, motorway or road network concurrently. Such analyses could use the SimSmartMobility platform.
Match-rate based on freight traffic intensities	We base the match-rate in our Value Case model on freight traffic intensities at certain cross-sections along the corridor, which leads to having to estimate average platoon kilometrages	Micro-simulations based on geo-spatial data from multiple large transport fleets can provide more robust evidence on lower- and upper-bound thresholds for the match-rate
Representativeness	In this study, we take a corridor approach and model one freight-intensive corridor. The results, however, are not representative for other corridors, which may have different traffic and truck intensities for instance	Future studies can apply our model for other corridor studies without significant changes to the model necessary.
Multi-brand factor	We base our Value Case model principally on a situation where multi-brand platooning is possible and we calculate the full platooning potential. Potential additional safety margins for multi-brand platoons (over mono-brand platoons) – and thus lower savings potentials - have not been taken into account	Results from the future ENSEMBLE project and Sweden4Platooning projects could perhaps provide additional details on this matter.
Distinguishing truck platooning benefits	Our approach for assessing the potential safety benefits from truck	Transport insurance firms, governmental parties and research

from other active safety systems	platooning is not able to precisely pinpoint the net benefit of truck platooning from other active safety systems. Our analysis therefore takes the benefit of mandatory AEB and LKA systems, together with the V2V communicating capabilities of truck platooning	organizations should jointly aim to investigate the net benefits of AEB, LKA and platooning systems on traffic safety. Analysis should try to include influences of following distances and also estimate near-incidents that were prevented.
Major 'black swans' that are going to happen in the next decade(s)	We principally model truck platooning until 2035. That is a long time away, with many very disruptive innovations potentially happening. Think of fully-electric price-competitive long range trucks, nuclear fusion power for electricity generation, drone deliveries et cetera. Such 'black swans' cannot be estimated and are therefore not included in the Value Case model	Electrification of heavy-duty transport could be considered in a full business case analysis as a potential competitive trade-off, with lower costs per kWh decreasing the importance of the fuel savings in this Value Case.

10 Recommendations: courses of action for truck platooning deployment based on the Value Case

Truck platooning deployment is potentially very valuable in the long run, as evidenced by the Natural Deployment Value Case (see Figure 23). Still, that is a long time away, so in this chapter we aim to provide some guidelines and courses of action in order for businesses and society to be able to capture the potential value of truck platooning earlier in time based on active stimulation.

Based on the Value Case calculations in the previous chapter, we have developed four main courses of action that can stimulate the deployment of truck platooning (see Figure 25).

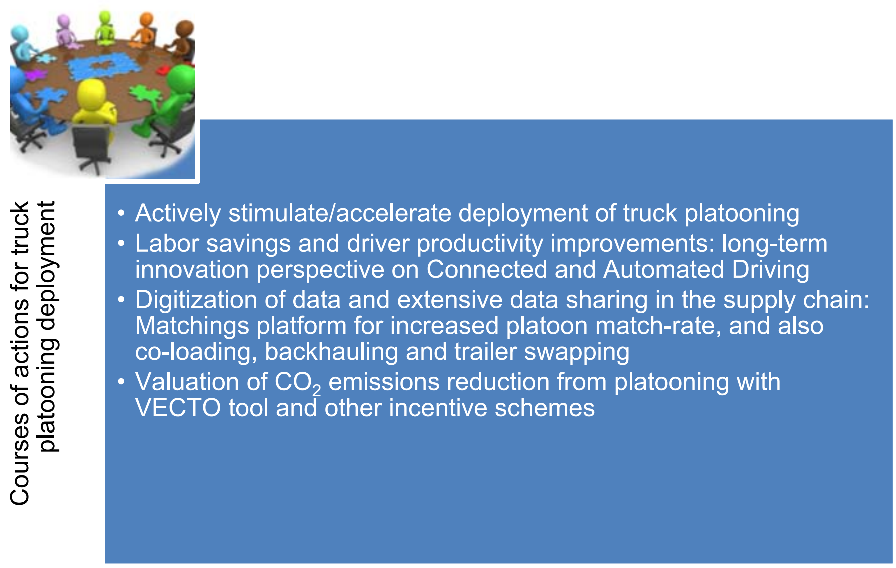


Figure 25: Courses of actions for truck platooning deployment

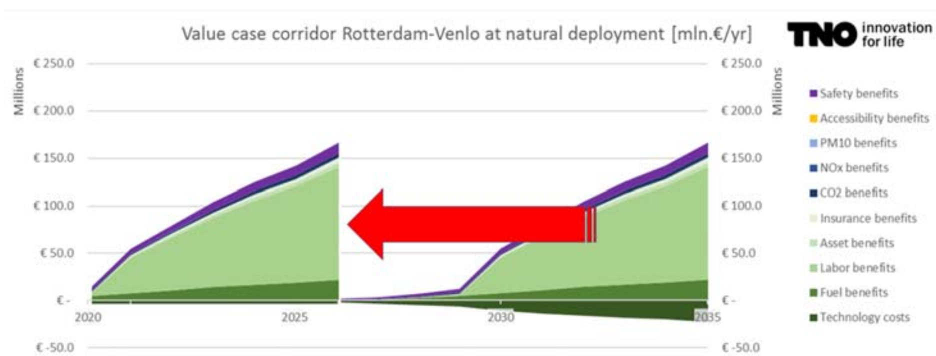
10.1 Actively stimulate/accelerate truck platooning deployment

The Value Case shows that truck platooning has a long-term attractive Value Case (annually almost 44m EUR in 2030, Net Present Value of 305m EUR for 2020-2035) on its own, independent of other developments following a Natural Deployment path. Truck platooning mainly drives benefits for parties in the logistics chain with potential labor savings and fuel savings, and improved asset utilization and lower insurance premiums to a lesser extent, being the main variables of interest here. Also, we expect traffic safety to improve due to the increased use of active safety systems of which truck platooning can be considered a part. Finally, CO_2 and other harmful emissions reduce, thanks to the application of truck platooning technology, although these benefits do not represent strong financial value as of yet.

Potential drawbacks identified in this study are mainly in the area of increased strain on the infrastructure, especially on bridges and with regard to tracking/rutting of asphalt, but no concrete empirical and quantified findings are yet available, even though these are major for road operators. Similarly, we were unable to identify positive effects of truck platooning on accessibility and traffic throughput, but at the same time strong negative effects are not something we can currently firmly establish from the literature.

These values make truck platooning an attractive technology with limited foreseen drawbacks, with the slow Natural Deployment path being something to address by actively stimulating uptake of platooning technology. This brings the benefits of platooning closer in time. The quantification of the value elements of truck platooning in this study therefore provide a rationale for public and private parties to consider (continuing) investing in the active deployment of truck platooning technology. Especially, it should be noted that the Value Case is still negative for the initial years with break-event point taking longer than usually applied timelines for returns on investment analysis. This means that financing should be made available that can help bridge that gap and speed up deployment.
Also, along the way, additional empirical investigations into potential drawbacks can be made, such as the potential adverse consequences on infrastructure, traffic flow et cetera. These analyses should not be put on the critical path, as long as safety is guaranteed, as it would function as roadblocks impeding progress and losing momentum, rather than providing informed opinions on how truck platoons should actually be deployed. Rather, the research can be programmed in parallel to the large-scale roll-out of truck platooning, using iterative small steps in policy development and regulatory enforcement.

Complementary technological innovations can be developed in conjunction with truck platooning deployment that also address current driver shortages and focus on goals of less emissions, better accessibility and traffic flow and/or improved traffic safety. For heavy-duty vehicles, one can think of longer High-Capacity vehicles such as 32 meter combinations (2x 13.60m trailers behind a single tractor) or automated docking using hybrid drivelines and e-Dollies in the trailers.



Costs of stimulation to be determined:

- Platooning technology cost per truck at scale
- Research and development for safety and efficiency assessments
- PPP-based deployment program execution, financing arrangements
- Physical infrastructure upkeep and adjustments
- Enabling digital infrastructure, road-side technology

Figure 26: Actively stimulate deployment of platooning by moving timelines forward

10.2 Labor savings and driver productivity improvements: long-term innovation perspective on Connected and Automated Driving

The various Value Cases of Truck Platooning clearly emphasize when the largest benefits of truck platooning can be captured: if labor savings are part of the Value Case. This is no surprise as labor costs currently can make up 50% of the total operating cost of a truck. Labor cost savings only accrue from SAE Levels 3 and upwards, denoted as Mid-term (MOC) and Full Operating Capabilities (FOC) in this study. However, the truck manufacturers are not there yet in their product development cycles. Whereas Scania and Toyoto-Tsusho are tasked with developing driverless following platoon vehicles in an assignment for the Singaporean Port Authority PSA (Scania, 2017), the ACEA truck platooning roadmap (ACEA, 2017) for deployment thus far focuses on SAE Level 2 multi-brand truck platoons commercialization by 2023, with no further specific timeline for other SAE Levels.

We see this as a potential chicken-and-egg problem: if the logistics industry does not adopt truck platooning technology in their fleets, the truck manufacturers will not keep innovating such that SAE Level 4 will be reached. And the other way around, if vehicle manufacturers stop developing their truck platooning systems after reaching SAE Level 2 the full benefits of truck platooning technology will not accrue to logistics services providers and shippers. This mutual dependence is a key challenge that is not easy to solve such that this chicken-and-egg problem does not occur.

Policy-oriented action could be taken to be able to have some labor savings benefits accrue earlier in time especially with regard to driving and resting time legislation. Willingness and political support to pilot with amendments to this legislation (and dealing with the potential backlash from driver lobbies) may show goodwill to the vehicle manufacturers that need to continue investing in platooning technology. At the same time, it creates additional financial incentives for the logistics industry to consider large-scale investments in platooning technology across fleets, reaching the needed high penetration rates to capture the full benefits of the technology. Finally, while we admit the potential threat of platooning technology toward job security of truck drivers, we can just as easily foresee a future role of the truck driver similar to an aircraft pilot who is in control of extensive and reliable autopilot/cruise control systems, but keeps adding significant value to freight transport operations while loading and unloading cargo and performing diverse tasks while driving. At the same time, this might alleviate safety risks of boredom and lack of attention by truck drivers driving long stretches of motorways, especially if supported by systems that reduce the dynamic driving tasks such as platooning technology (VIL, 2017). In that sense, policy-oriented action could focus on seeing truck platooning as a test case for evaluating future roles of truck drivers and the emergence of automation and robotics in the transport industry.

10.3 Digitization of data and extensive data sharing in the supply chain: Matchings platform for increased platoon match-rate

As becomes apparent from the Value Case, the match-rate is very important to capture the benefits from platooning.

A slight increase in match-rate effectively improves the numbers of kilometers driven in platoon formation across the corridor, and enables benefits from truck platooning technology to happen.

Increasing the match-rate is not at all easy. The match-rate heavily relies on high numbers of vehicles outfitted with interoperable (multi-brand) platooning technology, and the ability to exchange real-time operational data across fleets of transport companies and to act upon this information. With additional challenges with regard to data access rights, cyber security and privacy. In essence, truck platoon matching requires significant digitization of data and sharing of data across actors in the supply chain. For instance data about exact geo-spatial locations of trucks, delivery destinations, delivery times and time windows, cargo information, vehicle performance, driver schedules, and insurance records. The logistics industry is currently undergoing the digital transformation from using telephone, e-mail and paper forms towards standardized digital information usage from multiple sources (vehicle sensors and CANBUS data, digital tachograph, transport orders and e-waybills, fleet management systems, transport management systems, traffic management systems, road infrastructure messages, etc.), but the industry is not there yet.

