



# ENSEMBLE

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### ENSEMBLE

ENabling Safe Multi-Brand platooning for Europe

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# 1. EXECUTIVE SUMMARY

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## 1.1. Context and need of a multi brand platooning project

Platooning technology has made significant advances in the last decade, but to achieve the next step towards deployment of truck platooning, an integral multi-brand approach is required. Aiming for Europe-wide deployment of platooning, 'multi-brand' solutions are paramount. It is the ambition of ENSEMBLE to realise pre-standards for interoperability between trucks, platoons and logistics solution providers, to speed up actual market pick-up of (sub)system development and implementation and to enable harmonisation of legal frameworks in the member states.

## 1.2. Project scope

The main goal of the ENSEMBLE project is to pave the way for the adoption of multi-brand truck platooning in Europe to improve fuel economy, traffic safety and throughput. This will be demonstrated by driving up to seven differently branded trucks in one (or more) platoon(s) under real world traffic conditions across national borders. During the years, the project goals are:

- Year 1: setting the requirements and the specifications and developing a reference design with acceptance criteria
- Year 2: implementing this reference design on the OEM own trucks as well as perform impact assessments with several criteria
- Year 3: focus on testing the multi-brand platoons on test tracks and international public roads

The technical results will be evaluated against the initial requirements. Also, the impact on fuel consumption, drivers and other road users will be established. In the end, all activities within the project aim to accelerate the deployment of multi-brand truck platooning in Europe.

## 1.3. Abstract of this Deliverable

This document is a starting document of ENSEMBLE, gathering experiences in general and requirements in particular of past (EU) projects on truck platooning as part of WP2. In the course of writing this deliverable it turned out that no detailed public information is available on requirements or specifications. Hence this deliverable should be seen as a State of the Art. This should be a starting point in defining platooning level A: scenarios, use cases, operational conditions, driver-vehicle interaction, communication protocol, safety, and security.

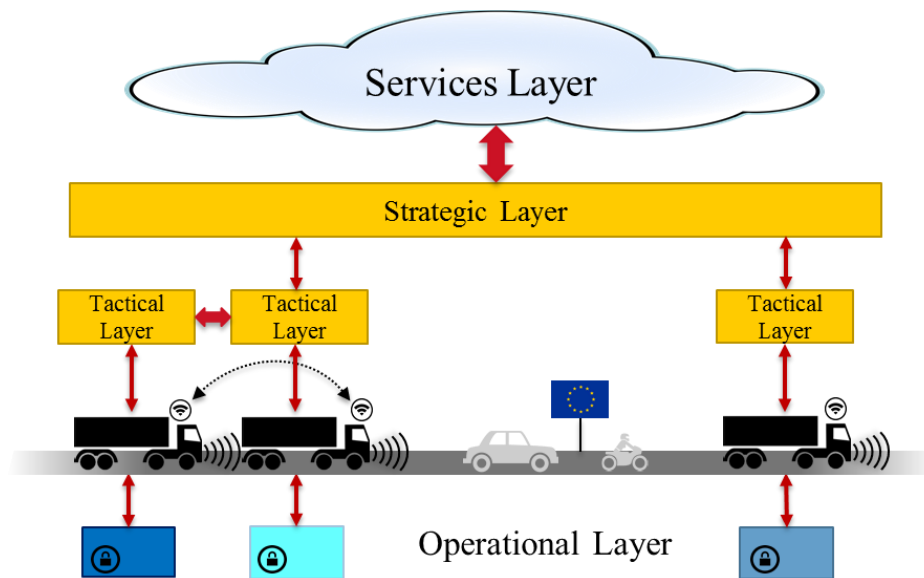
Input for above topics came from the European Truck Platooning Challenge (ETPC), which had a mono-brand demonstration of platooning by all European truck manufacturers in 2016. Besides that, the following projects contributed to this deliverable: CHAUFFEUR II, KONVOI, SARTRE, i-GAME, COMPANION, AUTONET2030, ROADART, CONCORDA, and AUTOPILOT. For some topics, like e.g. Driver Interaction and heterogeneous platooning, results of other projects and more academic research were reviewed as well.

### *Functionality*

With respect to use cases and in-vehicle architectures, many commonalities are seen on a high level. However, details are often not published. This also holds for the low-level controllers used in the different projects. Moreover, tactical layer functionalities and operational layer functionalities have mostly been



implemented as one ‘controller’, i.e. there was no separation between ‘common’ and ‘truck specific’ functionalities, which is needed for ENSEMBLE’s separation in a general tactical and less general operational layer (Figure 1-1).



**Figure 1-1. Layered concept of ENSEMBLE**

Hence, a clear task is reserved for ENSEMBLE to separate the functionalities in a way that the technology is still usable for all OEMs.

Despite the substantial academic work on platooning, applied control design for heterogeneous platooning (i.e. platooning of trucks with different properties) is still an open issue. Only very limited publications deal with implementation relevant aspects and/or heterogeneity of platoons. This thus is still an open area also for ENSEMBLE.

### *Human factors*

Many projects have addressed human factor issues, mostly for automated driving, less for platooning. Nevertheless, several well-founded methods could be used in ENSEMBLE, like e.g. the one from the AdaptIVe project. There is, however, a number of human factors knowledge gaps:

- there is a lack of data from driving in platoon in real traffic environments with real weather and lighting conditions,
- long-term effects on human behaviour from driving in platoon, ranging from days of working (8-10 hours/day) to months of daily driving in platoons are not known,
- appropriate driver training programs for platooning may be needed,
- in platooning systems, the driver of the following trucks, as result of the reduced intervehicle distance, may not be able to timely react on system failures and hazards, due to the limited view and his/her reaction time. This means that a platooning system cannot rely on the driver as fall back and consequently the automation should provide a safe solution for handling failures and hazards.

## Communication

Almost all previous platooning projects used ITS-G5 communication. A message set specifically for platooning is currently being discussed. Especially the project Sweden4Platooning is of high interest to ENSEMBLE due to their goal towards standardisation of communication for platooning.

## Security

No previous projects on platooning has implemented security mechanisms as far can be concluded from project deliverables. However, much work has been done for securing the communication between vehicles and between vehicles and smart infrastructure, e.g. resulting in an overall security framework for Cooperative ITS (C-ITS), which is based on the concept of Public Key Infrastructure (PKI).

Hence, the ENSEMBLE project considers to use the already standardized onboard security protocol outlined in TS 103 097 V1.3.1 for reaching interoperability between different brands using ATs. However, there are additional considerations regarding performance of signage and authentication, and confidentiality of application data. These may lead to the consideration for symmetric cryptology whilst platooning, since platooning vehicles know each other. TS 103 097 has support for the exchange of symmetric keys. The requirements and specification will be worked out in D2.6.

## Safety

The ENSEMBLE project will analyse the safety risks related to both functional safety (ISO26262) and SOTIF and derive requirements to lower these risks to an acceptable level. Since these activities will not only define requirements for hazards arising from E/E malfunctions but also address hazards resulting from performance limitations or insufficiencies of the function itself, the safety activities carried out for the project are enough to have a safe platoon deployment on public roads.

## Infrastructure

Concerning the *digital infrastructure* for strategical communication (tactical and operational communication is reported in the topic 'Communication' above), little information is available from recent project on platooning. The used communication technology appeared to be cellular data "4G/LTE", e.g. let platoon trucks communicate with cloud hosted services for gathering weather conditions. Only minimal real-life experience and lab test proofs are available to conclude on the requirements for services. Hence there is a potential risk that specifications are going to be incomplete and it is recommended follow the running projects/initiatives that are also targeting truck platooning like e.g. AUTOPILOT and CONCORDA.

The projects performed so far do not take into account the *physical infrastructure*. This may pose a risk on the ENSEMBLE project since the specifications can be incomplete and are not based on (scientific) tests and proofs.

## Strategic functions and services

For large scale platooning a platform to support platooning between different freight companies is required. This necessitates support in the strategic layer for revenue sharing when platooning. Relevant information may be platoon formation, position in the platoon, time, distance and route.

ENSEMBLE will benefit from the results of the EU project COMPANION, where design of the strategic layer has been researched and evaluated in extended simulations and on public road, as the main partners from COMPANION involved in the design and evaluation are also partner in ENSEMBLE.



## *Impact*

Various projects are evaluated, however, most of the projects base their estimation on simulations, as no real platooning on public road was available on the scale required for sound evaluation, and the exact details on the implemented platooning functionality is not always stated. Hence following results must be read with reservations.

Fuel saving and emission reduction are in-line with each other and different studies report between 7 and 15% possible reductions (ADAPTIVE , 2017), (SARTRE Report 2011, 2018). With respect to traffic safety high numbers ranging from 43 till 60% reduction in accidents are reported, however, different projects report different numbers (i.e. truck related accidents, highway accidents, all recorded and analysed accidents in Germany). It should be noted that these numbers very much depend on what is taken as basis, trucks without any active safety systems, or already trucks with systems like Automated Emergency Braking. Sometimes the literature is unclear about this.

Impact on traffic flow is expected to improve slightly due to different mechanisms like more smooth traffic flow and higher road usage as a result of smaller inter-vehicle distances, but no conclusive numbers can be stated. Moreover, this requires higher penetration rates and possibly connections to other (cooperative) applications.



## 2. INTRODUCTION

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### 2.1. Background

The main goal of the ENSEMBLE project is to pave the way for the adoption of multi-brand truck platooning in Europe to improve fuel economy, traffic safety and throughput. This will be demonstrated by driving seven differently branded trucks in one (or more) platoon(s) under real world traffic conditions across national borders.

Following objectives are defined:

1. **Interoperable Platooning:** When forming a scalable, multi-brand truck convoy, the vehicles must be compatible to ensure correct and safe operation.
2. **Safe platooning:** Safety is one of the key aspects to ensure acceptance of platooning technology. In ENSEMBLE, this will be achieved by 1) designing fail-safe and fault-tolerant mechanisms, which include the safe interaction both within the platoon and with other road users. This will be supported by secure wireless communication. Furthermore, 2) ENSEMBLE will approach the relevant authorities to jointly define road approval requirements, also taking into account impact of platoons on the road and infrastructure like e.g. road wear, geometry, platooning management and required V2I communication.
3. **Real-life platooning:** The intended practical tests on test tracks and in real life serve a three-fold purpose: 1) “learning by doing” testing across a C-ITS corridor in Europe, 2) assess the impact on traffic, infrastructure and logistics, while gathering relevant data of critical scenarios and 3) promote multi-brand platooning through a final event.
4. **Embedded platooning:** The platooning concept should allow for seamless integration into the (logistic) value chain. Hence the fourth objective in ENSEMBLE is to design an interface to cloud-based services to embed the platooning concept into the logistics chain.

The concept of the envisioned technology to implement above objectives, consists of a hierarchical platooning system with interacting layers. The envisioned concept is presented in Figure 2-2. The different layers have the following responsibilities:



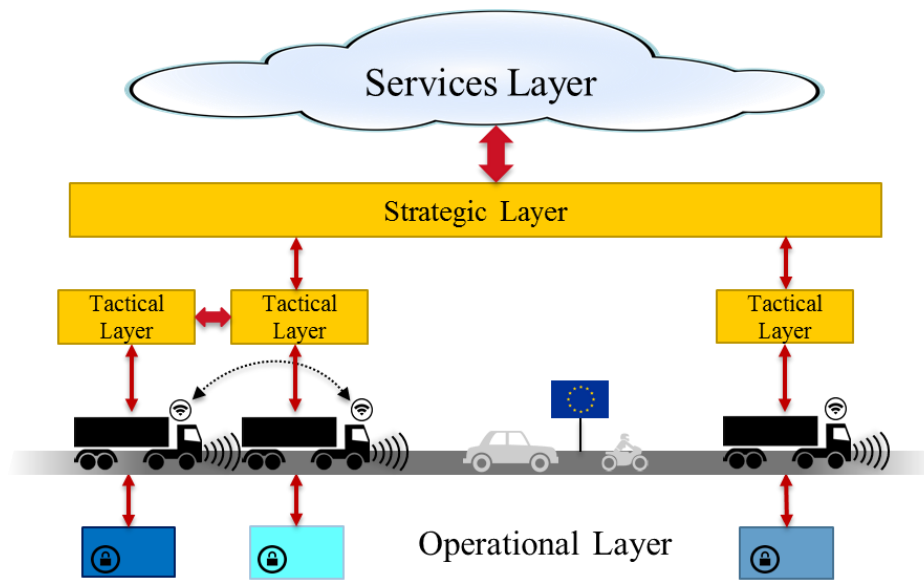


Figure 2-2. Layered concept of ENSEMBLE

- The **service layer** represents the platform on which logistical operations and new initiatives can operate.
- The **strategic layer** is responsible for the high-level decision-making regarding the scheduling of platoons based on vehicle compatibility and Platooning Level (see below), optimisation with respect to fuel consumption, travel times, destination, and impact on highway traffic flow and infrastructure, employing cooperative ITS cloud-based solutions. In addition, the routing of vehicles to allow for platoon forming is included in this layer. The strategic layer is implemented in a centralised fashion in so-called traffic control centres. Long-range wireless communication by existing cellular technology is used between a traffic control centre and vehicles/platoons and their drivers.
- The **tactical layer** coordinates the actual platoon forming (both from the tail of the platoon and through merging in the platoon) and platoon dissolution. In addition, this layer ensures platoon cohesion on hilly roads, and sets the desired platoon velocity, inter-vehicle distances (e.g. to prevent damaging bridges) and lateral offsets to mitigate road wear. This is implemented through the execution of an interaction protocol using the short-range wireless inter-vehicle communication (i.e. V2X). In fact, the interaction protocol is implemented by message sequences, initiating the manoeuvres that are necessary to form a platoon, to merge into it, or to dissolve it, also taking into account scheduling requirements due to vehicle compatibility.
- The **operational layer** involves the vehicle actuator control (e.g. accelerating/braking, steering), the execution of the aforementioned manoeuvres, and the control of the individual vehicles in the platoon to automatically perform the platooning task. Here, the main control task is to regulate the inter-vehicle distance or velocity and, depending on the Platooning Level, the lateral position relative to the lane or to the preceding vehicle. Key performance requirements for this layer are vehicle-following behaviour and (longitudinal and lateral) string stability of the platoon, where the latter is a necessary requirement to achieve a stable traffic flow and to achieve scalability with respect to

platoon length, and the short-range wireless inter-vehicle communication is the key enabling technology.

Furthermore the concept foresees in a staged introduction of platooning along different platooning levels, which will be defined in the course of the project. The definition of “platooning levels of automation” will comprise elements like e.g. the minimum time gap between the vehicles, whether there is lateral automation available, driving speed range, operational areas like motorways, etc.. Three different levels are anticipated; called A, B and C.

## 2.2. Aim

Aiming for Europe-wide deployment of platooning, ‘multi-brand’ solutions are paramount. It is the ambition of ENSEMBLE to realise pre-standards (i.e., mature input for standardisation) for interoperability between trucks, platoons and logistics solution providers, to speed up actual market pick-up of (sub)system development and implementation and to enable harmonisation of legal frameworks in the member states. As such, a technology readiness level (TRL) of 7 is aimed for (Commission, 2018).

The project is structured as illustrated in Figure 2-3.

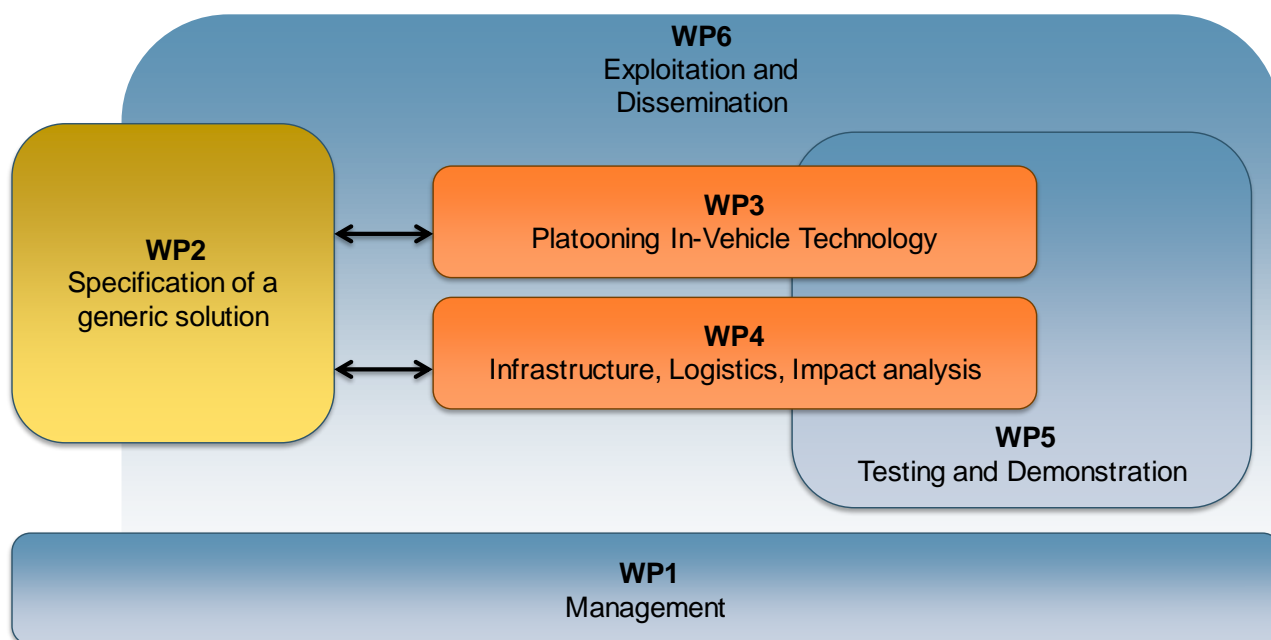


Figure 2-3: Project structure of ENSEMBLE

In WP2 the specifications of the whole multi-brand truck platooning concept to be implemented in the demonstration trucks of the 6 OEMs will be defined. Starting from the current state of the art, common specification of the Strategic, Tactical and Operational Layers and their interfaces will be provided. The iteration process to validate and modify the specification during the whole project life-cycle is an essential part of the work. Focus is on Platooning Level A for implementation in the trucks, however, initial definitions for Platooning Levels B and C are foreseen.



WP3 implements the requirements and specifications of WP2 into demonstrator trucks. This implementation includes the operational and the tactical layer, as well as the interface to the strategic layer. The implementations will be verified in WP5 against the specifications and requirements given in WP2. If necessary a change advice on the specifications is fed back to WP2.

WP4 performs the impact assessment of multi-brand platooning on road infrastructure, environment, other road users and logistics. It also contains the development of cooperative ITS functionality, for logistic automation, including forming and dissolution of platoons (i.e., the strategic layer). For logistics, this WP will consider different platooning models, the specification of a Platooning Service Provider to support platoon scheduling, and the impact on logistical automation systems (i.e., the services layer).

The objective of WP5 is the testing, validation and demonstration of the multi-brand platoon implementation in the ENSEMBLE project. In this work package all testing is comprised, from integration testing until the final demonstration.

WP6 concerns the exploitation and dissemination of the project. Here, the communication of the project results and the interaction with standardization bodies, road approval authorities, and fleet owners are the main focus.

This document is a starting document of ENSEMBLE, gathering experiences in general and requirements in particular of past (EU) projects on truck platooning as part of WP2. In the course of writing this deliverable it turned out that no detailed public information is available on requirements or specifications. Hence this deliverable should be seen as a State of the Art. This should be a starting point in defining platooning level A: scenarios, use cases, operational conditions, driver-vehicle interaction, communication protocol, safety, and security.

## 2.3. Structure of this report

This report is the result of the first task of WP2 and serves as the basis for the other tasks in the work package, hence it is structured along the required information for the other tasks (functional specifications, communication including security, and functional safety):

- Chapter 2 concentrates on the functionalities attained in other projects:
  - What use cases were present?
  - What hardware was used?
  - Low level and intermediate level control
  - Interaction with the driver,
- Chapter 3 summarises the relevant results for the communication,
- Chapter 4 describes which techniques will be pursued for security in ENSEMBLE,
- Chapter 5 outlines the safety process that is intended to be followed in ENSEMBLE; it also describes a possibly interesting safety function from a past project,
- Chapter 6 summarises finding of a questionnaire among stakeholders on their knowledge of the use of infrastructure in platooning related projects, as the infrastructure elements are badly documented and straightforward information is not available,
- Chapter 7 discusses strategic functions and services for platooning, and
- Chapter 8 gives an overview of the state of the art of impacts of truck platooning,
- Chapter 9 summarises the findings and formulates conclusions for the ENSEMBLE project.



Input for above chapters came from the European Truck Platooning Challenge, which had a mono-brand demonstration of platooning by all European truck manufacturers in 2016. Besides that, the following projects contributed to this deliverable:

CHAUFFEUR II (2000 - 2003): Due to the age of this project it was decided (WP2 meeting June 2018) to not further take it into account.

KONVOI (2005 - 2009): This was a German research project mainly focussing on analysing the impact of platooning (driver acceptance, traffic flow and environment) and its implications on legal and economics. For ENSEMBLE mainly the impact on other road users may be of interest as other results are also quite dated.

SARTRE (2009 - 2012): aimed to encourage a step change in personal transport usage by developing of environmental road trains called platoons: develop strategies and technologies to allow vehicle platoons to operate on normal public highways with significant environmental, safety and comfort benefits.

i-GAME (2013 - 2016): The objective of i-GAME was to develop technologies that speed-up the real-life implementation of automated driving, supported by communication between the vehicles and between vehicles and road-side equipment. For i-GAME the solution was found in so-called supervisory control, that provides both event-driven control to initiate vehicle manoeuvres (e.g. a car wants to merge on a highway) and real-time control to execute the manoeuvres (i.e. vehicles make a space for the merging vehicle and the merging vehicle steers into the empty space). To focus on interoperability and thus speed up real-life implementation, i-GAME organised the 2<sup>nd</sup> Grand Cooperative Driving Challenge (GCDC). In this challenge different cooperative scenarios were to be driven by the participants. A total of ten teams participated in this 2<sup>nd</sup> edition of the GCDC.

COMPANION (2013 - 2016): The objective of COMPANION was to develop and validate off-board and onboard systems for coordinated platooning ('creation, coordination, and operation'), research potential legal solutions and standards to advance platooning adoption, and demonstrate of platooning operations on European roads. A new real-time coordination system was proposed, which will define an optimized flow of vehicles in order to dynamically create, maintain and dissolve platoons according to an online decision-making mechanism, taking into account also historical and real-time information about the state of the infrastructure. With such a technology, platoons will be no more composed just of vehicles with common origins and destinations, but they will be created dynamically on the road, by merging vehicles (or sub-platoons) that share also only subparts of their routes.

AUTONET2030 (2013 - 2016): aimed to develop and test a co-operative automated driving technology, based on a decentralised decision-making strategy which is enabled by mutual information sharing among nearby vehicles. The project aimed for a 2020-2030 deployment time horizon, taking into account the expected preceding introduction of co-operative communication systems and sensor-based lane-keeping/cruise-control technologies. It did, however, not specifically concentrate on platooning and therefore the use cases and developed technologies are deemed out of scope here.

ROADART (2015 - 2018): The main objective of ROADART was to investigate and optimise the integration of ITS communication units into trucks. Due to the size of a truck-trailer combination the architecture approaches investigated for passenger cars are not applicable. New architecture concepts have to be developed and evaluated in order to assure a sufficient Quality of Service for trucks and heavy-duty vehicles. An example of a specific use case is the platooning of several trucks driving close behind each other through tunnels with walls close to the antennas that support the communication systems. Due



to the importance of tunnel safety, significant research effort is needed in order to check the behaviour of the antenna pattern, diversity algorithms and ray tracing models especially for trucks passing through tunnels. V2V and V2I systems specified from the C2C Communication Consortium are focussing on road safety applications. The ROADART project aimed to demonstrate especially the road safety applications for Truck-to-Truck and Truck-to-Infrastructure systems under critical conditions in a real environment, like tunnels and platooning of several trucks driving close behind each other. Demonstration and Evaluation of the use cases was performed by simulation and by practical experiments on several levels.

CONCORDA (2017 - 2020): The CONCORDA (Connected Corridor for Driving Automation) project contributes to the preparation of European motorways for automated driving and high-density truck platooning. The main objective of the project is to assess the performance of hybrid communication systems, combining 802.11p and LTE connectivity, under real traffic situations. CONCORDA paves the way for solutions based on the combination of connectivity and infrastructure that will help build the vehicle's environmental perception model. Moreover, the project aims to aid in the improvement of accuracy and integrity of the localisation services. The CONCORDA project will commence based on common application specifications that will be updated during the project in an iterative manner (during the pilot operation according to evaluations and lessons learned) and in cooperation with C-Roads. New standards, or evolutions of existing standards, will be proposed as a result of this process.

AUTOPILOT (2017 – 2019): this project concerns the use of Internet of Things for enabling Automated Driving. The extent and volume of information sources that can be addressed through internet of things is seamlessly unlimited, offering potential improvements of automated driving functions (including improvements in security, efficiency, accuracy, etc.) and the information will enable services involving automated driving. Various use cases will be implemented and large scale demonstrations will be executed to evaluate the potential and calculate the related impacts of using Internet of Things for Automated Driving. The for ENSEMBLE relevant use case is Platooning. In Autopilot, the main research questions for Platooning concern scheduling and organisation of platoons, interactions with legacy traffic, and driving efficiency and comfort. Several variants of platooning will be deployed and evaluated in AUTOPILOT:

- An urban variant to enable rebalancing of a group of driverless vehicles, involving one driver, driving the lead vehicle.
- A highway variant, where one or more highly automated vehicles follow a lead vehicle on the highway. The scenario to be implemented will start from a platooning appointment that has been made using a Platooning Service and will consider forming of the platoon. Dynamic pick up of vehicles will be explored, where platoon forming is done while driving. The platooning vehicles will anticipate on traffic lights, legacy traffic, etc. addressing information published to an Internet of Things platform from different sources.

The project is ongoing and first pilots are scheduled in the second half of 2018.

For some topics, like e.g. Driver Interaction and heterogeneous platooning, results of other projects and more academic research were reviewed as well.



### 3. FUNCTIONALITY

This section gives an overview of the relevant functionalities developed in past projects as listed in Section 1.3. Some other project results are reported here as well due to relevance for ENSEMBLE although these specific projects did not target platooning technologies. Moreover, some topics were not touched in the past platooning project, hence, for these topics a literature study was performed to provide an overview of the current status of research in that area.

#### 3.1. Use Cases

This section gives an overview over the different use cases implemented in the different platooning projects. It should be noted that the exact implementation of the use cases may differ. Next table gives a main overview.

**Table 3-1. Overview of use cases in the different past EU platooning projects**

Categories	Use Cases / Manoeuvres	"DAF ETPC"	"DAMLER ETPC"	"IVECO ETPC"	"MAN ETPC"	"SCANIA ETPC"	"VOLVO ETPC"	Sweden4Platooning	Singapore (phase 1)	SARTRE	I-GAME	COMPANION	ROADART
Platoon formation	Platoon formation	x			a			x		x		x	
Platoon engaging	Platoon engaging - from behind by single vehicle	x	x	x	x	x		x	d	x	d		
	Platoon engaging - from front by single vehicle	x								x			
	Platoon engaging - from side by single vehicle									x			
	Platoon engaging - from behind by platoon ("merging")							?					
Platooning	Platooning - fixed time gap (incl acc & dec)	x	x	x	x	x		x		x	x		x
	Platooning - gap adaptation (intruder; e.g. cut-in)	x	x		x	x		x	x	x	x'	x	
	Platooning - gap adaptation (system status; e.g. packet loss)	x	x		x	x							x
	Platooning - Emergency braking	x	x		x	x		x	x		x	x	
	Platooning - Lane Change								x	x	x'		
	Platooning - Stop & Go handling					x					x		
Platoon disengaging	Platoon disengaging - leave	x						x		x		x	
	Platoon disengaging - split			x	c	x		x					
	Platoon disengaging - dissolve	x	x										
OTHER	Crossing country borders	x	x	x	x	x	x						
	Hilly road												
	Lateral support	x											
	Lateral control		x		x								
	Max. no. of trucks in a platoon	2	3	2	2	3	3						
	Tunnels												x
	Platooning through exit / entry ramps	x							x				
	narrow lanes								x				
	driving through city / city-like environment								e				

a: approach and acknowledge, b: detection, c: requiring approval, d: stand still joining, e: with all possible use-cases/manoeuvres like turning, junctions, traffic lights, etc.

