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ENabling **S**af**E** **M**ulti-**B**rand p**L**atooning for **E**urope

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Contents

REVISION HISTORY

Version	Date	Author	Summary of changes	Status
0.1	20/10/2021	CLEPA	First draft with Platooning Support Function and Platooning Autonomous Function	For review in WP2
0.2	17/11/2021	CLEPA	Second draft with feedbacks implemented. Additional chapter on lessons learned from testing included.	For review in WP2
1.0	22/12/2021	CLEPA	Final after approval on the content	For Review by WP Leader
1.2	31/01/2021	CLEPA	Approved by WP2	For review by Coordinator
1.3	18/02/2021	CLEPA	Feedback from Coordinator implemented	Final

FIGURES

TABLES

EXECUTIVE SUMMARY

Context and need of a multi brand platooning project

Context

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.

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 traffic safety, fuel economy, and throughput. This has been demonstrated by driving up to seven differently branded trucks in one (or more) platoon(s) under real world traffic conditions. During the years, the project was organised as follows:

- Year 1: setting the specifications and developing a reference design;
- Year 2 and 3: implementing this reference design on the OEM own trucks, as well as performing impact assessments with several criteria;
- Year 4: focus on testing the multi-brand platoons on test tracks and public road.

The technical results were evaluated against the initial requirements, after which these were updated. 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.

Abstract of this Deliverable

This deliverable provides the definition of the requirements and specifications of the multi-brand truck platooning concept. After first publication of the requirements and specifications (Konstantinopoulou, 2018), a review towards implementation in the demonstration trucks and a preliminary safety analysis (Dhurjati, 2019) were performed. This preliminary safety analysis, revealed that the original Platooning Level A as defined in the D2.2 is ASIL D, when having the driver responsible while having time gaps of 0.8 s. For this reason, strict safety requirements were needed that were not in line with the aims of a "first" platooning level that could be deployable on short term considering the readiness level of the required technology and the existing regulatory framework. Hence, after thorough review with the project partners, new levels were defined and documented in D2.3 (Willemsen, 2022):

- **Platooning Support Function (PSF)**: the driver is responsible for the driving task. Hence (s)he is also responsible to choose a safe following distance and monitor the system e.g. whether the right platooning partner is being followed (though supported by the system as much as possible). To give the driver sufficient time to react, minimum time gaps around 1.5 s have to be respected. The Platooning support function is a longitudinal control function, but lateral driver assistance systems, such as e.g. lane centring, might be optionally available as well,

- **Platooning Autonomous Function (PAF)**: The lead truck has a driver responsible for the driving task, but the following trucks are fully automated, i.e. the system performs the complete driving task within the specified (limited) operational design domain. Taking the driver(s) out-of-the-loop offers the possibility to reduce time gaps to a minimum of 0.3 s.

The Platooning Support Function has been implemented, tested and evaluated in the project.

Inside this deliverable, besides the requirements and specifications for the Platooning Support Function, all the feedbacks and lessons learned after the final 7-brand test at IDIADA in September, on all the aspects of the Platooning Support Function (requirements, specifications, platooning protocol and communication security), are included.

The project also aims to provide a future vision of platooning to accelerate and initiate research and development into next levels of platooning and (digital) infrastructure, and to reflect on potential future needs for adaptation of regulations. For this reason, the second level, i.e. the Platooning Autonomous Function, is also specified. However, the specification of the Platooning Autonomous Function and its use cases is solely done on theoretical considerations to sketch a future perspective of platooning. The latter is also due to the low technology readiness level (TRL) of certain required autonomous driving subfunctions at the time of writing.

The white-label truck concept is introduced as a vehicle that collects all the common features among different OEMs. It is for this truck that the specifications are made; only for the tactical layer (this deliverable). Requirements are formulated for the operational layer, as the implementation will be brand specific.

Chapter 1 - gives a background overview, aim and structure of this report; and relation to the other work packages.

Chapter 2 - focuses on the Platooning Support Function. All the requirements and specifications linked to this level are listed here.

Chapter 3 – gives some reflections on the Platooning Support Function following the 7-Brands test in IDIADA, Barcelona

Chapter 4 – focuses on the Platooning Autonomous Function. All the requirements and specifications linked to this level are listed here.

Chapter 5 – Includes the conclusions of this deliverable followed by the references (chapter 6).

Apart from being a reference for the specifications and requirements of the white-label truck, this final deliverable is also an important input for WP6, where the requirements are consolidated towards pre-standards and recommendations and guidelines for future policy and regulatory frameworks for the wide scale implementation of multi-brand platooning.

1 INTRODUCTION

1.1 Background

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. As analysed in D2.1 (Willemsen, 2018), there are several (early) platooning projects which 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). 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, here these functionalities are separated in a way that the technology is still usable for all OEMs.

1.2 Relation to ENSEMBLE work packages

According to the description of action (DoA), the ENSEMBLE project follows the 'learning by doing' principle methodology resulting in a spiral inspired development process with feedback (see Figure 1).

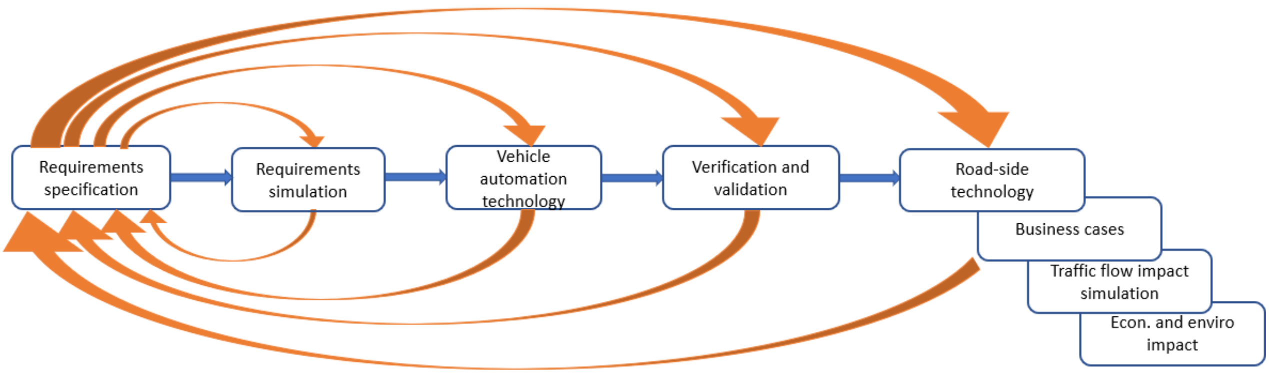

Figure 1: Evolution cycles for the derivation of the relevant requirements for multi-brand truck platooning

The work in ENSEMBLE is organised in different work packages:

WP1 – This is the management work package with as main objective to ensure the successful execution of the project.

WP2 - During the requirements specification phase, specifications and requirements for multi-brand platooning are defined using the earlier identified use cases. In order to perform a reality check on the feasibility and the relevance of the requirements specifications, first-principles simulations were performed. This deliverable concentrates on the operational and tactical layer, but also identifies required interactions with the higher layers (Strategic and Services Layers). The main focus in WP2 focus is on specifying the Platooning Support Function for implementation in the trucks. In addition, WP2 focusses on specifying the Platooning Autonomous Function to sketch a future perspective of platooning. The work on the Platooning Autonomous function is done on theoretical considerations due to the low technology readiness level (TRL) of certain required autonomous driving subfunctions at the time of writing.

WP3 – For the Platooning Support Function, this work package implements the requirements and the specifications of WP2 into demonstrator trucks (i.e. comprising hardware and software). The implementations are verified in WP5 against the specifications and requirements given in WP2. Change requests on the specifications and requirements from the design and implementation process are collected in WP2 and are included in D2.5 (this deliverable).

WP4 - In this WP, business cases and economical and environmental impact analyses are performed. Requirements on the white-label truck arising from these analysis are included in this deliverable.

WP5 - During the verification and validation phase the functionality of the equipped vehicles is tested and verified against the requirements specification defined mainly in WP2.

After each development step, the requirement specifications are updated if necessary, depicted as the feedback arrows in Figure 1.

WP6 - Here, the requirements are consolidated towards pre-standards and recommendations and guidelines are developed for future policy and regulatory frameworks for the wide scale implementation of multi-brand platooning. D6.13 will provide a standardisation and regulation gap analysis of the specified requirements and specifications.

1.3 Aim of the deliverable

This deliverable provides the definition of the requirements and specifications of the multi-brand truck platooning concept. After first publication of the requirements and specifications (Konstantinopoulou, 2018), a review towards implementation in the demonstrator trucks and a preliminary safety analysis (Dhurjati, 2019) were performed. This preliminary safety analysis revealed that the original Platooning Level A as defined in D2.2 is ASIL D, when having the driver responsible while having time gaps of 0.8 s. For this reason, strict safety requirements were needed that were not in line with the aims of a “first” platooning level that could be deployable on short-term considering the readiness level of the required technology and the existing regulations framework. Hence, after thorough review with the project partners, new levels were defined in a first version of D2.3 that has been used for implementation internally in the project:

1. **Platooning Support Function:** the driver is responsible for the driving task;

2. **Platooning Autonomous Function:** the driver is not responsible anymore, the system performs the complete driving task within the specified operational design domain. A lead tuck with a driver responsible for the driving task remains.