The value of this digital transformation extends benefits of truck platooning alone. Whereas matchmaking to form platoons is a useful application, as witnessed by the effect of the match-rate on platoon formation, this data exchange and data fusion has other highly attractive applications. Think of jointly bundling cargo, sometimes referred to as co-loading (see Figure 27), or arranging return trips (back-hauling) to minimize empty running. Even complete container or trailer loads, sometimes referred to as street turns, can be swapped between transport companies. These initiatives are not new – indeed the Dutch Topsector Logistics actively invests in the so-called Cross Chain Control Centers (4C) roadmap to strengthen horizontal collaboration for backhauling and co-loading in logistics, and in the iSHARE and OpenTripModel initiatives to standardize data exchange and sharing in logistics. At the same time, many of the ICT firms developing such matching solutions have not yet reached very large customers bases as of yet, which leaves valuable optimization potential.

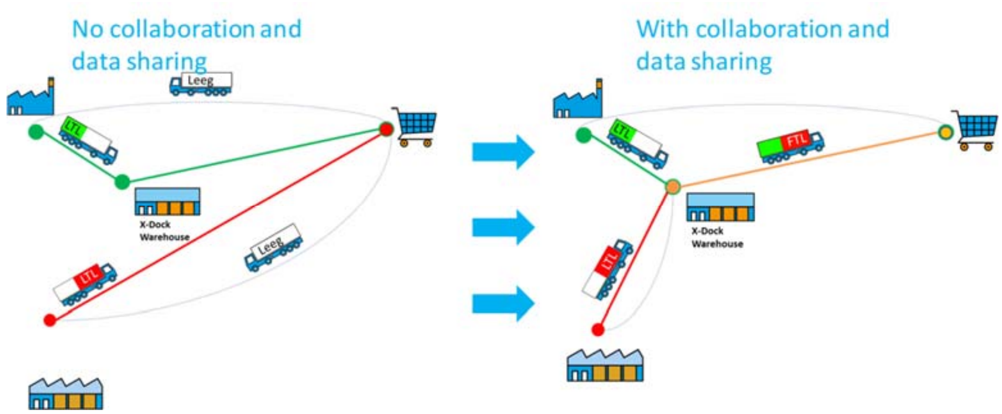


Figure 27: Example of co-loading – a form of cargo bundling - facilitated by data exchange and collaboration

For instance truck platooning is expected to lead to 4-16% fuel savings for kilometers driven as platoon, whereas cargo bundling can lead to 10+% reductions in empty kilometers, and about the same for trailer swapping. Yet, these are the independent benefits; the real impact develops if all services are used in an integrated way, changing whole supply chains. In our vision, trucks will be filled to the brim by bundling loads, then drive as a semi-automated truck platoon to their destination, picking up an additional trailer on the way and minimizing empty running. Then we would see improvements of over 30+% in transport efficiency. Eventually, the benefits of these combined measures could make it so attractive that transport flows move to other times of the day, for instance to night times. Then measurable impacts on accessibility and traffic throughput could be expected. It will take time to reach this, restricted by technological advancement and by behavioral aspects. For instance, truck platooning technology is on the brink of being rolled-out across Europe, but based on the Value Case results it will take quite some years before large-scale adoption has taken place. Cargo bundling and trailer swapping services can reach large scale impact at an earlier timeframe, but requires a challenging mental shift in the willingness of people to collaborate across company boundaries, share sensitive operational data, and breaking with competitive interests and pressures. Still, we could see truck platooning as the breakthrough technology where logistics, vehicle and traffic information come together for the first time.

10.4 Valuation of CO_2 emissions reduction from platooning with VECTO tool and other incentive schemes

The Value Case shows that fuel savings and corresponding CO_2 emissions can be reduced quite significantly over time. However, while the fuel savings hold quite some value for the logistics parties, it does not yield a lot of societal value yet. This is mainly due to the fairly low financial value of a ton of CO_2 at current price levels. The large-scale deployment of truck platooning, and thus releasing less CO_2 emissions into the atmosphere, can benefit from an increased valuation of CO_2. The key instrument towards that end on a European scale is through the VECTO tool (VECTO, 2017).

Since 2010, the European Commission has been developing a computer-based vehicle simulation tool called VECTO, which will model CO_2 emissions from a wide variety of truck and trailer configurations, with a focus on the heavy-duty and long-haul segment. VECTO will provide vehicle-specific CO_2 figures for various operational and mission profiles, taking into account variables such as specific usage patterns, vehicle configurations and different payloads. With VECTO, transport operators and logistics service providers will be able to choose the most fuel-efficient vehicle more easily, based on a standardized way of comparing fuel efficiency.

The intended use of VECTO will be to certify, report and monitor CO_2 emissions of newly-registered heavy-duty vehicles. Once this legislation is in force, the most apparent option is to set mandatory limits on average CO_2 emissions from newly-registered vehicles, similar to what is already happening for passenger cars and vans (that is, having lower taxation rates for vehicles with lower emissions).[7]

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[7] Van Zyl, S., et al. (2017). Great challenges lie ahead for low-carbon long-haul transport, TNO 2017 R10953

In our Value Case, transport and logistics companies do have trouble finding a positive business case for procuring truck platooning technology in the initial years. The low financial value of CO_2 does not help towards solving that solution. However, if truck platooning becomes adopted in the VECTO tool as a measure to lower the vehicle-level CO_2 emissions, it would function as an additional driver that effectively increases the valuation of CO_2 emissions. To that end, deployment of truck platooning technology can really be stimulated by means of societal CO_2 emissions reductions, by means of including truck platooning as measure in the VECTO tool to help solve the negative consequences of CO_2 emissions. Also, increasing valuation of CO_2 also functions as safeguard to maintain the attractiveness of truck platooning technology, if platooning system capabilities do not grow beyond Stage 1 or 2 at later times.
Before truck platooning is taken up in the VECTO tool, its performance and reliability in saving CO_2 emissions needs to be clearly demonstrated. Field trials and pilots across Europe in different locations and different circumstances would be plausible courses of action to pursue, in which CO_2 reduction rates determined in VECTO should be validated and replicable, and the operations should closely resemble those of the final customers being transport operators and logistics service providers.

On a national level, other incentive schemes can be considered. For the Netherlands, the 2017 coalition agreement for the Rutte III cabinet mentions additional mileage-based taxation of heavy-duty vehicles (Kabinetsformatie 2017, 2017). Truck platooning could be incentivized as a measure to reduce such taxations. A similar argument could be considered for the Eurovignet which is also taxation applicable to heavy-duty transport in the Netherlands, Luxemburg, Sweden and Denmark (Ondernemersplein.nl, sd).

10.5 Benefits per stakeholder category and potential roles in deployment path

The following section briefly details expected impacts per stakeholder group, and potential actions that this type of stakeholder can take in a scenario for stimulated deployment. This list is by no means complete, but serves as initial starting point.

Table 19: Benefits and impacts per stakeholder category and potential roles in deployment path

Type of organization	Expected benefits/impacts per stakeholder and role in deployment
National government / ministries	Benefits / impacts: • Better traffic safety and less emissions from heavy-duty transport, • Improved competitiveness of transport sector, • Attractiveness of the Netherlands as key region of deployment for smart mobility innovations, • Physical infrastructure impacts unsure. Actions: • Allocate multimillion EUR budget for public-private partnership program to deploy truck platooning, urge private sector to co-finance as well, • Initiate studies on driver state during platooning operations and open discussions on local/national amendments and exemptions on driving and resting times legislation Strive for harmonized legislation across Europe, • Contemplate inclusion of platooning in VECTO tool or other incentivization schemes,

	• Strive for European-wide collaboration and harmonization and sharing of knowledge.
Regional governments / provinces	Benefits / impacts: • Better traffic safety and less emissions from heavy-duty transport. Actions: • Develop positive attitude towards large-scale experimentation with truck platooning on specifically assigned provincial roads, • Investigate the interaction of platooning with other C-ITS technologies such as green light priority (GLOSA) systems and others, • Examine the interaction of platooning with cooperative and automated cars in to improve accessibility and traffic flow on key provincial roads.
Road authorities	Benefits / impacts: • Better traffic safety and less emissions from heavy-duty transport • Traffic flow improvements are not necessarily expected. Actions: • Conduct research to quantify the impact of platooning on physical infrastructure (bridges, pavements, et cetera) and assess the trade-off in deployment versus costs of maintaining infrastructure, • Investigate potential interfacing between platooning systems and C-ITS applications such as intelligent traffic lights for improved traffic flow in non-motorway environments (GLOSA, green light optimized speed advisory).
Vehicle approval authority	Benefits / impacts: • Better traffic safety and less emissions from heavy-duty transport, • Learn from attractiveness and ‘first-mover’ advantages of the Netherlands as key region of deployment for smart mobility innovations. Actions: • Encourage testing and deployment of automated vehicles on public roads and develop certification schemes, • Strive for harmonization of vehicle admission legislation across European members states.
Vehicle manufacturers (OEM) and automotive tier suppliers	Benefits / impacts: • Accelerated return-on-investment of platooning technology, • Improved fuel efficiency and safety perception of heavy-duty freight transport, • Positive public attention based on automation, safety and emissions advantages. Actions: • Ascertain multi-brand interoperable platooning technology availability, • Further develop platooning technology towards higher technical capability levels (Stage 3 / Stage 4 capabilities) , • Engage in testing on public roads in the Netherlands to validate operational performance of platooning systems, especially with regard to safety and fuel efficiency, • Develop business models and concepts for large-scale deployment, • Lobby for incentivization of truck platooning, for instance by inclusion of the VECTO tool.
Logistics service providers /	Benefits / impacts: • Long-term strong savings potential (almost 10%) based on labor cost reductions, fuel efficiency and safety,

transport firms / logistics branch organizations	• Digitization of transport operations for platoon matchmaking will benefit other parts of logistic operations too, • Positive public attention for heavy-duty transport operations based on automation, which requires sector-wide collaboration rather than competition, • Potential backlash of driver lobbies due to focus on increased automation of vehicles. Actions: • Organize the industry around the topic of truck platooning, develop innovation funds, identify willingness to test and deploy platooning vehicles, • Improve willingness and ability to share and use real-time data across companies and fleets in order to be able to capture maximum benefits from platooning-equipped vehicles, • Consider how the logistics sector can participate in system-wide transitions such as platooning, and mitigate concerns of free-riding and unequal investments, • Actively support and co-finance testing and deployment of platooning technology, teaming up with their customers (shippers and receivers) and other transport firms and logistics service providers,
Shippers	Benefits / impacts: • Long-term strong transport savings potential based on labor cost reductions, fuel efficiency and lower emissions and safety, • Digitization of transport operations for platoon matchmaking will benefit other parts of logistic operations too. Actions: • Conduct network studies to analyze implicit potential of platooning savings in logistics network in order to base investment decisions on, • Actively support and co-finance testing and deployment of platooning technology, teaming up with their principal transport and logistics service providers.
Telematics / fleet management / mapping providers	Benefits / impacts: • Potential for business model based on platoon coordination and matchmaking, based on real-time data use, analysis and exchange across companies, fleets and platforms. Actions: • Enable the logistics industry to improve real-time data use, analysis and sharing based on industrial standards and solid privacy/data protection, • Develop map-independent solutions that enable real-time platoon matchmaking services across companies, fleets and platforms.
Insurance firms	Benefits / impacts: • Better traffic safety and less accidents from heavy-duty transport, • Better information about accidents based on use of event data recorders for automated systems such as truck platooning, • Long-term uncertainty about business model of insurance firm since strong improvements in traffic safety may adversely influence need and willingness to pay insurance premiums. Actions: • Conduct research to quantify the impact of platooning systems on traffic safety, decomposing the effect of platooning systems from legally required AEB and lane keeping systems.