As can be seen from the table, most of the implementations use one way of platoon engaging: from behind. This is a straightforward solution, it is in the view of the driver, quite simple manoeuvring, closing the gap, and no (automated) steering is involved.

Considering the platooning phase three use cases stand out: 'normal' platooning at a fixed (time) gap, automated gap adaptation and emergency braking. 'Normal' platooning should be the most prevalent use case, offering the envisaged benefits. Hence, in the reviewed projects the used gap was smaller than normally allowed.

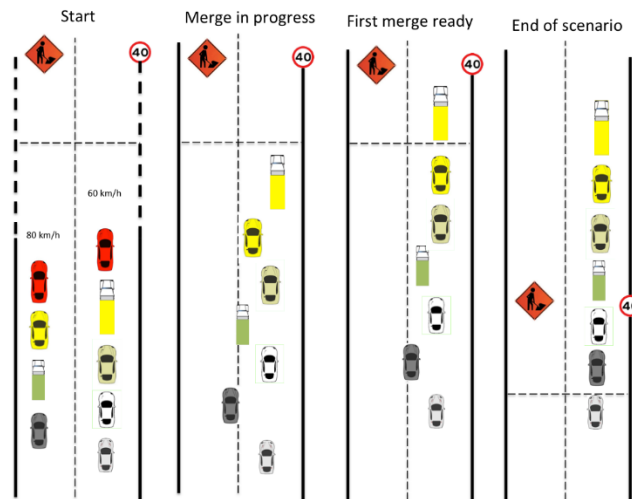


Automated gap adaptation is mostly implemented as a reaction to an intruder (i.e. non-platooning vehicle) entering the platoon. Since the platooning gap is smaller than normally allowed, an intruding vehicle forms a potential safety threat and hence the gap to this vehicle is opened. Some of the projects reported to also open the gap in case of system failures like missing communication or adverse platooning system state(s).

An emergency braking use case was implemented in most projects, and probably in all, but mostly no specific information was found about it, probably because the main aim of the project was on other subjects like e.g. communication devices and antennas like for ROADART.

Very special manoeuvres were implemented in the project i-GAME. One is worth mentioning here, as it may give an outlook on what may be implemented in higher levels of platooning like level B or C. The use case was called Highway merging of platoons of vehicles. Two platoons are approaching a construction site on a highway. The site is out of view for all participants when the scenario starts. The left platoon (A) and the right platoon (B) receive information from a roadside unit (RSU) that they are approaching a road construction site. The RSU message contains information about position and speed limit on the construction site. The participating vehicles should merge the two platoons to one platoon in the available lane for passing the site. The merge should take place in a specified area before the Construction Site.





**Figure 3-4. i-GAME highway merging scenario**

A specific scheme was setup to perform the merging of the two platoons (see Figure 3-5):

1. All vehicles in the right lane (i.e. the vehicles of the platoon that stays in the lane) pair up with a vehicle in the left lane, driving close and in front (i.e. this vehicle will merge before the paired vehicle in the right lane).
2. Then the (first) vehicle in the left (merging) lane, pairs up with a vehicle in the right lane after which it will merge (normally this is the forward vehicle of the paired vehicle of step 1), while gap making is started in by the first vehicle in the right lane. This is done sequentially to avoid very low speeds of the last vehicles in the platoons. The IDs of the pairs are communicated (i.e. Forward MIO (most important object) on the left, and forward MIO on the right).
3. Once the gap is considered large enough by the gap maker in the right lane, a message is sent to the merging vehicle that it can merge.
4. After the first vehicles have paired, the gap is made, and the vehicle has started merging, the following vehicle in platoon A, in the left lane, pairs up with a vehicle on the right. This is triggered by the first pairs by setting the paired IDs in the communicated message to zero.

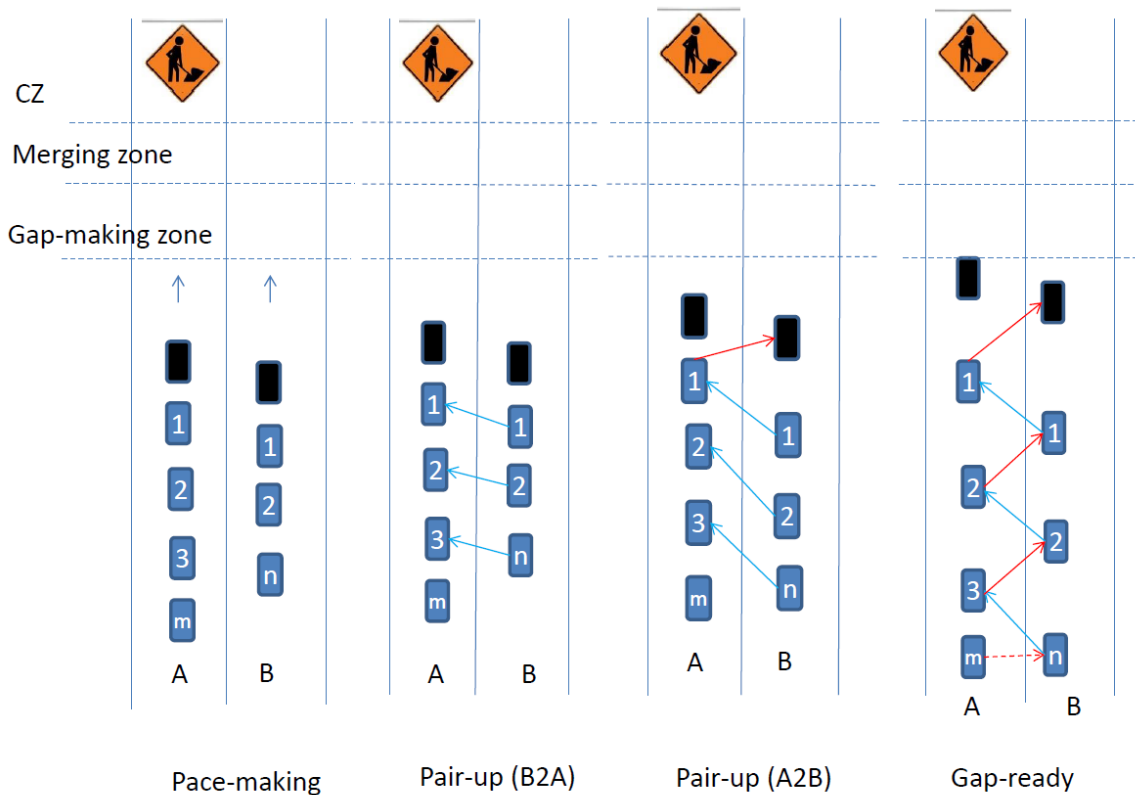


Figure 3-5. i-GAME merging of two platoons (note pairing from A to B is sequential after the gap is large enough to merge by the previous vehicle)

### 3.2. Physical Architecture

This section provides a short overview of the physical architectures typically used in past platooning projects, with the remark that these are all prototype systems. The basic elements are:

- Vehicle sensors, providing information on the state of the vehicle like speed, acceleration, steering angles, etc. These are mostly already available from systems used in a current production truck. GPS sensor is added for location data.
- Environmental sensors, providing information on the objects around the ego vehicle and information on the road. Typically, a radar is used as it is already available from the off-the-shelf ACC or AEB systems. The radar is often completed by a camera system, as it provides better object classification and lateral position data of objects and road markings. Sometimes more sensors, like e.g. lidar, are added to either improve object tracking or to enhance fault tolerance. Most projects only implement so-called forward-looking sensors, i.e. sensors that try to capture objects and road information in front of the vehicle. A few projects (e.g. SARTRE) also use side looking and rear looking sensors.
- Computational platform: this device runs the different functions of the platooning application. In rare cases these functions are distributed over different devices. In most projects a rapid control prototyping platform is used.



- Communication, including antennae: In most projects one level of communication is used: V2V and this is mostly based on the 802.11p/ITS-G5 standard. Some projects also implement a 'second' level of communication either to road-side units or to back offices. These mostly use the cellular network.
- HMI: all projects implement an HMI to at least activate, deactivate and monitor the platooning system. Sometimes the already available instrument panel is (re)used, sometimes additional (touch) screens, buttons, audio are used. Even haptic seats were reported.
- Interface to the low-level truck systems (engine and brake management systems): this is commonly done through CAN.

The ROADART project has published a very specific list and overview of all elements, see Figure 3-6.

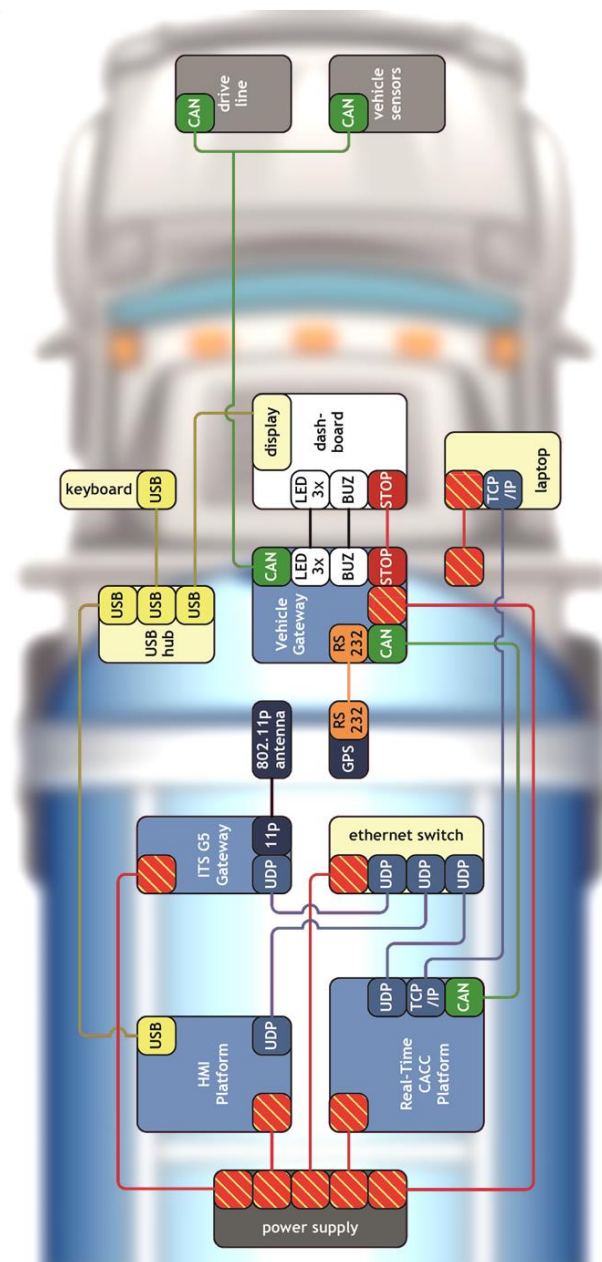




Figure 3-6. Physical architecture of an equipped truck of the ROADART project, D5.1 (Sinan Öncü, 2015)

The ECOTWIN 2 truck platooning project has published an overview of all elements, see Figure 3-7 (Bijlsma & Hendriks, 2017).

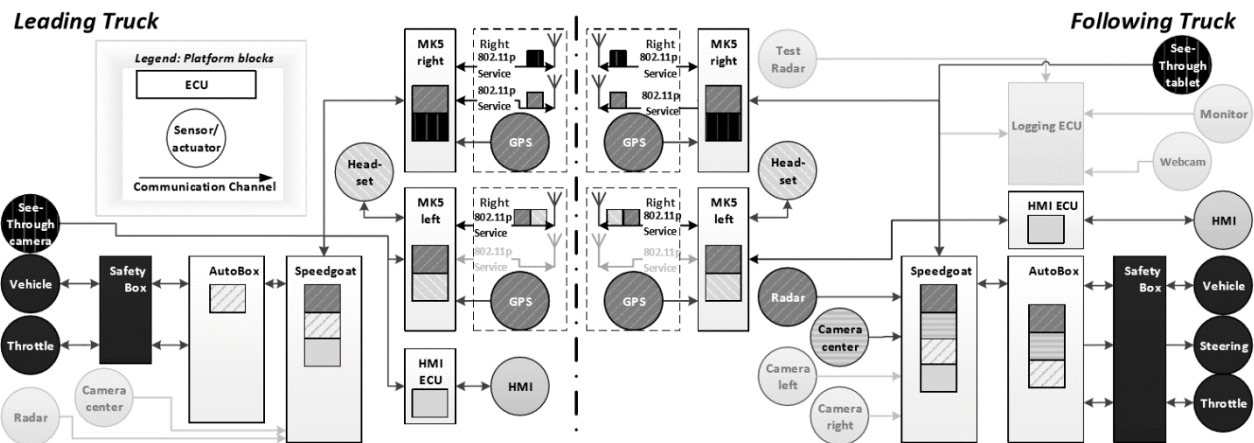


Figure 3-7. Physical architecture of an equipped truck of the ECOTWIN 2 truck platooning project

The different grey scales/patterns in the physical architecture of **Figure 3-7** refer to the high level functional architecture which is presented in **Figure 3-8**.

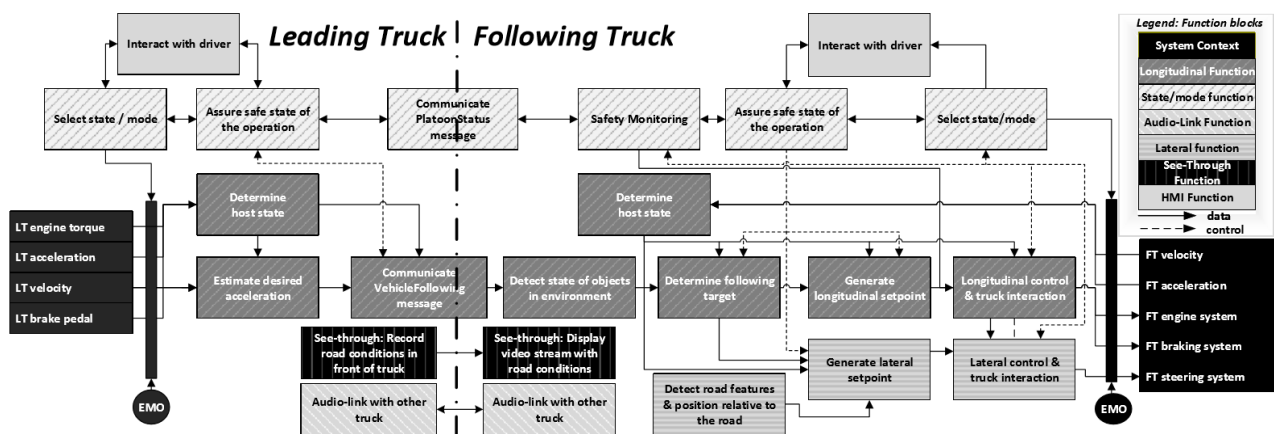


Figure 3-8. Functional architecture of the ECOTWIN 2 truck platooning project

### 3.3. Human Factors in vehicle-automation systems

#### 3.3.1. Introduction

One of the driving forces for developing platooning is to reduce the fuel consumption by driving closely behind each other. The development of Adaptive Cruise Control (ACC) and Connected Adaptive Cruise Control (CACC) has made it possible reduce the distances and still maintain a certain level of safety. However,

platooning also comprises several driver related challenges, for example, the time head way in platoons is often below human reaction time, which implies that the human driver cannot timely intervene in case of system failures if no special measures are taken in the system design.

Platooning can be regarded as a vehicle automation system. A considerable amount of research in Human Factors has been made in the field of vehicle automation, but still there is limited knowledge about empirical experiences regarding driver behaviour, acceptance, cognitive workload, situational awareness etc. from driving automated vehicles in real traffic environments. This is also the case for platooning. Moreover, most of the collected data and gained knowledge about platooning originate mainly from driving on test tracks and in driving simulators, which means that data availability from platooning in real traffic environments is even less. However, in order to understand the challenges, possibilities and limitations of driver related matters in platooning it is important to have an understanding of some of research that has been made in the field of driver vehicle automation interaction.

The following sections will mention some of the key-issues that need to be considered as to develop requirements and specifications related to platooning.

### 3.3.2. Driver-in-the-loop, Driver out-of-the-loop

In manual driving the driver is in charge of the driving tasks in all three levels (operational, tactical and strategic). In this case the driver is “In-The-Loop” (ITL), i.e. in full control of the vehicle and actively engaged in the driving tasks. As the automated systems are taking over the driving tasks, the human driver becomes “Out-Of-The-Loop” (OOTL), i.e. not being active and not in control of the driving tasks (Banks, 2014). With increasing automation levels the driver is going from being an active agent in the driving tasks to being a supervisor of the automation system. Consequently, the driving safety will increasingly depend on the quality of the interaction between the driver and the automated system (Merat N. L., 2012).

OOTL also refers to a state where an operator loses awareness of the system state due to limited human-system interaction (Endsley & Kiris, The out-of-the-loop performance problem and the level of control in automation, 1995). Early vigilance studies have shown that it is almost impossible for an individual to maintain constant visual attention towards a source of information that does not change often (Mackworth, 1950). Later studies have also shown that humans are poor supervisors and not good at detecting system errors (Parasuraman & Riley, Humans and automation: Use, misuse, disuse, abuse, 1997). These facts contrast to the SAE levels 2-3 that require the human driver being responsible for the monitoring the driving environment as well as being the fall back of the dynamic driving tasks.

Automated systems that require the driver to take over control of the driving while the driver is OOTL can put the driver (and other road users) in dangerous situations, since the driver may not be able to take over control safely (Merat N. L., 2012).

In addition, in the event of automation or system failure, the time that it would take to re-orient a driver being OOTL to being ITL would most likely result in either a diminished effectiveness of the task or even in a total failure to complete the task (Kaber & Endsley, 2003). Paradoxically, with increasing automation, which brings the drivers OOTL, it is increasingly important that drivers are kept ITL, for example via decision and action selection as well as action implementation (Merat & Jamson, 2008).

However, the need to return to manual driving will always be present in SAE Levels 2 and 3, which emphasizes the question how to re-engage the driver to manual driving with minimal risk to safety. This question is



paramount for platooning considering the close distances (in meters and in seconds) between the trucks in a platoon and the limited field of view, which constrain the driver to resume control in a safe way.

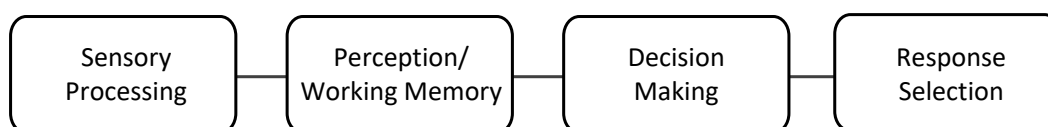
### 3.3.3. Situational awareness and mental models

Situation awareness (SA) is about being aware of what is happening in the surrounding environment and to understand how information, events and actions can have impact on goals and objectives, both immediately and in a near future. For high level of SA humans need appropriate mental models (Endsley & Jones, Designing for situation awareness: An approach to user centered design, 2004). A mental model is a human's perception of a system's structure and it is used by humans to predict how the system will respond, for example to different control inputs and environmental changes (Klein & Crandall, 1995).

Mental models, therefore, play an important role for the drivers' SA, including problem solving, judgment, decision making and planning. The level of SA also affects the drivers' actions and behaviours when interacting with automated vehicles. Therefore, it is important that drivers can develop appropriate mental models of the automated system in order to "co-operate" with the system in a safe and efficient manner. If not, there is a risk that drivers may misunderstand the system which could result in inappropriate interactions and putting him/herself and other road users at risk.

For platooning the drivers' mental model(s) may be of utmost importance for the driver to understand ones' own vehicle's system as well as to understand the platooning system (including the other trucks in the platoon) and how these systems interact.

The mental processes to achieve SA include information processing. Early human information processing models described a four-stage process: (i) Sensory Processing, (ii) Perception, (iii) Decision Making and (iv) Response Selection (Figure 3-9).



**Figure 3-9. A four-stage human informational processing.**

However, later research has suggested that humans use a less sequential, but more interlinked informational processing models based on the concept of SA. SA implies that in order to understand a particular situation, humans have to (i) perceive, (ii) comprehend and (iii) to project the future states of that situation (Endsley, Toward a theory of situation awareness in dynamic systems, 1995)(Figure 3-10). This process is influenced by different 'states' of the agents, such as the agents' experiences, abilities, goals, stress, etc. as well as the agents' perceived state of the environment.

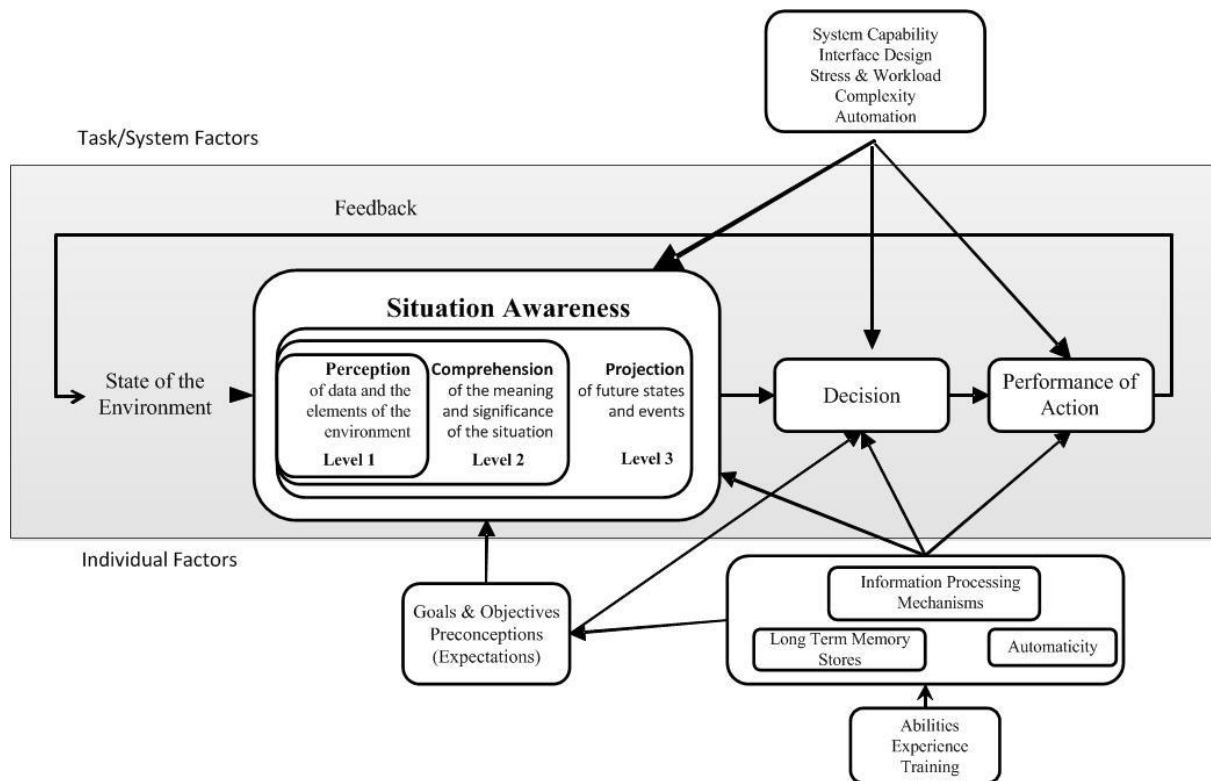


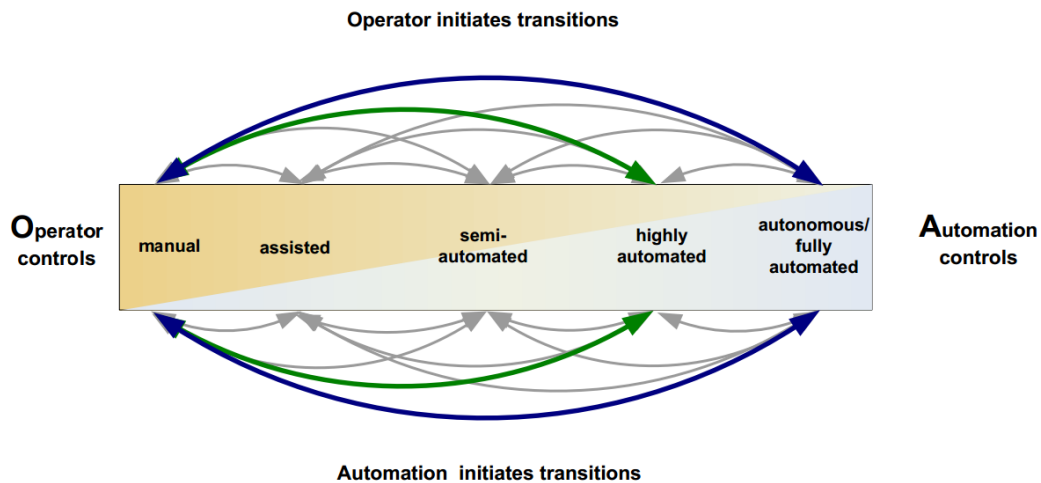
Figure 3-10. Concept of Situation Awareness in dynamic decision-making (after Endsley, 1995)

### 3.3.4. Transitions

As described in SAE's classification (SAE J3016: Taxonomy and Definitions for Terms Related to OnRoad Motor Vehicle Automated Driving Systems, 2016), the dynamic driving tasks in levels 2-4 are in control of the automation system, but in critical conditions which the system cannot handle the drivers are expected to take over control, i.e. being the fall back. The transitions of control and responsibility have been classified into three principles (Flemish, Kelsch, Löper, Schieben, & Schindler, 2008):

1. The direction in which a transition can occur. Figure 3-11 shows that the control can be transferred from the driver to the automated system, e.g. driver activating Adaptive Cruise Control, or transferred from the automated system towards the driver, e.g. system deactivation of a Lane Keeping System due to missing lane markings.
2. The agent initiates the transition (the driver or the automated system). A driver-initiated transition is, for example when the driver wants to take control because he/she feels his/her own ability is more beneficial and/or safer. A system-initiated transition is, for example when the system has reached its limits, or due to automation failure, road obstacles, poor weather conditions, sudden/unpredicted manoeuvres by other vehicles etc. (Saffarian, De Winter, & Happee, 2012).
3. The agent that is in control at the point of the transition and the agent that is addressed in the transition. (Martens, et al., 2007) define four different classes of transition:
  - a. Human initiated transfer to automation

- b. Automation initiated transfer to automation
- c. Human initiated transfer to manual control
- d. Automation initiated transfer to manual control



**Figure 3-11. All possible transitions between an operator and the automation system at different levels of automation. The green arrows show the transitions between manual control and highly automated driving. The blue arrows show the transitions between manual control and fully automated driving ( (Flemish, Kelsch, Löper, Schieben, & Schindler, 2008)**

In manual driving the drivers are assumed to have adequate levels of SA and, therefore, the transition from manual driving to automation is unlikely to be critical from a safety point of view given that this transition is not very complex. For the same reason, a transition request from the system to go from manual driving to automation is not likely to be critical, because the driver can choose to accept or to reject the request.