Deliverable D2.3 (Willemsen, 2022) contains the final description of the use cases for these two levels, which form the basis for the functional decomposition and the here reported specifications and requirements. In addition to that, the main feedback and lessons learned from the 7-brand testing in IDIADA in September 2021, on all the aspects of the Platooning Support Function (requirements, specifications, platooning protocol and communication security), are included.

For the interest of the reader, the main documents that describe the two platooning levels defined in ENSEMBLE are:

- Levels definitions and Use Cases – D2.3 (Willemsen, 2022)
- Requirements and Specifications - D2.5 (this deliverable)

Additional details on the Communication protocol and the strategic and services layers can be also found in:

- V2X Protocol - D2.8 (B. Atanassow, 2022a)
- Security - D2.9 (B. Atanassow, 2022b)
- Intelligent infrastructure - Strategic and Services Layers – D2.6 and D2.7 (Villette, 2018) (C. Villette, 2022)

Furthermore, the deliverable related to the safety analysis performed on the two levels are:

- Safety of the intended functionality (SOTIF) - D2.13 (P. Dhurjati, 2022a)
- Functional Safety - D2.14 (A. Pezzano, 2022)
- Item Definition - D2.15 (P. Dhurjati, 2022b)

1.4 Structure of report

This deliverable is structured into 6 chapters:

Chapter 1 - gives a background overview, aim and structure of this report; and relation to the other work packages.

Chapter 2 - focuses on the Platooning Support Function. All the requirements and specifications linked to this level are listed here.

Chapter 3 – gives some reflections on the Platooning Support Function following the 7-brands test in IDIADA, Barcelona

Chapter 4 – focuses on the Platooning Autonomous Function. All the requirements and specifications linked to this level are listed here.

Chapter 5 – Includes the conclusions of this deliverable followed by the references (chapter 6).

2 PLATOONING SUPPORT FUNCTION (PSF)

2.1 Introduction

This section presents the ENSEMBLE platooning system consisting of a hierarchical system, with interacting platooning layers. This deliverable concentrates on the operational requirements and tactical layer specifications, but also identifies required interactions with the higher layers (Strategic and Services Layers). This architecture is the basis for the decomposition and detailing of the modules for Platooning Support Function.

2.1.1 Platooning Layers

The concept of the ENSEMBLE platooning system consists of a hierarchical system, with interacting layers. This is common to the Platooning Support Function and the Platooning Autonomous Function. The envisioned concept is presented in Figure 2. Different layers have the following responsibilities:

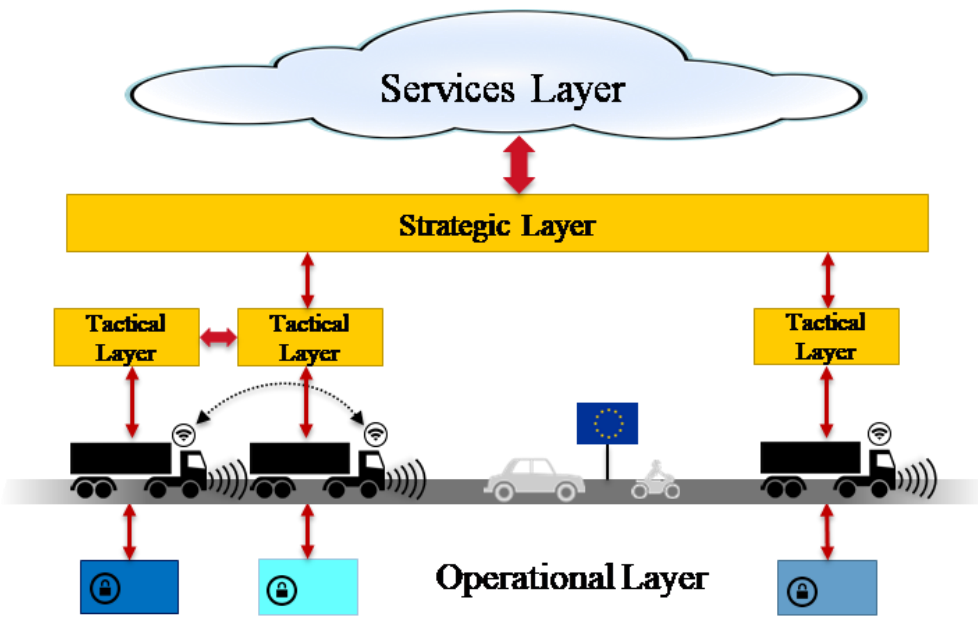

Figure 2: ENSEMBLE Platooning Layers

- The service layer represents the platform on which logistical operations and new initiatives can operate.

- The strategic layer is responsible for high-level decision-making regarding 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.

- The tactical layer coordinates 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 speed, 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 considering scheduling requirements due to vehicle compatibility.

- The operational layer involves the vehicle actuator control (e.g. accelerating/braking, steering), the execution of the 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 speed 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.

2.1.2 White-label truck platooning functional modules

The white-label truck concept is a vehicle that collects all the common features among different OEMs. It is for this truck that the specifications are made; only for the tactical (this deliverable) and the strategic layer (C. Villette, 2022) (Villette, 2018). Requirements are formulated for the operational layer (this deliverable), as the implementation will be brand specific.

Figure 3 gives a high-level overview of the platooning functional modules of the white-label truck.

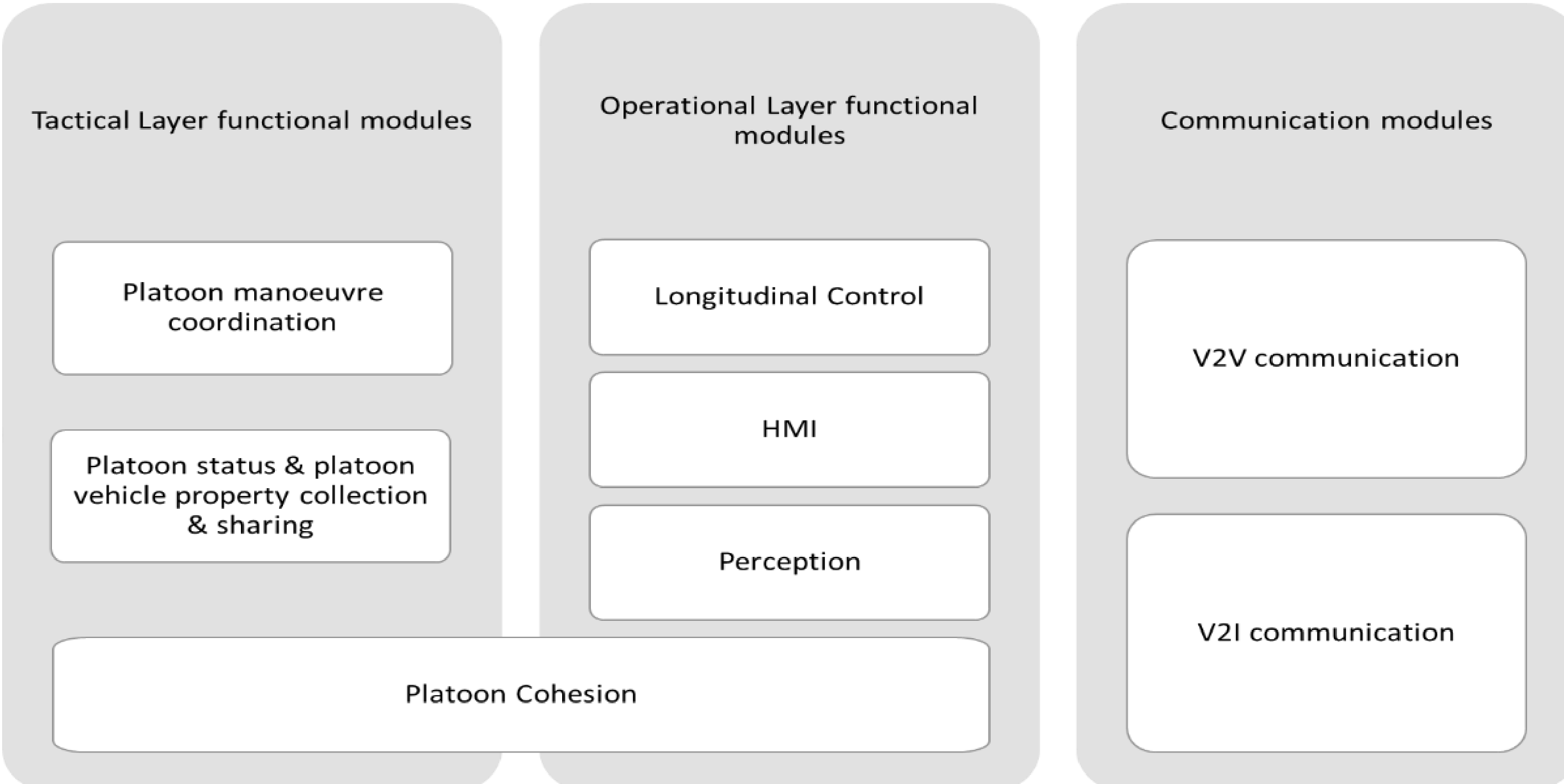

Figure 3: Platooning functional modules of the white-label truck (high-level view)