Digital infrastructure providers	Benefits / impacts: • Accelerated truck platooning deployment may function as additional use case for the deployment and financing of enabling digital infrastructures (cellular LTE+ connectivity, Mobile-Edge Computing, etc.). Actions: • Quantify value-adding potential, benefits and costs of enabling digital infrastructure and deploy initial versions of enabling digital infrastructure on/along deployment corridors.
Port authorities	Benefits / impacts: • Better traffic safety and less emissions from heavy-duty transport, • Attractiveness and competitiveness of the Netherlands and its ports, • Road authority perspective: physical infrastructure impacts unsure. Actions: • Encourage uptake of platooning in multimodal environments and port areas, • Conduct research to quantify the impact of platooning on physical infrastructure (bridges, pavements, et cetera) and assess the trade-off in deployment versus costs of maintaining infrastructure, • Assess integration of platooning vehicles in overall port-hinterland systems and ensure end-to-end supply chain optimization based on platooning.
Knowledge institutes	Benefits / impacts: • Attractiveness and competitiveness of the Netherlands by leading in deployment of truck platooning and other automation innovations. Actions: • Facilitate public-private partnerships and knowledge programs around truck platooning to ensure knowledge exchange and system-wide collaboration, • Interface with European initiatives and projects for knowledge sharing, • Independent analysis of large-scale truck platooning deployment on logistics systems integration, traffic safety, traffic flow, real-world emissions, driver state, cyber security, et cetera, • Further development of incremental and disruptive innovations for improved traffic flow, reduced emissions and increased traffic safety.

11 Conclusions

Summarizing, the Value Case Truck Platooning has delivered the insight that truck platooning, on its own, is an attractive technology for large-scale deployment. However, some challenges have to be overcome, such as speeding up the course of deployment and various legislative/policy topics such as labor costs incentives and having truck platooning be included in the VECTO tool. Also, the eventual effectiveness of truck platooning technology resides for a large part in the number of platoons that can be formed, which resides with the willingness and ability of transport companies and logistics service providers to exchange data in order to increase the platoon match-rate.
Also, there are uncertainties into how truck platooning will evolve as technological solution, how society will adopt and adapt to the technology, and how policy and regulations will come into play. To that end, it is clear that there is still a lot of work to be done.
In the end, it is not just about truck platooning as a goal on its own, but about a way to develop an efficient, safe and sustainable automated logistics system (Figure 28). Truck platooning is in a way a first application where digitization and automation in logistics come together. Truck platooning has a strong Value Case on its own with attractive value for businesses and improvements in traffic safety and decreases in emissions in the long-term (44 million EUR in 2030 on the freight corridor). Further investments in truck platooning also pave the way for further R&D investments in vehicle technology to reach higher automation levels, unlocking stronger Value Cases for businesses and societies. The Value Case also shows that impacts on accessibility and traffic flow are not as significant as perhaps expected. The large-scale sharing of data needed for matching of platoons can also be used for bundling loads, exchanging containers and trailers or execute backhauls, which could really help to lower CO_2 emissions and improve traffic throughput by being able to shift loads to other (less congested) times of the day. Still, the attractiveness of truck platooning on its own, and its potential for making transport and logistics safer and more efficient is such that further stimulated large-scale deployment is recommended.

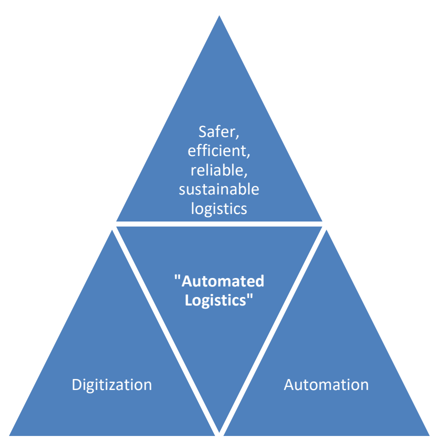

Figure 28: Automated Logistics: convergence of digitization and automation for safer, more efficient, more reliable and more sustainable logistics

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13 Appendices

Overview of all appendices:

A) Adoption rate
B) SAE levels of automation
C) Truck Platoon Operational capability
D) Current traffic situation on the Rotterdam-Venlo corridor
E) Current safety situation on the Rotterdam-Venlo corridor
F) Reduction in fuel consumption
G) Trends in truck fuel consumption
H) Optimizing fuel, waiting, and travel time costs for scheduled and on the fly platoon matching
I) Productivity of assets
J) Cost of platooning technology
K) Division of costs for logistic service provider
L) Insurance costs

A) Adoption rate

Adoption is defined by Rogers (1983) as the decision that full use of an innovation is the best course of action available. The rate of adoption is the relative speed at which an innovation is adopted by members of a social system (Rogers, 1983). For truck platooning, this rate of adoption heavily impacts the number of possible platoon matches and therefore the net result a Logistics Service Provider (LSP) might obtain from truck platooning. There are four main factors influencing the adoption of truck platooning: the adoption rate itself, development of related technologies, the depreciation rate of the fleet of trucks, government regulation, and the adoption rate itself.

First, the adoption rate has a reinforcing effect on itself. The higher the adoption rate, the higher the net benefit for an LSP, and thus the more likely an LSP will invest in truck platooning technology. This process was first defined by Rogers (1983) in a framework that is now known as the five stages of customer adoption.

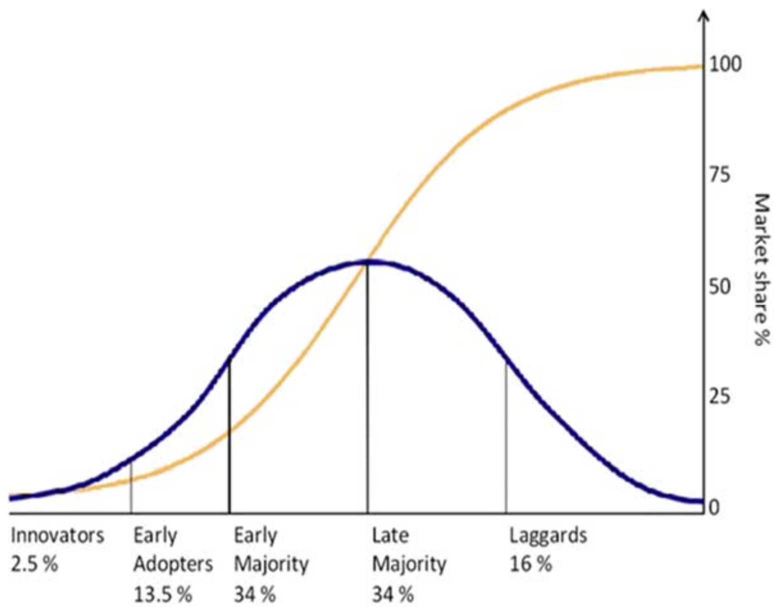

Figure 29: Five stages of customer adoption

Roger's graph shows that adoption accelerates once a critical group of innovators, representing 2.5% of the market, has adopted the technology. Initially large LSPs, harbor- and transport authorities, Original Equipment Manufacturers (OEMs), relevant government bodies, knowledge institutes, and other stakeholders will have to push to reach this critical 2.5% market share.

Litman (2017) expanded Roger's concept to automated vehicles and drew the following curve to predict the market share of automated vehicles over time. His predictions are based on the development of adoption rates of previous vehicle technologies such as automatic transmissions.

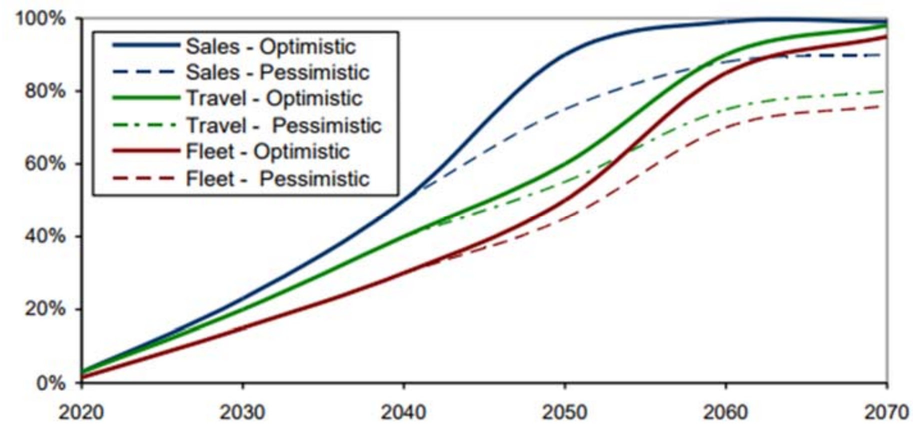

Figure 30: Market share of automated vehicles over time

According to Litman's predictions, in 2040 autonomous vehicles will represent 50% of all vehicles sold, 30% of the entire vehicle fleet, and 40% of all vehicle traffic. Note that adoption accelerates as in 2050 more than 50% of the vehicle fleet will be autonomous.

Second, truck platooning is not a stand-alone technology. Autonomous driving requires the same technology as is needed for truck platooning. The European Transport Safety Council (ETSC, 2016) and OEM's, like Scania (Scania Group, 2016) argue that truck platooning is a first step towards full autonomous driving. As new technologies are added to trucks the cost barrier towards truck platooning will decrease. For example, Lane Departure Warning (LDW) and Advanced Emergency Braking (AEB), which are two required technologies for truck platooning, are now part of the default set of features on new Scania trucks.

Third, the speed of vehicle renewal has an important effect on the implementation of new technologies. According to TNO (Heijne, 2015) the average export age of trucks in The Netherlands is seven years. This suggests that LSPs (logistics service provider) renew their trucks when these are on average seven years old.

Last, government can heavily influence the adoption rate with subsidies or legislation. For example, the European Commission (European Commission, 2009) published new legislation that required AEB and LDW for all new trucks and buses sold after 31st of October 2015.

B) SAE levels of automation

SAE International (2014) proposes a standard for automated driving (J3016), which defines 6 levels of automation. These levels are displayed below (see Figure 31).