However, transitions from automation to manual control are more complex and critical due to the fact that the driver may be OOTL and not capable to take over control safely. In addition, transitions from automation to manual control also comprise technically advanced challenges: the system needs to “measure” the drivers’ state to ensure that the drivers are capable to take over the control safely (Endsley & Kiris, The out-of-the-loop performance problem and the level of control in automation, 1995). There are several systems to measure driver state, e.g. eye-tracker, facial recognition systems, psychophysical metrics (heartbeat, blood pressure, transpiration etc.), but up to this date there are no validated systems that can determine whether drivers are capable or not to take over control safely.

### 3.3.5. Role and task awareness/confusion

According to SAE levels 2 and 3 the driver is not engaged in the dynamic driving tasks, but still requested to monitor the driving environment and being the fall back in situations the system cannot handle. The drivers are in these levels supervisors of the system, but as earlier mentioned, humans are very poor at monitoring

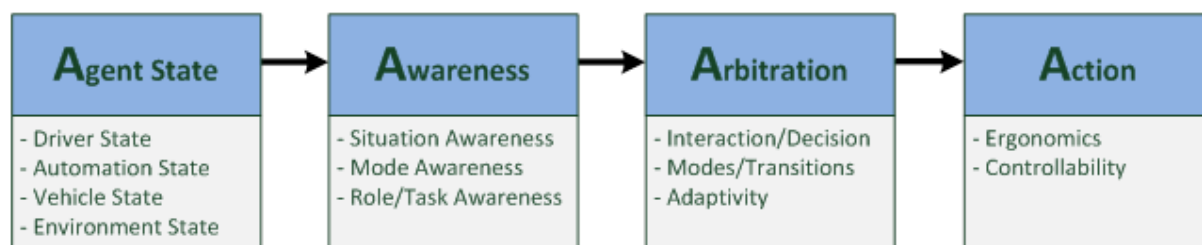


and supervising. Studies have also shown that with increasing automation drivers tend to engage in non-driving related tasks (Carsten, Lai, Barnard, Jamson, & Merat, 2012), for example text-messaging, reading, talking in phone, engaging in games or other activities on their smartphones or tablets. This means that drivers engaging in non-driving related tasks are even more OOTL, their levels of SA are very low and, therefore, they have very limited capability to take control safely in case of an unexpected transition to manual control. In addition, the drivers' role and task awareness may be affected in a negative way when the system allows for engaging in non-driving related tasks, but still requires the drivers to supervise the system, and thus can put the drivers in conflicting and confusing situations.

### 3.3.6. Human Factors Recommendations for Driver-Automated vehicle interaction

In order to understand driver-vehicle interaction it is useful to look at the research in information processing. (Parasuraman, Sheridan, & Wickens, A model for types and levels of human interaction with automation, 2000) established a taxonomy based on (Sheridan & Verplank, 1978) with four stages in information processing: Perception, Analysis, Decision-making and Execution.

Based on these categories a new structure for multi-agent systems such as a Driver-Automation-Vehicle-Environment system called the 4A-structure (Figure 3-12) was created in the project AdaptIVE (Kelsch, 2017).



**Figure 3-12. 4A-Structure with the four main categories and their sub-categories describing the informational processing in a DAVE system. These categories and sub-categories are used to structure the HF-recommendations in the AdaptIVE project.**

The 4A-Structure can serve as framework or methodology to discover challenges and problems that drivers may experience in a Driver-Automation-Vehicle-Environment system. After the challenges and problems have been described high level functional Human Factors recommendations to the challenges/problems can be formulated. These serve as a basis for the formulation of non-functional recommendations, which are more solution oriented towards how to solve or tackle the challenge/problem. If available, examples of different solutions to the challenges/problem can be added.

In the current version of the Human Factors recommendation catalogue (Figure 3-13, 2017) there are in total 26 functional Human Factors recommendations, distributed to the four categories Agent state (6), Awareness (9), Arbitration (2) and Action (9).



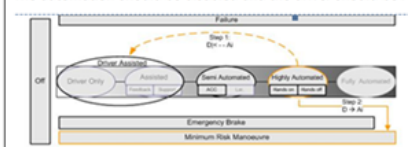
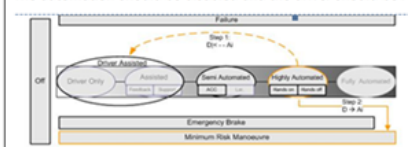
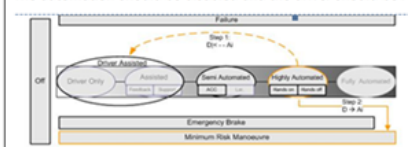
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Figure 3-13. Explanation of the Human Factors catalogue.

The Human factors recommendation catalogue can be regarded as guidelines for engineers, HMI-designers and other practitioners in the field of driver- automated vehicle interaction.

The catalogue should be regarded as a living document and as such being subject to revisions and amendments as the knowledge, technology development and experience in the field of Driver-Automation-Vehicle-Environment are progressing, not least in the field of platooning. Although, many of the human factors recommendations in the catalogue are applicable to platooning, there are currently no platooning specific human factors recommendations.

### 3.3.7. Take over request

A central question in a Driver-Automated-Vehicle system is the drivers' ability to take over control when this transition is initiated by the system. In cases of planned transitions, the system can be designed to inform the driver well in advance to prepare for take over. The system can also be designed to make this transition smooth and safe, e.g. by keeping relevant ADAS active in order to support the drivers in the transition. If the take-over request (TOR) is initiated by the system due to unplanned events or to system failures, the outcomes of the situations are dependent on either (i) the drivers' vigilance and ability to take over control in a safe way, or (ii) the system's technical specifications to handle unplanned events or system failures.

However, research has shown that human performance diminishes in situations of cognitive underload (Davies & Parasuraman, 1982), e.g. during monitoring tasks. In such circumstances, drivers should not be expected to be able to take control safely after a period of being OOTL.

A meta-analysis study of determinants of TORs by (Zhang, De Winter, Varotto, & Happee, 2018) investigated 373 mean take-over-times (TOT) from 93 studies with in total 3288 participants. The mean TOTs ranged from 0.69 s to 19.79 s and the overall average mean TOT was 2.76 s (SD= 1.55, N=373). The study highlights some interesting findings, for example; (i) the drivers use the time available to take over, i.e. the more time there is, the more time the drivers use to take over. Dependent on the situation and the time available to take over, the drivers assess the situation and decide on how to act; (ii) drivers that are engaged in non-driving tasks with a handheld device strongly increase the mean (TOT); (iii) high level of automation (SAE L3 and above) showed higher mean TOTs compared to partial automation (SAE L2), possibly due to a combined effect of a longer time budget, less urgency, and more involvement in (handheld) non-driving tasks; (iv) visual messages only for TORs showed longer TOTs than auditory or vibro-tactile TORs. A plausible explanation is that drivers may overlook a visual signal, especially if they are engaged a visually-distracting non-driving task; (v) no clear effect of age was found (young drivers < 30y, older drivers >60y). Although older drivers have a slower reaction time they may be generally more cautious and be likely to take-over even when this is not strictly necessary. They may also use less handheld devices for non-driving tasks, and instead focus on the driving task.

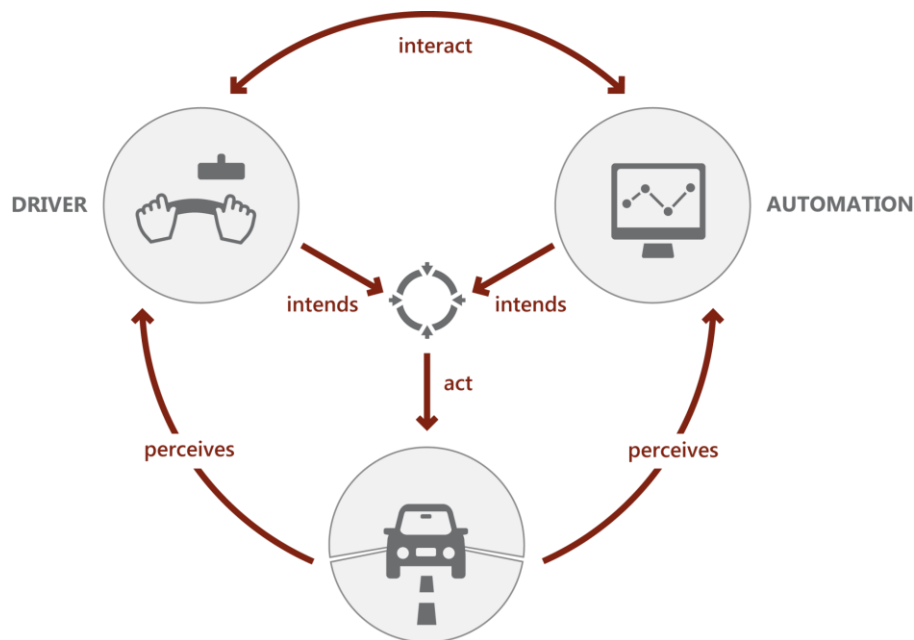
Considering the results with mean TOTs ranging from 0.69 s to 19.79 s and the overall mean TOT of 2.76 s and comparing these figures with the time/distances in platooning, which are much shorter (0,5 s - 1,5 s), put high demands on the platoon systems' capacities to handle unplanned and critical situations in a safe way. The human driver cannot be counted on as being the fall back in such circumstances.

### 3.3.8. Acceptance and Trust

The human driver and the automation system co-exist within the same system. Therefore, Driver-Automation-Vehicle-Environment (DAVE) system is often described as a multi-agent system in which the driver, automation system and the vehicle are interacting to achieve common goals at all three levels (Figure 3-14).







**Figure 3-14. The model in shows the interrelationships between the agents, their intentions and the constant communication between them that is required in order to accomplish common goals**

The findings from research in the area of Driver-Automation-Vehicle-Environment (DAVE) are to a great extent also applicable to platooning, because platooning can be regarded as a DAVE system. Some of the issues discussed above may even be more critical for platooning since the drivers in the following trucks are driving very close behind each other, which is a circumstance that stresses matters such as Time-to-take over Transitions schemes from automation to manual control, limited field of the driving environment and surrounding traffic, low level of situational awareness and being OOTL.

(Larburu, Sanchez, & Domingo, 2012) also point out Trust and Acceptance as important factors for platooning. Systems will only be accepted if the systems are safer or more comfortable than driving without the systems. A general result from their simulator study (no professional drivers, cars and only one truck in the study) showed that the shorter the distance to the vehicle in front, the lower the ratings for comfort and safety. The study also measured the participants' acceptance of driving near platoons and showed that the longer the platoon, the lower the acceptance ratings.

Professional truck drivers' experiences of driving in platoons are limited (due to the fact that no commercial platoons exist) and documented truck driver experiences, acceptance and trust in platooning system are scarce. There are a few on-road projects for platooning, for example the Truck Platooning Challenge in 2016 (<https://www.eutruckplatooning.com/home/default.aspx>), which was initiated by the Netherlands during their EU presidency in 2016 to support dialogue and cooperation and to challenge different European trucks brands to drive in platoons on public roads from various European cities to the Netherlands. However, there are no publications from this event about the drivers' experience, even though there may be internal reports made by the participating brands, but these are not public.

A research and development program that has tested truck platooning on real roads is PATH (California Partners for Advanced Transportation Technology) at the University of California, Berkeley in the United



States (<https://path.berkeley.edu/research/connected-and-automated-vehicles/truck-platooning>). In a study by (Yang, et al., 2018) they measured the drivers' experiences of using the Connected Adaptive Cruise Control (CACC). The results showed that the drivers were satisfied with the driving experience with the driver assist capabilities of CACC. However, CACC did not have a large enough effect to make the commercial vehicle operation job more attractive to them. One explanation could be that there are other factors than automation technology that affect the drivers' job satisfaction. The study also investigated drivers preferred time gaps and the results showed that the preferred time gaps were of 1.2 s and 1.5 s (the speed was 55 mph, 88km/h). Moreover, the drivers did not prefer to drive too close ( $< 0.9$  s) or too far (1.8 s) behind the lead truck. The shorter time gaps limited their driving field of view from following too closely and the largest time gap seemed to encourage more frequent vehicle cut-ins. Overall, the drivers felt comfortable with the CACC system, but preferred the manual mode in cases of heavy traffic and merging on the highway.

### 3.3.9. Knowledge gaps

There are several human factors knowledge gaps in the field of platooning. Firstly, there is a lack of data from driving in platoons in real traffic environments. Most data are from simulator studies and from driving on test tracks. Secondly, the long-term effects on human behaviour from driving in platoon, ranging from working days (8-10 hours/day) to months of daily driving in platoons are not known. Thirdly, there is limited knowledge of driving in platoons in varying weather conditions and driving in darkness. Fourthly, appropriate driver training programs for platooning are needed.

## 3.4. Platoon Controls

In this section the control functionalities involved in the operational and tactical layer of a platooning system are described. This structure is chosen to comply with the layers defined in the ENSEMBLE project. As mentioned in the Introduction, the operational layer involves the control of the individual vehicles in the platoon to automatically perform the platooning task, the vehicle actuator control (e.g. accelerating/braking, steering) and the execution of the manoeuvres initiated from the tactical layer. The tactical layer coordinates the platoon cohesion and the platoon forming. Further, this layer not only interacts with the operational layer, but also with the strategic layer.

This section attempts to give a general overview of the controls of a platooning system, rather than describing the controls per project. The reason for this is that in all projects platoon controls are used, but detailed information about the used controls is often not available. A main reason for this is that the development of the platooning controls is mostly not the main aim of the project. Furthermore, many control developments elaborate on developments done in previous projects by e.g. the same OEM. For ENSEMBLE it is however important to understand the platooning system as a whole in order to identify those parts of the system for which common functionality is required.

### 3.4.1. Operational Layer

#### *Longitudinal motion control*

The main control aim of platooning is to move vehicles at almost identical speed, while maintaining a desired, relatively small, intervehicle distance. To achieve this, the following vehicles in the platoon measure the distance to the vehicle in front using on board sensors, e.g. radar, camera and lidar. Additionally, wireless communication is used to obtain information of other vehicles in the platoon (at least from the preceding vehicle). The usage of wireless communication is required for maintaining the desired, relatively small,



intervehicle distances. The reason is that the response of the preceding vehicle can only be obtained with a relatively large delay when using onboard sensors, because the estimation algorithm needed to translate the discrete range measurements (supplied by radar, camera or lidar) to a metric of change in range over time (i.e. acceleration and deceleration of the preceding vehicle) requires time. By communicating acceleration and deceleration information of the preceding vehicle to the host vehicle, the response of the preceding vehicle can be obtained with much smaller, although nonzero, delay. In this way, shorter safe following distances can be achieved. The longitudinal control function that regulates the intervehicle distance and utilises information of other vehicles using wireless communication is called Cooperative Adaptive Cruise Control (CACC). The CACC principle is illustrated in Figure 3-15.

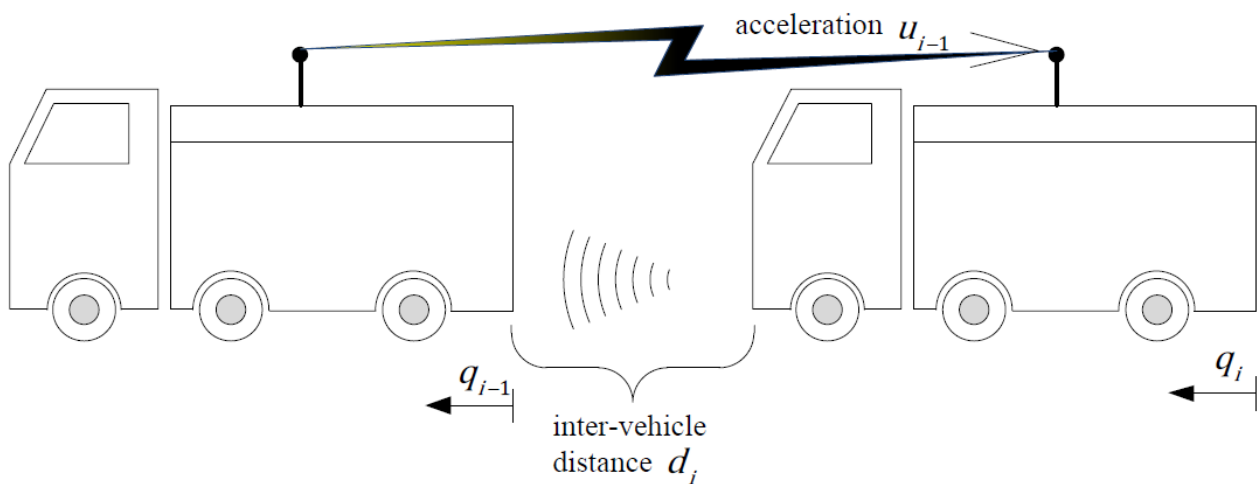
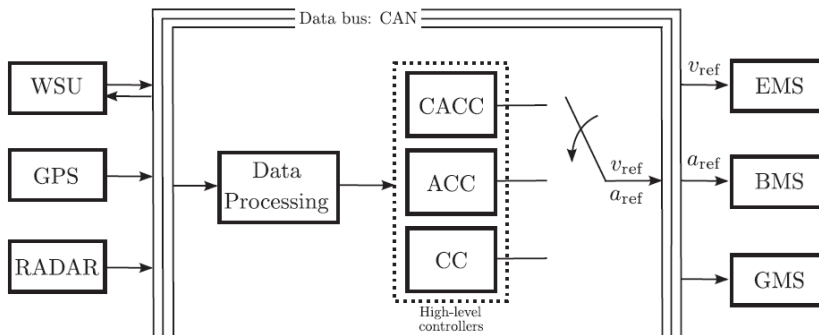


Figure 3-15. Schematic representation of CACC principle from ROADART (Sinan Öncü, 2015)

CACC can be considered as an extension of the adaptive cruise control (ACC) function, which is standard on many new vehicles. ACC, however, only uses the onboard sensors to maintain a safe distance from vehicles ahead. As explained above, due to the relatively large delay for obtaining the dynamic information of the preceding vehicle compared to CACC, the safe following distance has to be much larger. It is expected that in a platooning system the vehicles will always have both a CACC and ACC function. The reason is that receiving vehicle response information of the preceding vehicle may disappear, e.g. due to cut-in of a non-equipped vehicle or due to communication loss. In such case, the relatively small safe headway distance of CACC cannot be maintained and the control switches to ACC with the larger safe headway distance. Finally, besides the CACC and ACC functions, the platooning vehicles also have a standard cruise control (CC) functionality. Although this CC functionality is not directly used in platooning, it uses the same lower level vehicle controls to actuate the powertrain or brake systems of the vehicle. Further, since different longitudinal control functions (CC, ACC and CACC) are available in a platooning system, a higher level control functionality, also called a supervisor, is required to decide about which longitudinal control function to use and with what settings, e.g. headway distance, speed setpoint, etc. An example of this typical vehicle control system architecture is shown in Figure 3-16.





**Figure 3-16. Example of vehicle control system architecture showing the 3 types of high-level longitudinal controllers (CACC, ACC, CC). The switch shows the selection of the different controllers. The figure further shows the in-vehicle information sharing via CAN bus. On the left side, the connection with vehicle sensors (GPS, radar) and the wireless sensor unit (WSU) is shown, and on the right with the lower level actuator controllers (engine, brake and gear management systems, EMS, BMS and GMS respectively). (Alam A. J., 2015)**

In Figure 3-16 it is also seen that the high-level longitudinal controls generate reference signals, in this case a reference acceleration  $a_{ref}$  and a reference velocity  $v_{ref}$ , for the lower level controllers. These lower level controllers use the engine, gearbox and braking systems of the truck to realise these setpoints. One should not associate 'lower level' with 'simple', as the powertrain and brake systems of a truck are highly nonlinear systems. Typically, the design objective of the lower level controllers is to achieve a linear and first order system behaviour. Furthermore, switching between different actuators should be smooth, e.g. deceleration can be achieved using multiple actuators: engine, foundation brakes, retarder. As these lower level controllers are OEM and vehicle specific, performance differences between trucks may occur. These performance differences may affect high level control performance and ultimately platoon performance.

An important performance indicator for CACC control is the so-called string stability. A platoon is considered string stable if spacing errors do not amplify downstream from one vehicle to another. If a platoon lacks string stability the amplification of errors may negatively impact the traffic flow, fuel consumption and the scalability with respect to platoon length is limited. String stability is relevant during CACC operation. The topic has been and still is of great concern in academic research. For linear and homogeneous platoons string stability can be mathematically proven. However, in real-life, system behaviour can become nonlinear and platooning vehicles are heterogeneous due to loading condition, vehicle brand, different control algorithms, etc. Especially in case of truck platooning this is very relevant as acceleration capabilities of trucks are heavily affected by loading condition, road slope and powertrain characteristics. Furthermore, different truck OEMs may use different sensors and CACC control algorithms.

Although the basic idea of CACC is the same, some concerns that arose from the state-of-the-art study are:

- V2V communication: different CACC implementations use different signals, e.g. real acceleration versus intended longitudinal acceleration of the preceding vehicle.
- String stability: in ENSEMBLE suitable methods have to be found to assess the string stability of the platoons.



Typically, the cruise control functions are developed for operation in normal driving conditions, i.e. meaning that longitudinal accelerations and decelerations are relatively small. During emergency braking events, a collision avoidance functionality is used to conduct automated emergency braking. The collision avoidance functionality used in platooning is similar to that of autonomous emergency braking systems (AEB, AEBS), which use the onboard sensors (radar, camera, lidar) to detect a possible collision and activate the braking system to avoid or reduce the severity of a collision. The reduced headway distances in platooning however require the usage of wireless communication to timely detect the preceding vehicle's deceleration. Several signals of the preceding vehicle may be communicated that indicate an emergency braking e.g. an emergency braking flag, a flag indicating the brake pedal engagement, the brake pedal position and the vehicle's longitudinal acceleration. An important aspect of the collision avoidance functionality is to avoid unintended braking (false positive), e.g. due to receiving a false emergency braking flag. Therefore, decision logic, sensor fusion and brake strategies are applied to reduce the probability on having false positives and the impact of these. For more details refer to (Ellwanger & Wohlfarth, 2017). Last but certainly not least, the difference in deceleration performance of vehicles must be accounted for in the spacing policy. A major factor to consider is that the actual brake performance of trucks is heavily dependent on maintenance and age of the truck/trailer. Deceleration differences of  $2 \text{ m/s}^2$  may occur.

### *Lateral motion control*

So far longitudinal control has been discussed. Platooning vehicles may also have lateral automation. Depending on the platoon level, the lateral control can be on an individual vehicle level or cooperative, i.e. using information of other vehicles via communication in addition to information of onboard sensors. The control objectives may be split into:

- Path following: vehicles follow a certain path that is planned based on perceived road information, e.g. lane markings, road boundaries, etc. The simplest example is automated lane keeping functions, but also more advanced automated lane change functions, which plan the lane change path using road information, fit into this category. A complexity for platooning is that the field of view of standard automotive sensors used for localisation and path planning is significantly reduced by reducing the headway, e.g. a camera may just see the back of the preceding truck and almost no road markings at very small headways.
- (Lateral) vehicle following: the vehicle 'copies' the lateral motion of the preceding vehicle. This may be achieved by vehicle tail following using onboard sensors or (additionally) by providing motion data of the preceding vehicle via communication. Simple vehicle tail following approaches, which do not have any information about the preceding vehicle beyond the observed tail location, lead to increasing lateral position errors in the platoon. Especially tractor semi-trailer combinations will cut corners, as tractor and semi-trailer tail travel at different radii. Furthermore, laterally connecting a string of vehicles may lead to downstream amplification of disturbances. The latter problem has similarity with the string stability problem in longitudinal control and is therefore sometimes called lateral string stability.

Depending on the application and implementation, controllers aiming for both path following and lateral vehicle following may exist. In such cases a supervisory controller decides on which controller to use in which situation.

In contrast to longitudinal control, where collision avoidance with other platooning vehicles is of highest importance, for lateral control mainly dangerous situations for and collisions with other road users must be

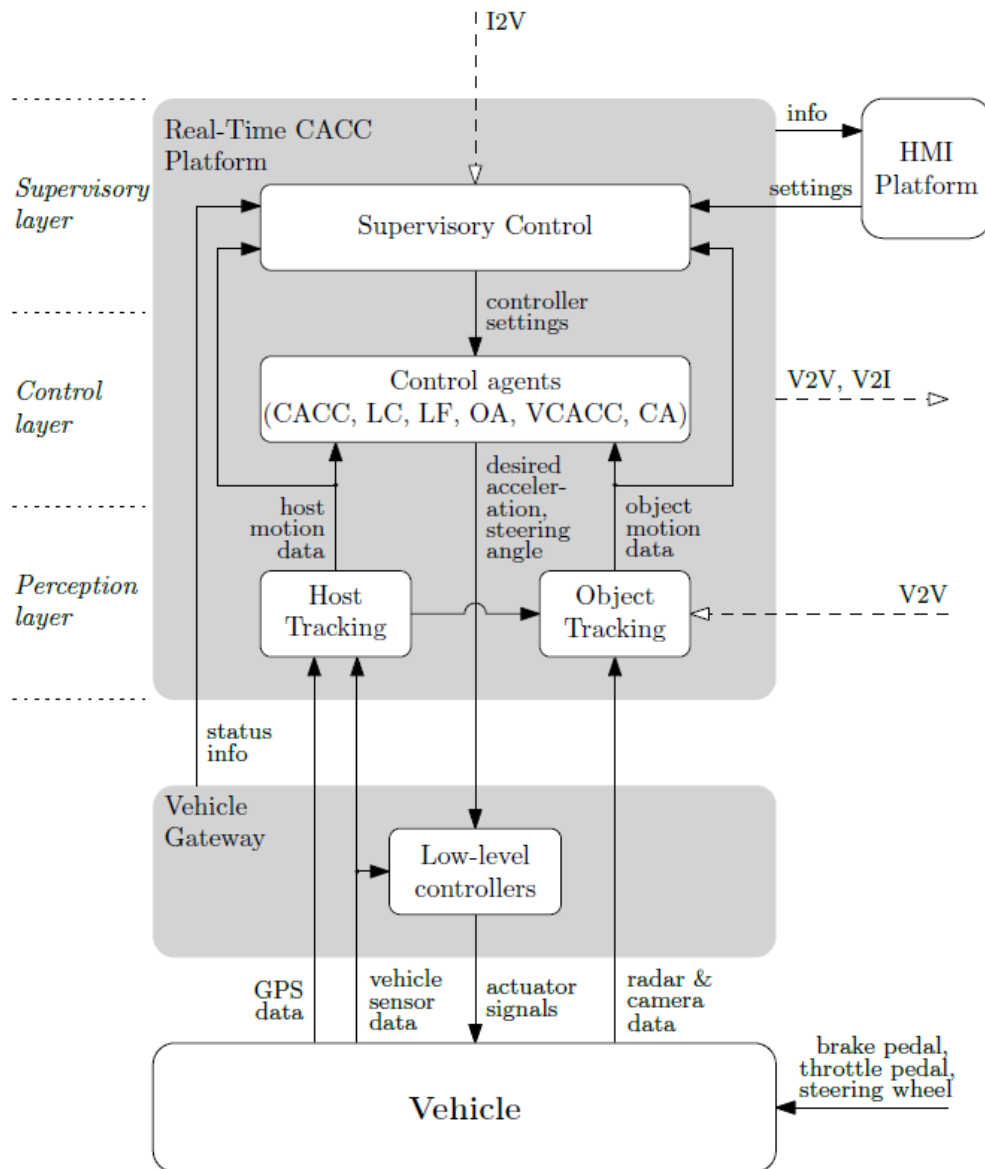


avoided, as well as collisions with infrastructure elements. In this respect, there is no (direct) reason to network the vehicles on operational control level. However, beyond the relatively simple application of lane keeping, communication within the platoon is required to coordinate more complex manoeuvres like performing an automated lane change with the platoon. Furthermore, sharing of environmental perception via communication may improve the environmental perception of a single vehicle in the platoon, which can be beneficial for the lateral control using this perception. But this is not special for platooning, it also holds for more general cooperative driving applications.