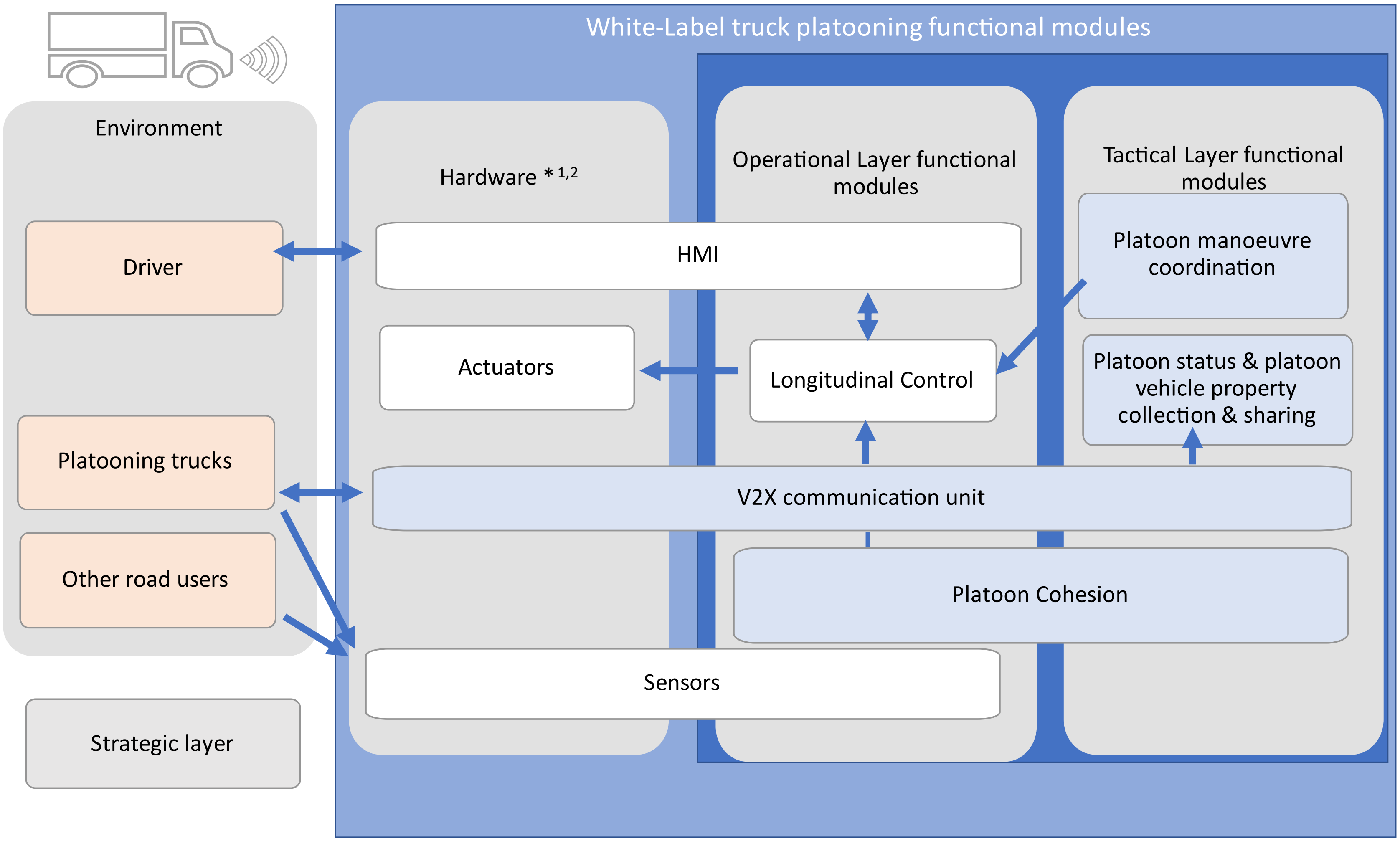

Figure 4: Platooning modules of the white-label truck (detailed view)

Figure 4 describes a more detailed description of the functional modules and the layers. The light blue boxes indicate the common functionality for which specifications have been made (Tactical and operational layer):

- V2X communication: this is the whole set of hardware and software to establish the communication required for platooning (the specifications will be described in D2.8 (B. Atanassow, 2022a) and D2.9 (B. Atanassow, 2022b).

- Platoon status & platoon vehicle property collection and sharing: this is a module that collects and contains the relevant information (properties, status) of the platoon and the platooning vehicles that must be commonly shared in the platoon (specified in Chapter 2.3, Tactical Layer).

- Platoon manoeuvre coordination: this is a module that coordinates specific manoeuvres that need a cooperative approach rather than an individual one (specified in Chapter 2.3, Tactical Layer).

- Platoon cohesion mechanism: this is a module that contains the common tactical strategies to preserve the cohesion of a platoon, e.g. on hilly road, after a cut-in, etc. Platoon cohesion as a function is addressed both in the tactical layer and the operational layer. The tactical layer provides the required information, the operational layer uses this information to perform the platoon cohesion in longitudinal control. The operational part will be explained in Chapter 2.5 and the information sharing part will be described in Chapter 2.3.

For the white blocks in Figure 4 requirements have been formulated for the Operational Layer which implementation are OEM specific:

- HMI: this module provides the required logic for the interfacing to the driver (described in Chapter 2.5).
- Sensors: this module provides the requirements for the on vehicle-mounted sensors to perform host vehicle environmental perception and localisation.
- Longitudinal control: this module contains the control algorithms for automatically executing vehicle acceleration and deceleration, e.g. to drive at a certain speed or to maintain a desired time gap (described in Chapter 2.5).

Related to the Environment block in Figure 4, communication needs to be established with other road users, platooning trucks (V2V), infrastructure (V2I) to provide the necessary information and interact with the platoon.

The parts that are OEM specific (*1 and *1.2 in Figure 4) are:
- V2X Antennas

- Front vehicle estimator and sensor set up
- Braking system
- Instrument cluster / Buttons

The braking system, and instrument cluster / buttons will probably only need an (extra) interface.

2.1.3 Functional Safety considerations

A safety analysis (Dhurjati, 2019) was done for the initial version of Platoon Level A function. It concluded that safety cannot be guaranteed if the function has full longitudinal control/automation with a low time gaps (e.g. 0.8 sec) under normal working conditions and the driver is the backup/fall back in case of failures. This is caused by the driver getting accustomed to using the function for full longitudinal control over time. Consequently, the average reaction time in case of malfunctions (e.g. loss of braking) may increase to more than 2 seconds. This was not compatible to the 0.8s of time gap to guarantee safety.

The project partners agreed to alternatively have the following levels for safe platooning:

1. **Platooning Support function:** larger time gaps with the driver responsible for longitudinal and lateral control, so that the platooning functionality is supporting the driver by his/her task;

2. **Platooning Autonomous Function:** the driver is not responsible for the safety of the longitudinal and lateral control. This would permit to achieve lower time gaps.

After a steering committee meeting, it was decided to implement the Platooning Support Function for the current project. Further discussions amongst the partners lead to the approach to use ACC as a basis and add additional functionality and safety through V2V and V2I communication.

The Platooning Support Function is safer than the previous Level A function due to the following main reasons:

1. Since the time gaps between trucks is at least 1.4 seconds (ACC distances), loss of the support function (e.g. communication, , ..) is safer as it gives the drivers more time to react.
2. Since the deceleration that can be provided by the trucks is limited to -3.5 m/s² (ACC accelerations), the drivers will not rely on the function for full longitudinal control.
3. V2V information will be used to advance forward collision warning even before the on-board sensors measure the movements of the forward vehicle, hence giving more time for the driver to react.

Further information can be found in D2.14 (A. Pezzano, 2022).

2.2 Approach – Platooning Support Function

In order to gather the common set of requirements and specifications for the Platooning Support Function the following steps have been followed, with the purpose to gather and validate the information provided by the WP2 partners.