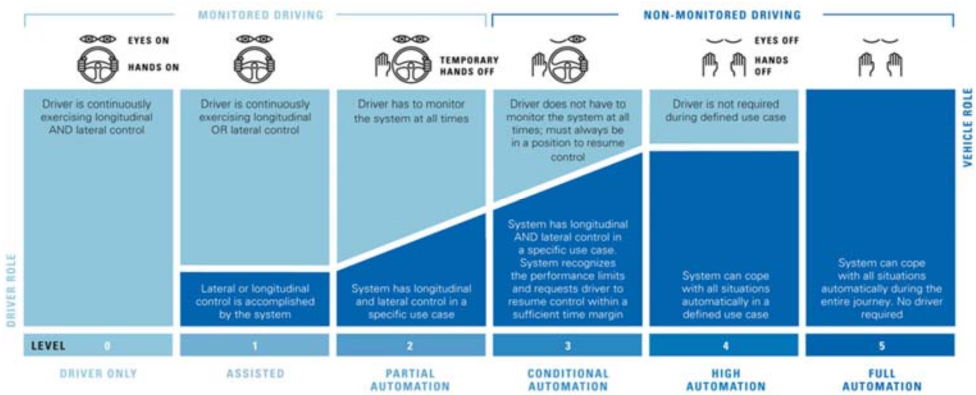

Figure 31: SAE levels of automation (Smith, 2016).

Truck platooning is possible from SAE Level 1 onwards. The SAE Levels are defined with autonomous vehicles in mind. These are useful when assessing the capabilities of a truck platooning system, but are not fully adequate. However, we do explain the SAE Levels in this section for completeness.

According to SAE (SAE International, 2016) the level of automation allowed by an autonomous vehicle systems may be assessed on the basis of four aspects:

1. Dynamic Driving Task (DDT)
2. DDT fallback
3. Object and event detection, recognition, classification, and response (OEDR)
4. Operation Design Domain (ODD)

In general, with each and every SAE level upwards, the role of the driver becomes smaller and the role of the system becomes larger. We will explain the technical language in more detail below (using Table 20).

Table 20: SAE levels of automation in relation to aspects of autonomous vehicle systems

Level	Name	Narrative definition	DDT: Sustained lateral and longitudinal vehicle motion control	DDT: OEDR	DDT fallback	ODD
Driver* performs part or all of the *DDT						
0	**No Driving Automation**	The performance by the *driver* of the entire *DDT*, even when enhanced by *active safety systems*.	*Driver*	*Driver*	*Driver*	n/a
1	**Driver Assistance**	The *sustained* and *ODD*-specific execution by a *driving automation system* of either the *lateral* or the *longitudinal vehicle motion control* subtask of the DDT (but not both simultaneously) with the expectation that the *driver* performs the remainder of the *DDT*.	*Driver* and *System*	*Driver*	*Driver*	Limited
2	**Partial Driving Automation**	The *sustained* and *ODD*-specific execution by a *driving automation system* of both the *lateral* and *longitudinal vehicle motion control* subtasks of the *DDT* with the expectation that the *driver* completes the *OEDR* subtask and *supervises* the *driving automation system*.	***System***	*Driver*	*Driver*	Limited
***ADS* ("*System*") performs the entire *DDT* (while engaged)**						
3	**Conditional Driving Automation**	The *sustained* and *ODD*-specific performance by an *ADS* of the entire DDT with the expectation that the *DDT fallback-ready user* is *receptive* to *ADS*-issued *requests to intervene*, as well as to *DDT performance-relevant system failures* in other *vehicle* systems, and will respond appropriately.	*System*	***System***	*Fallback-ready user (becomes the driver during fallback)*	Limited
4	**High Driving Automation**	The *sustained* and *ODD*-specific performance by an *ADS* of the entire *DDT* and *DDT fallback* without any expectation that a *user* will respond to a *request to intervene*.	*System*	*System*	***System***	Limited
5	**Full Driving Automation**	The *sustained* and unconditional (i.e., not *ODD*-specific) performance by an *ADS* of the entire *DDT* and *DDT fallback* without any expectation that a *user* will respond to a *request to intervene*.	*System*	*System*	*System*	**Unlimited**

At Level 1 the system automates either acceleration and braking or steering. As such it takes over part of the DDT. In addition, the driver continuously monitors the environment (OEDR) and thereby functions as the “fallback” in case of system failure. This limited form of automation restricts the number of roads and circumstances in which the system can be activated (ODD).

Level 2 automation is achieved when *both* longitudinal (acceleration and braking) and lateral control (steering) are automated by the system. This may sound as if the vehicle is ready to drive completely on its own, but in reality the system cannot guarantee to accelerate, brake, and steer forever. This means the driver needs to monitor the vehicle (OEDR) and the environment. The driver functions as a fallback whenever the system stops, and the driver has full responsibility. As such the driver is actively *driving* or at the very least “fully in the loop.

At Level 3 the system takes over the dynamic driving tasks of acceleration, braking and steering for a certain amount of time. Theoretically speaking, the driver is now able to go ‘out of the loop’, that is, not actively being busy with driving.

However, the driver is still responsible for fallback operations whenever the system reaches its limits.

At Level 4, a driver may be out of the loop for as long as (s)he wishes, but only as long as the vehicle functions in the area and circumstances for which it was developed (ODD). Truck platooning at Level 4 would allow following vehicles to drive fully automated, but only on highways and motorways and not in city areas.

Finally, at Level 5, the system is able to cope with any situation without expecting human intervention.

C) Truck Platoon Operational capability

Truck platooning requires a certain level of automation functions to allow for (semi-) autonomous driving. Litman (2017) identifies the following vehicle equipment and service requirements for autonomous vehicles:

1. Automatic transmissions.
2. Diverse and redundant sensors (optical, infrared, radar, ultrasonic and laser) capable of operating in diverse conditions.
3. Wireless networks. Short range systems for V2V communications, and long-range systems to access maps, software upgrades, road condition reports, and emergency messages.
4. Navigation, including GPS systems and special maps.
5. Automated controls (steering, braking, signals, etc.).
6. Servers, software and power supplies with high reliability standards.
7. Additional testing, maintenance and repair costs for critical components such as sensors and controls.

The EcoTwin consortium (Bijlsma, 2017) presented a platooning system architecture, as depicted in Figure 32, that is SAE level 2+. The schematic overview shows the complexity of the computer-driver interaction that allows for platooning.

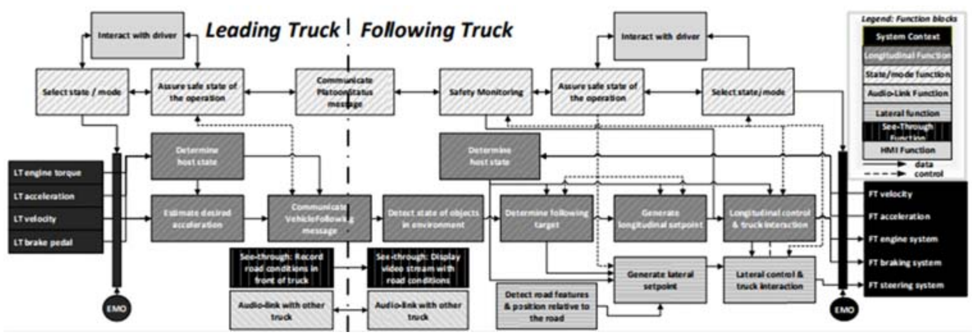

Figure 32: Platooning system architecture

D) Current traffic situation on the Rotterdam-Venlo corridor

To represent the actual traffic data and the physical layout of the corridor, nine cross sections of the highway are described. For these cross sections the physical characteristics such as length, location, traffic speed and number of infrastructural objects (bridges, tunnels etc.) have been summarized in Table 21. Moreover this table also contains the traffic intensities for inside and outside the peak hours. For the intensity data we have combined the data for three vehicle categories (light, medium and heavy) into Passenger Car Equivalent (PCE) by assuming a medium truck is 1,5 PCE and a heavy truck is 2,3 PCE. The intensities are retrieved from the INWEVA 2015 database, the spatial information is retrieved from the WEGGEG 2016 database.

Table 21: Actual traffic on the Rotterdam-Venlo corridor

Direction	Highway	Subsection	Location for cross section	Mean number of lanes at subsection	Distance of subsection	Maximum speed (all vehicles)	Assumed speed truck traffic	Number of infrastructural objects (bridges, tunnels)	Intensity (PCE/hour) during peak hour	Intensity (PCE/hour) outside peak hour	Number of trucks during peak hour	Number of trucks outside peak hour
Direction 1: Maasvlakte Venlo	A15	Maasvlakte-Botlek	Thomassentunnel	2	25	100	80	5	2217,1	1648,5	36	47
		Botlek-Ridderkerk	Tankstation Charlois	3	15	100	80	27	5061,6	3133,7	13	28
	A16	Ridderkerk-Moerdijk	Drechttunnel	3	20	100	80	10	5030,7	3922,2	18	33
		Moerdijk-Galder	Prinsenbeek	3	20	130	80	16	3814,4	3119,7	22	37
	A58	Galder-Tilburg	Vliegbasis Gilze-Rijen	2	25	130	80	12	3840,5	3321,5	24	39
		Tilburg-Eindhoven	Wilhelminakanaal	2	20	130	80	9	2995,3	2890,6	26	40
	A2	Randweg Eindhoven	Knooppunt De Hogt	2	15	120	80	8	3319,4	2953	26	43
	A67	Eindhoven-Someren	Spoorlijn Geldrop	2	17	120	80	5	4151,7	3177,5	27	46
		Someren-Venlo	Aansluiting Helden	2	36	130	80	13	2182,9	2117,6	52	64
Direction 2: Venlo Maasvlakte	A15	Maasvlakte-Botlek	Thomassentunnel	2	25	100	80	5	2803,5	1912,4	21	48
		Botlek-Ridderkerk	Tankstation Charlois	3	15	100	80	27	4050,4	2724,6	16	30
	A16	Ridderkerk-Moerdijk	Drechttunnel	3	20	100	80	10	4863,6	4177	18	39
		Moerdijk-Galder	Prinsenbeek	3	20	130	80	16	3535,8	3284,3	23	39
	A58	Galder-Tilburg	Vliegbasis Gilze-Rijen	2	25	130	80	12	3774,4	3166,4	19	39
		Tilburg-Eindhoven	Wilhelminakanaal	2	20	130	80	9	3653,6	2916,6	20	39
	A2	Randweg Eindhoven	Knooppunt De Hogt	2	15	120	80	8	2933	2847,6	31	44
	A67	Eindhoven-Someren	Spoorlijn Geldrop	2	17	120	80	5	3441,2	2959,3	29	44
		Someren-Venlo	Aansluiting Helden	2	36	130	80	13	2251,3	1964,5	44	62

Moreover the INWEVA 2015 also allows us to more specifically assess the truck share that is currently registered on the highway.

For an average working day the truck share in percentages is depicted in Figure 33.