### *Operational supervisory control*

So far, longitudinal and lateral control functions have been considered separately. However, for vehicles equipped with both longitudinal and lateral control, these control functions can be active simultaneously. Therefore, the higher-level controls are typically combined in a supervisor. For example, during a lane change manoeuvre, the longitudinal control settings and used control function may have to change during this manoeuvre depending on the observed traffic in the lanes. Think e.g. of a vehicle (automatically) leaving the platoon by taking a highway exit. In that case, while moving laterally the longitudinal control function has to change from CACC to ACC and at some point in time, the vehicle speed may have to be reduced. An example of such control architecture, applied in the i-Game project, is shown in Figure 3-17.



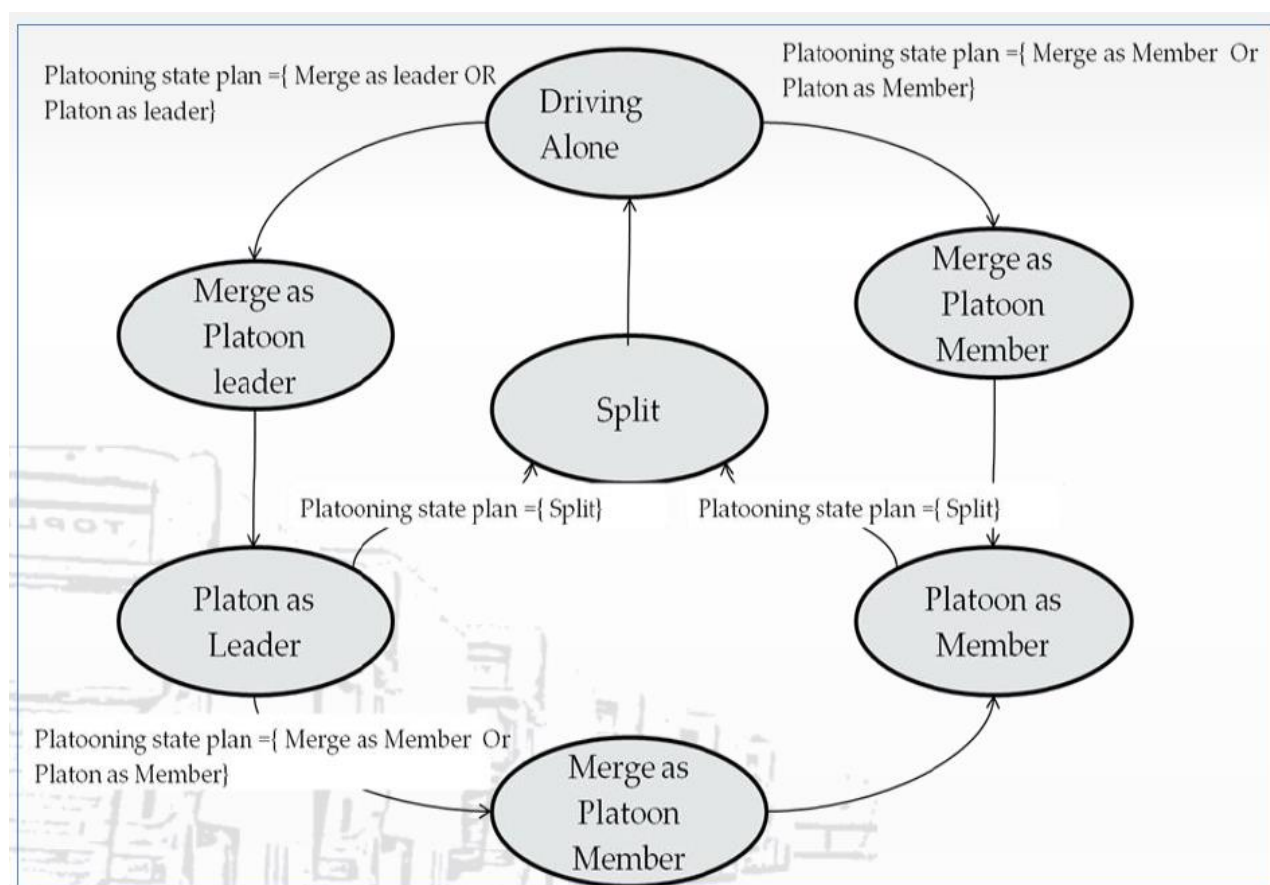


**Figure 3-17. Control system architecture of the i-GAME benchmark vehicles, showing the supervisory control on top and the various longitudinal and lateral motion control functions (here called agents) below in the Control layer**

In order to function properly, the supervisory control needs to have information about the role of the vehicle in the platoon and the manoeuvre that the vehicle is performing. In control terminology, this information is captured in states and typically (finite) state machines are programmed that describe the various possible states of the system and how to go from one state to another, i.e. the state transitions. A state transition is only possible if formulated conditions are fulfilled. Further, the system can only be in one of the states at any given time. The state machine is fully defined by a list of its states, its initial state, and the conditions for each transition. State machines are generally visualised in state diagrams.



An example state diagram of the operational (vicinity) control of the COMPANION project is shown in Figure 3-18. The states are shown in the ovals and the transitions are indicated by the arrows. Table 3-2 shows the relation between the states and the control functions that are active in each state. From the states and the transitions, it is obvious that information exchange is required to fulfil the necessary conditions. This information can come from wireless communication, the onboard sensors, the tactical layer and the driver via the HMI in the vehicle.



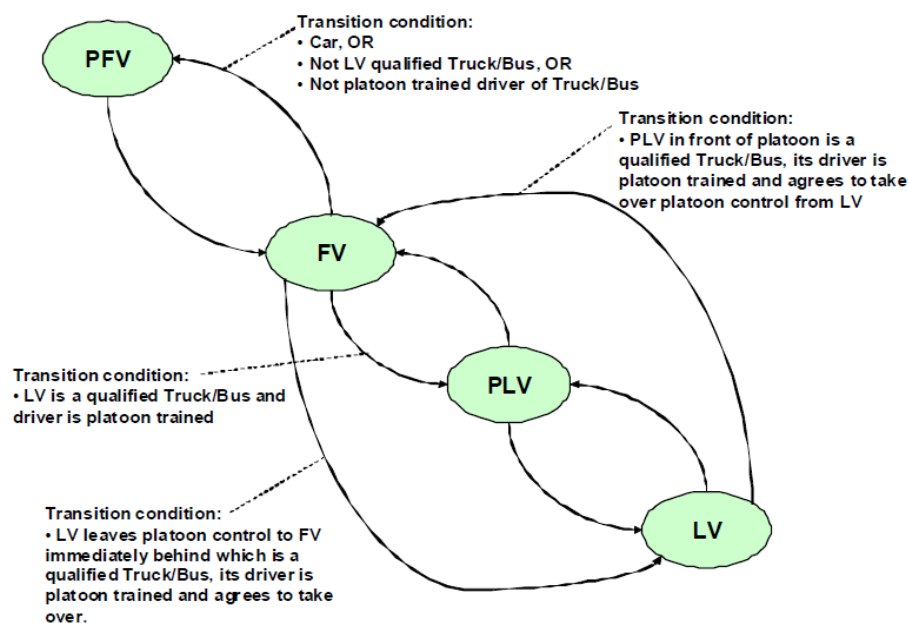
**Figure 3-18. State diagram of the Operational (Vicinity) Control of the COMPANION system, showing states and state transitions (arrows) (Pettersson, 2016)**



**Table 3-2. Relation main states and control functions from the COMPANION project (Pettersson, 2016)**

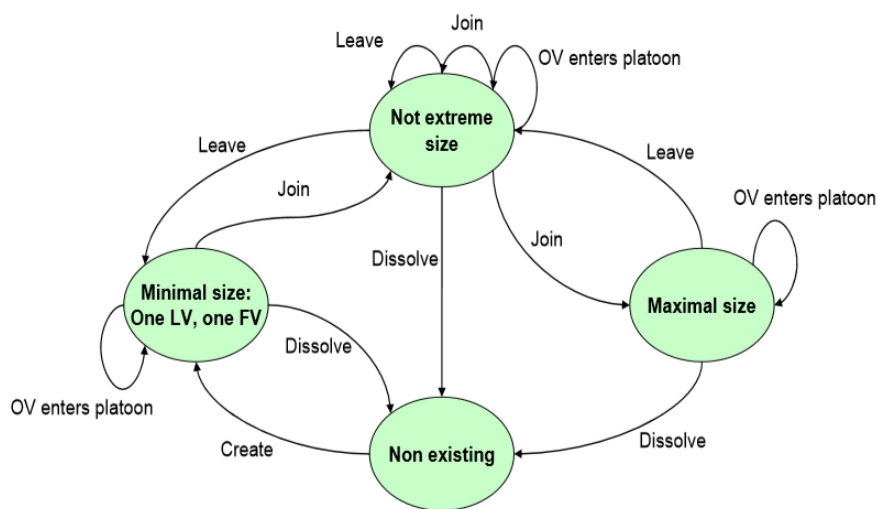
Main states	Control Function
Driving alone	ACC
Platoon as Leader	ACC
Platoon as Member	Platoon control (CACC)
Merge to Platoon Leader	ACC
Merge to Platoon Member	Speed up to catch platoon
Split	ACC
Intruder	ACC

Other examples of state diagrams are shown in Figure 3-19, Figure 3-20 and Figure 3-21 (Robinson, Chan, & Coelingh, Operating Platoons on Public Motorways: An introduction to the SARTRE Platooning Programme, 2010). Note the similarities and differences. It is obvious that for ENSEMBLE some alignment on state machines has to be done in order to enable multiband platooning. The (common) state machine is considered part of the tactical layer, which is described in the next section.



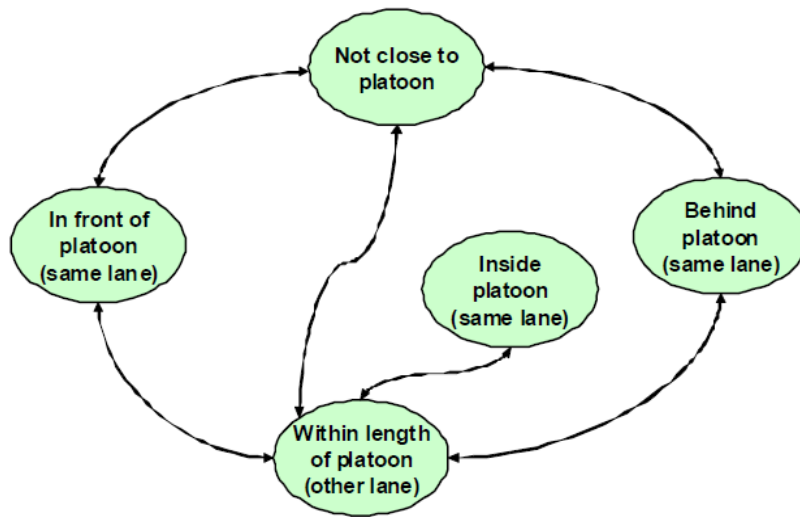
Platoon Vehicle States

Figure 3-19. State diagram of the Platoon Vehicle States of the SARTRE project, where: LV = lead vehicle, FV = following vehicle, PLV = potential lead vehicle, PFV = potential following vehicle.



Platoon States

Figure 3-20. State diagram of the Platoon States of the SARTRE project.



**Other Vehicle States**

**Figure 3-21. State diagram of the Other Vehicle States of the SARTRE project.**

### *Object tracking, V2V association and Host tracking*

To be able to map the V2V messages to the correct target typically the functions object tracking, V2V association and host tracking are needed.

In general, the forward in lane object tracking is performed by the radar sensor and optionally the camera sensor. Typically, the radar is used for an accurate estimation of the longitudinal relative position and velocity. The camera is typically used to estimate the type of the object and the lateral position.

By means of host tracking an accuracy absolute position of the vehicle is determined by either directly the GPS information or the fusion (e.g. by means of an EKF) of GPS information and the local odometry information of the vehicle.

This absolute information is then used to generate the relative distance / position and relative velocities between the host vehicle and the V2V message GPS position and object velocity. This relative information can then be used to associate the V2V message to the forward target yes or no (Ellwanger & Wohlfarth, 2017). This absolute information, together with the content of the V2V message (e.g. ID) can *also* be used to check the existence of a backward V2V target.

When the V2V relative distance does not match with the target in front, then this can e.g. indicate the presence of a cut-in vehicle (Ellwanger & Wohlfarth, 2017).

### **3.4.2. Tactical layer**

The tactical layer of a platooning system coordinates the platoon as a whole. The layer is implemented in the platooning vehicles and primarily interfaces with the operational layer. Besides that, the tactical layer also



interfaces with the strategic layer, typically via cellular communication. The main tasks of the tactical layer are:

- Coordination of platoon manoeuvres:
  - platoon forming and dissolution (both from the tail of the platoon and through merging in or splitting the platoon)
  - increasing inter-vehicle distances, e.g. to make space to allow other vehicles to cut-through or to prevent damaging bridges
  - performing automated lane changes with the platoon, or other coordinated manoeuvres
- Maintaining platoon cohesion:
  - while vehicles cutting in and cutting out of the platoon
  - to avoid platoon split up due to road load and performance differences as result of e.g. different loading conditions, hilly roads, vehicle power train characteristics, etc.
  - to avoid platoon split up at traffic lights
- Platoon state machine & data management:
  - Keeping track of / manage the state of the platoon and the states of the platoon members
  - Keeping track of the platoon properties (e.g. duration, size, time to remain)
  - Share platoon state information and configuration data with platooning vehicles and the strategic layer
- Request handling & HMI interaction:
  - Coordinate tactical requests coming for example from the lead truck driver, any other truck driver or the strategic layer
  - Coordinate which information to present to the driver
- Status monitoring and failure detection of the platoon
  - Failure detection and identification
  - String stability monitoring
  - Check consistency of V2X messages

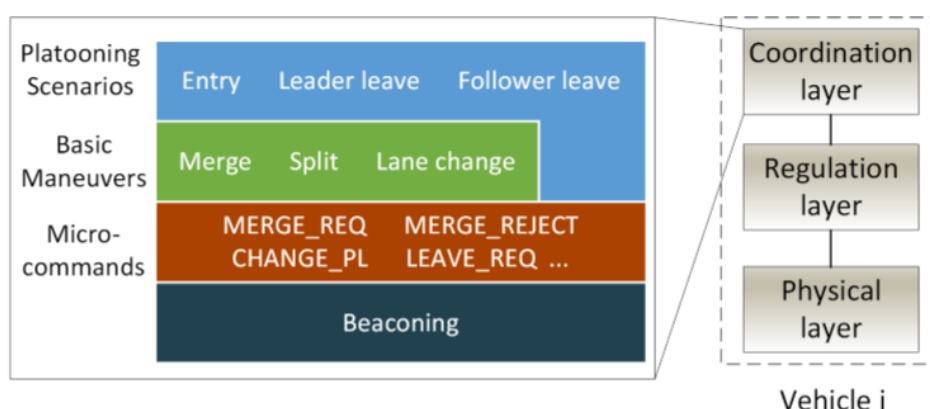
In order to achieve these tasks, the tactical layer typically contains decision algorithms, e.g. state machines, and receives information from the vehicle sensors, the wireless communication channels and the HMI. Example state machines who could be part of the tactical layer can be found in Figure 3-19, Figure 3-20 and



Figure 3-21 (Robinson, Chan, & Coelingh, Operating Platoons on Public Motorways: An introduction to the SARTRE Platooning Programme, 2010).

Besides these decision algorithms, the tactical layer may contain different algorithms for monitoring the health of the platoon or maintain platoon cohesion. In many past projects, the functionalities mentioned above are available, but mostly part of a single operational layer.

The paper “Platoon Management with Cooperative Adaptive Cruise Control Enabled by VANET” by Mani Amoozadeh et al ( Amouzadeh, Deng, Chuah, Zhang, & Ghosal, 2018) represents how CACC control is mapped to the regulation layer and how platoon management (in this case the coordination of 3 types of manoeuvres (merge, split, lane change) is mapped to the coordination layer.



**Figure 3-22. Platoon management protocol resides in the coordination layer of each vehicle and uses wireless V2V communication to exchange micro-commands between neighbouring vehicles in order to coordinate different manoeuvres.**

The paper “Heavy-duty Truck Platooning: A Review” by André de Souza Mendes et al (de Souza Mendes, 2017) presents an overview regarding truck coordination (see below cited section). The first section refers to coordination function on platoon level (for existing platoon), which in the context of ENSEMBLE mostly could be part of the tactical layer. The second section refers to platoon formation strategies which in the context of ENSEMBLE mostly could be part of the strategic layer.

A brief overview of the related work within the tactical layer and a first outlook towards the intended functionality in ENSEMBLE is presented. Despite performed work, the design for the functionality in the tactical layer is still an open problem, at least there is no consensus yet. Research into more implementation relevant aspects is only recently emerging and therefore ENSEMBLE can rely only marginally on existing solutions, more specific mostly within the context of platoon state and coordination of platoon manoeuvres.

As the aim of the ENSEMBLE project is to split the common functionality required for platoon control in a separate tactical layer, the challenge will be to define the functionality of this layer and the interfacing with the proprietary and OEM specific operational layers



### 3.5. Vehicle factors and heterogeneity

In the ENSEMBLE project the aim is to have trucks of different OEMs platooning together. These trucks, including their platooning technology, are independently developed. Due to this, it is expected that differences in the technology exist. This may impose a challenge in developing a compatible solution for multi-brand truck platooning. In literature, a platoon composed of vehicles with different dynamics is classified as a heterogeneous platoon, whereas a platoon composed of vehicles with (almost) identical dynamical capabilities is called homogeneous. It must be remarked that a heterogeneous platoon can also be made of mono-brand vehicles if the vehicles in the platoon have different dynamical capabilities due to e.g. different mass, powertrain characteristics, etc.

Despite the substantial academic work on platooning, applied control design for (heterogeneous) platooning is still an open issue. Only very limited publications deal with implementation relevant aspects and/or heterogeneity of platoons. For an extensive overview of platooning literature, refer to e.g. (Alam A. , 2014), (Li, Zheng, Li, & Wang, 2015), (de Souza Mendes, 2017), (Kalbitz, 2017). As literature on applied control design is lacking, the impact of heterogeneity needs to be researched and assessed further in the ENSEMBLE project.

The main components that need to be considered are highlighted below using the four-component framework of Li (Li, Zheng, Li, & Wang, 2015). Figure 3-23 from (De Souza Mendes, De Toledo Fleury, Ackermann, & Leonardi, 2017) illustrates this framework.

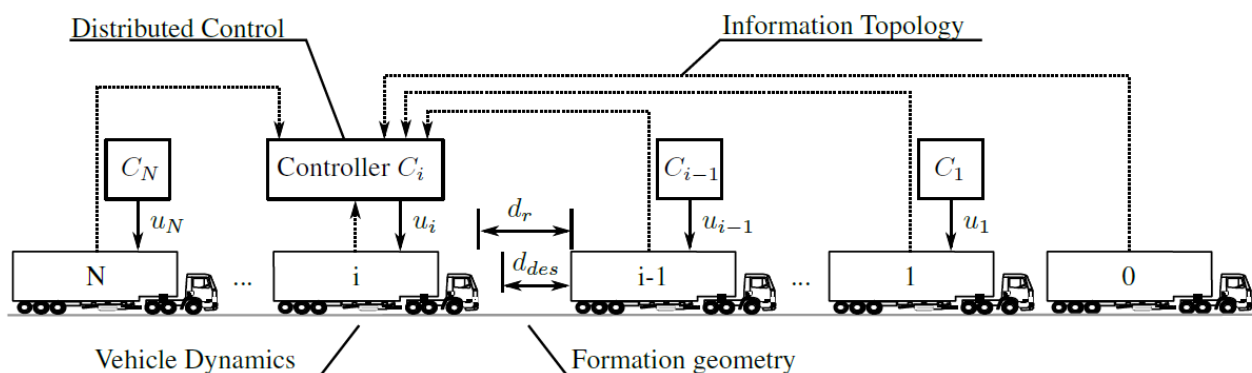


Figure 3-23. The four-component framework.

- **Vehicle Dynamics:** the longitudinal dynamics, including the low-level (actuator) controllers for accelerating and braking, is different for different vehicles and loading conditions. This leads to performance limitations, e.g. currently available acceleration/deceleration in platooning mode, maximum braking performance, velocity (due to maximum speed limitations) and differences in dynamic response.
- **Distributed controllers:** as mentioned above, CACC is the main controller used for platooning. Different implementations exist of CACC, meaning that control methods/algorithms are likely to be different. String stability is a major performance criterion for CACC. String stability should be assessed for the multi-brand platoon. Besides, CACC most practical implementations have collision avoidance controllers that can overrule the CACC function if required. The functioning of these collision avoidance algorithms should also be assessed for multiband platoons.



- Information topology: very related with the high-level controller design is the information topology. The simplest topology is “one-vehicle look-ahead” or “predecessor following”. Other possibilities exist as well, e.g. bi-directional (communication is from the follower vehicle and the preceding vehicle), multiple-vehicle look-ahead, and so-on. The basic idea is that using more information could increase controller performance. On the other hand, complexity is also increased by using more information. Further, it is obvious that the information topology is very much related to the V2V communication possibilities.
- Formation geometry: different spacing policies are possible. These policies might be classified in 3 main categories: constant distance, constant time headway and nonlinear distance spacing policies. The used spacing policy has amongst others impact on string stability, aerodynamic drag, safe distance for emergency braking and platoon cohesion on hilly roads. For ENSEMBLE it must be investigated if a common spacing policy should be used or individual policies per vehicle.



## 4. COMMUNICATION

### 4.1. Topologies

The communication technology used in the various projects is based on vehicular ad hoc networks (VANET). Such wireless networks are decentralized in the sense that they are made up of nodes having equal rights and exchanging information via direct communication. There is no need for managing infrastructure like access points, routers or similar. In addition to vehicle nodes there is a possibility of installing communication nodes in road side infrastructure to support for certain applications. In the figure (source [www.car-2-car.org](http://www.car-2-car.org)) below the direct communication between cars, trucks, busses and infrastructure is depicted for a better understanding.

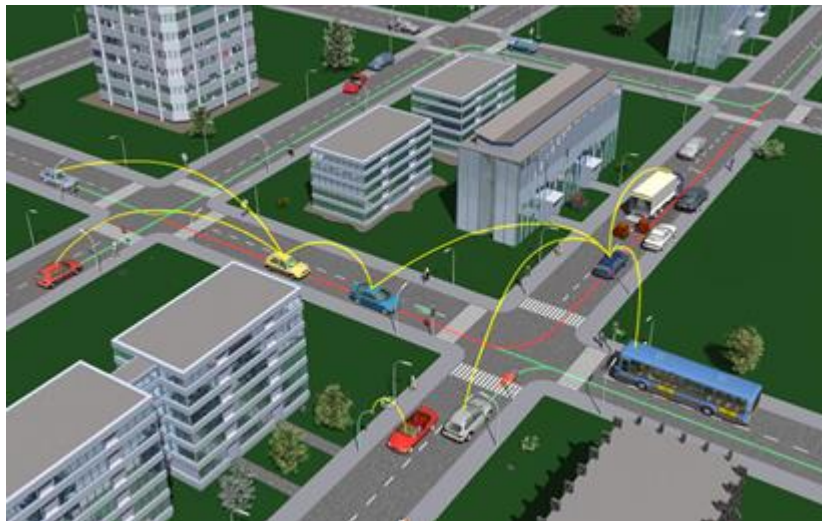


Figure 4-24. VANET communication between cars, busses and infrastructure

Direct communication between vehicles (V2V) and between vehicles and smart infrastructure (V2I) has the potential to save lives and reduce the environmental impact (V2V and V2I is collectively known as V2X). Frequency bands for V2X were allocated in 2008 in Europe and already in 1999 in the US at a carrier frequency of 5.9 GHz. Communication standards have been developed to establish interoperability between different brands, in particular in the contexts of ISO TC 204, CEN TC 278 and ETSI TC ITS.

### 4.2. Information exchanged

Day-one applications (or services) have been defined such as stationary vehicle warning, slow vehicle warning, emergency electronic brake light etc. These day-one services are using two distinct protocols developed by ETSI TC ITS called Cooperative Awareness Messages (CAM) and Decentralized Environmental Notification Message (DENM). CAMs are always used (transmitted) and are triggered by vehicle dynamics. CAM messages contain information about the vehicle such as type, speed, position and heading. DENMs are only triggered on behalf of a dangerous situation and contain information about the dangerous event itself. Day-one services are support functions for the driver and are deployed as infrastructure services (I2V). CAMs and DENMs are set on top of a so-called geo-networking stack, which in itself exchanges information about the vehicle's position, speed and heading, etc. In Figure 4-25 the ITS V2X communication stack with all its layers is depicted. CAMs and DENMs reside in the facilities layer whereas Geo-Networking related





information resides in the Network and Transport layer. The Access Technology used in Europe and within ENSEMBLE is commonly referred to as ITS-G5. Along with the US V2V standard, known as WAVE ("Wireless Access for Vehicular Environments"), it builds upon the (former) p-amendment of the IEEE 802.11 standard for WLAN.



**Figure 4-25. Layers of the ITS V2X communication stack**

### *AdaptIVe*

In the project an extension of the standardized CAM as well as a Negotiation message was used to facilitate for several ADAS relevant use cases.

The CAMs was extended with additional data of interest concerning vehicle control and trajectory prediction. The usage of CAM has the purpose to transmit position, vehicle sensors data and infrastructure control data over 5.9 GHz wireless channel, as additional source of information within the receiving vehicle, for the enhancement of ADAS and automated driving.

**Request for Cooperation Message (RCM):** When one vehicle identifies a conflict situation this is broadcasted to the environment via RCM.

**Offers of Cooperation Message (OCM):** After the request the other involved vehicles have to plan a potential cooperative manoeuvre and send an OCM.

**Evaluation of Cooperation Message (ECM):** The involved vehicles evaluate the offers in terms of cost and benefits. This evaluation is performed based on the individual knowledge and criteria of the vehicle in question.

**Accept Cooperation Message (ACM):** The selection is used to choose the best manoeuvre. In order to determine the best manoeuvre, the combination of evaluation and selection has to weigh up the costs within the field of efficiency and safety.

**Status of Cooperation Message (SCM):** The SCM are sent to the other vehicles in order to adjust, terminate or re-plan the manoeuvre.

### *Sweden4Platooning*

The project facilitates an extended CAM which indicates if a truck first of all is in general able to platoon and second if it can be joined. The CAM is sent with the frequency of 1 Hz.



Other messages are used to establish a kind of handshake procedure. These messages are called Management and Control messages, the former ones are used to establish the platoon in a kind of handshake procedure. The latter ones are exchanged during the platooning operation with a high frequency of 20 Hz.



## 5. SECURITY

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There is no specific security solution for the platooning application, however, much work has been done for securing the communication between vehicles and between vehicles and smart infrastructure to facilitate applications aiming for increased road traffic safety and efficiency (the so-called day one applications). The overall security framework for Cooperative ITS (C-ITS) is based on the concept of Public Key Infrastructure (PKI), which consists of public and private keys and a detailed security architecture offboard. A PKI environment works with hiding keys. The European Commission has through its work in the C-ITS Deployment Platform (Platform, 2018) (arranged by DG MOVE) compiled two documents playing an important role for the implementation of C-ITS PKI on the back-office side. The documents are: (i) the certificate policy (European Commission, Vertificate Policy for Deployment and Operation of European Cooperative Intelligent Transport Systems (C-ITS) Release 1.1, 2018) and the (ii) the security policy (European Commission, Security Policy & Governance Framework for Deployment and Operation of European Cooperative Intelligent Transport Systems (C-ITS) Release 1.1, 2018).