- Step 1: New Platooning Support Function definition
- Step 2: Update of use cases in D2.2 with regards to the new Platooning Level definition (former version A of D2.3 for internal use)
- Step 3: Update of the specifications and requirement of D2.4 with regards to the new Platooning Level definition and updated Use Cases.
- Step 4: First round of TelCos for feedbacks on the requirements/specifications for the Platooning Support Function
  - 08/10/2019 – V2V, V2I, Sensing Technologies
  - 09/10/2019 – Longitudinal Control, Tactical Layer, HMI
- Step 5: Update of the specifications/requirements following input received
- Step 6: Meeting for final consensus on the requirements/specifications:
  - WP2 – D2.5 (former Version A of the document for internal use) Workshop 17/10/2019
- Step 7: Update of the entire D2.5 (former Version A of the document for internal use) document with the new requirements/specifications
- Step 8: TelCos for final consensus for the D2.5 (former Version A of the document for internal use)
  - 20/11/2019 – Longitudinal Control, Tactical Layer, Sensing Technologies
  - 21/11/2019 – V2V module, V2I module, HMI, introduction/conclusions of the deliverable

Red squared tables throughout the deliverable are defining a unique Requirement/ Specification for the modules of the tactical, operational layers and the communication functional modules for V2V and V2I.

The format is PSF_yy_00X, where:

- *PSF* identifies that the specification/requirement holds for the Platooning Autonomous Function
- *yy* identifies the domain function of the tactical, operational layer and the communication functional modules (e.g. ‘Tactical layer’).
- *00X* identifies the number of the requirement within the domain.

e.g. PSF_Long_Control_001: The driver shall be able to select a time gap to the preceding vehicle.

2.3 Tactical layer Modules & specifications

The tactical layer is one of the four layers defined for the hierarchical overall platooning system architecture. The tactical layer coordinates the actual platoon forming (both from the tail of the platoon and through merging in the platoon), potential partner identification and platoon dissolution. In addition, this layer gathers the information that enables platoon cohesion functionality. 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 identify a partner, to form a platoon, to merge into it, or to dissolve it and to share certain information in the platoon.

The needed functionality in the tactical layer is captured by 3 functional modules which will be detailed further in this chapter, being:

- Platoon Manoeuvre coordination module (section 2.3.1)
- Platoon status & platoon vehicle property collection & sharing modules (section 2.3.2)
- Platooning partner identification module (section 2.3.3)

Finally, an overview of the information shared in the platoon is provided in section 2.3.4.

The tactical layer modules, especially the “Platoon status & platoon vehicle property collection & sharing” can be mapped to all use cases as described in D2.3 (Willemsen, 2022).

2.3.1 Platoon manoeuvre coordination module

The purpose of this functional module is to coordinate the manoeuvres on platoon level. For the Platooning Support Function, the coordination of the manoeuvres (e.g. the join action) is described by an interaction protocol, which is the subject of section 2.4.1.

2.3.2 Platoon status, platoon vehicle property collection and sharing modules

Platoon status & sharing

The required platoon status & data information is gathered from HMI and strategic & service layer functional requirements. The following list is retrieved:

Platoon status item ID	Platoon status item description	Source of requirement/specification
PS_001	Number of trucks in the platoon	HMI, Strategic layer
PS_002	Ego-truck's position in the platoon	HMI
PS_003	Platoon speed	HMI, Long_Control _005
PS_004	Reasons for speed and gap adjustment	HMI
PS_005	Platoon ID	Strategic Layer and Service Layer

Table 1: platoon status & data information

Since this information is not time critical, the update frequency can be chosen substantially lower compared to control related V2V information.

PSF_Tactical_Layer_001: The platoon system over the tactical layer will gather platoon status and data information (Number of trucks in the platoon, Ego-truck's position in the platoon, Platoon speed, Reasons for speed or gap adjustments, Platoon ID) and distribute this information over the platoon.

PSF_Tactical_layer_002: The platoon system status information gathered by the tactical layer is updated cyclically.

The platoon status items need to be determined and maintained at the tactical layer. To be able to do this it is of importance to ensure sharing of information between the vehicles in the platoon.

PSF_Tactical_layer_003: The platoon system status information in the tactical layer is shared between all trucks in the platoon.

<u>Vehicle property collection & sharing</u>

There are two main purposes for the vehicle property collection and sharing:

1) To make available relevant truck information to the service & strategic layer

2) To share relevant truck information between the trucks to enable optimization of e.g. operational modules

For point 1, the tactical layer only serves as a gateway. As the details regarding the type of information that needs to be shared can be found in D2.6 (Villette, 2018) and D2.7 (C. Villette, 2022) and will be further explored in T4.2, this list is not detailed here.

For point 2, the relevant information that needs to be shared is currently needed solely for the cohesion functionality. The cohesion functionality is also part of the operational layer. That part is described in the Longitudinal Control section 2.5.2.

The following information should be shared between vehicles:

Vehicle item ID	Vehicle item description	Source of requirement/specification
V_001	Maximum acceleration request (to the platoon)	Platoon cohesion
V_002	Desired maximum platoon speed	Platoon cohesion
V_003	Optional container (e.g. relative positioning error)	
V_004	Optional container	
V_005	Optional container	

Table 2: Vehicle property collection & sharing

The vehicle information can be shared in a similar fashion as the platoon status shared matrix.

PSF_Tactical_layer_004: The platoon system over the tactical layer gathers the vehicle property information (Maximum acceleration request (to the platoon), Desired maximum platoon speed), within the platoon and distributes this information over the platoon.

Note: the platoon system property information within the tactical layer is shared between all the trucks in the platoon.

The proposed implementation is to upstream communicate the most limiting property (e.g. maximum acceleration). Every vehicle receives the limit from the backward vehicle and compares it with its own and shares that with the vehicle in front. Since the information is not time critical, the update frequency can be chosen substantially lower compared to control related V2V containers.

PSF_Tactical_layer_005: The platoon system property information is updated cyclically.

2.3.3 Platooning partner identification module

The purpose of this functional module is to identify the correct vehicle to platoon with. For the Platooning Support Function (the system) the partner identification functionality uses the information available at communication level to evaluate if the vehicle in front is the correct one to join. The module will be used in the joining procedure, e.g. during the platoon creation or after a long cut-in.

The solution proposed in this document foresees the use of the GNSS (Global Navigation Satellite System) coordinates and vehicle length information received via V2V from the vehicle in front to be compared with the own information from environmental sensors (e.g. radar and GNSS).

PSF_Tactical_layer_006: The system shall be responsible for Partner Identification.

PSF_Tactical_layer_007: The system shall use GNSS information (values and accuracy) and vehicle length for partner identification.

The GNSS coordinates, together with the accuracy information related to them, and the vehicle length to be sent via V2V are evaluated in the ego vehicle, according to the following ETSI specification for the Cooperative Awareness Message (CAM) (ETSI, 2019):

- **ReferencePosition**: "Position and position accuracy measured at the reference point of the originating ITS-S [Ed.: Intelligent Transport Systems Station]." … "the reference point shall be the ground position of the centre of the front side of the bounding box of the vehicle."
- **VehicleLength (value)**: "Vehicle length of the vehicle ITS-S that originates the CAM. If there are vehicle attachments like a trailer, or overhanging attachments like a crane, that extend the vehicle length to the front and/or rear; then the *vehicleLengthValue* shall provide the length for the vehicle including the attachments"

The identification steps are:

Pre-condition: V2V information is received that indicates a platooning opportunity from a vehicle in front of the ego vehicle.

1. Using the Reference Position and the Vehicle Length received via V2V, and the ego Reference Position, the module calculates the distance from the ego vehicle to the sender (i.e. the relative distance of the sender's back with respect to the ego front bumper).
2. Using its on-board vehicle sensors, the ego vehicle identifies vehicles driving in front of it in a region of interest covering at least the left and right adjacent lanes, if these are present. Similarly to ACC systems (ISO 15622) (ISO, 2018), the platooning function identifies the front target vehicle, which is driving in the same lane (target discrimination). In case, besides the front target vehicle, another vehicle is found in an adjacent lane, and the relative longitudinal distance of such adjacent vehicle to the identified target vehicle is within a certain range (e.g. 5 m), the identification procedure is on hold until the position difference between the adjacent and front vehicles exceeds this range.
3. After 2 is successful, the above-mentioned calculated distance from V2V and GNSS (Global Navigation Satellite System) information of step 1 is compared with the distance to the front target evaluated by the on-board vehicle sensors (a result of step 2).

Now two situations can occur:

A. The two values are equal within a certain range (e.g. 5 m) and the sender is identified as front target. The identification procedure is concluded with the joining procedure finalisation.
B. The two values are not equal within a certain range (e.g. 5 m): the module shall monitor the situation, waiting for situation [A] that can only happen if step 2 is not on hold. The waiting time in this situation shall be defined; a first guess is 1 minute. If the time threshold is reached without the conditions for [A] becoming valid, the identification is stopped and the identification procedure shall start again (Step 1).

2.3.4 Information sharing

Next to the platoon status, platoon vehicle property collection and sharing modules that were defined previously for the Tactical Layer to share information in the entire platoon, other information is shared to do platoon partner identification and to enable the development of improved longitudinal and optional lateral control functions, i.e. functions that perform better than existing functions like ACC and AEBS due to the availability of information from other trucks by V2V communication. This information that is exchanged in a specific a Platoon Control Message is listed in Table 3.