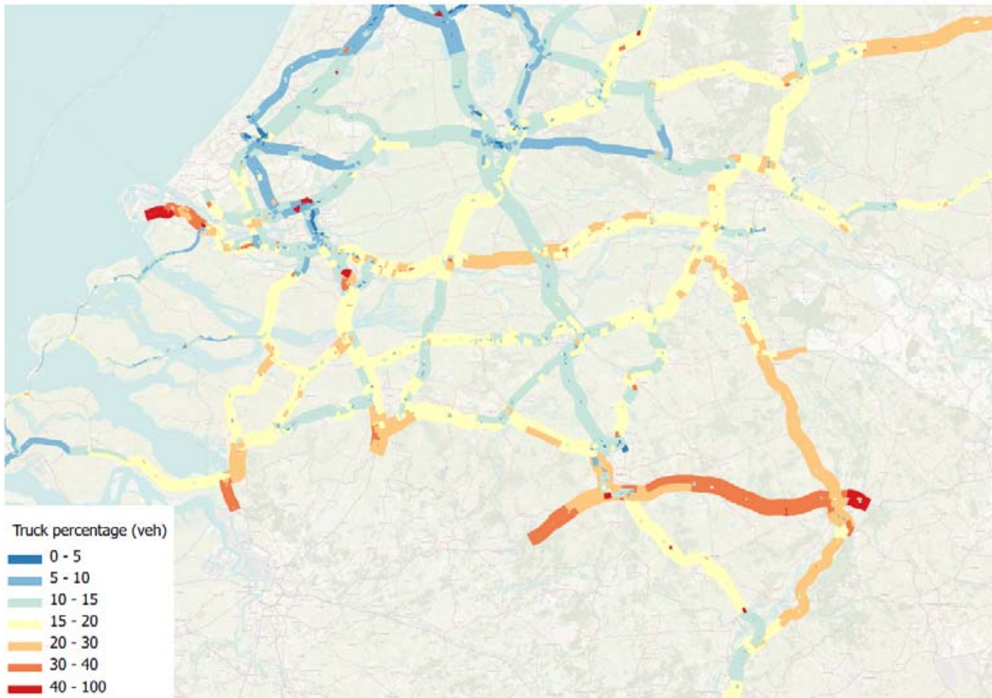

Figure 33: Truck share on southern highways of the Netherlands (source INWEVA 2015).

E) Current safety situation on the Rotterdam-Venlo corridor

Within the Netherlands there are several information and registration systems that describe incidents that have occurred on the highways. All road traffic crashes in the Netherlands that are recorded by the police in reports or statements are included in the national road crash register “BRON” database. Moreover all incidents for which ‘incident mitigation’ procedures were applied such as sending a tow truck to remove the vehicle are recorded in a database. Lastly, when the highway is equipped with electronic information signs, it is possible to retrieve the status of the various traffic lanes which are also historically stored (Mistica data).

Figure 34 visualizes the amount of accidents (for all traffic) per kilometer for the year 2015 for south-west part of the Netherlands. What mainly becomes apparent is that relatively a low amount of accidents occur on the two main freight routes from Rotterdam towards Venlo, both the route via the A15, A50 and A73 and the route via the A15, A16,A58 and A67 show a lower amount of accidents in comparison to the road sections above Rotterdam (A20) and Utrecht (A15). What this figure also shows is that most of the accidents that occur are related to locations were merging or weaving takes place.

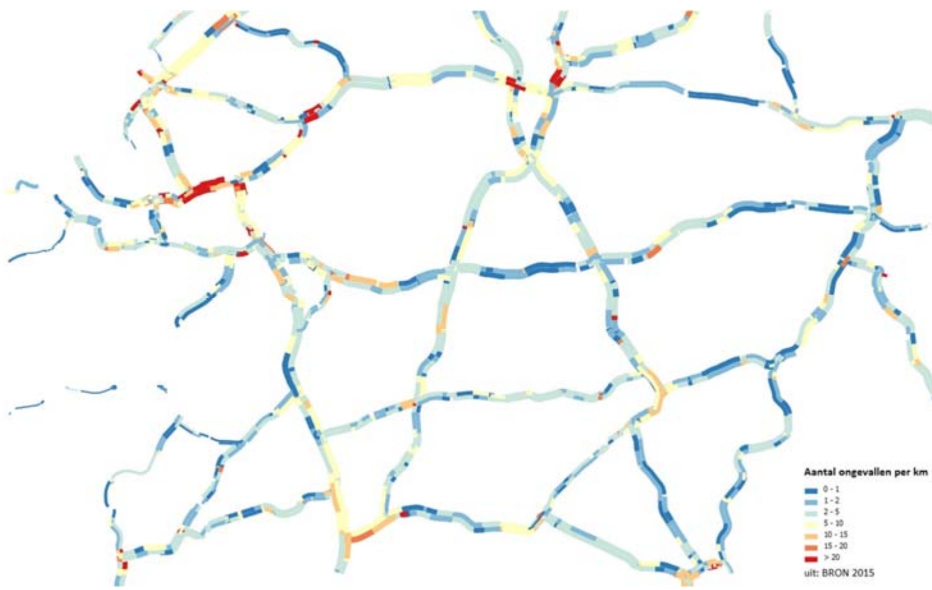

Figure 34: Accidents per kilometer (Source BRON database 2015)

However, Figure 34 does not include the fact that the amount of accidents is also dependent on the traffic intensity. As an alternative it is possible to describe the traffic safety as the risk for a road user to become involved in a serious accident. This results in a risk per vehicle kilometer instead of the number of accidents per infrastructure kilometer. Rijkswaterstaat, the Dutch road authority for highways, determined this risk score (Rijksoverheid, 2017) as depicted in Figure 35. It can be seen that the risk level on roads itself can differ quite significantly. For example the A15 near Rotterdam has a significant higher risk score than the section between Dordrecht and Nijmegen. Moreover, the direction of the traffic flow also seems to be an important factor since there is often a difference between the opposing road segments.

To gain more insight in the specific effects of freight transport on the traffic safety and the possible effect of truck platooning a more detailed investigation has been conducted on the Rotterdam-Venlo corridor. Based on a historic database between 2007 and 2009 we have specifically extracted the accidents that were registered on the A15, A16, A58, A2 and A67. This database is particularly interesting because it has the combined loggings of the Incident Management database, the BRON accident database and all loggings from the traffic management centers. This database differentiates the incidents from accidents and by sorting these on the vehicle class we gain more insight in the amount, cause and severity of the incidents and accidents related to freight traffic.

Figure 35: Risks-core for the highway network of the Netherlands; in comparison with the 'mean' average. Source: Rijksoverheid 2016

The term incident in this context is being used for a collective term under which all unwanted events at highways are captured, an accident thus falls within the incident category but is depicted separately.

In total 31078 incidents were registered of which 5471 (17.0%) were related to freight traffic. Figure 36 shows the incident type and the involvement of freight traffic (combining data from both directions of the corridor). Both individual directions were also extracted, analyzed and both showed a similar pattern.

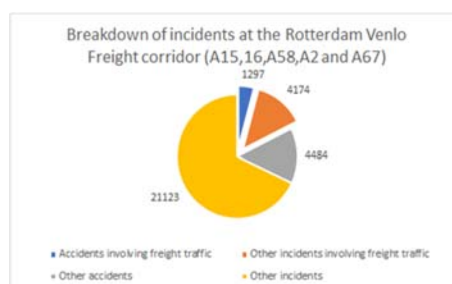

Figure 36: Breakdown of incidents at the Rotterdam

In 61% of the incidents an incident cause has been registered, as depicted in Figure 37. Both road directions are added within this figure. The most important incident cause for both all and truck related incidents is 'vehicle breakdown'. For truck related incidents 'roadworks' and 'vehicle lost freight' are not significantly important causes, whereas these are for other incidents.

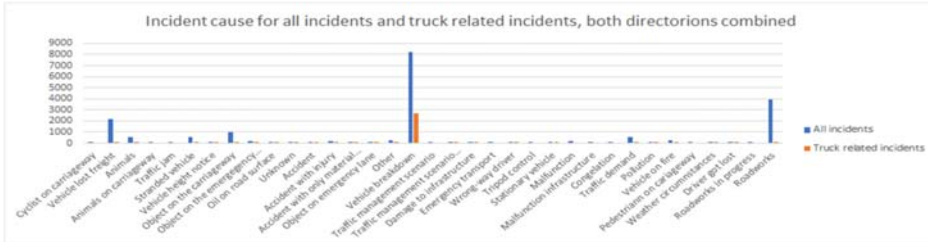

Figure 37: Incident cause for all incidents and truck related incidents.

It is also worthwhile to explore the time windows at which incidents and truck related incidents occur. If a majority of the truck related incidents coincides with the morning or evening peak hours the possible effect is twofold. On the one hand, the safety aspect can be improved. On the other hand, the accessibility could also be significantly improved if incidents at a crucial time period are mitigated.

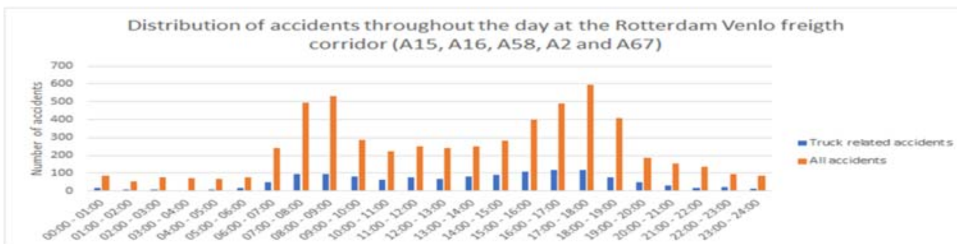

Figure 38: Distribution of all accidents and truck related accidents throughout the day at the Rotterdam Venlo freight corridor.

It can be derived from Figure 38 that the incidents for all vehicle types are significantly apparent in the morning and evening peak hours. However, the accidents and incidents related to freight traffic are more evenly distributed throughout the day. We also investigated the distribution of incidents during the day and these show a similar pattern.

For the accidents that were registered a subset is available for which an accident cause has been denoted in the database. The results from this breakdown are shown in Figure 39 and Figure 40. These figures show that the head/tail and flank accidents together describe 80% of the accidents related to trucks on this specific corridor.

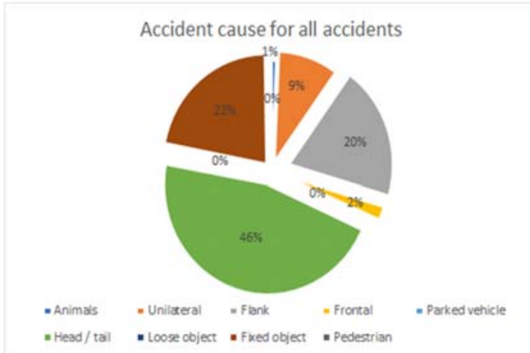

Figure 39: Accident cause for all accidents

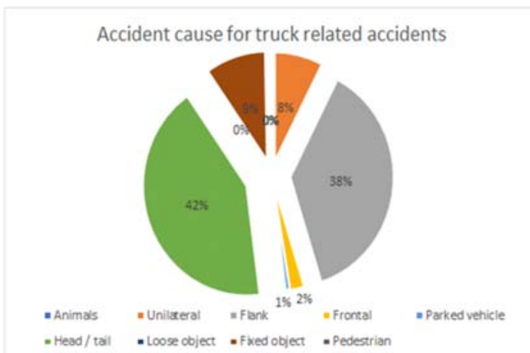

Figure 40: Accident cause for freight related accidents

It should be noted that the cause of an accident does not represent the damage or injury that an accident has inflicted. Often four separate accident severities are applied, being: only material damage accidents, light injury accidents, severe injury accidents and deadly accidents. For 20% of the accidents registered at the freight corridor a severity is described within the data. A complicating factor is that the severity is only divided in three classes instead of four classes (the light and sever injuries are combined).