In short, the C-ITS security works as follows. Vehicles will regularly receive authorization tickets (AT) from the back-office system (through cellular connectivity), which are used to sign outgoing messages. ATs are only valid for a short period of time (e.g., 5 minutes) to make it more difficult to trace individual vehicles. On the receiving side the packet is verified. The transmitted message itself is not encrypted and can be read by anyone but only stations having access to C-ITS world will receive ATs and can sign outgoing messages. The goal with the security of C-ITS is to build a trust domain, where all participants trust each other. The onboard security consisting of the security header, the algorithm for signing and verifying, and the certificate formats, is outlined in TS 103 097 V.1.3.1 (ETSI TS 103 097 V1.3.1 (2017-10), 2018).

The ENSEMBLE project will use the already standardized onboard security protocol outlined in TS 103 097 V1.3.1 for reaching interoperability between different brands using ATs. But to further enhance the security also encryption of application data is proposed to be used. Encryption of data using symmetric keys can be facilitated in the platooning application since the vehicles are known to each other and TS 103 097 has support for the exchange of symmetric keys.



## 6. SAFETY

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### 6.1. Safety process

This section gives an overview of the processes and methodologies used to develop a safe product in the automotive industry, especially when working on the development of autonomous driving features.

For the development of autonomous driving features, two distinct safety areas have to be addressed:

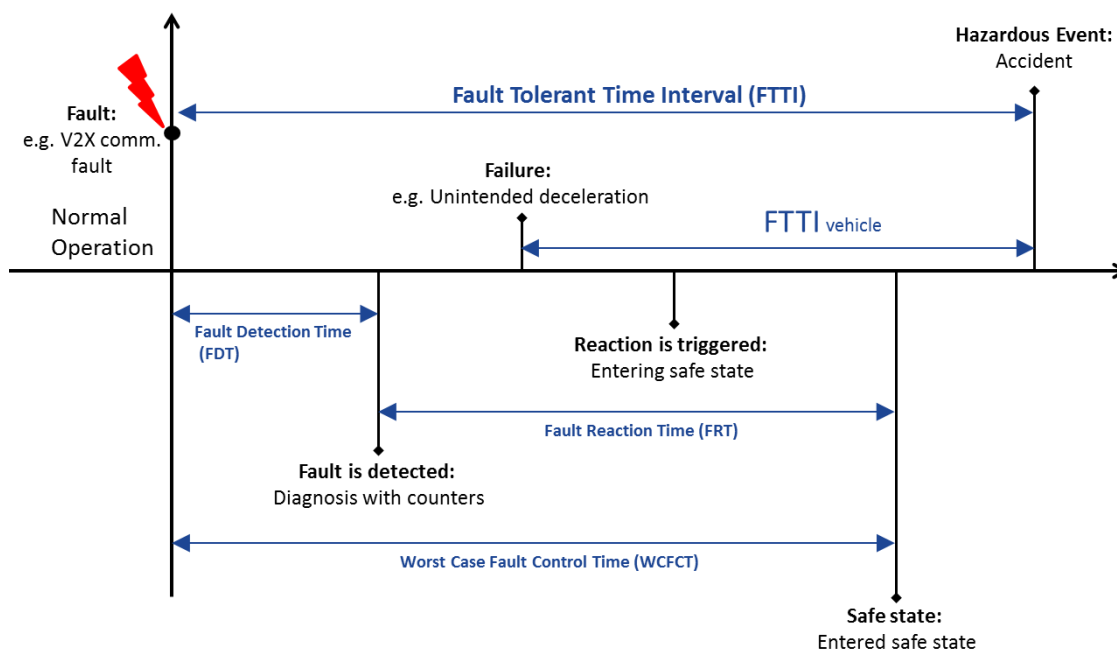
1. **Functional Safety:** Functional safety seeks to ensure absence of unreasonable risk due to hazards caused by malfunctioning behaviour of E/E systems.
2. **Safety Of The Intended Functionality (SOTIF):** SOTIF seeks to ensure absence of unreasonable risk due to performance limitations or insufficiencies of the function itself. SOTIF does not deal with malfunctions due to failure of E/E components.

#### 6.1.1. Functional Safety

The state of the art reference standard for functional Safety is the ISO 26262 which had its first version published in 2011. It is important to note that ISO 26262 does not address nominal performance of the system.

The fundamental concept behind functional safety is to identify malfunctions in the system that might lead to hazards (danger or risk of injury to humans) and implement mechanisms to detect these faults and control their consequences.





**Figure 6-26. Fault Reaction Time and Fault Tolerant Time Interval**

The above schematic provides an overview of basic concepts like “Fault Detection Time”, “Fault Reaction Time”, “Worst Case Fault Control Time” and the “Fault Tolerant Time Interval”. Essentially the developers have to detect all the faults that can lead to hazards and implement safety mechanisms that react to them in time, before crossing the “Worst Case Fault Control Time” (WCFCT). The Fault Control Time Interval (FTTI) is the time span after which the fault can lead to a hazard. Finally, the WCFCT is defined such that the fault is detected and controlled (by entering a safe state) before reaching the FTTI.

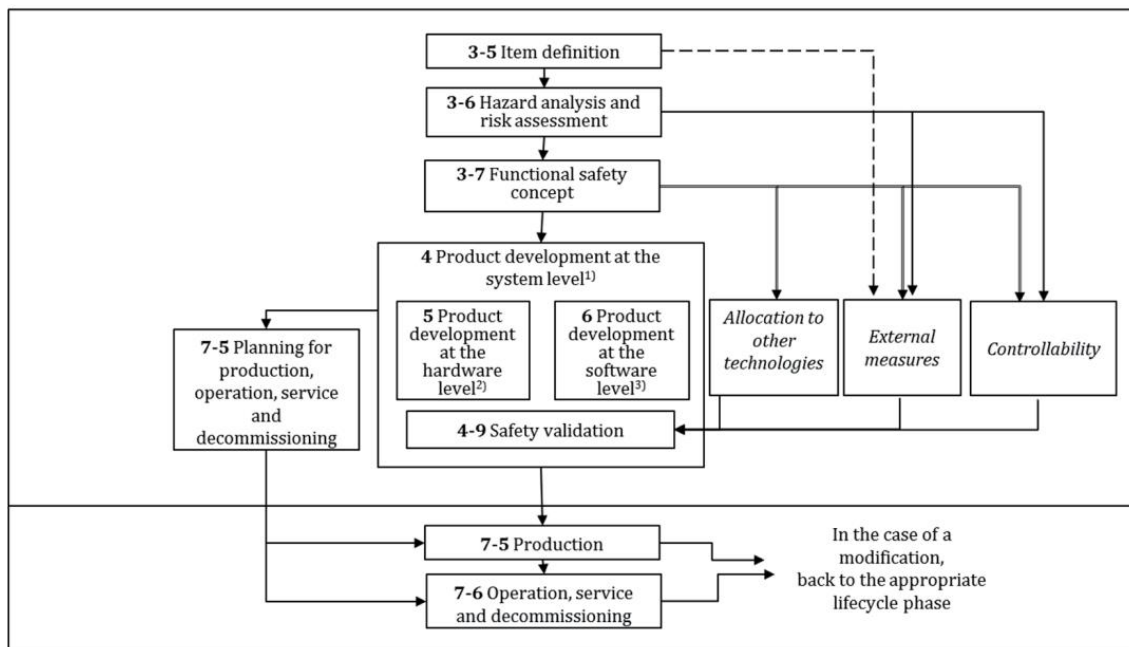
ISO 26262 aims to achieve Functional Safety by defining a systematic methodology that gives importance to both the process followed (to control systematic faults) during development and the technical work products generated (to control both systematic and random faults) throughout the project.

The following table outlines some of the arguments that have to be provided by the developers to show that their product is ISO 26262 compliant.

**Table 6-3. Relation main states and control functions from the COMPANION project (Pettersson, 2016)**

Process Argument	Product Argument
Carryout all the phases as per ISO	Carryout the H&R correctly.
Delivering all the work products	Define relevant FSR, TSR correctly.
Have all the traceability and coverage mechanisms implemented	Diagnostics of safety relevant faults.
Use certified tools & have a qualified team (with evidence)	Define relevant HSR, SSR correctly.
Implement change & configuration Management	Correct implementation at the HW & SW level.
Provide evidence of Safety culture.....	Complete verification & validation of the requirements (HW-SW level, System Level, Vehicle Level)...

ISO 26262 also provides a reference Safety lifecycle that can be tailored as per the project requirements.

**Figure 6-27. Reference functional Safety lifecycle (Image source: ISO 26262 part 2)**

A detailed description of items mentioned in the safety lifecycle can be found in the standard.

The technical work products to be generated for Functional Safety are shared between the OEM and their Tier 1 suppliers. The responsibilities of each party and the work products to be shared between them during the development are documented via a “Development Interface Agreement (DIA)”.

The table below provides an overview of the typical distribution of responsibilities between the OEMs and the Tier 1 suppliers, for systems that go into mass production.

**Table 6-4. Overview of the typical distribution of responsibilities between OEMs and Tier 1 suppliers**

Stakeholders	Left side of the V-model	Right side of the V-model
OEMs	<b>Concept phase:</b> <ul style="list-style-type: none"> <li>Item Definition</li> <li>Hazard Analysis &amp; Risk Assessment (To derive the ASILs)</li> <li>Definition of the safety goals</li> <li>Definition of functional Safety Concept</li> </ul>	<b>Vehicle level integration and testing:</b> <ul style="list-style-type: none"> <li>Simulation of various faults and verify system reaction/safety mechanisms</li> </ul> <b>Safety Validation:</b> <ul style="list-style-type: none"> <li>Validate the controllability of the vehicle under fault condition</li> <li>Validate the safety requirements allocated to other technologies</li> <li>Validate safety mechanisms allocated to other systems (external measures)</li> </ul>
	<b>Product Development:</b> <ul style="list-style-type: none"> <li>Definition the technical safety requirements</li> <li>System Design/Architecture definition</li> <li>HW Safety requirements &amp; HW design</li> </ul> SW Safety requirements & SW design	<b>Component &amp; system level integration &amp; testing:</b> <ul style="list-style-type: none"> <li>HW Integration &amp; Testing</li> <li>SW Integration &amp; Testing</li> <li>HW-SW integration &amp; Testing</li> </ul> System Integration & Testing
Tier 1 Suppliers		

Usual measures to meet Functional Safety are:

1. Complete diagnostic coverage: Detect all the safety related faults and have back up measures for safe operation (Enter safe state).
2. Redundancy: If required (for fault tolerant systems) have redundant system components (sensors, controllers, actuators) as back-up during failures.

Platooning adds some extra challenges to functional safety that go beyond the state of the art:



1. Since the item is spread over multiple vehicles, the consequence of faults in one vehicle of a platoon may result in hazards on other vehicles that are fault free. Special care has to be taken during the Hazard Analysis and Risk Assessment phase to capture all these aspects of platooning.
2. ISO 26262 has just one phase for vehicle integration and testing, where as in platooning this task has to be divided into 2 or more phases based on the number of vehicles in the platoon. i.e. once the item is integrated and tested on a single vehicle, it has to be integrated and tested in the platoon with other vehicles.

### 6.1.2. Safety of the Intended Functionality (SOTIF)

The state of the art reference standard for SOTIF is ISO PAS 21448, which is still under development and presently only available to the members of the working group. It is expected to be published by the end of this year.

Unlike functional safety, SOTIF does not deal with hazards resulting from malfunctions in the E&E systems. It solely focuses on hazards resulting from performance limitations or insufficiencies in the function while it is in use under nominal conditions (no malfunctions).

#### *Handling of performance limitations*

As per the ISO PAS 21448, all the driving scenarios of a feature can be classified into the following 4 categories:

1. Known unsafe scenarios
2. Known safe scenarios
3. known unsafe scenarios
4. Unknown unsafe scenarios





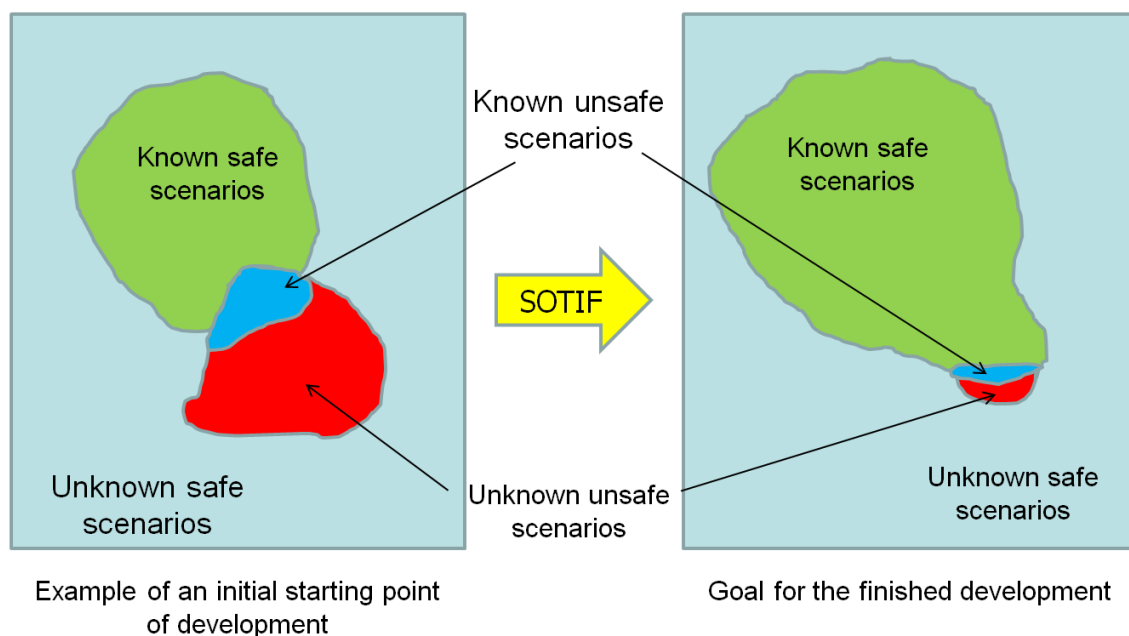


Figure 6-28. SOTIF scenarios (image source: ISO PAS 21448)

The objective of SOTIF is to reduce the area of the unsafe scenarios (both known and unknown) to an “acceptable level”.

The 4 steps usually followed to meet SOTIF:

1. Risk identification and function improvement
2. Definition of acceptance criteria for the unsafe scenarios
3. Planning of V&V activities
4. Release of SOTIF activities

If the performance limitations of the features are well known, then most of the work to ensure SOTIF happens on the right side of the V-Model. The performance of the system under known unsafe scenarios is verified through testing in the proving grounds, whereas the systems reaction to unknown unsafe scenarios can only be assessed through Field Operational Testing (e.g. Real life testing or long term testing) on public roads.

### *Responsibilities for SOTIF*

The below table provides an overview of the typical distribution of responsibilities between the OEMs and the Tier 1 suppliers for SOTIF:

Table 6-5. Overview of the typical distribution of responsibilities between OEMs and Tier 1 suppliers for SOTIF

Stakeholders	Left side of the V-model	Right side of the V-model
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OEMs	<b>Concept phase:</b> <ul style="list-style-type: none"> <li>• Clear definition of feature performance</li> <li>• Clear definition of use case scenarios</li> <li>• Identification of major SOTIF risks or triggering events (Performance-FTA)</li> <li>• Definition of V&amp;V strategies &amp; targets</li> </ul>	<b>Vehicle level integration and testing:</b> <ul style="list-style-type: none"> <li>• Verification according to V&amp;V targets</li> <li>• Test tracks (Known unsafe scenarios)</li> <li>• Field Operational Tests (Unknown unsafe scenarios)</li> </ul>
Tier 1 Suppliers	<b>Product Development:</b> <ul style="list-style-type: none"> <li>• Function modifications (based on testing feedback)</li> <li>• Definition of System level testing strategies</li> </ul>	<b>Component &amp; system level integration &amp; testing:</b> <ul style="list-style-type: none"> <li>• Simulation and testing of unknown unsafe scenarios</li> </ul>

Usual measures to meet SOTIF:

1. Identify major SOTIF risks (use cases): Identify triggering events or scenarios to validate the performance of the feature.
2. Define V&V strategies and targets: Plan and execute testing activities on both controlled environments and public roads.
3. Function modification: Redefinition of the requirements or redesign the system to meet the performance targets.
4. Modification of use case boundaries: Redefinition of the use case scenarios (lower the performance targets of the function)

Platooning adds some extra challenges to SOTIF that go beyond the state of the art:

1. SOTIF scenarios can present different levels of risk to the vehicles based on their position in the platoon; hence the reaction of each vehicle in the platoon may be distinct for the same situation.
2. Any reaction of a vehicle to a SOTIF situation has to also consider its consequences on different vehicles in the platoon.

References:

- ISO 26262 – Road Vehicles – Functional Safety
- ISO/PRF PAS 21448: Road Vehicles – Safety of the intended functionality
- Bosch Case study: Application of SOTIF for ADAS (DR. SUSANNE EBEL, Robert Bosch GmbH)



## 6.2. Specific safety functions

As an example of used specific safety functions, an implementation of the ETPC is described here.

To sense the environment, two concepts are used: Firstly, to acquire the lateral acceleration of the truck in front, wireless communication is used. In case of the wireless communication channel being reliable, the lateral acceleration of the truck in front is duplicated. The reliability of the wireless communication is measured by using a-priory knowledge that messages are transmitted periodically. This way one or multiple missing message can be detected and the system can react accordingly (possible reaction: increasing following distance or even dissolve platoon).

In addition, a windshield camera is used to detect lanes and keep the vehicle in lane.

The second part of the safety concept is the distance measuring sensor that observes the area in front of the truck. For this the current active brake assist radar is used to give a reliable distance measure to the front vehicle. Based on the radar information the lead vehicle drives in ACC mode with normal distance and all following vehicles drive in ACC mode with reduced following distance. The distance measurement is used to cross-check the wireless messages. Moreover, cut-in vehicles that disturb the platoon can be detected as well.

In case the distance to the front vehicle is getting rapidly shorter without wireless notice a cut-in is assumed and a brake procedure is issued (min.  $-1\text{m/s}^2$  up to full emergency brake depends on relative speed).

There are three ways to react: A gradual deceleration that slows down the truck in a very soft way (up to  $-1\text{m/s}^2$ ) can be used. This type of deceleration can be observed every day in almost any traffic situation and thus do not pose a big concern.

The second option is to use a distinct deceleration (around  $-3\text{ m/s}^2$ ) that is noticeable to all vehicle passengers and surrounding traffic alike. However, most traffic rules and law interpretations consider this a reaction that other motorists must be able to react to.

The last option is a full emergency brake with all available deceleration. This is a critical action and must only be executed when no other options are available. Emergency brakes are hard to detect by other motorists and their reaction might be inadequate. Before issuing an emergency brake every decision input has to be validated and cross-checked. On the other hand, if the truck fails to execute an emergency brake if and only if it is required and justified a crash into the front vehicle is eminent, this scenario must be avoided as well.

With the HARA the system and its functions is evaluated. For ASIL rated risks safety goals are defined and the FSC, consequently, derives safety requirements from the safety goals and addresses those to the relevant components.

In order to inform all other motorists about driving in platoon mode, the yellow flashing lights on all platooning vehicles are on.



## 7. INFRASTRUCTURE

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### 7.1. Introduction

It is envisioned that infrastructure plays an important role in enabling truck platooning. This chapter is a study on the availability and the role that infrastructure played in platooning projects of the near past. Although a lot of information and publications are available from previous projects, the infrastructure elements are badly documented and straightforward information is not available. Therefore, relevant contacts from the projects were contacted and asked to fill in a dedicated questionnaire to get a deeper insight.

The process to build the questionnaire followed a staged approach by:

1. Realising a deep state of the art on truck platooning based on gathering and analysing several academic and industry papers.
2. Building a list of known relevant projects and contact names based on ERTICO portfolio partners and projects.
3. Checking the contacts on GDPR compliance and target the contacts that accepted to participate to ERTICO's questionnaires.
4. Establishing the questionnaire based on the state of the art and analysis done for this purpose. The by issuing the questionnaire to the selected contacts.
5. Analysing the received responses and establishment of the APPENDIX B reflecting the current truck platooning field snapshot.
6. Processing the obtained results in order to phrase usable information for the ENSEMBLE project.
7. Matchmaking the obtained results with some literature and published information.
8. Phrasing the conclusions.

The detailed results from the questionnaire are listed in Appendix B.

Up till writing of this deliverable there was only a low response. Hence, future actions are therefore highly recommended in order to monitor ongoing projects and bring better view on the impact of infrastructure on truck platooning. Moreover, the conducted questionnaire is still available online and ERTICO is reminding the remaining contacts to kindly bring their answers. Hence, foreseen actions are:

- 1) An update of the data with additional respondents to be planned in October 2018.
- 2) Issue another questionnaire when the specifications are ready to check the practical acceptance of these specs in the project experiences gained by December 2018.
- 3) Investigate the literature and check for the consistency with received data
- 4) Correlate the literature with the results by October 2018.

## 7.2. Preliminary findings

### 7.2.1. Physical infrastructure

Targeted truck platooning related projects do not take deeply into account the physical infrastructure aspect. The ETPC project has a dominant role in the conducted questionnaire answers, but it is a show case. For instance, commonly involved road infrastructure like **Off ramps**, **On ramps** and **bridges** have a weak representation. By consequence, there is no really significant experience on how physical infrastructure impacts platooning. This is a big risk for the ENSEMBLE project since the specifications can be incomplete and may not be based on scientific tests and proofs.

### 7.2.2. Digital Infrastructure

On Strategic level, the ETPC project has again a dominant role in the conducted questionnaire. The used communication technology appeared to be cellular data “4G/LTE”, e.g. let platoon trucks communicate with cloud hosted services for gathering weather conditions.

On the tactical level, the ETPC project has again a dominant role in the conducted questionnaire. Used communication technology appeared to be V2X “ITS-G5”.

Only minimal real-life experience and lab test proofs are available to conclude on the requirements for services. Hence there is a potential risk that specifications are going to be incomplete and it is recommended follow the running projects/initiatives that are also targeting truck platooning like e.g. AUTOPILOT and CONCORDA.



## 8. STRATEGIC FUNCTIONS AND SERVICES

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### 8.1. Business case

The initial business driver of platooning is fuel consumption reduction and environment impacts. This has been shown in several projects as achievable short-term. For large scale platooning a platform to support platooning between different freight companies is proposed. This requires support in the strategic layer for revenue sharing when platooning.

According to (Van de Hoef, 2018) a substantial reduction of diesel consumption and CO<sub>2</sub> emissions can be achieved by large scale platooning.

In the longer-term higher automation levels will lead to less driver costs, initially with platooning time counted as none driver time and later with following vehicles without drivers.

Since business models are still researched and may change over time it is crucial to secure as part of the specification that business relevant information is passed between the trucks and agreed. Such relevant information may be platoon formation, position in the platoon, time, distance and route.

### 8.2. Strategic functions and services

As part of the EU funded project COMPANION and a doctoral thesis (Van de Hoef, 2018) an architecture and design of the strategic layer has been researched and proposed. The focus was to investigate a large-scale fleet coordination approach focusing on platooning possibilities to reduce fuel consumption and environment impact.

Based on vehicle start position, destination and required arrival time a platoon coordinator was developed as part of the fleet management system to find platooning opportunities. The coordinator calculates a desired speed profile and the vehicles on board systems regulate to follow the profile. It has been shown that platoons can be formed on route. If the tracking show more than 30 seconds deviation a new traffic profile is calculated. By real time updates from platoons also additional vehicles can join using the same scheme with desired speed profiles, start and destination positions and arrival times. The detailed step for this route calculation and optimization has been described in (Van De Hoef, Johansson, Dimos, & Dimarogonas, 2018).

A system for coordinating thousands of vehicles was developed and proven to work. In simulations of 10% of Germany's heavy-duty truck fleet it was shown that a 65% platooning rate could be achieved with a fuel consumption reduction of more than 5%. As part of this 40% of the distance was travelled in a platoon. The simulation was done by generating random transport assignments and then in a number of calculation steps optimizing the traffic profile and creating the platoon plans.

The demonstrator system was also used in demonstrations on public roads creating platoons of three vehicles joining at different locations. This was proven successful, including also environments like road toll plazas. Further tests in Sweden and Spain show similar results of successful creation of platoons on public roads.



In ENSEMBLE the strategic layer and the service layer mainly reflect the functionalities as described in the mission & transport planner and vehicle & platoon coordinator as shown in below figure. A remark has to be made that parts of the vehicle & platoon coordinator may be incorporated in the tactical layer in ENSEMBLE, but that will be reflected later into the functional architecture which will be detailed in task 2.2 of the project.

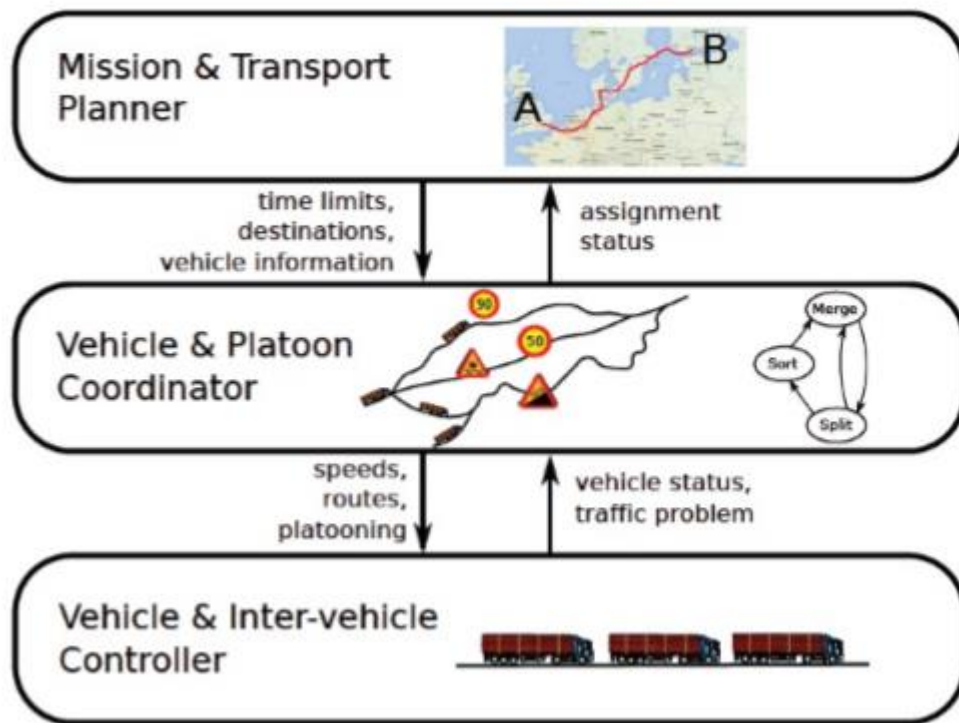


Figure 8-29. Three layer hierarchical transport architecture (van Doremalen, 2014)

## 9. IMPACT

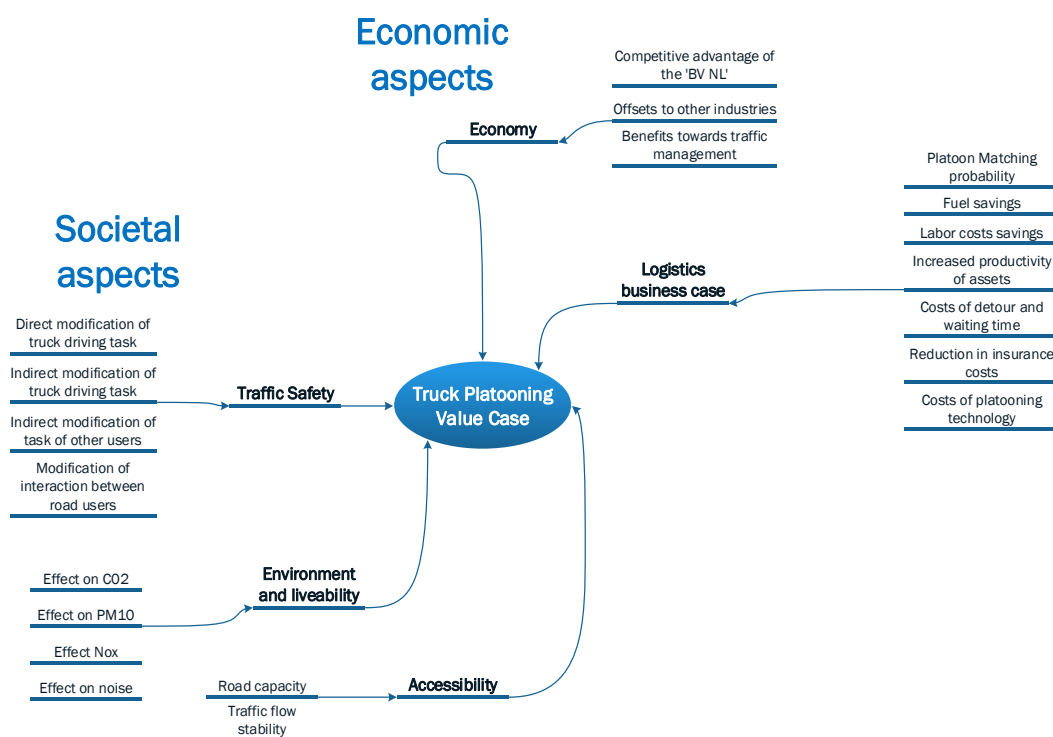
In this chapter an overview of the state of the art of impacts of truck platooning is provided. First, the general impact areas of truck platooning are described. Subsequently, various projects are evaluated based on the impacts that were found in literature and other publications.