In addition to the Platoon Control Message, also some messages have to be exchanged for platoon build-up, see chapter 2.4. Besides, as the Platoon Control Message is secured, similar signals that are already available in the CAM message can be used for partner identification during a join sequence, see also previous section.

Table 3 - Data shared by the vehicles in the platoon

Data	Meaning	Possible usage and remarks
Reference position	Position (latitude, longitude) of the ego vehicle measured at the reference point of the ego vehicle. The reference point shall be the ground position of the centre of the front side of the bounding box of the vehicle, i.e. below the centre of the front bumper of the tractor.	Target tracking and preceding vehicle's path reconstruction. This is an important signal for platoon partner identification: does the reference position of the preceding vehicle match with the predicted position, calculated from the ego vehicle's position, the distance to the observed front target, and the received preceding vehicle's length?
Heading	Heading of the tractor in the WGS84 coordinate system.	Target tracking: in addition to position, heading provides the orientation. This information can be used to verify if the front target sensed identified by the ego vehicle's sensors correspond to the

Data	Meaning	Possible usage and remarks
		one of which V2V messages are received.
Length	Length of the vehicle. This is the length including trailer (when attached).	Information is necessary for target tracking, as the reference position received is measured at the front bumper of the tractor.
Other identification information: StationID, StationType	Unique V2V station identifier and station type, e.g. here: heavy Truck	Target tracking: do we receive messages of the same vehicle and is it e.g. a heavy truck and not a motorcycle, car, etc.
Information about the timing of messages, such as generation time and sequence number.	It is important to know how old a message is that is received and if it is the latest.	Target tracking: signals like position and heading only make sense in the context of time. Since the vehicles are driving the position continuously changes. In principle it is not problem to have some latency, but for correct target tracking it must be known what this latency is.
Predicted longitudinal acceleration	The acceleration demand to the ego vehicle's control system. This is the setpoint of the longitudinal control functionality or the demand to the powertrain/brake system given by the driver when pressing the accelerator or brake pedal.	The acceleration demand is the earliest signal that indicates a change of speed. Communication of this signal provides the lowest delay/latency acceleration following vehicles can react on, e.g. in a feedforward loop in the distance controller of the ACC, or for giving an early indication of hard braking such that the driver can be warned timely for an emergency braking.
Current longitudinal acceleration	The actual longitudinal acceleration of the ego vehicle.	Target tracking. Does the received longitudinal acceleration correspond to the longitudinal acceleration obtained from vehicle sensors? Is the predicted longitudinal acceleration reliable? Note: the predicted longitudinal acceleration is the signal with the lowest delay/latency. This signal can best be used to react on, but its reliability should be monitored.
Longitudinal speed	The actual speed of the ego vehicle	Target tracking. The following truck can verify if the

Data	Meaning	Possible usage and remarks
		speed of the preceding vehicle detected with the ego vehicles sensors corresponds to the communicated speed.
Reference speed	The set speed of the ego vehicle	This signal gives an indication if the vehicle in front for some reason is driving slower than it desires.
Road inclination	If available, the ego vehicle can share the actual road inclination.	For the vehicles behind, the road inclination can be used as preview information, which can be used to optimise the longitudinal control, e.g. for fuel efficiency reasons. Furthermore, the received road inclination can be compared with the ego vehicle's sensed/estimated road inclination to check the reliability of the information received.
Information about a preceding vehicle: intruder	Share speed of the vehicle ahead and distance to vehicle ahead.	This information can be used by following vehicles in the platoon to adapt their speed or change their time gap.
Information about a preceding vehicle: vehicle ahead	Share the speed of the (platooning) vehicle ahead of the ego vehicle.	This information can be used to optimise the longitudinal control of the following vehicles and enables the usage of control algorithms that not only react to the direct preceding vehicle, but also to vehicles ahead of this.
Lateral acceleration and yaw rate	The ego vehicle's lateral acceleration and yaw rate.	Target tracking: does the communicated lateral acceleration and yaw rate correspond to the expected lateral acceleration of the front target? The expected lateral acceleration can e.g. be obtained from speed estimation and road curvature estimation using radar, camera and map data. Furthermore, the lateral acceleration signal can be used for potential hazard detection and reactions to this, e.g. a high lateral acceleration may indicate a hazard and the system can automatically

Data	Meaning	Possible usage and remarks
		increase the time gap and warn the driver. Besides the above the signals can be used for improved lateral control functionality, e.g. for: - Tracking and reconstructing the driven path of the preceding vehicle. - Obtain estimates of the road curvature ahead, i.e. for long distance preview information.
Road curvature	The curvature of the road centre line sensed by the ego vehicle.	This information can be used to improve the lateral control: obtain an estimate of the road curvature ahead, i.e. for long distance preview information. Additionally, the information can be used to assess the state of the preceding vehicle, e.g. to assess if the preceding vehicle is following the lane.
Distance to left and right lane markers	The distances to the left and right lane markers, as e.g. observed by the camera system of the ego vehicle.	Target tracking, path reconstruction. Note that this signal gives some information about the lateral position of the tractor with respect to the lane markings. Especially, for tractor-semitrailers, this lateral position could deviate from the observed lateral position by the following vehicle's ego sensors, due to the rearward amplification.

2.4 Communication modules & Specifications

2.4.1 Communication functional module for V2V

The implementation of the use cases described in deliverable D2.3 (Willemsen, 2022) requires coordination of vehicle manoeuvres by means of interaction between vehicles using V2V-communication. The communication protocol is described in D2.8 (B. Atanassow, 2022a) and D2.9 (B. Atanassow, 2022b).

In order to allow for interaction between the trucks within the platoon, a communication link must be established between the platoon participants. It is assumed that it is enough that the ego vehicle at least receives messages from the first preceding and the first following truck in the platoon (if present). Establishing a communication link with a platoon means to first agree on the connection using Platoon Management Messages (PMMs) and subsequently exchange Platoon Control Messages (PCMs) When the ego vehicle is in the platoon, It must send PMMs and PCMs.

In order to describe the interaction of the trucks we use the so-called “roles”. The roles that the ego vehicle can have in the platoon are:

- **Platoon candidate:** not platooning with either a forward or backward platooning partner
- **Leading vehicle:** platooning with at least one backward platooning partner (without a forward platooning partner). A truck with a Leader role can join another platoon or platoon candidate.
- **Trailing:** platooning with at least one forward platooning partner (without a backward platooning partner). A trailing vehicle can be joined by another platoon or platoon candidate.
- **Following:** platooning with a forward and backward platooning partners. A following vehicle is driving inside a platoon and cannot join or be joined.

Each vehicle in the platoon can always have one (and only one) of these roles.

With these roles the single use cases can be described. By activating the Platooning functionality, the driver agrees on any role changes.

<u>Security</u>

The cybersecurity requirements for the PSF are described in D2.9 (B. Atanassow, 2022b). In this deliverable, all the requirements to enable certificates signing and verification and encryption are listed.

These requirements, together with the Platooning Partner Identification Procedure (described in section 2.3.3) contributes to provide a sufficient level of trust in the messages received, to enable the ego vehicle to adjust its own kinematic behaviour on V2V information.

Beside the encryption of messages (that ensures that the content stays secret), these are the main functionalities that enable this sufficient level of trust:

- Certificates signing/verification

Ensures that the message received is coming from a trusted source and it has not been changed.

- Platooning Partner Identification Procedure

Ensures that the message received is coming from the vehicle in front of the ego vehicle.

When certificates signing/verification and the Platooning Partner Identification Procedure are satisfied, then the ego vehicle is aware that the message is trustable and is coming from the vehicle in front so it can start adjusting its kinematic behaviour based on V2V.

Platooning

Among the use cases listed in deliverable D2.3 (Willemsen, 2022), the use case “Platooning” contains 3 sub use cases, namely the “Steady state platooning”, “Follow braking target” and the “Emergency braking” use cases.

Steady state platooning/Follow to stop

In the first sequence of the “Steady state platooning” use case, the ego vehicle is receiving platooning information via V2V from vehicles in the platoon. To clarify this, we can define three subsets (leading, trailing, and following truck). When the ego vehicle is the leading truck, it shall at least receive V2V messages from the first following platoon member. In case of the trailing vehicle, the ego vehicle shall receive platooning information at least from the first preceding platoon member. When the ego vehicle is a following truck, it shall receive V2V information at least from first preceding and the first following platoon member.

PSF_Interaction_of_the_trucks_001: The platoon system in the ego vehicle shall receive platooning information via V2V (described in D2.8 (B. Atanassow, 2022a)) at least from the preceding and succeeding vehicle, if present.

PSF_Interaction_of_the_trucks_002: The platoon system in the ego vehicle shall broadcast the platooning information via V2V (described in D2.8 (B. Atanassow, 2022a)).