For the accidents in which a severity is described a breakdown for all and truck related accidents have been depicted next (see Figure 41 and Figure 42).

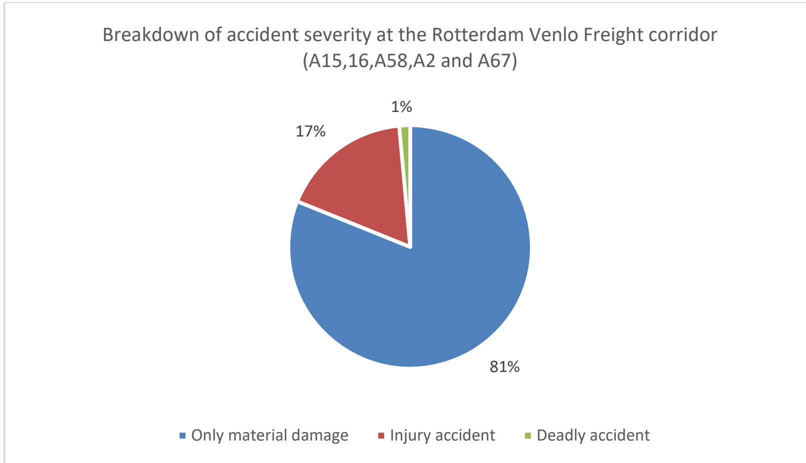

Figure 41: Breakdown of accidents severity at the Rotterdam Venlo-Corridor

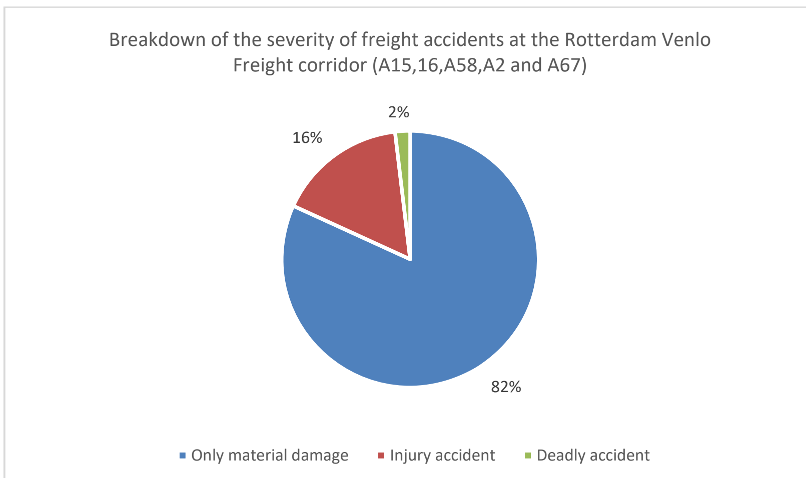

Figure 42: Breakdown of freight accidents severity at the Rotterdam Venlo-Corridor

F) Reduction in fuel consumption

Truck platooning decreases fuel consumption because of reduced aerodynamic drag and less air resistance compared to a solo truck. The fuel saving of an individual truck in a platoon is determined by the gap distance and the platooning position, as shown in the graph below (Tsugawa S. K., 2011).

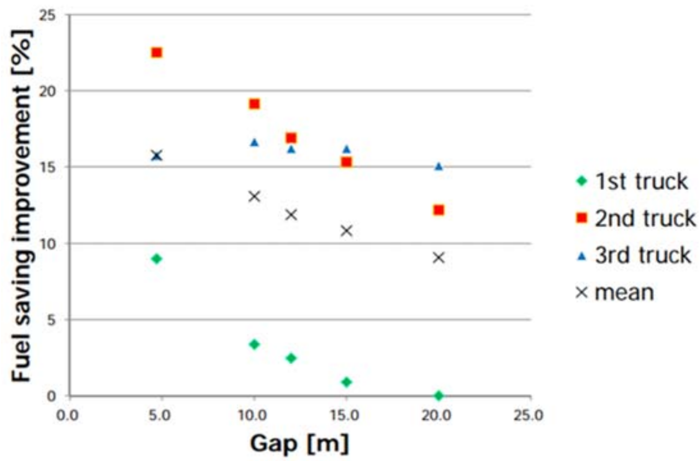

Figure 43: Platoon position vs fuel savings vs gap distance

At the moment of writing fuel consumption tests have only been executed on specialized test tracks or highways that were not in public use. These tests were performed with a wide variation of trucks, gap distances, and speed. As a result, the average fuel savings per truck vary from 4-16% (Alam et al.; 2015; Auburn University, 2015; Browland, 2004; Dávila, 2013; Nowakowski, 2015; Roeth, 2013; Tsugawa, 2011; Tsugawa, 2013).

We've plotted the results of these various studies in the graph below.

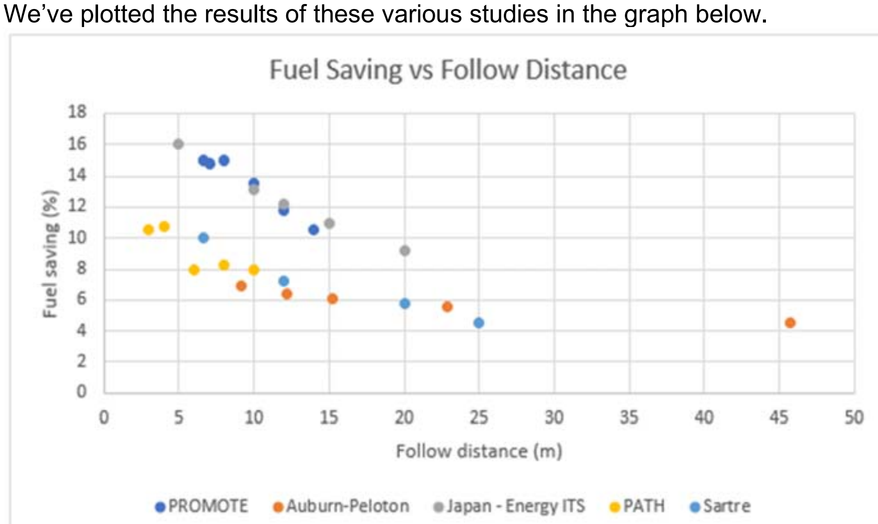

Figure 44: Fuel saving vs gap distance

In addition, Davila (2013) noted that at a speed of 85km/h the optimal gap (in terms of drag) is between 6 and 7 meters. A smaller gap of 3 or 4 meters caused lateral instability of the follow vehicles. This statement is confirmed by a simulation model of Sokolov et al. (2017) who showed an optimal headway distance between 6-8 meters, leading to fuel savings of 7-15%.

G) Trends in truck fuel consumption

Todts (2015) wrote a report with the title: “Europe’s Lost Decade of Truck Fuel Economy”. He claims that OEMs focused on performance, not on fuel consumption. The figure below shows the average fuel consumption of European trucks. Over a period of 20 years there is not much deviation from 35 liters per 100 kilometers.

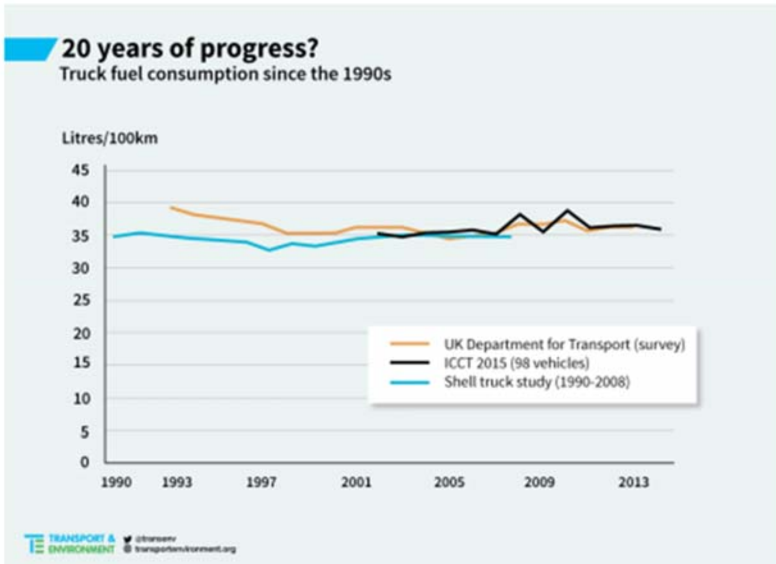

Figure 45: Truck fuel consumption since the 1990s

This argument is supported by Muncrief and Sharpe (2015) and defended in 2017. Their findings are displayed below. Muncrief (2017) concludes: “[…], that is, essentially no change at all in fuel efficiency over fifteen years, and if anything a change in the wrong direction.”

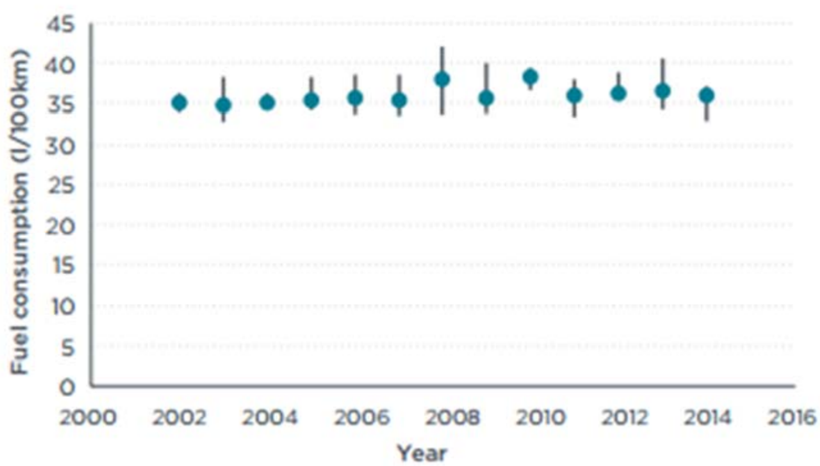

Figure 46: Development of truck fuel consumption

Todts (2015) is estimating the decrease of average fuel consumption per truck. This is displayed in the graph below. The notable difference between the US and the EU originates in the strict fuel efficiency standards adopted by the US. A decrease of 0,5% per year is deemed realistic.