### 9.1. Impact areas

The potential (societal) impacts 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. Adding to the complexity is the uncertainty to what truck platooning systems will be in terms of system capabilities and the market up-take.

Research shows that truck platooning can have various impacts. In the Value Case Truck Platooning (Van Ark, 2017) an early exploration of the value of large-scale deployment of truck platooning (on a freight corridor in the Netherlands) is executed. Based on modelling and literature review, this report describes potential value elements: improved driver productivity and fuel savings (magnitude of both depends on match-rate), improved traffic safety and emission savings.

Figure 9-30 shows the impact areas, or so-called value elements, of truck platooning that have been identified in the Truck Platooning Value Case (Van Ark, 2017).



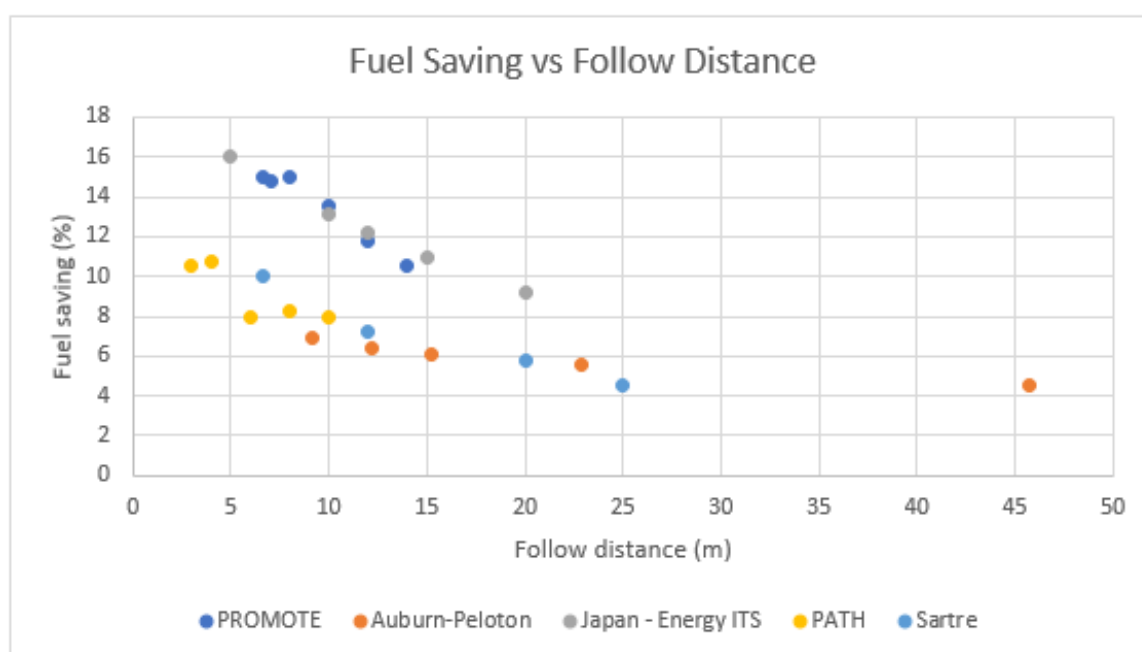


**Figure 9-30. Impact areas of truck platooning (derived from (Van Ark, 2017))**

In the following paragraphs the societal benefits per subject are further discussed based on the value case research.

### 9.1.1. Logistics business case

Driver productivity improvements and fuel savings (between 4 – 16%) are key value drivers. Fuel savings already appear at early platooning system capability levels and relatively large inter-vehicle gap distances (up to 20 meters / 1 second). Figure 9-31 plots the results of various studies.



**Figure 9-31. Fuel savings vs. following distances. Compared across studies. (Alam A. J., 2015)** Invalid source specified.,Invalid source specified.,Invalid source specified.,Invalid source specified.,Invalid source specified.,Invalid source specified.,Invalid source specified.

Driver productivity improvement and reductions of labour costs (up to 90% for following vehicles (Roland Berger, 2016)) 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 kilometres driven as platoon as ratio of annual kilometres driven. The match-rate relies primarily on active coordination such that brand-neutral and fleet-interoperable platooning becomes feasible.

### 9.1.2. Traffic safety

Extensive use of advanced driver assistance systems (ADAS) can significantly improve traffic safety (European Commission, November 2016.). A challenge in researching the impacts 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. The impact of truck platooning



towards road safety is strongly related to the EU compulsory safety systems such as AEB and LDW active safety and advanced driver assistance systems. Therefore determining the net individual benefits of each individual technology is challenging. The main improvements found are based on estimations of compounding effects of Advanced Emergency Braking, Lane Keep Assist, and the platooning-based vehicle-to-vehicle (V2V) wireless communication. A main, but largely unknown, factor is the interaction with other users, that is, how will car users react on the platoons while manoeuvring on highways? Apart from some driving simulator studies (i.e. (Aramrattana, Larsson, Jansson, & Nåbo, 2016) and KONVOI, ADAPTIVE, SARTRE...) and researches based on microsimulation studies (i.e. (Kuijpers, 2017)) this is a relatively uncultivated field of research due to the lack of real-life field tests.

### 9.1.3. Emissions

The fuel savings mentioned have a one-on-one relationship to CO<sub>2</sub>, NO<sub>x</sub> and PM10 emissions (Scora, 2006). In regard to noise pollution the expected impacts can be 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.

### 9.1.4. Accessibility and traffic flow

Truck platooning is expected to improve traffic flow due to smoothening of the flow and vehicles taking up less space on the road. However, (Van Ark, 2017) did not find conclusive evidence to state that truck platooning can have a positive effect on accessibility of the roads and traffic flow. For CACC technology a penetration rate of 40% of the total traffic flow is regarded as a lower limit in which an effect becomes measurable and apparent (Van Arem, Van Driel, & Visser, 2006). Due to the fact that trucks mostly account for a smaller part of the traffic flow (and especially in congested traffic situations) this minimum threshold is difficult to reach solely with truck platooning technology.

### 9.1.5. Economy

Truck platooning will impact or influence various economic indicators, however, further 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 (Vervuurt, 2017).

## 9.2. Reported impacts past platooning projects

Table 9-6 summarizes the projects that reported impacts with respect to traffic safety and traffic flow next to results on fuel savings. The main focus of these projects is related to technology and technology safety, fuel savings (and in some instances human factors). It should be noted that many of the studies reviewed are based on simulations (a.o. emissions, traffic safety and traffic flow), specific assumptions (a.o. economy, business case) or both. Therefore the studies are not directly comparable. Nevertheless, the impacts that are reported in these studies are addressed below in order to give an overview of the focus of these projects.



**Table 9-6. Impacts Truck platooning - Projects**

	Logistics business case	Traffic Safety	Emissions	Accessibility & Traffic Flow	Economy	Comments
DB Schenker	X	X	X	X	Impact on Infrastructure and noise	
Ertico - CONCORDA						Focus on business case, no impacts reported
MAN / DB Schenker – EDDI						No impacts reported
Scania – COMPANION	X		X	X		
Volvo – SARTRE	X	X		X		
Volvo - ADAPTIVE	X	X		X		*

\* Scope of ADAPTIVE involves automated driving functions in mixed traffic: 3 passenger cars and 1 truck.

### 9.2.1. Logistics business case

In its COMPANION project Scania mainly focused on assessing impacts of platooning on fuel consumption. The PhD project that was related to COMPANION estimated (through simulation) that using a specific platoon controller will result in a possible fuel saving up to 12% for the follower vehicles compared to existing platoon controllers (Turri, 2015).

In ADAPTIVE, a simulation (using data sets from Germany) was executed calculating the energy savings for automated driving in mixed traffic. With a 50% penetration, about 12% of possible energy savings are possible (ADAPTIVE, 2017). SARTRE determined fuel consumption savings based on physical tests on a test track and simulation studies (for mixed traffic platoons). At a gap of 8m the actual fuel consumption savings range from 7 to 15% on test track (SARTRE Report 2011, 2018).

### 9.2.2. Improved traffic safety

SARTRE reports some figures on improved traffic safety: a reduction of 50% of highway related accidents is expected for following passenger cars in a platoon led by a professional truck driver (SARTRE Report 2011, 2018). It is stated that trucks that are driven by professional drivers are exposed to less accidents per kilometre while driving on highways. Additionally, it is argued that the driver of the lead vehicle is assisted by active safety technology and thus the accident frequency might be reduced even further. Note that in SARTRE a very specific platoon formation was implemented: the platoon was always headed by a truck then followed by either another truck and/or passenger vehicles.

In ADAPTIVE, a simulation was executed (using euroFOT data from 98 vehicles and 8000 driving hours as a reference for human driving) for determining the impact on safety once vehicles drive in a platoon. Various scenarios (the source of assumptions is no longer publicly available) were identified, resulting in an estimated accident reduction of 43% to 57%, compared to the accident data for Germany (ADAPTIVE, 2017). The report justly nuances these outcomes as this reduction highly depends on the penetration rate of platooning



vehicles and the actual use of these functions. The analysis assumed that the automated driving functions were always switched on when driving on a highway. Thus, the actual impact of improved traffic safety will probably be lower.

DB Schenker reports a 60% decrease of accidents compared to regular truck driving by 2030 (DB summary 2017, 2018).

### 9.2.3. Emissions

SARTRE determined – based on fuel consumption savings – that a truck can potentially save 2.8 tons CO<sub>2</sub> per year by platooning (SARTRE Report 2011, 2018). SARTRE bases this on a typical annual mileage of 100.000 kilometre per year for a truck and an 8 meter gap between the vehicles. Furthermore, a one-on-one relationship is found between fuel savings and emission savings. Thus about 7-15% of emissions can be saved for trucks.

### 9.2.4. Improved traffic flow

With respect to the COMPANION project it is stated that a close driving distance in combination with automatic acceleration and deceleration can reduce congestion. ADAPTIVE also expects improved traffic flows, though does not provide any further evidence to support this.

Furthermore, SARTRE lists among the benefits that road trains bring positive impact on traffic flow. Reduced speed variations improve traffic flow, creating more efficiently used road capacity. In SARTRE a traffic model (PELOPS) was used to investigate vehicle longitudinal behaviour as well as the traffic flow (specific assumptions are not listed in the available literature though). First of all, platooning is expected to delay collapsing traffic by maintaining a constant speed and gap between vehicles. Secondly, in case of inhomogeneous traffic, an improvement in traffic flow can be expected as autonomous guidance helps reducing dynamics. Lastly, in stop & go traffic platooning is expected to lead to a faster dissolving of the congestion when the acceleration when leaving a traffic jam is sufficient enough and controlled.

### 9.2.5. Economy

DB Schenker conducted a study for assessing the impact of truck platooning. In this study it is estimated that in Sweden by 2030 platooning compared to regular truck driving will result in a 59% decrease of infrastructural costs (wear & tear) and a 4% increase in noise (DB summary 2017, 2018). It should be noted that the assumptions of this study are not clearly stated in the reference, nor are the exact use cases that are compared.



## 10. SUMMARY AND CONCLUSION

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This report gives an overview of the knowledge on platooning gained in previous, mostly EU, projects. The focus is on technical achievements in the area of vehicle and platoon functionality, human factors, communication, security, infrastructure, strategic functions and services, and impact of platooning. The following can be summarised and concluded on the selected topics.

### 10.1. Functionality

When evaluating the different platooning projects it can be seen that the early projects (2000 – 2008) mostly concentrate on developing the in-vehicle platooning technology, whereas later projects more concentrate on either a specific technological challenge (e.g. antennae design and placement) or on the use of platooning technology (e.g. platoon coordination).

With respect to use cases and in-vehicle architectures, many commonalities are seen on a high level. However, details are often not published. This also holds for the low-level controllers used in the different projects. Moreover, tactical layer functionalities and operational layer functionalities have mostly been implemented as one ‘controller’, i.e. there was no separation between ‘common’ and ‘truck specific’ functionalities, which is needed for ENSEMBLE’s tactical and operational layers. Hence, a clear task is reserved for ENSEMBLE to separate these functionalities in a way that the technology is still usable for all OEMs. Besides that, the impact of non-homogeneous platoons is still unclear. Heterogeneous platooning may stem from different sources: different operational implementations (spacing policies, control algorithms and information used for control, for instance), different vehicle capabilities in accelerating and decelerating (vehicle total mass, available engine power, brake capacity). Additionally, road profile may affect platoon performance. Despite the substantial academic work on platooning, applied control design for (heterogeneous) platooning is still an open issue. Only very limited publications deal with implementation relevant aspects and/or heterogeneity of platoons. This thus is still an open area also for ENSEMBLE.

### 10.2. Human factors

Many projects have addressed human factor issues, mostly for automated driving, less for platooning. Nevertheless, several well-founded methods could be used in ENSEMBLE, like e.g. the one from the Adaptive project. There is, however, a number of human factors knowledge gaps. Firstly, there is a lack of data from driving in platoon in real traffic environments. Most data are from simulator studies and from driving on test tracks. Secondly, the long-term effects on human behaviour from driving in platoon, ranging from days of working (8-10 hours/day) to months of daily driving in platoons are not known. Thirdly, connected to the first point, there is limited knowledge of driving in platoons in varying weather conditions and driving in darkness. Fourthly, appropriate driver training programs for platooning may be needed, although the goal should be not to require any mandatory driver training program as with current vehicle functions in modern trucks. Last but not least, the major issue in Platooning systems is that the driver of the following trucks, as result of the reduced intervehicle distance, may not be able to timely react on system failures and hazards, due to the limited view and his/her reaction time. This means that a Platooning system cannot rely on the driver as fall back and consequently the automation should provide a safe solution for handling failures and hazards.



### 10.3. Communication

Almost all previous platooning projects used ITS-G5 communication, as well as current ones like Sweden4Platooning. This technology has also been used in many C-ITS projects and standards are available. A message set specifically for platooning is currently being discussed. Especially the project Sweden4Platooning is of high interest to ENSEMBLE due to their goal towards standardisation of communication for platooning.

### 10.4. Security

No previous project on platooning has implemented security mechanisms as far can be concluded from project deliverables. However, much work has been done for securing the communication between vehicles and between vehicles and smart infrastructure, e.g. resulting in an overall security framework for Cooperative ITS, which is based on the concept of Public Key Infrastructure.

The ENSEMBLE project considers to use the already standardized onboard security protocol outlined in TS 103 097 V1.3.1 (ETSI TS 103 097 V1.3.1 (2017-10), 2018) for reaching interoperability between different brands using Authorization Tickets. However, there are additional considerations regarding performance of signage and authentication, and confidentiality of application data. These may lead to the consideration for symmetric cryptology whilst platooning, since platooning vehicles know each other. TS 103 097 has support for the exchange of symmetric keys. The requirements and specification will be worked out in D2.6.

### 10.5. Safety

Two approaches for achieving safe functionalities are presented: for functional safety, the ISO 26262 process, and for safety of the intended functionality, the SOTIF. The ISO 26262 is already a standard, whereas SOTIF is still being discussed.

Platooning adds extra challenges to functional safety that go beyond the state of the art:

1. Since the platooning system (also referred to as 'item' in functional safety) is spread over multiple vehicles, the consequence of faults in one vehicle of a platoon may result in hazards on other vehicles that are fault free. Special care has to be taken during the Hazard Analysis and Risk Assessment phase to capture all these aspects of platooning.
2. ISO 26262 has just one phase for vehicle integration and testing, whereas in platooning this task has to be divided into 2 or more phases based on the number of vehicles in the platoon. i.e. once the platooning system is integrated and tested on a single vehicle, it has to be integrated and tested in the platoon with other vehicles.
3. SOTIF scenarios can present different levels of risk to the vehicles based on their position in the platoon; hence the reaction of each vehicle in the platoon may be distinct for the same situation.
4. Any reaction of a vehicle to a SOTIF situation has to also consider its consequences on different vehicles in the platoon.

The ENSEMBLE project will analyse the safety risks related to both functional safety and SOTIF and derive requirements to lower these risks to an acceptable level. Since these activities will not only define requirements for hazards arising from E/E malfunctions but also address hazards resulting from



performance limitations or insufficiencies of the function itself, the safety activities carried out for the project are enough to have a safe platoon deployment on public roads.

## 10.6. Infrastructure

Many stakeholders were questioned on their knowledge of the usage of infrastructure in different platooning projects. Regretfully the response was low, hence care should be taken by reading the results and conclusions. Three out of 36 projects were represented by the answers of the stakeholders (ETPC, C-Roads, KONVOI).

Concerning the *digital infrastructure* for strategical communication (tactical and operational communication is reported in the topic 'Communication' above): little information is available from recent project on platooning. The used communication technology appeared to be cellular data "4G/LTE", e.g. let platoon trucks communicate with cloud hosted services for gathering weather conditions. Only minimal real-life experience and lab test proofs are available to conclude on the requirements for services. Hence there is a potential risk that specifications are going to be incomplete and it is recommended follow the running projects/initiatives that are also targeting truck platooning like e.g. AUTOPILOT and CONCORDA.

The projects performed so far do not take into account the *physical infrastructure*. This may pose a risk on the ENSEMBLE project since the specifications can be incomplete and are not based on (scientific) tests and proofs.

## 10.7. Strategic functions and services

The initial drivers for platooning are fuel consumption reduction, road safety, improved traffic flow and reduction of environmental impacts. This has been shown in several projects as achievable in the short-term. On longer term, amongst others due to technology developments and gained experiences, higher automation levels will lead to less driver costs, initially with platooning time counted as none driver time and later with following vehicles without drivers. For large scale platooning a platform to support platooning between different freight companies is proposed. This requires support in the strategic layer for revenue sharing when platooning. Relevant information may be platoon formation, position in the platoon, time, distance and route.

ENSEMBLE will benefit from the results of the EU project COMPANION, where design of the strategic layer has been researched and evaluated in extended simulations and on public road, as the main partners from COMPANION involved in the design and evaluation are also partner in ENSEMBLE.

## 10.8. Impact

Various projects are evaluated based on the impacts that were found in literature and other publications: logistic business case (i.e. fuel savings), traffic safety, traffic flow, and emissions. It must be stated that most of the projects base their estimation on simulations, as no real platooning on public road was available on the scale required for sound evaluation, and the exact details on the implemented platooning functionality is not always stated. Hence also here, the results must be read with reservations.



Fuel saving and emission reduction are in-line with each other and different studies report between 7 and 15% possible reductions (ADAPTIVE , 2017), (SARTRE Report 2011, 2018). With respect to traffic safety high numbers ranging from 43 till 60% reduction in accidents are reported, however, different projects report different numbers (i.e. truck related accidents, highway accidents, all recorded and analysed accidents in Germany). It should be noted that these numbers very much depend on what is taken as basis, trucks without any active safety systems, or already trucks with systems like Automated Emergency Braking. Sometimes the literature is unclear about this.

Impact on traffic flow is expected to improve slightly due to different mechanisms like more smooth traffic flow and higher road usage as a result of smaller inter-vehicle distances, but no conclusive numbers can be stated. Moreover, this requires higher penetration rates and possibly connections to other (cooperative) applications.





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## 12. GLOSSARY

### Definitions

Term	Definition	
Cut-in	A lane change manoeuvre performed by vehicles from the adjacent lane to the ego vehicle's lane, at a distance close enough (i.e., shorter than desired inter vehicle distance) relative to the ego vehicle.	
Cut-out	A lane change manoeuvre performed by vehicles from the ego lane to the adjacent lane.	
Cut-through	A lane change manoeuvre performed by vehicles from the adjacent lane (e.g. left lane) to ego vehicle's lane, followed by a lane change manoeuvre to the other adjacent lane (e.g. right lane).	
Ego Vehicle	The vehicle from which the perspective is considered.	
Emergency brake	Brake action with a strong deceleration, often to avoid an emergency situation like a collision.	
Event	An event marks the time instant at which a transition of a state occurs, such that before and after an event, the system is in a different mode.	
Following truck	Each truck that is following behind a member of the platoon, being every truck except the leading and the trailing truck, when the system is in platoon mode.	
Leading truck	The first truck of a truck platoon	
Manoeuvre ("activity")	A particular (dynamic) behaviour which a system can perform (from a driver or other road user perspective) and that is different from standing still, is being considered a manoeuvre.	
ODD (operational design domain)	The ODD should describe the specific conditions under which a given automation function is intended to function. The ODD is the definition of where (such as what roadway types and speeds) and when (under what conditions, such as day/night, weather limits, etc.) an automation function is designed to operate.	
Operational layer	The operational layer involves the vehicle actuator control (e.g. accelerating/braking, steering), the execution of the aforementioned manoeuvres, and the control of the individual vehicles in the platoon to automatically perform the platooning task. Here, the main control task is to regulate the inter-vehicle distance or velocity and, depending on the Platooning Level, the lateral position relative to the lane or to the preceding vehicle. Key performance requirements for this layer are vehicle following behaviour and (longitudinal and lateral) string stability of the platoon, where the latter is a	



necessary requirement to achieve a stable traffic flow and to achieve scalability with respect to platoon length, and the short-range wireless inter-vehicle communication is the key enabling technology.

Platoon	A group of two or more automated cooperative vehicles in line, maintaining a close distance, typically such a distance to reduce fuel consumption by air drag, to increase traffic safety by use of additional ADAS-technology, and to improve traffic throughput because vehicles are driving closer together and take up less space on the road.
Platoon Automation Levels	<p>In analogy with the SAE automation levels subsequent platoon automation levels will incorporate an increasing set of automation functionalities, up to and including full vehicle automation in a multi-brand platoon in real traffic for the highest Platooning Automation Level.</p> <p>The definition of “platooning levels of automation” will comprise elements like e.g. the minimum time gap between the vehicles, whether there is lateral automation available, driving speed range, operational areas like motorways, etc. Three different levels are anticipated; called A, B and C. Note that a generic naming proposal is being prepared by the VDA, which can cover the SAE levels 1 through 5, see Appendix A.</p>
Platoon candidate	A truck who intends to engage the platoon either from the front or the back of the platoon.
Platoon cohesion	Platoon cohesion refers to how well the members of the platoon remain within steady state conditions in various scenario conditions (e.g. slopes, speed changes).
Platoon disengaging	<p>The ego-vehicle decides to disengage from the platoon itself or is requested by another member of the platoon to do so.</p> <p>When conditions are met the ego-vehicle starts to increase the gap between the trucks to a safe non-platooning gap. The disengaging is completed when the gap is large enough.</p> <p>This is sometimes also called ‘leave platoon’.</p>
Platoon dissolve	<p>All trucks are disengaging the platoon at the same time.</p> <p>This is sometimes also called ‘decoupling’, or ‘disassemble’.</p>
Platoon engaging	<p>Using wireless communication (V2V), the Platoon Candidate sends an engaging request. When conditions are met the system starts to decrease the time gap between the trucks to the platooning time gap.</p> <p>This is sometimes also called ‘join platoon’.</p>
Platoon formation	<p>Platoon formation is the process before platoon engaging in which it is determined if and in what format (e.g. composition) trucks can/should become part of a new / existing platoon. Platoon formation can be done on the fly, scheduled or a mixture of both.</p> <p>Platoon candidates may receive instructions during platoon formation (e.g. to adapt their velocity, to park at a certain location) to allow the start of the engaging procedure of the platoon.</p>





Platoon split	The platoon is split in 2 new platoons who themselves continue as standalone entities.
Requirements	Description of system properties. Details of how the requirements shall be implemented at system level
Scenario	A scenario is a quantitative description of the ego vehicle, its activities and/or goals, its static environment, and its dynamic environment. From the perspective of the ego vehicle, a scenario contains all relevant events. Scenario is a combination of a manoeuvre (“activity”), ODD and events
Service layer	The service layer represents the platform on which logistical operations and new initiatives can operate.
Specifications	A group of two or more vehicles driving together in the same direction, not necessarily at short inter-vehicle distances and not necessarily using advanced driver assistance systems
Steady state	In systems theory, a system or a process is in a steady state if the variables (called state variables) which define the behaviour of the system or the process are unchanging in time. In the context of platooning this means that the relative velocity and gap between trucks is unchanging within tolerances from the system parameters.
Strategic layer	The strategic layer is responsible for the high-level decision-making regarding the scheduling of platoons based on vehicle compatibility and Platooning Level, optimisation with respect to fuel consumption, travel times, destination, and impact on highway traffic flow and infrastructure, employing cooperative ITS cloud-based solutions. In addition, the routing of vehicles to allow for platoon forming is included in this layer. The strategic layer is implemented in a centralised fashion in so-called traffic control centres. Long-range wireless communication by existing cellular technology is used between a traffic control centre and vehicles/platoons and their drivers.
Tactical layer	The tactical layer coordinates the actual platoon forming (both from the tail of the platoon and through merging in the platoon) and platoon dissolution. In addition, this layer ensures platoon cohesion on hilly roads, and sets the desired platoon velocity, inter-vehicle distances (e.g. to prevent damaging bridges) and lateral offsets to mitigate road wear. This is implemented through the execution of an interaction protocol using the short-range wireless inter-vehicle communication (i.e. V2X). In fact, the interaction protocol is implemented by message sequences, initiating the manoeuvres that are necessary to form a platoon, to merge into it, or to dissolve it, also taking into account scheduling requirements due to vehicle compatibility.
Time gap	Elapsed time to cover the inter vehicle distance by a truck, indicated in seconds.
Trailing truck	The last truck of a truck platoon



Truck Platoon	A truck platoon may be defined as trucks that travel together in convoy formation at a fixed gap distance 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
Use case	<p>Use-cases describe how a system shall respond under various conditions to interactions from the user of the system or surroundings, e.g. other traffic participants or road conditions. The user is called actor on the system, and is often but not always a human being. In addition, the use-case describes the response of the system towards other traffic participants or environmental conditions. The use-cases are described as a sequence of actions, and the system shall behave according to the specified use-cases. The use-case often represents a desired behaviour or outcome.</p> <p>In the ensemble context a use case is an extension of scenario which add more information regarding specific internal system interactions, specific interactions with the actors (e.g. driver, I2V) and will add different flows (normal &amp; alternative e.g. successful and failed in relation to activation of the system / system elements).</p>

### Acronyms and abbreviations

Acronym / Abbreviation	Meaning
ACC	Adaptive Cruise Control
ACM	Accept Cooperation Message
ADAS	Advanced driver assistance system
AEB/AEBS	Autonomous Emergency Braking/System
ASIL	Automotive Safety Integrity Level
AT	Authorization Tickets
BTP	Basic Transport Protocol
CACC	Cooperative Adaptive Cruise Control
C-ITS	Cooperative ITS
CAD	Connected Automated Driving
CAM	Cooperative Awareness Message
DAVE	Driver-Automation-Vehicle-Environment
DENM	Decentralized Environmental Notification Message






DIA	Development Interface Agreement
ECM	Evaluation of Cooperation Message
ETPC	European Truck Platooning Challenge (a membership platform that co-operates with the ENSEMBLE project)
ETSI	European Telecommunications Standards Institute
EU	European Union
FSC	Functional Safety Concept
GN	GeoNetworking
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
HARA	Hazard Analysis and Risk Assessment
HMI	Human Machine Interface
HW	Hardware
IEEE	Institute of Electrical and Electronics Engineers
ISO	International Organization for Standardization
ITL	In-The_Loop
ITS	Intelligent Transport System / Service
LTE	Long-Term Evolution (standard for high-speed wireless communication)
MIO	Most Important Object
OCM	Offers of Cooperation Message
ODD	Operational Design Domain
OEM	Original Equipment Manufacturer
OOTL	Out-Of The-Loop
PKI	Public Key Infrastructure
RCM	Request for Cooperation Message
RSU	Road Side Unit
SA	Situation Awareness
SAE	SAE International, formerly the Society of Automotive Engineers
SCM	Status of Cooperation Message

SOTIF	Safety Of the Intended Functionality
TC	Technical Committee
TOR	Take-Over Request
TOT	Take-Over Time
TRL	Technology Readiness Level
V2I	Vehicle to Infrastructure
V2V	Vehicle to Vehicle
V2X	Vehicle to any (where x equals either vehicle or infrastructure)
VDA	Verband der Automobilindustrie (German Association of the Automotive Industry)
WAVE	Wireless Access for Vehicular Environments
WIFI	Wireless Fidelity
WLAN	Wireless Local Area Network
WP	Work Package




## 13. APPENDIX A: VDA PROPOSAL FOR PLATOONING LEVELS

Following slides summarise a proposal for platooning levels that is being worked on by the VDA.