Emergency braking

The emergency braking functionality is described in the Longitudinal Control section (Section 2.5.4). Regarding the communication module, for this functionality, at least the actual and intended acceleration must be broadcasted. This way each vehicle can detect an emergency braking manoeuvre by comparing these acceleration values to a certain threshold. Moreover, these acceleration values are available in all platooning conditions and can be used for the regulation of the intervehicle distance to enable faster anticipation on acceleration changes of the preceding vehicle. How the information required to be communicated in Interaction_of_the_trucks_003 (below), should be broadcasted is further detailed D2.8 (B. Atanassow, 2022a).

PSF_Interaction_of_the_trucks_003: The platoon system in the ego vehicle shall broadcast its actual and intended acceleration via V2V to enable following vehicles to regulate the intervehicle distance and detect emergency braking events.

Leaving the Platoon

The procedure of leaving the platoon by the ego vehicle occurs in the following basic sequence:

1. The ego vehicle has the intention of leaving the platoon. This may have different reasons, such as a driver wish or the system status.
2. Therefore, the ego vehicle stops sending/receiving PMMs and PCMs with its direct platooning partners (first preceding platooning partner and first platooning partner behind, if they are present).
3. Afterwards, the ego vehicle continues as a stand-alone vehicle (role "platoon candidate").

When there are residual platoon parts (bigger than one vehicle each) in front of and/or behind the ego vehicle, they will continue as separate platoons. From a communication point of view a subsequent join request, to join the remaining parts of the platoon when the ego vehicle has physically left, could be triggered by the Operational Layer.

The role of the ego vehicle determines to which use case this sequence refers:

- Leaving the platoon by trailing truck
- Leaving the platoon by leading truck
- Leaving the platoon by following truck

Additionally, there are the use cases:

- Split platoon by follower truck
- Leaving by steering out as trailing truck
- Leaving by steering out as leading truck
- Leaving by steering out as following truck

Regarding the mentioned use cases and the required communication interactions, the following manoeuvres for the ego vehicle are defined:

- Front split:

1. The ego vehicle starts this procedure as a follower or a trailing vehicle.
2. The ego vehicle notifies its preceding platooning partner about its intention to split.
3. Then, (if necessary) the ego vehicle increases the distance to the preceding platooning partner and (if necessary) notifies the driver.
4. When the ego vehicle decides that it is ready to disconnect from the platoon to the preceding platooning partner, it notifies its preceding platooning partner about this.

5. If there are followers, the ego vehicle becomes the leading vehicle of the new platoon, else it continues as a stand-alone vehicle. If the ego vehicle becomes a stand-alone vehicle, then it will stop sending/receiving PMMs and PCMs.

- Back split

1. The ego vehicle starts this procedure as a follower or a leading vehicle.
2. The ego vehicle notifies following platooning partner about its intention to split.
3. The platooning partner behind the ego vehicle starts a front split procedure as described above.
4. Upon receiving the message that the follower vehicle is ready (step 4 of the front split) the ego vehicle can stop sending/receiving PMMs and PCMs unless the ego vehicle is a follower vehicle, then it will continue as a trailing vehicle.

For both the front split and back split manoeuvres, for the Platooning Support Function there is no mandatory action specified before sending the confirmation of being ready to stop sending/receiving PMMs and PCMs with the preceding platooning partner, since the used time gaps are based on the ACC time gaps. Specific OEMs may, however, add additional/different criteria.

The previously mentioned use cases for leaving and split (disengagement procedures) can be described as a combination of front split and back split manoeuvres. In particular:

- Leaving the Platoon by leading vehicle:
  - The ego vehicle (leading vehicle) performs a back split
- Leaving the Platoon by follower vehicle:
  - The ego vehicle (follower) performs a front split and a back split simultaneously
- Leaving the platoon by trailing vehicle
  - The ego vehicle (trailing) performs a front split
- Split platoon by follower vehicle
  - the ego vehicle (follower) performs a front split
- Leaving by steering out as a leading vehicle

- The ego vehicle is the leading vehicle and steers out of the platoon. The platooning partner that is behind the ego vehicle (leader), detects that is not following the leading vehicle anymore and starts a front split

- Leaving by steering out as a trailing vehicle

  - The ego vehicle is the trailing vehicle, the ego vehicle detects that is not following the preceding platooning partner anymore and starts a front split

- Leaving by steering out as a following vehicle:

  - The ego vehicle is a following vehicle, the ego vehicle detects that is not following the preceding platooning partner anymore and starts a front split
  - The platooning partner that is behind the ego vehicle, detects that is not following the ego vehicle anymore and starts a front split

Requirements linked to the leave and split (disengagement procedure) use cases:

PSF_Interaction_of_the_trucks_004: The platoon system of the ego vehicle shall broadcast its intention of leaving the platoon through V2V communication.

Note: the intention of leaving the platoon is broadcasted through V2V communication by starting a front split (trailing role), back split (leading role) or front and back split (following role) procedure.

PSF_Interaction_of_the_trucks_005: During a disengagement procedure of the preceding vehicle, when the ego vehicle is ready for a front split, it shall broadcast this information.

PSF_Interaction_of_the_trucks_006: When the disengagement procedure is finished, the platoon system of the leaving vehicle shall disconnect the platooning specific communication.

Note: a vehicle leaving the platoon always becomes a standalone vehicle.

PSF_Interaction_of_the_trucks_007: During a disengagement procedure of the first following vehicle, when the first following vehicle is ready to disconnect the communication with the ego vehicle, the platoon system of the ego vehicle shall receive this information.

Note: this requirement is linked to Interaction_of_the_truck_005, as it specifies to send the information.

PSF_Interaction_of_the_trucks_008: If the platoon system of the ego vehicle starts a back split procedure it shall broadcast this information via V2V.

PSF_Interaction_of_the_trucks_009: If the platoon system of the ego vehicle starts a front split procedure it shall broadcast this information via V2V.

PSF_Interaction_of_the_trucks_010: If the V2V connection is lost between two adjacent trucks in the platoon, the detecting truck shall get into a split with the 'lost' partner.

Note: Interaction_of_the_truck_010 is related to two different cases. When the ego vehicle detects a loss of communication with respect to the platooning partner behind, the ego vehicle will trigger a back split. If the ego vehicle detects loss of communication with respect to the platooning partner in front, the ego vehicle starts a front split.

2.4.2 Communication functional module for V2I

Communication with infrastructure helps to facilitate limits in dynamic road allowances based on real-time data (traffic conditions, traffic incidents, weather information etc), provide feedback and redundancy information from the infrastructure (lateral position, weight by axle, inter-distance, weather or road conditions) and to pre-register arriving platoons to RSU's (i.e. when vehicles are not (yet) in V2I range). The overall objective is to receive data from the infrastructure to keep platoons together as much as possible and to keep all vehicles safe (platoons and vehicles surrounding them). The first set of requirements is related to the communication between the platoons and road side units.

Zone policy publication

PSF_Interaction_with_Infrastructure_001: Individual vehicles of the platoon system shall be able to receive communications on policy based on zone (zone policy or geofencing) (described in D2.7 (C. Villette, 2022) and D2.8 (B. Atanassow, 2022a))

The objective is to be able to communicate limitations/advices on driving policies such as maximum speed and minimum gap between vehicles based on real-time data (traffic conditions, traffic incidents, weather information, road conditions). For the Platooning Support Function the platoon will receive information on maximum speed and gap adjustments. This information will be displayed on the HMI (see Section 2.5.1-2.5.2). This will be for example valid for toll zones: in this case, the objective is to get the pre-information by positioning the Road Side Unit (RSU) in advance, to plan properly the reduction of power and avoid close-to-emergency braking in the toll zone.

Zone policy update

PSF_Interaction_with_Infrastructure_002: Individual vehicles of the platoon system shall be able to receive communications to update policy based on zone (zone policy or geo-fencing) (described in D2.7 (C. Villette, 2022) and D2.8 (B. Atanassow, 2022a))

The objective is to ensure that the information communicated via RSU stays up to date (refresh period to be defined).

2.5 Operational Layer modules & Requirements

This section describes the minimum requirements needed for a white-label truck to satisfy, with in vehicle technology implementations, functionalities of a Platooning Support Function level platoon while still leaving room for flexibility and vehicle specific control strategy. The most important goal for the operational layer chapter is to assure comparability of many different technological implementation inside many different vehicle brands. Each vehicle implementation needs to be able to handle all foreseeable events regarding Platooning Support Function modules in a safe way. This above all means to be able to implement an in vehicle efficient networking that can share information with the off-board systems. The platoon should also participate to all off board cooperative communication scenarios as foreseen by C-ITS V2X communication message set, while each vehicle keeps working with all the Platooning Support Function modules in a safe and efficient way. To being able to fulfil the use cases, several requirements have been found that need to be considered by each on board Vehicle systems.

The requirements for the in-vehicle hardware components which are specific for platooning can be grouped into the following categories:

- HMI – the driver interface to the vehicle and the platooning solution
- Longitudinal control consists of sensors, control computation, communication hardware and control actuation components.