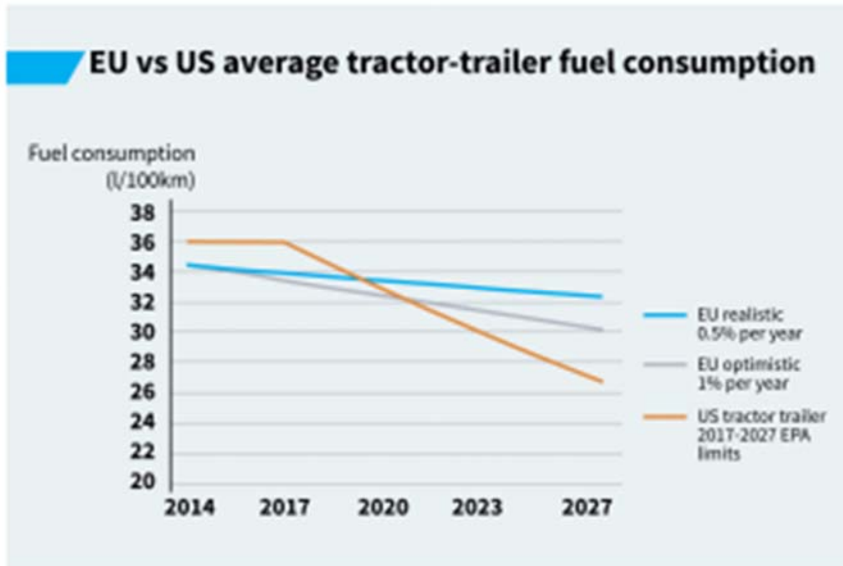

Figure 47: EU vs US average tractor-trailer fuel consumption

Another factor impacting fuel efficiency is electrification. According to Centraal Bureau voor de Statistiek (CBS, 2016) 134.000 trucks were registered in The Netherlands in 2016. RVO (2017) lists that 66 of those where electric, a negligible amount.

Nederland Elektrisch (2015), an action group supported by a wide variety of national partners, proposes an agenda aiming for 1.000 electric trucks by 2020, and 4.000 electric + 4.400 plug-in hybrid trucks by 2030. The action group aims to assist OEM's in their R&D and talks to various municipalities about the introduction of environment-zones. So far the Dutch government has reserved 4.2 million EUR to support in their efforts. If Nederland Elektrisch proves successful in their efforts around 1% of trucks will drive on alternative fuels in 2020, and around 6% in 2030.

In our model, we are not taking this shift to electric trucks into account for two reasons. First, we are focusing on highway truck platooning, an unlikely location for the introduction of electric trucks. Second, there are currently very few electric trucks in operation, and, to our knowledge, no research is done on the speed of introduction. Electric trucks will still benefit from truck platooning (less use of energy). However, the calculation of fuel savings for electric trucks differs from the one used in our model.

H) Optimizing fuel, waiting, and travel time costs for scheduled and on the fly platoon matching

How big of a detour or waiting time is acceptable to still benefit from platooning? Zhang (2016) tried to answer this question with a mathematical approach. He developed a model around three scenarios:

1. Common route: Two trucks leave from the same location and have the same destination
2. Diverging route: Two trucks have the same origin and diverge at some point
3. Converging route: Two trucks have the same destination and need to converge

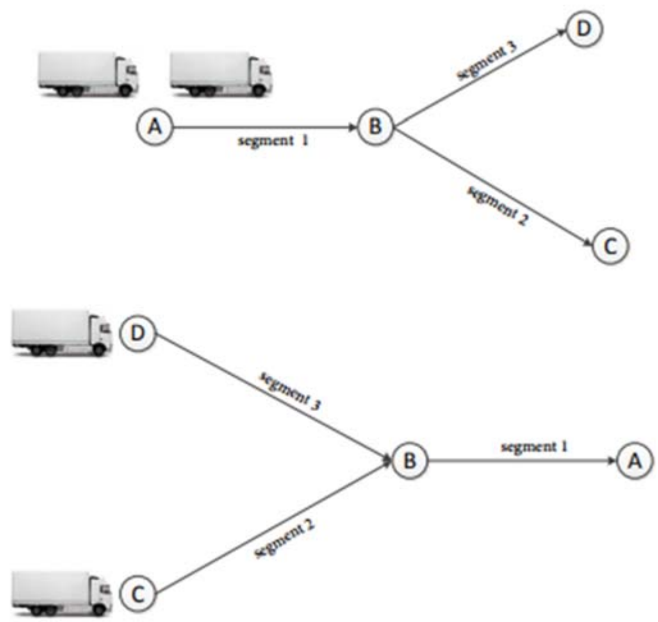

Figure 48: Routing possibilities

The model aims to minimize costs that consist of fuel, travel time and penalties for deviating from the schedule. He demonstrates that there is conflict between arriving on time and saving fuel. The figure below shows that cost increase when deviation from the schedule increases. The steeper slope for converging right originates in the fact that additional delay may be incurred by waiting for the other vehicle as there is more uncertainty around its arrival time.

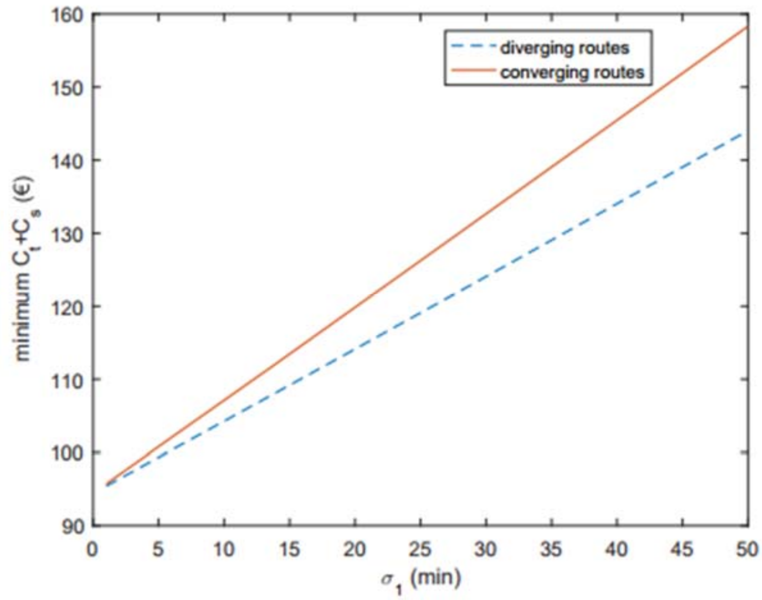

Figure 49: Diverging vs converging routes

It might be acceptable to ignore the problems of scheduling altogether when we adopt on the fly platooning. Bhoopalam (2017) conducted an extensive literature review on scheduled platooning. Under the assumption that platoon length will likely be restricted by law, he came up with 4 basic platoon arrangements. He concludes that is very difficult to solve these scheduling problems for moderately sized instances and “it is unlikely that […] large instances can be solved to optimality in an acceptable time period”.

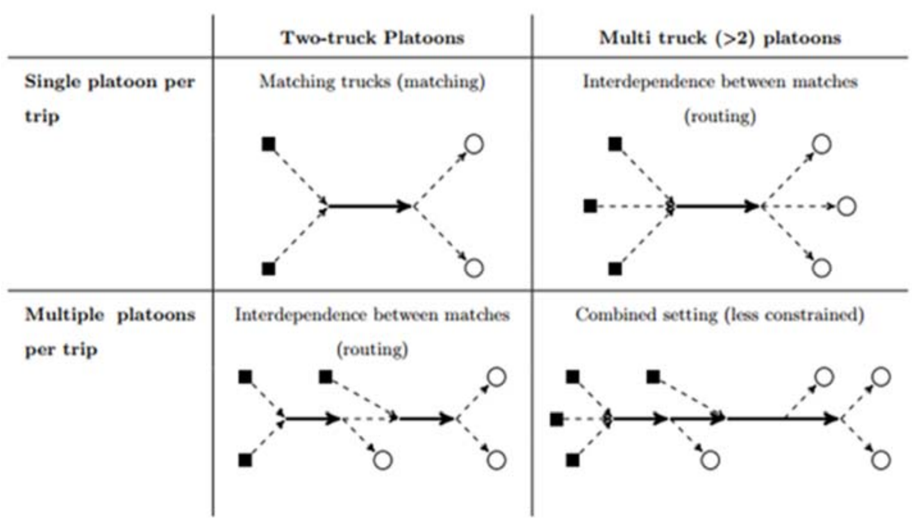

Figure 50: Scheduled platooning challenges

The main issue with on the fly platooning is how much of a gap distance allows for a successful merge with a minimum loss of time.

Liang (2016) conducted an experiment in Sweden, consisting of 600 test runs with 2 trucks on an 11 kilometer stretch of highway. They used several variations in vehicle speed and a gap distance ranging from 400-1300 meters. 447 test-runs of the 517 included in the research succeeded to merge. There are 2 findings that are important:

- As soon as the gap size increases over 1 kilometer it becomes very difficult to merge.
- Highly congested traffic makes it difficult for the follow vehicle to catch up to the lead vehicle.

The table below shows a summary of their test-scenarios and test-runs conducted. The normalized merge distance is the distance that two trucks are expected to cover before merging given their relative speed (Liang, 2016).

Table 22: Test-scenarios

Test-scenario and	Test-runs		Normalized merge distance			
traffic case	total	successful	min	max	mean	std
(75,85) km/h light	59	57	0.85	1.56	1.14	0.16
(75,85) km/h medium	83	72	0.79	2.10	1.17	0.21
(75,85) km/h heavy	21	19	1.10	1.61	1.33	0.17
(75,89) km/h light	48	48	0.90	2.19	1.16	0.24
(75,89) km/h medium	94	86	0.93	1.99	1.18	0.18
(75,89) km/h heavy	28	24	1.03	2.60	1.39	0.39
(80,89) km/h light	57	48	0.93	1.66	1.13	0.17
(80,89) km/h medium	89	70	0.83	1.97	1.19	0.23
(80,89) km/h heavy	40	23	0.74	2.10	1.24	0.26

If we adopt Liang's scenario as a limitation to our model, than the following logic holds:

- Gap distance should be less than 1 kilometer
- First truck drives 75 km/h, second truck drives 85km/h
- Fuel cost saved by driving 75 km/h equals out fuel cost lost by driving 85 km/h
- Trucks should merge within ~10 km/h
- First truck loses 26 seconds at medium traffic density because of reducing his speed to 75km/h for the distance needed to merge. This loss can be increased to 30 seconds at most in a heavy traffic situation.
- We may assume that a one minute delay will not result in additional cost

It should be noted that on the fly platooning is only possible when a road segment has sufficient freight density. In other words, if two trucks are more than 1 kilometer apart then they will not be able to merge within 10 kilometers.

I) Productivity of assets

A large gain in productivity of assets lies in the assumption that truck platoons are (in time) able to cover larger distances than single trucks. In other words, if the second driver's time can be considered as resting time, we may optimize driving times, minimize truck idle time and therefore make better use of our truck assets.

Tavasszy (2016) estimated the potential impacts and possibilities under the assumption that the time in follow vehicles evolves twice as slow as in the leading truck. Under this assumption, the travel distance of a two trucks platoon can be increased with 25%. This can increase up to 50% for a platoon consisting of multiple trucks. Bakermans (2016) warns that the legislation currently does not allow for this and expects that the necessary levels of automation will not be available for at least another decade. For example, time may evolve slower in following trucks when the drivers are able to rest or sleep on highways (SAE level 4 (SAE International, 2014)), but this assumption may not be valid when drivers still have tasks (SAE level 2 and 3 (SAE International, 2014)).