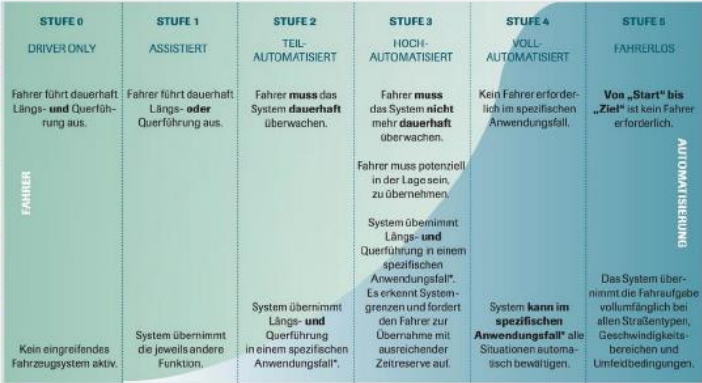

 Verband der  
Automobilindustrie

# VDA proposal for Platooning Category


 Verband der  
Automobilindustrie

## Level of automatisisation

SAE level	Name	Narrative Definition	Execution of Steering and Acceleration/Deceleration	Monitoring of Driving Environment	Fallback Performance of Dynamic Driving Task
<b>Human driver monitors the driving environment</b>					
0	No Automation	the full-time performance by the human driver of all aspects of the dynamic driving task, even when enhanced by existing or future systems	Human driver	Human driver	Human driver
1	Driver Assistance	the driving mode-specific assistance by a driver assistance system of either steering or acceleration/deceleration using information about the driving environment and with the expectation that the human driver perform all remaining aspects of the dynamic driving task	Human driver and system	Human driver	Human driver
2	Partial Automation	the driving mode-specific execution by one or more driver assistance systems of both steering and acceleration/deceleration using information about the driving environment and with the expectation that the human driver perform all remaining aspects of the dynamic driving task	System	Human driver	Human driver
<b>Automated driving system ("system") monitors the driving environment</b>					
3	Conditional Automation	the driving mode-specific performance by an automated driving system of all aspects of the dynamic driving task with the expectation that the human driver will respond appropriately to a request to intervene	System	System	Human driver
4	High Automation	the driving mode-specific performance by an automated driving system of all aspects of the dynamic driving task, even if a human driver does not respond appropriately to a request to intervene	System	System	System
5	Full Automation	the full-time performance by an automated driving system of all aspects of the dynamic driving task under all roadway and environmental conditions that can be managed by a human driver	System	System	System



\* Anwendungsfälle beinhalten Straßentypen, Geschwindigkeitsbereiche und Umfeldbedingungen

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Grafik: VDA

SAE level does not address a possible complex Platooning scenario

## Platooning Category

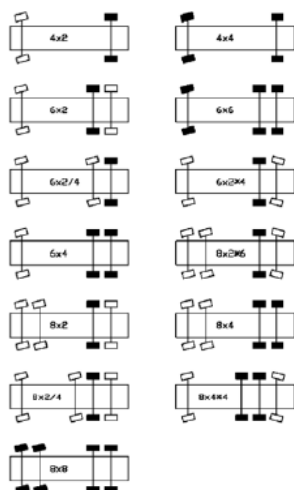
Kriterien	Parameterraum		Kategorie Platooning								VIII	IX
	Deutschland	international	I	II	III	IV	V	VI	VII			
Anzahl der Fahrzeuge	2 bis 3	international auch größer 3	2	2	2 -(3)	3	3	3	3	4	4	
Abstand zw. Fahrzeugen	5 bis 25m		15-25	15-25	15-20	5-15	5	5-15	5	5	5	
Automatisierungsgrad Führungsfahrzeug	L1 bis L3 (Grenzzenario L4)		L1	L2	L2	L2	L2	L3	L3	L4	L4	
Automatisierungsgrad Folgefahrzeug		mind L1	L1	L2	L3	L4	L4*	L4	L4*	L4*	L5	
Taktischer Layer	ja/nein		ja	ja	ja onboard					ja	ja	
Spurwechselfähigkeit ja/nein	ja/nein		nein	nein	nein					ja	ja	
CO2												
Sicherheit												
L4* Mensch nicht zwingen in Kabine												
Platoon erfordert mind. 2 Spuren												
Platoon mind 1 Platoonführer vor im Platoon												
Innerhalb des Platoons wird direkt zwischen den Fahrzeugen kommuniziert. (Richtwert 15-20ms)												
Dt Meinungsbildung wichtig												
Auch als input für ensemble												
VDA Position Platooning Sommerpause												

Result of VDA internal discussion (no link to ENSEMBLE)

## Platooning Category

### Proposal according wheel formular

Example:



The formula is defined as follows:

$$A \times B / C$$

or

$$A \times B * C$$

with:

A = number of wheels (twin-mounted tires count as one wheel)

B = number of driven wheels

/ = the fore of the rear axles is steered (pusher axle)

\* = the rearmost of the rear axles is steered (tag axle)

C = number of steered wheels

[Source: Wikipedia]



## Platooning Category proposal



**Rough classification: Platooning Category P1, P2, P3, P4, P5**

=> number after P describes the SAE automatization level in the Platoon

**Detailed classification according following characteristic:**

1. character: Number of vehicles in the Platoon
2. character: SAE automatization level for lead vehicle (LV)
3. character: SAE automatization level of following vehicle (s) (FV)
  - Assumption, following vehicles typically based on same category
  - Optional, separation with backslash
4. character: Letter for possible platooning distance (system capability)
  - S (Short)           => up to 5m
  - M (Medium)       => range 5m.....15m
  - L (Large)          => range 15m.....25m

**Advantage:** Detailed information and consideration of possible combinations

## Platooning Category proposal - example



**Platooning Category P1 (2x1x1xL)**

Description: 2 vehicles / both vehicles according SAE Level 1 / large distance

**Platooning Category P2 (2x2x2xL)**

Description: 2 vehicles / both vehicles according SAE Level 2 / large distance

**Platooning Category P3 (3x2x3xL)**

Description: 3 vehicles / LV SAE Level 2 / FV SAE Level 3 / large distance

**Platooning Category P4 (3x2x4xM)**

Description: 3 vehicles / LV SAE Level 2 / FV SAE Level 4 / medium distance

**High flexibility => theoretical mapping: Platooning Category P4 (5x2x4/3/3/2xS)**

Description of 5 vehicles with different level of automatization



## 14. APPENDIX B: RESULTS OF PUBLIC SURVEY ON INFRASTRUCTURE

This appendix comprises the detailed results of the public survey that was performed to gather detailed information on used infrastructure in different (EU) projects (see Chapter 6).

The detailed steps performed were:

1. Make a list of known relevant projects and contact names
2. Check the contacts on GDPR compliance
3. Establishing and issuing the questionnaire
4. Analyse the received data
5. Process the obtained results in order to phrase usable information for the project
6. Matchmaking the obtained results with some literature and published information
7. Phrasing the conclusions.

Here steps 1 – 6 are reported.

### B.1. Make the list of projects and contact names

The first list of the most relevant platooning projects is obtained by screening all available presentations of the ETPC of the last three years, noting down the relevant projects and major contact names.

In addition, using the already published information in an extensive web inquiry process revealed projects that added more relevant information and contact names. Few additional literature studies complemented the complete lists of projects and contacts. Finally, a list of 36 projects was identified that were directly dealing with Platooning or indirectly via CAD (Connected Automated Driving) related objectives. This list is published in the questionnaire.

### B.2. Establishing and issuing the questionnaire

An online questionnaire was established on the Survey Monkey platform (Link <https://www.surveymonkey.com/r/TH7BK5W>). The questionnaire contains a number of chapters

- 1) The identity of the contact and GDPR related questions

Name of the contact, the name of the related company and other relevant data is asked, as well as a number of obligatory questions related to the GDPR rules.

- 2) Project related information

The contact is asked to fill in a questionnaire per project in which he/she was involved in.

Questions are related to the **physical** and **digital infrastructure** (see further) that was available and used in the project.

The questionnaire makes a distinction between [physical and digital infrastructure](#). For both infrastructures, relevant objects were listed. In the digital infrastructure the distinction between strategic and tactical layer services is applied, as documented in the ENSEMBLE project proposal Figure 2-2.



- 3) A third section that asks in what conditions the project was carried out.  
These conditions can be weather conditions that were present during the project, clear sky or night conditions, etc..

### B.3. Analysing the received data:

Following the collection of data and information, a thorough analysis was performed based upon the original data received via Survey Monkey service and its specific visualization tools, but also by applying selected mathematical techniques, which can translate the data into a more comprehensive format. This allowed us to build a better graphical representation of the outcomes and provided us with better options for obtaining clear insights on each result.

The techniques allowed us to detect interesting correlations between the data and based on them ERTICO was able to derive clear conclusions and guidance for the subsequent ENSEMBLE Work Packages.

#### B.3.1 Stakeholders' roles

**Question: Which role are you occupying in the Truck platooning related projects?**

Stakeholder respondents are occupying the following roles (figure below):

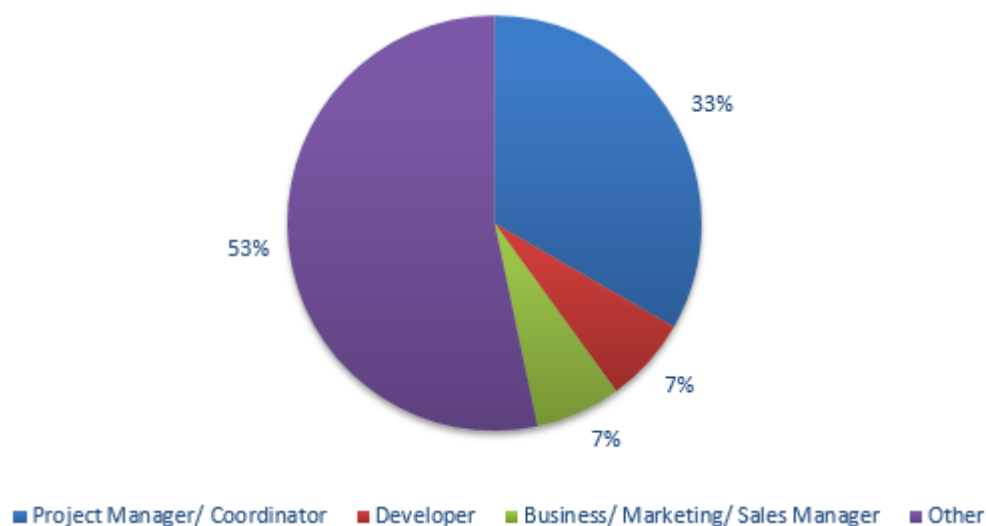


Figure 14-1. Stakeholders' roles

The questionnaire is issued to 694 addresses.

109 addresses were rejected by the system, leaving 585 suitable addresses. 25.9% of those addresses opened the questionnaire. Leaving a target group of 151 addresses.

16 valid answers were received which represents 11% respondents.

Three out of 36 projects were represented by the answers (ETPC, C-Roads, KONVOI).

Most of the respondents were occupying miscellaneous roles and positions.



Considering miscellaneous roles as less priority than “Project Manager/Coordinator” and “Developer, Business/Marketing/Sales Manager”, most of the respondents can be considered as “Project Managers/coordinators”.

#### Question: Which sector related to Truck platooning does your organisation belong to?

The sectors related to Truck platooning field were compiled based on academic papers and sources (Brizzolara & Toth, 2016), (Janssen, 2015).

##### a. Developers

Developers are involved in the technical development and facilitation of the equipment and complementary technologies.

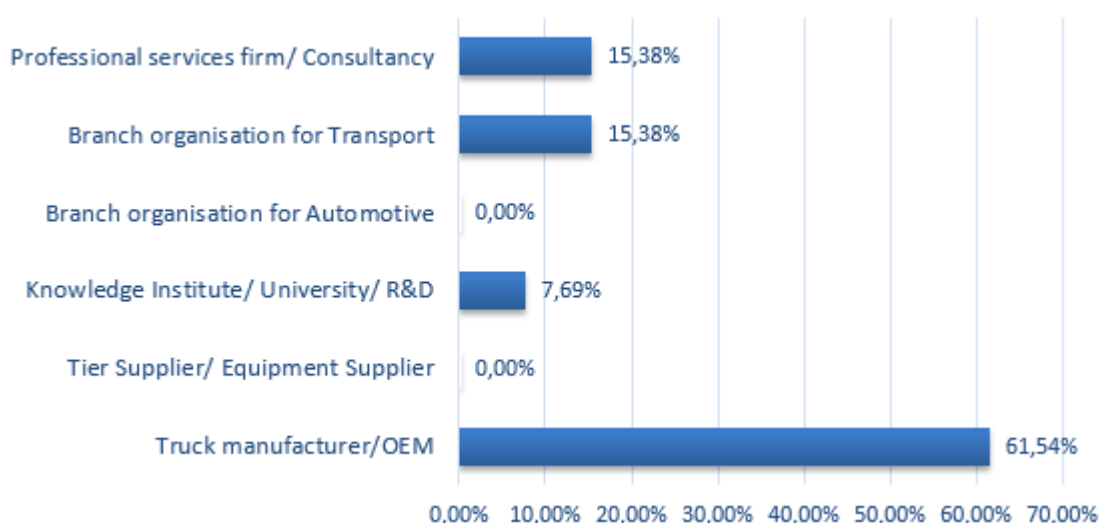


Figure 14-2. Developers

The **Developers sector** contains the following stakeholders:

- **Truck manufacturer/OEM (Original Equipment Manufacturer):** are companies producing trucks and they themselves can integrate technological innovations – in a role as OEM – that enables platooning.
- **Tier Supplier/ Equipment Supplier:** Tier suppliers provide components or products that are used to assemble a truck.
- **Knowledge Institute/ University/ R&D:** Research and Development organisations
- **Branch organisation for Automotive:** an automotive company/organisation involved in the design, development, manufacturing, marketing and selling of motor vehicles.
- **Branch organisation for Transport:** a company/organisation involved in transport activities.
- **Professional services firm/ Consultancy:** a professional practice that gives expert advice within a particular field.

From Developers' sector, Truck manufacturer and OEM are the most represented in this questionnaire.

##### b. Users





Users of platooning technology are the parties involved in logistics:

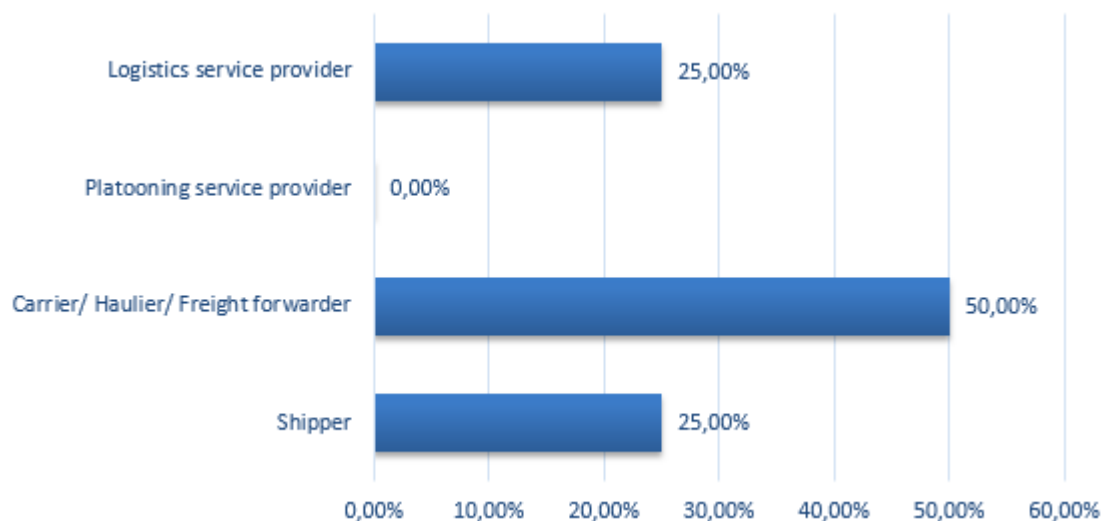


Figure 14-3. Users

The **Users sector** contains the following stakeholders:

- **Shipper:** Shippers want their products to be transported from one location to another. Although their role in the process will not change, their influence in the implementation of platooning could be significant.
- **Carrier/ Haulier/ Freight forwarder:** Carriers transport products that are commissioned by shippers.
- **Platooning service provider:** provide services around platooning, with the significance of their role developing through time. During the initial development phase of platooning, a minor adjustment to the transport management software of a carrier is sufficient. However, when trucks of different carriers cooperate and platoon on-the-fly, an independent service provider is necessary to link the trucks.
- **Logistics service provider:** logistics service providers are motivated to use platooning when the business case is positive. When societal benefits are large, the government is encouraged to adjust regulation and make platooning possible.

For Users' sector, most of the respondents to the questionnaire are "Carrier or Haulier or Freight forwarder" followed by "Logistics services provider" and Shipper".

### c. Policy maker

There are actions, mostly related to legal aspects that need to be taken before platooning can become reality. How long and heavy can a platoon be? When are platoons allowed to drive on public roads? Can the law around driving and resting times be adapted for the driver of the Following Vehicle? Can the second driver eventually be omitted? These are just a few examples of questions that policy makers must answer.



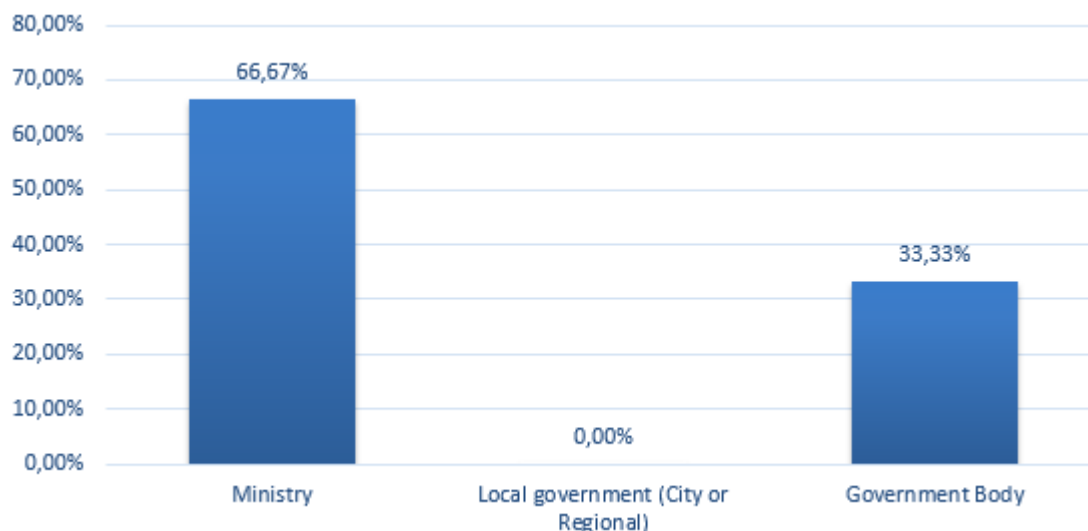


Figure 14-4. Policy maker

The **Policy maker sector** contains the following stakeholders:

- **Ministry:** The interest of the ministry is to have enabling innovations in their countries. These innovations can target better usage of existing infrastructure, increased accessibility and reduced environmental impact of the transportation system.
- **Local government (City or Regional):** The interest of the local authorities is to increase the innovation in their region. Local authorities can permit platooning on the local road. A local authority focused on innovation could permit the testing of platooning on a local road.
- **Government Body:** any person or organization authorized by law to perform any executive, legislative, judicial, regulatory, administrative, military, or police functions of any such government. Is a group of people that has the authority to exercise governance over an organization or political entity.

For Policy maker sector, most of the respondents are **Ministries**.

#### d. Regulator

Regulators enforce the law or make the law implementable.



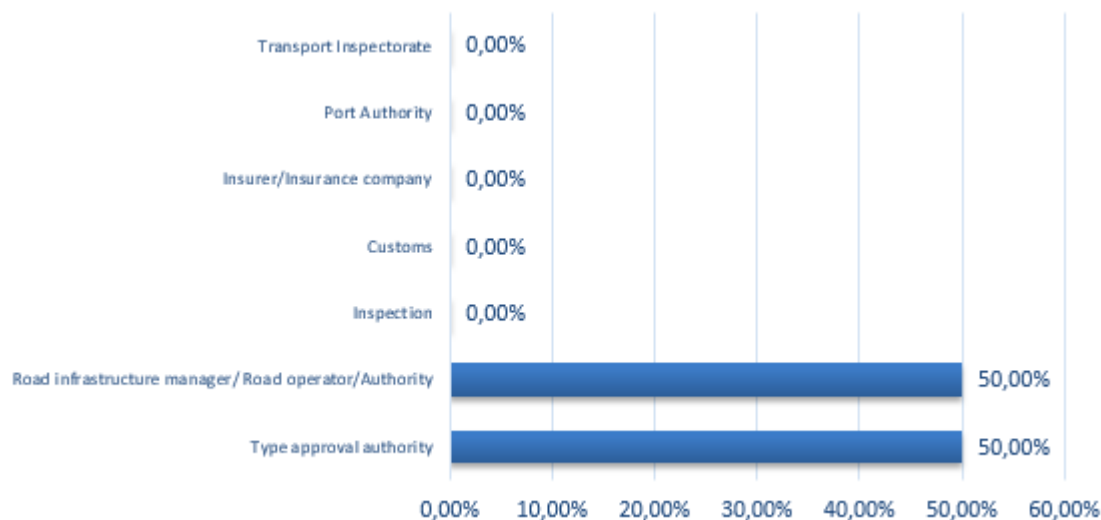


Figure 14-5. Regulator

The **Regulator sector** contains the following stakeholders:

- **Type approval authority:** is responsible for the type approval and licensing, so has multiple interests for platooning. Trucks equipped with technology that enables platooning must have type approval before they are allowed to use the technology on public roads.
- **Road infrastructure manager/ Road operator/Authority:** Road infrastructure manager is responsible for the maintenance and expansion of the road infrastructure network, and should investigate the impact of platooning on road capacity, the environment, the road safety, the incidents and road works.
- **Inspection:** The ILT (Inspection Environment and Transport) has regulations for enforcement of driving and resting times for truck drivers (e.g., EC 561/2006). Different aspects of platooning have influence on the driving task of the truck driver. The truck driver in the second truck of the platoon has a reduced required alertness, which could be seen as resting time.
- **Customs:** The Customs Authority has procedures on (documents of) cargo that require a truck driver to be present in the truck, as the driver needs to be able to show the documents when needed. Cross-border platooning may also require new customs legislation to be developed.
- **Insurer/Insurance company:** Since liability is addressed in law, although a commercial party, insurance firms also need to adapt to platooning.
- **Port Authority:** is a governmental or quasi-governmental public authority for a special-purpose district usually formed by a legislative body (or bodies) to operate ports and other transportation infrastructure.
- **Transport Inspectorate:** The activities of the transport inspectorate focus on good provision of services, fair enforcement and appropriate detection.

For Regulator sector, most of the respondents are Road infrastructure manager/ Road operator/Authority or Type approval authority.



### B.3.2. Organizations' involvement in Truck platooning projects.

Question: In which projects was your organization involved? (If you were involved in more than one project from the list below, please consider to fill in again the questionnaire for the other project).

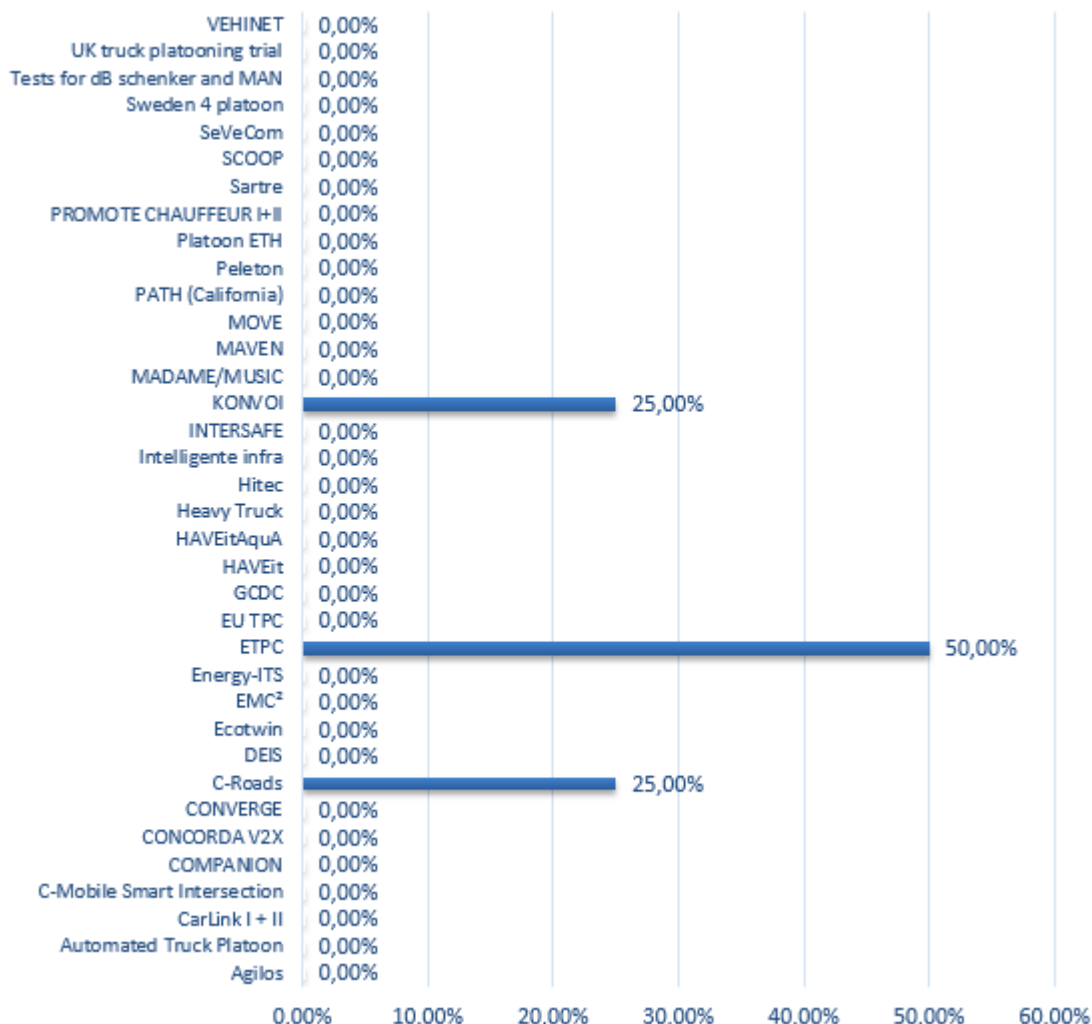


Figure 14-6. Stakeholder Involvement in projects

This questionnaire is related to one single project and the respondents are asked to fill a new questionnaire for each different project. The list of projects dealing with Truck platooning was compiled based on several academic papers and sources (Lu & Blokpoel, 2016), (Aarts & Feddes), (Robinson, Chan, & Coelingh, Operating platoons on public motorways: An introduction to the SARTRE platooning programme, 2010).