The specific requirements for the in-vehicle HMI, the longitudinal control sensors and they will be described below.

2.5.1 HMI logic module

ENSEMBLE aims for multi-brand platooning which means that truck drivers should be able to drive in a platoon regardless truck brand. This requires that the truck OEMs have a common HMI-logic for the main functionalities for platooning, for example how to join, drive in and leave a platoon in a safe and efficient way. The development of a common HMI-logic has been made in several steps. Firstly, the state-of-art in the areas of Human interaction and Vehicle automation has been important to understand the basic Human Factor principles for driver-automated vehicle interaction. Secondly, gained knowledge from other platoon-related projects, such as PATH, SERET, S4P, SARTRE, EPICh-16 has provided with understanding about the challenges, user needs, and about potential solutions associated with driving in platoons. Thirdly, the Human Factors Guidelines for platooning (see Appendix B) were developed to complement the Human Factors recommendations from (Kelsch, J. et al., 2017), and were considered in the development of the common HMI-logic in ENSEMBLE. The methodology and Human factors guidelines for platooning behind the HMI-logic are described in Appendix B. Based on these three steps a first draft of a common HMI-logic was developed following the main functionalities in the use cases and was circulated to the partners in ENSEMBLE for further discussions. The HMI-logic was later thoroughly reviewed in two-day face-to-face workshop with ENSEMBLE partners in the HMI-group. Later on, in the project, after gaining the first insights for the HARA for the originally defined Level A for platooning (Dhurjati, 2019), the first level of platooning was re-discussed and redefined as explained in the introduction of this deliverable. This has also impact on the common HMI-logic specifications and hence, they were revised with respect to the 'new level A' definition (i.e. the Platooning Support Function).

The configuration of the platooning support function is basically a connected ACC (CACC). The platoon system is controlling and synchronizing the accelerations and decelerations of the connected trucks. The drivers are basically driving as they do with ACC, i.e. each driver is responsible of his/her driving and in charge of the tasks on the operational as well as on the tactical layers. Moreover, driving with a platooning support system means that the drivers do not have any specific roles, for example as and lead-, follower-, or trailing driver.

The distances between the trucks will vary as a result of (i) the OEM specific distances and (ii) the drivers' individual choice of distance (the driver can always change the distance to the truck in front). In sum, from a driver's perspective the Platooning support function means no or little difference compared to driving with ACC. The main difference is that the trucks driving with a platooning support function are communicating and reacting simultaneously on decelerations of the connected trucks in front. Therefore, the main benefits with the Platooning support function are synchronized behaviours.

2.5.2 A common HMI-logic linked to use cases and HMI-requirements

The purpose of the common HMI-logic is to provide a structure for coherent interactions between the driver and the platooning support function and still allow for OEM-specific solutions. The common HMI-logic should function as the "lowest common denominator" for the HMI-design for platooning, regardless truck brand. Moreover, the HMI-logic should follow the established regulations for functions that are part of the platooning system, for example the AEBS function, which is described in Commission Regulation (EU) No 347/2012 (EU347/2012, 2012).

The HMI logic consists of three items:

1. HMI requirements:

   - **HMI_001: The driver should be able to recognize that the ego-truck has a platooning support function.**
   - **HMI_002: The driver can activate the platooning support function at any time. The system determines if and when parameters are met to start connecting other trucks.**
   - **HMI_003: The driver can deactivate the platooning support function at any time.**
   - **HMI_004: The driver shall be informed about gap and speed adjustments of the ego-truck made by the system**
   - **HMI_005: The driver shall be able to manually adjust the gap setting, if a gap adaption is available.**
   - **HMI_006. The driver shall be informed about the ego-truck being the first or the last truck**
   - **HMI_007. The driver shall be informed about the active vehicle control status of the ego-truck**
   - **HMI_008. The driver shall be informed about system failures**
   - **HMI_009: The driver in the platoon shall be warned in case of an imminent platooning emergency braking situation**
   - **HMI_010: The driver be informed on the I2V information**
   - **HMI_011: The driver shall be informed about a cohesion request from a platooning partner behind, if the cohesion functionality is switched on**

2. Driver input (buttons, levers and other driver control devices etc.), and
3. System Output (displays, icons, text messages etc.) in specific use cases (see Table 4).

Table 4 - Overview of the main modules in the common HMI-logic for the Platooning Support Function

Driver Input (to the system)	Description	Related HMI-requirement
Manual lateral control	The driver is in lateral control, i.e. steering.	007
Activate system longitudinal control	The driver activates the longitudinal control, which is a prerequisite for platooning.	002
Activate platooning support function	The driver activates the platoon mode which starts the *Platoon Formation process*	002
Deactivate the platooning support	The driver deactivates the platooning support function which ends the wireless connection with the other trucks in the platoon.	003

function		
Gap adjustments	The driver can change the gap to the vehicle in front, if available by the specific implementation.	005
System Output (to the driver)	**Comment**	
Connected to the Platoon	Information about the ego-truck being connected to the platoon.	006 007 010 011
Ego-truck as first or as last truck of the platoon.	Information about ego-truck as being the first or last of the platoon (if neither, the ego-truck is consequently in between), since it has effect on the ego-truck's behaviour and control status. Being the first truck means that the vehicle in front (car or truck) is not a platoon vehicle, Therefore, the ego-truck control status to the vehicle in front is ACC or manual longitudinal control. Moreover, it is the lead truck (driver) that has to react to cohesion requests. As being the last truck additional trucks joining the platooning support system from behind can affect the behaviour of the ego-truck	005 006 011
Vehicle control status	Information to the driver of the control status of the truck: manual longitudinal control, ACC or Platooning support function. For example, when there is a cut-in in front of the ego-truck, the ego-truck goes from Platooning control to ACC control, but it is still connected to the truck(s) as part of the platoon.	007
Gap & speed adjustments	Changes in gaps and speed executed by the system due to, for example cut-ins, accelerations/decelerations, connection procedures.	004 009
Current Platooning support function status	Information to maintain mode and task awareness: ¤ Not connected (ACC) ¤ Connected, in ACC ¤ Connected in platooning control ¤ Connected, no ACC (first truck can drive with manual longitudinal control) ¤ AEBS/Emergency brake	007 008 009
Messages to the driver e.g. • Take over manual longitudinal control • AEBS/Emergency	Information to maintain mode and task awareness, e.g. take over long. control, Warning messages, AEBS/Emergency brake, connectivity. AEBS-information should follow the requirements as described in Commission Regulation (EU) No 347/2012.	008 009 011

brake • Warning messages		

The HMI-logic for platooning support system and the associated HMI-requirements should be regarded as a working document and subject for changes as knowledge and experiences are gained in the field of platooning, Moreover, the HMI-logic does not specify:

- which or what kind of devices, displays, interaction modes etc. for Driver input to the system and for System output to the driver are to be used,
- placement or location of Driver input to the system and System output to the driver, for example buttons, stalks, instrument cluster, secondary displays etc.,
- specific symbols, messages, colour schemes, arrangements of information and messages to the driver.

2.5.3 Platooning support function Use Cases, HMI-requirements and Input/Output

Linked Use Case	Driver input (to the system)	System output (to the driver)
		Truck is specified and equipped for platooning.

PSF_HMI_001: The driver should be able to recognize that the ego-truck has a platooning support function

Linked Use Case	Driver input (to the system)	System output (to the driver)
Platoon formation	• Manual lateral control • Activate platoon mode. Alternatives: 1. Activate ACC, which also activates the platoon mode. 2. Activate Platoon Mode (a button or similar) which also activates the ACC. • The driver can cancel the ego-truck's formation process by deactivating the longitudinal control (ACC and platooning) or with a dedicated button-press for deactivation platooning only.	• Ego-truck V2X status • Platooning available • Platoon mode activated ⟶ System searching for other platoon trucks. • When platoon truck found ⟶ Message; Join platoon • Deactivate platooning, for example a button-press or through the system longitudinal control (ACC) device.

PSF_HMI_002: The driver can activate the Platooning Support Function at any time. The system determines if and when parameters are met to start connecting other trucks.

PSF_HMI_003: The driver in a platoon can deactivate the platooning support function at any time

Linked Use Case	Driver input (to the system)	System output (to the driver)
Join from behind by single vehicle or existing platoon	• Manual lateral control. • Leave: The driver can always cancel the engaging process by pressing, for example a "Leave"-button, or switching the function off.	• Ego-truck V2X status • Platooning engage in process • Platoon set speed • Ego-truck gap adjustments to truck in front (by the system). • Ego-truck Leave, for example a button

PSF_HMI_004: The driver shall be informed about gap and speed adjustments of the ego-truck made by the system

inked Use Case	Driver input (to the system)	System output (to the driver)
Merge in-between by single vehicle in existing platoon.	See UC Join from behind by single vehicle or existing platoon	See UC Join from behind by single vehicle or existing platoon

Linked Use Case	Driver input (to the system)	System output (to the driver)
Steady state platooning	• Manual lateral control • Lead-truck: System longitudinal control (ACC) or manual longitudinal control. • Follow-truck: System longitudinal control (platooning) • Follow-truck: Adjustments of the distance to the vehicle in front.	• Ego-truck vehicle control status • Ego-truck position in the platoon • Ego-truck gap adjustments to truck in front (by the system). • Ego-truck Leave, for example a button

PSF_HMI_005: The driver shall be able to manually adjust the gap setting, if a gap adaption is available.