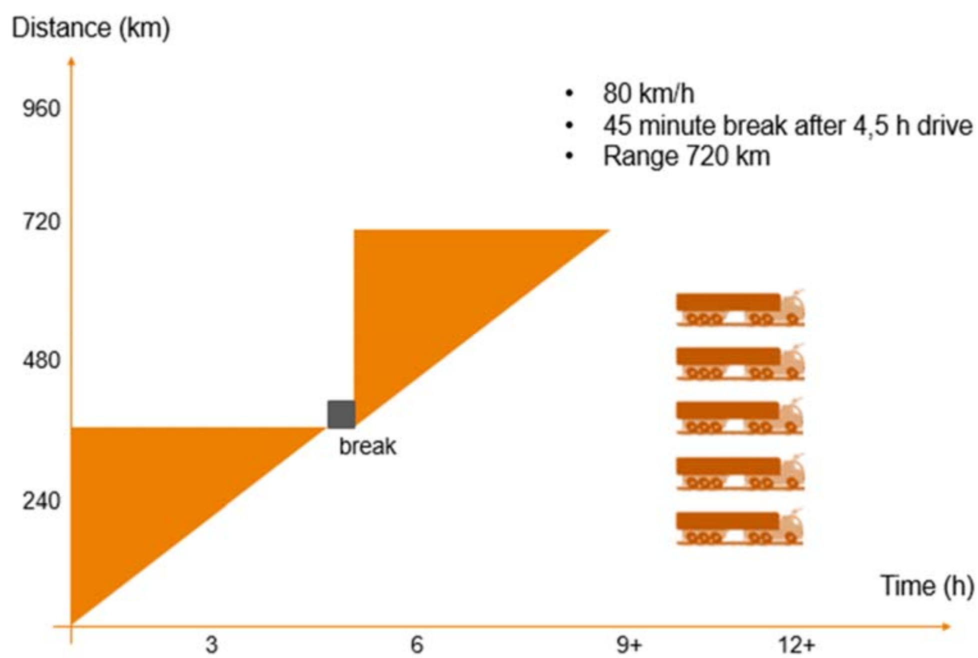

Figure 51: Current situation

Figure 51 shows the current situation. Figure 52 shows the productivity gained by switching from a single truck case to a cooperative platooning case (Tavasszy, Working paper). The logic here is that when the lead driver drives 3 hours, then the follower has legally driven 1,5 hours. After the switch this situation reverses. Therefore in 6 hours both drivers will have reached their 4,5 hour limit and need to take a break.

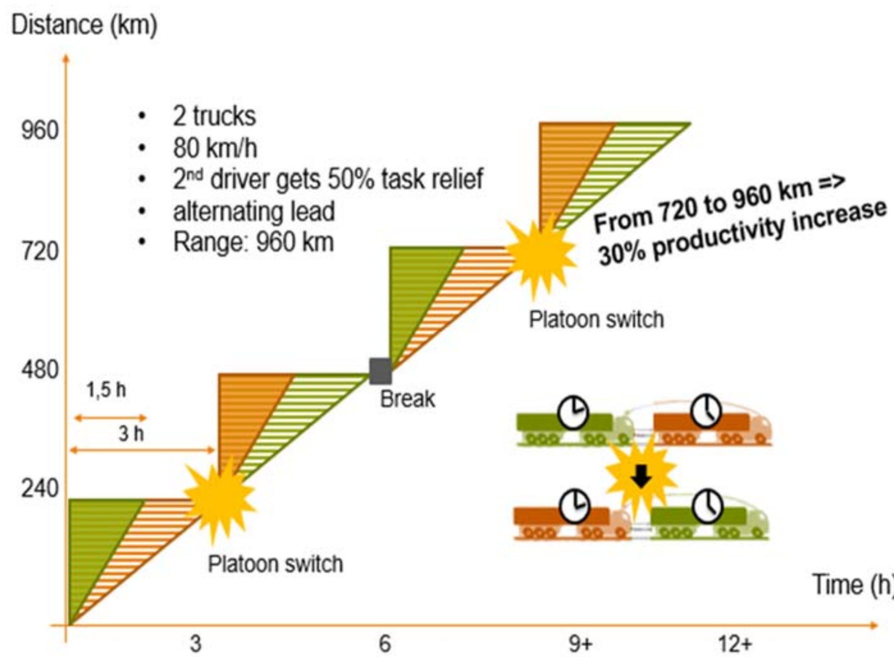

Figure 52: Productivity increase

J) Cost of platooning technology

Roland Berger (2016) published a useful estimation of the incremental cost of automated driving technology at the various stages of automation (see Figure 53).

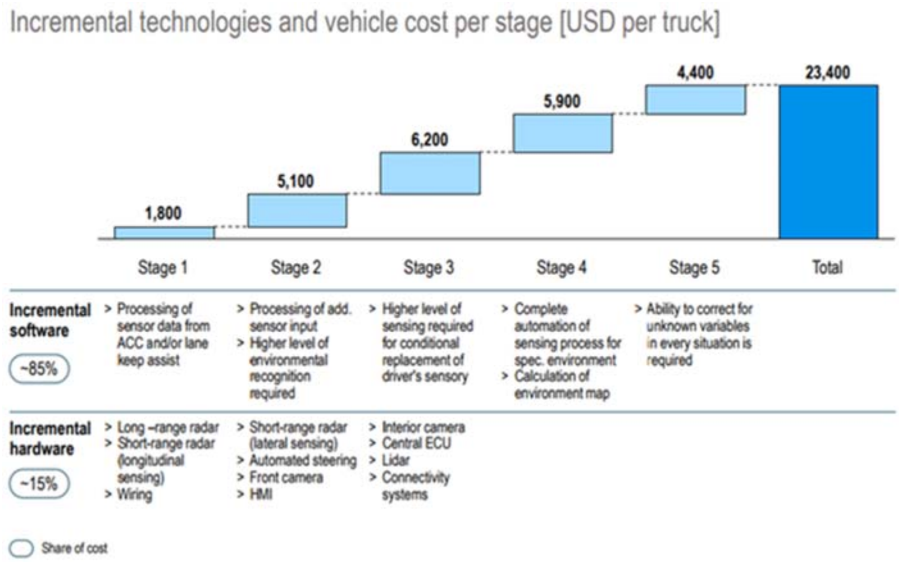

Figure 53: Cost of platooning technology

Any given truck will need the technology for stage 3 automation to be able to join a platoon. The cost of this technology is roughly 11,000 EUR (Roland Berger, 2016).

Litman (2017) estimates the costs of self-driving capability to range between $2,000 and $3,000 to annual vehicle costs. Several thousand added to the purchase price, plus a few hundred dollars for annual service costs.

These cost are likely to be reduced when the technology moves to mass production (KPMG, 2012). However, system failures may result in fatal accidents for both a truck driver and other road users. Therefore it is likely that all critical components will need high manufacturing, installation, repair, and maintenance standards (Litman, 2017).

Verweij (2016) points out that over time cost will be limited to software, because the hardware is already built into new trucks. Additional cost, however, will be necessary for yearly testing, maintenance, and training of personnel.

K) Division of costs for logistic service provider

Roland Berger (2016) calculated the potential impact of automated driving on operating costs, in US dollars per mile, by splitting these per cost element. The figure below shows that the current operating cost of driving a truck is $1,67 per mile. The driver and fuel both represent around one third of these costs.

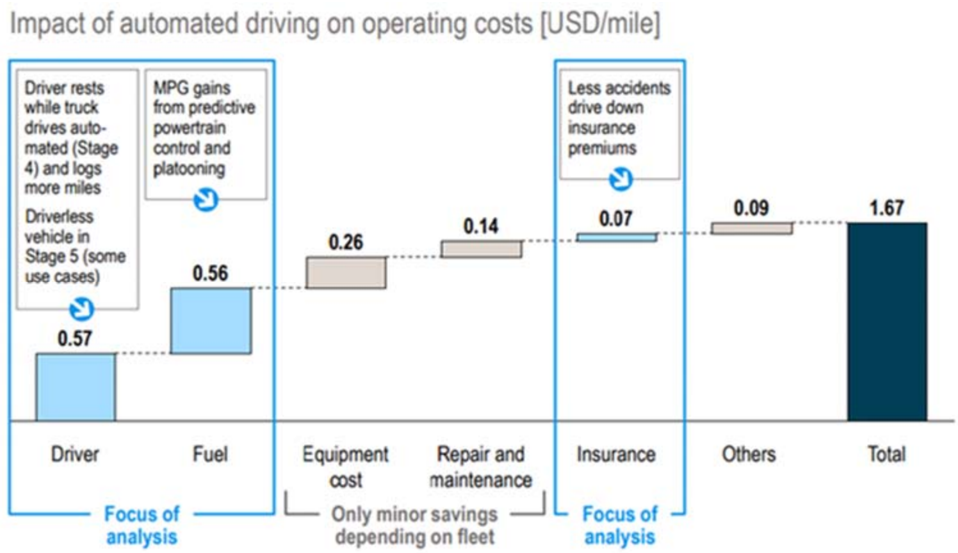

Figure 54: Division of operational costs

L) Insurance costs

Self-driving technology and insurance is a hot topic. In a whitepaper Bishop (2015) lists four factors that will impact insurance cost: accident reduction, shift of liability, increased hours of service, and enforcement. Another, unlisted factor is the increased value of the truck (see “Cost of Platooning Technology”). The last factor is the only factor that will have a negative effect on the cost of insurance for an LSP.

Bishop (2015) argues that approximately 11% of crashes is caused by mechanical or electrical issues. All other accidents are caused by human error. Self-driving technology should reduce these accidents and therefore reduce insurance costs.

Liability is likely to shift from drivers to OEMs as accidents will increasingly be the fault of their technology (Bishop, 2015). Insurance cost for the LSP should decrease. The question rises whether the driver of the lead vehicle is liable for the entire platoon when using stage 3 automation.

Automated driving might increase the hours of service of a vehicle (Bishop, 2015). That means that the risk of an accident increases for the particular vehicle, raising the premium for an insurance. The question here is whether it raises insurance cost for the OEM or the LSP. The answer likely finds itself in the degree of automation.

The Insurance Information Institute (2016) writes that the impact of automated driving on insurance cost is currently unclear. When the technology becomes more mainstream insurers will be able to determine to what extend accidents will be reduced and whether the accidents that do occur lead to a higher percentage of product liability claims.

Last, enforcement plays a role, as government bodies will have to oversee the rules and safety standards for (semi-)automated trucks (Bishop, 2015). Rules and oversight are a prerequisite before we will see an effect on the cost of insurance.

We assume that insurance cost will not be reduced until we reach a 50% adoption. Roland Berger (2016) estimated a 2% reduction for stage 3 automation, increasing to 30% reduction for further stages (see Figure 55).

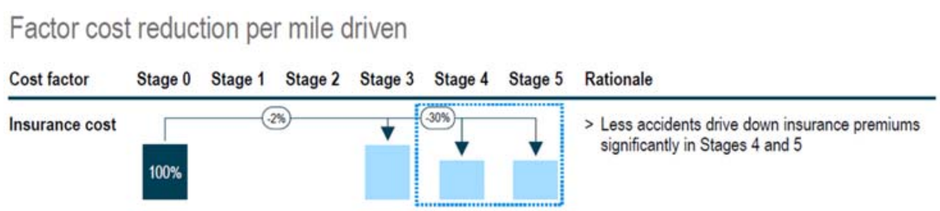

Figure 55: Reduction in insurance costs

14 Signature

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