Most of the respondents are involved in ETPC, C-roads or KONVOI.

### B.3.3. Road infrastructure involved in your demonstration trajectory

Question: Road infrastructure involved in your demonstration trajectory:



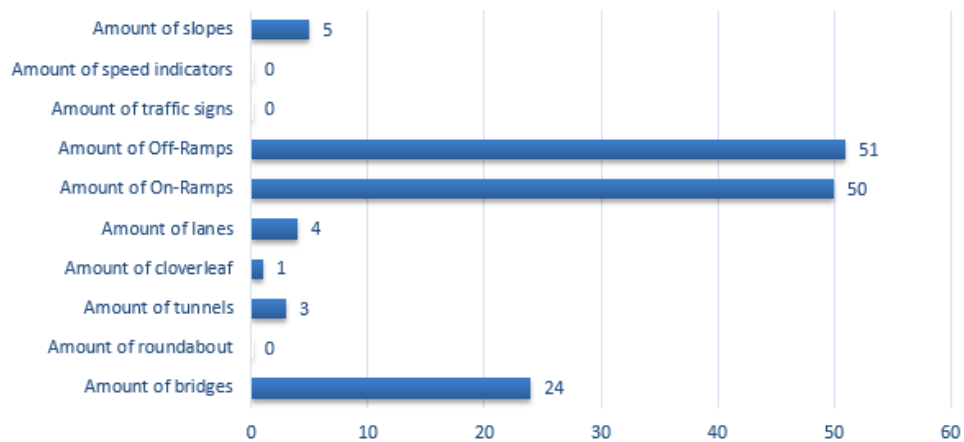


Figure 14-7. Road infrastructure involved in demonstration trajectory

The respondents are asked to fill the answers with numbers.

Commonly involved road infrastructure is **Off/On ramps** and **bridges**.

### B.3.4. Platooning dedicated lanes

Question: Were there specific platooning dedicated lanes involved?

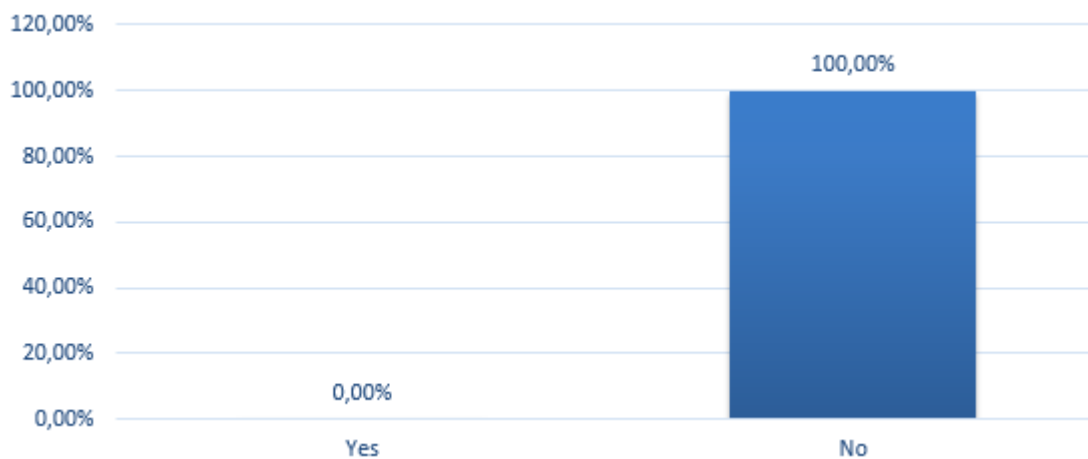


Figure 14-8. specific platooning dedicated lanes involved

Based on the answers received there is no dedicated platooning road infrastructure involved in the projects.

### B.3.5. Lane indicators

Question: Were there any lane indicators (paint on the roads, stripes, etc...)?

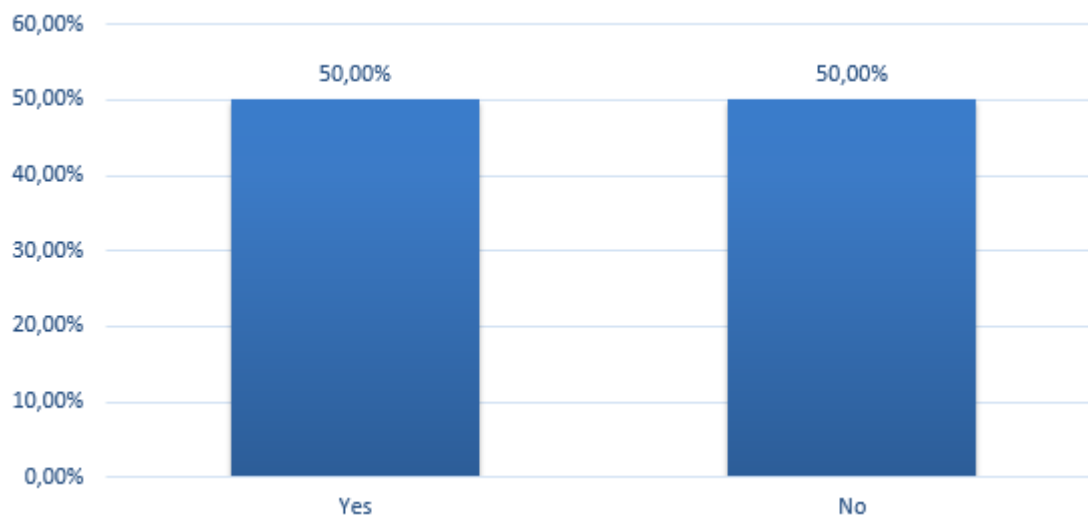


Figure 14-9. lane indicators

Lane indicators were involved in half of the projects.

### B.3.6. Rescue and emergency related infrastructure

Question: Was there any rescue and emergency related infrastructure?

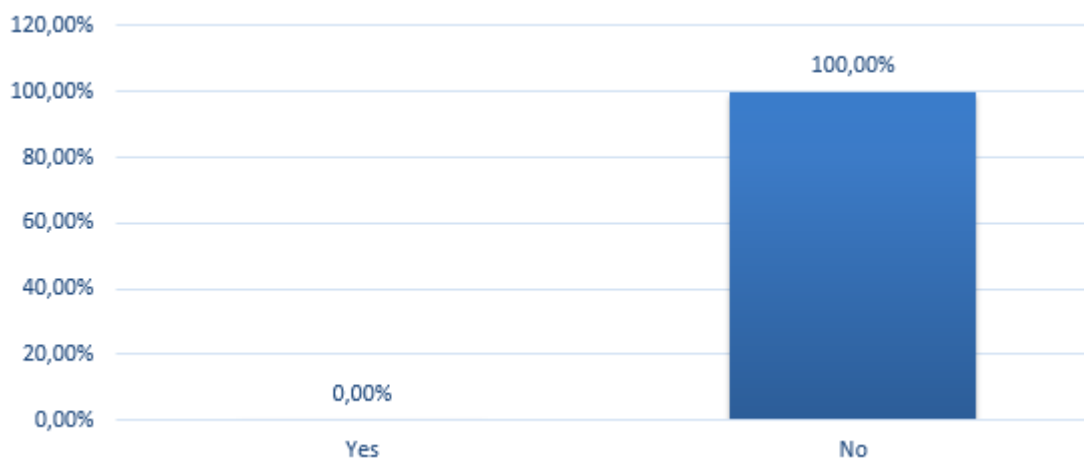


Figure 14-10. rescue and emergency related infrastructure

There was **no** rescue and emergency related infrastructure involved in the different projects.

### B.3.7. Impact of the road infrastructure on Truck Platooning

Question: Please indicate the impact of the road infrastructure on Truck Platooning (e.g. impact on the platoon distance gap between two trucks) (1= lowest, 2=medium, 3=highest impact)

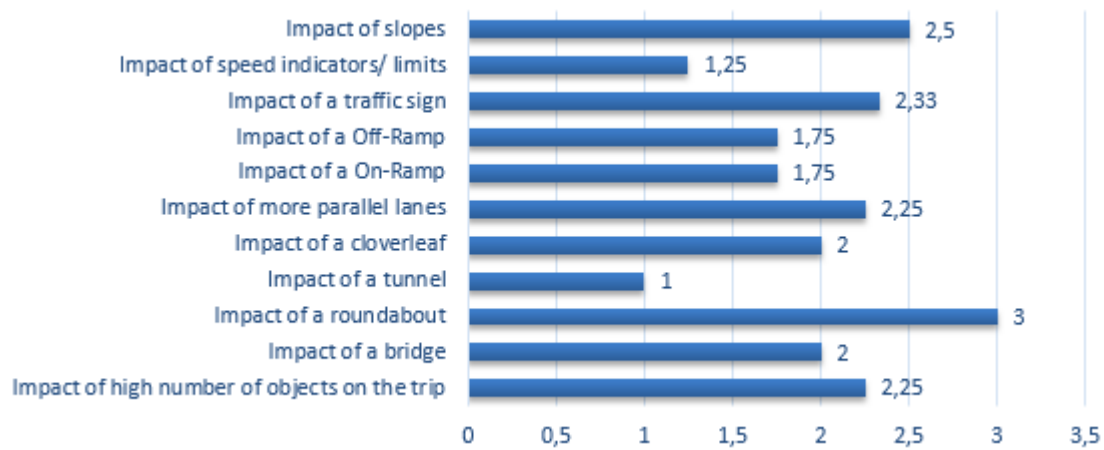


Figure 14-11. Impact of the road infrastructure on Truck Platooning

From the graphic below (Figure 14-11), almost all of the elements of the road infrastructure have impacts on a truck platoon. The following examples could be highlighted: **roundabouts, slopes, parallel lanes, number of objects on the road, traffic signs, cloverleaf**, etc.

### B.3.8. Estimated distance of the demonstration trips

Question: Road infrastructure properties: Please indicate the estimated distance of the demonstration trips (km)?

Respondents	Responses	Project
1	5km	KONVOI
2	1826km	ETPC
3	500km	ETPC



### B.3.9. Road network topology

Question: Road network topology (tick all applied)?

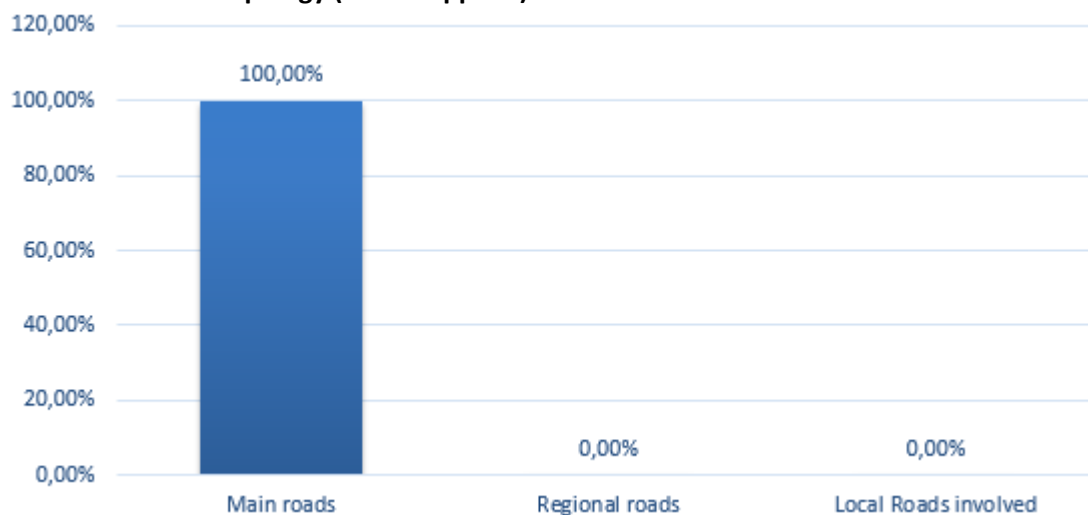


Figure 14-12. Road network topology

All projects related to truck platooning were happening on **main roads**.

### B.3.10. Road infrastructure environment

Question: Please describe the environment (tick all applied)?

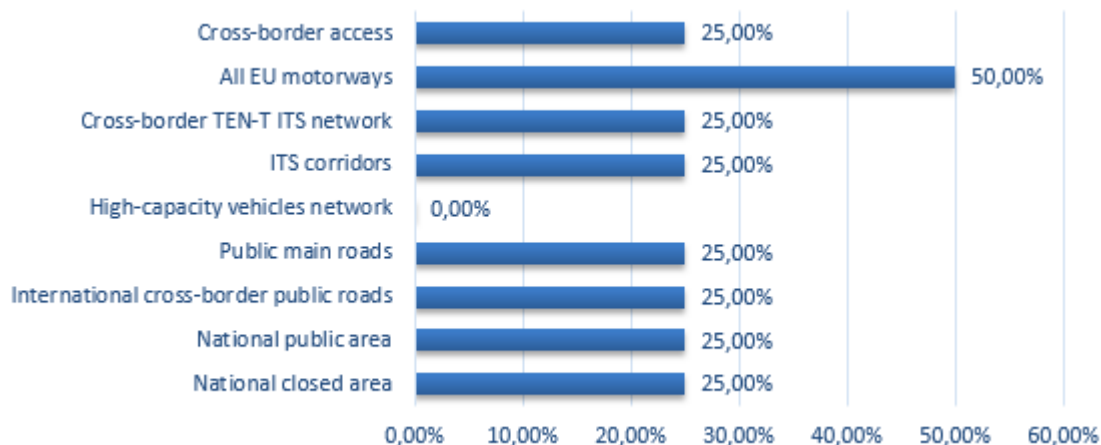


Figure 14-13. environment description

The road infrastructure environment involved in the projects are all **EU motorways**. Remember that almost all the road infrastructure environments are used, except high-capacity vehicles network.





B.3.11. Digital infrastructure - Strategic level

Question: Digital infrastructure - Strategic level (Please select all applied services and infrastructure):

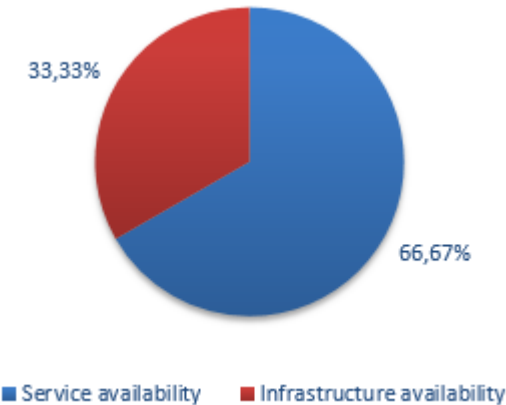


Figure 14-14. Digital infrastructure - Strategic level

From the graphic (Figure 14-14), Infrastructure availability is mostly represented than Infrastructure availability.

a. Service availability

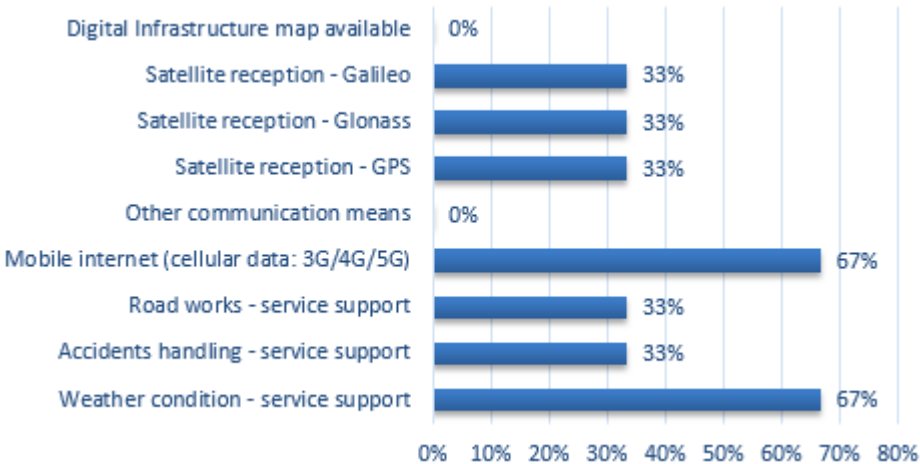


Figure 14-15. Service availability

In service availability graphic (Figure 14-15), Mobile internet (Cellular data ) and Weather condition are mostly represented.

### b. Infrastructure availability

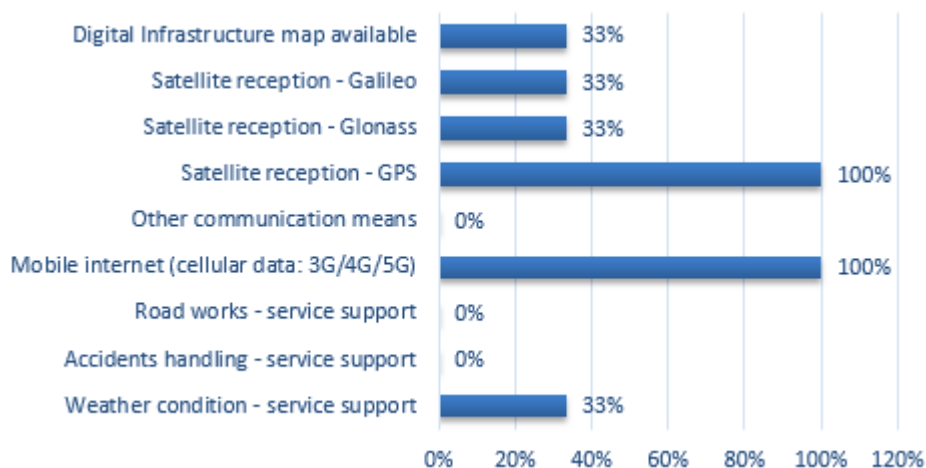


Figure 14-16. Infrastructure availability

In Infrastructure availability graphic (Figure 14-16), Satellite reception (GPS) and Mobile internet (cellular data: 3G/4G/5G ) are mostly represented.

### B.3.12. Digital infrastructure - Tactical level

Question: Digital infrastructure - Tactical level (Please select all applied services and infrastructure)

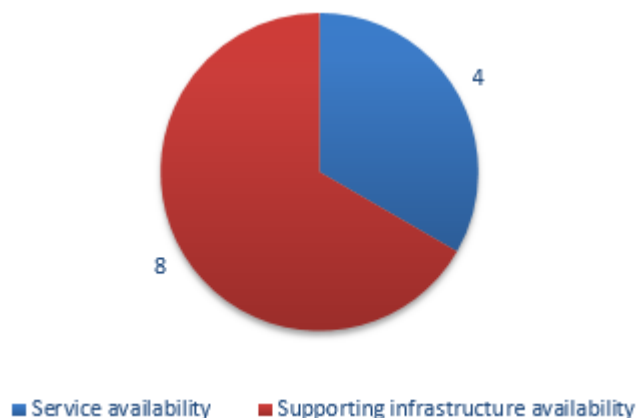


Figure 14-17. Digital infrastructure - Tactical level

From the graphic (Figure 14-17), **Service availability** is mostly represented than Supporting infrastructure availability.

### a. Service availability

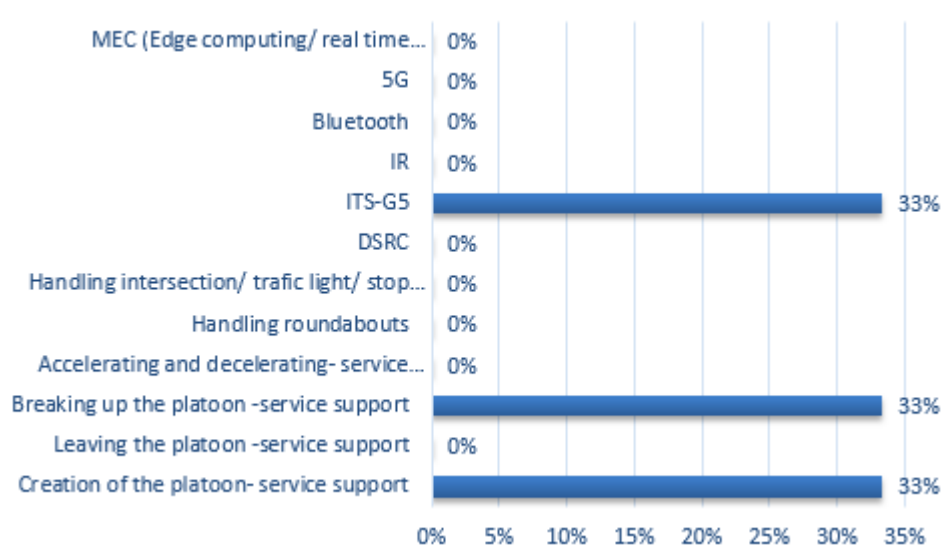


Figure 14-18. Service availability

From the graphic (Figure 14-18) related to Digital infrastructure - Tactical, mostly represented service availability items are: ITS-G5, Breaking up the platoon and Creation of the platoon.

### b. Supporting infrastructure availability

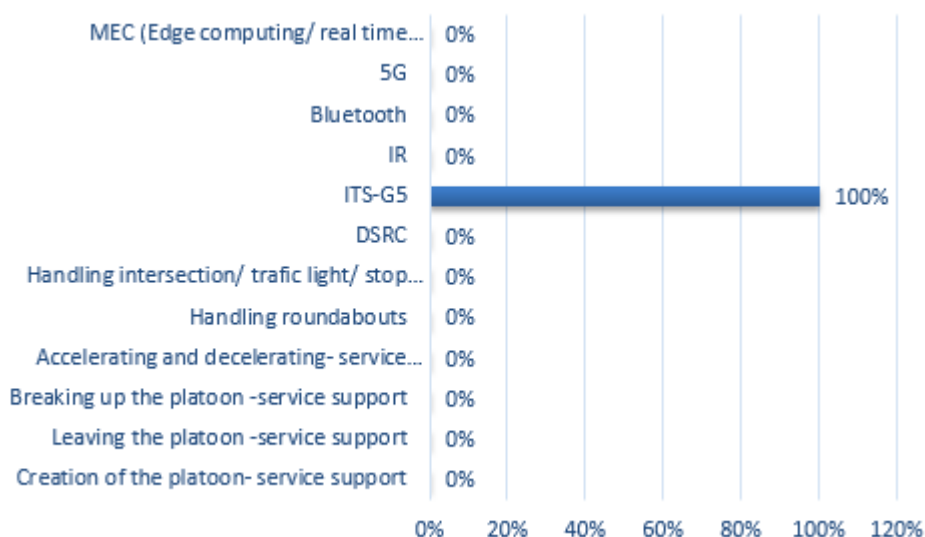


Figure 14-19. Supporting infrastructure availability

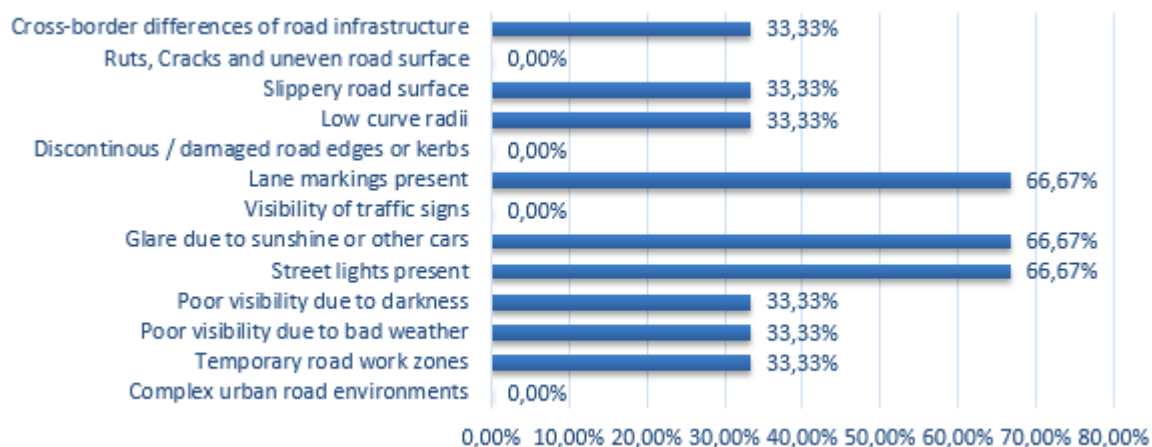
From the graphic (Figure 14-19.) related to Digital infrastructure - Tactical level, mostly represented Supporting infrastructure availability items are: ITS-G5.

## B.3.13. Conditions of the project

Question: In what conditions was the project carried out (please tick all relevant)?



The Road infrastructure conditions related to Truck platooning were compiled based on several academic papers and sources (Nitsche, Mocanu, & Reinthaler, 2014).

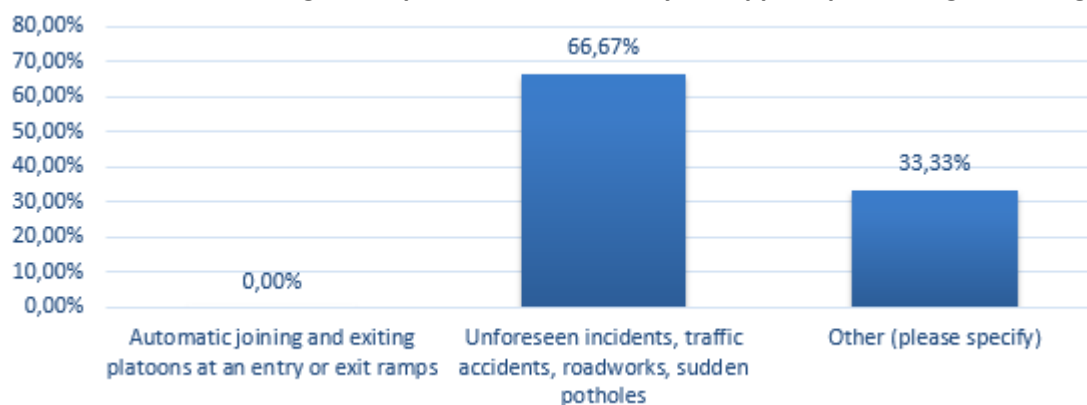


**Figure 14-20. In what conditions was the project carried out**

From the graphic (Figure 14-20. ) related to project conditions, mostly represented conditions are: Lane markings present, Glare due to sunshine or other cars, Street lights present.

### B.3.14. Detected blind spots by the applied platooning technologies

**Question: Which of the following blind spots were detected by the applied platooning technologies?**



**Figure 14-21. Blind spots were detected by the applied platooning technologies**

From the graphic (Figure 14-21) related to detected blind spots by the applied platooning technologies, Unforeseen incidents, traffic accidents, roadworks and sudden potholes are mostly represented.