PSF_HMI_006. The driver shall be informed about the ego-truck being the first or the last truck.

PSF_HMI_007. The driver shall be informed about the active vehicle control status of the ego-truck.

PSF_HMI_008. The driver shall be informed about system failures.

PSF_HMI_009: The driver in the platoon shall be warned in case of an imminent platooning emergency braking situation

PSF_HMI_010: The driver shall get the I2V information.

PSF_HMI_011: The driver shall be informed about a cohesion request from a platooning partner behind, if the cohesion functionality is switched on.

Linked Use Case	Driver input (to the system)	System output (to the driver)
Follow braking target	See Use Case Steady state platooning	See Use Case Steady state platooning • Information about the on-going process. • Information to driver if necessary, to take manual longitudinal control.

Linked Use Case	Driver input (to the system)	System output (to the driver)
Emergency braking	See Use Case Steady state platooning •In case of false emergency braking the driver can overrule.	See Use Case Steady state platooning • Alert the driver about the Emergency braking.

PSF_HMI_009

Linked Use Case	Driver input (to the system)	System output (to the driver)
Platoon gap adaptation because of I2V interaction	See Use Case Steady state platooning	See Use Case Steady state platooning • Information to the driver about the requested gap from 'infrastructure'

PSF_HMI_004

Linked Use Case	Driver input (to the system)	System output (to the driver)
Warning because of system status (e.g. packet loss)	See Use Case Steady state platooning	See Use Case Steady state platooning • Information about the system status, e.g. Loss of V2X • Information to driver if necessary, to take manual longitudinal control.

PSF_HMI_004

PSF_HMI_007

2.5.4 Longitudinal Control module

This subsection describes the minimum requirements needed for safe and fuel-efficient longitudinal control in the platooning support function while still leaving room for flexibility and vehicle specific control strategies. The most important goal for the longitudinal control of the platoon vehicles in is to assure safety. The system needs to support the driver with longitudinal control in a safe way. This above all means to be able to support the driver to prevent a collision with the preceding vehicle in the platoon. The platoon should also not disturb or cause safety issues for trailing traffic. Additionally, the platoon needs functionality to keep the platoon together if desired.

To being able to fulfil the use cases, several functionalities regarding longitudinal control have been addressed. See Table 5 for connection between use cases and needed functionalities. Requirements for the functionalities are described in the subsequent subsections.

Table 5 - Longitudinal control functionalities and use cases mapping

Functionality	Functionality description	Linked Use Case
Time gap selection	Requirements for how the minimum inter vehicle time gap is selected	Steady state platooning Cut in (long/short time) Platoon time gap adaptation because of system status (e.g. packet loss)
Braking	Requirements for safely handling braking in the platoon	Steady state platooning Follow to stop (&go) Emergency braking
Time gap increase	Requirements for how to increase the inter vehicle time gap in a safe way	Steady state platooning Platoon gap adaptation because of I2V interaction Platoon time gap adaptation because of system status (e.g. packet loss) Leaving platoon Split platoon
Platoon cohesion	Requirements for how to close gaps and keep the platoon together	Join from behind by single vehicle/Merge from behind by existing platoon Steady state platooning Platoon gap adaptation because of I2V interaction Cut in (short time) Platoon time gap adaptation because of system status (e.g. packet loss)

Time gap selection

The definition of time gap and other related terminology is provided in Figure 5, a). The difference between the target time gap, selected by the driver, and the (dynamic) time gap realised by the system is depicted in b).

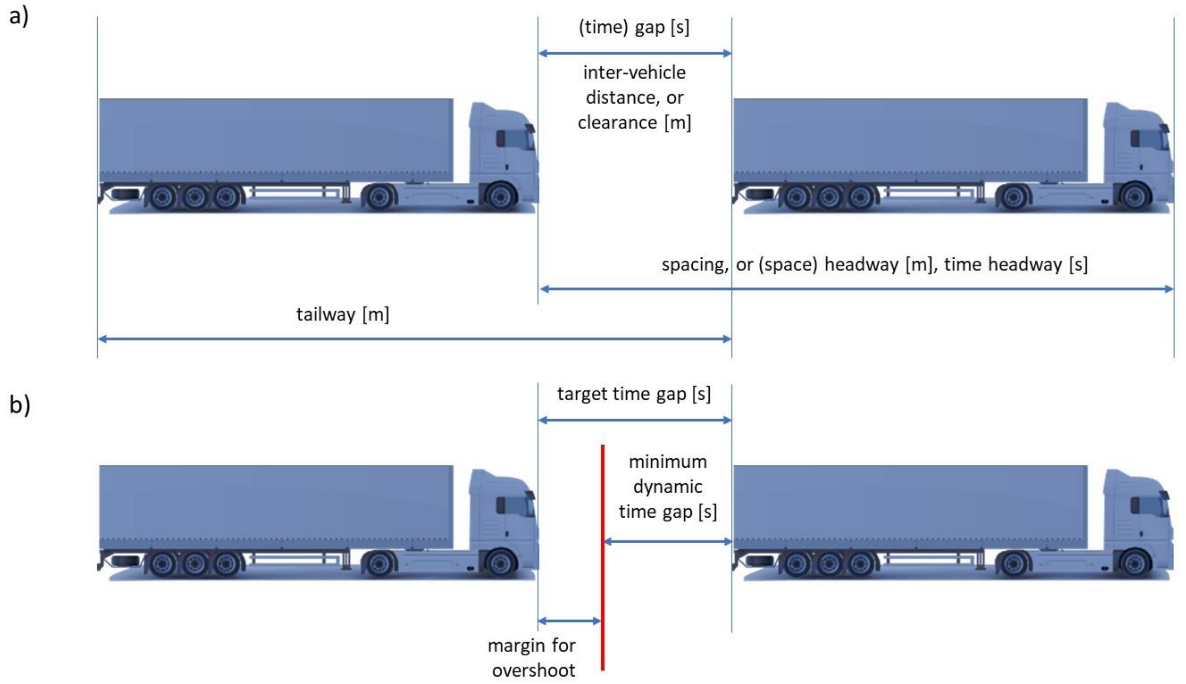

Figure 5: a) Terminology and b) relation target and dynamic time gaps.

To be able to always avoid collisions within the platoon, safe time gaps need to be kept between the vehicles.

PSF_Long_Control_001: The driver shall be able to select a target time gap to the preceding vehicle.

Target time gaps of the PSF are defined in the respective level definition in D2.3 (Willemsen, 2022). These time gaps are similar to the ACC ones (between 1.4 s and 1.6 s).

PSF_Long_Control_002: The system shall never keep a closer time gap than 0.8 s to the preceding vehicle in the platoon.

PSF_Long_Control_003: During steady state platooning, the system shall keep the selected time gap without amplifying disturbances (e.g. velocity variations) in the platoon, also known as string stability.

Note: Independently to the target time gap selected by the driver, the control system overshoot is limited to not get closer than the (dynamic) time gap of 0.8 s.

Braking

To be able to safely keep a close distance to the preceding vehicle, the system needs to know in advance how the preceding vehicle is going to brake. It is also important that the braking does not create a worse situation further back in the platoon. The brake function is relying on that requested and actual acceleration that are broadcasted by the truck in front.

PSF_Long_Control_004: The system shall not brake more than needed to keep the selected time gap to the preceding vehicle.

Note: To not amplify brake actions further back in the platoon that can cause an increased hazard for trailing traffic.

The initial braking is limited to decelerations up to –3,5 m/s^2, similar to the ACC ones, to decrease risks related to unnecessary braking. The requested deceleration received from the vehicle ahead should be the value-requested to its own brake system so the risks are not incorrect sensor target related. After warning the driver, similar to AEB cascade, the system may request accelerations higher then, in absolute value, 3,5m/s^2.

PSF_Long_Control_005: The system shall not brake with more than –3.5m/s^2 without a collision warning sequence completed.

PSF_Long_Control_006: A collision warning sequence shall be initiated if the V2x information indicates a risk of collision. If the risk of collision is no longer valid then the sequence is stopped.

PSF_Long_Control_007: OPTIONAL: *If the risk for collision is still present after the warning sequence and validated with at least one additional sensor a harder braking than –3.5m/s^2 shall be requested.*

Time gap increase

Another safety issue to address is the increased inter--vehicle distances in the platoon. When distances are increased simultaneously between several vehicles in the platoon, the trailing vehicle may need to reduce its speed significantly which may disturb trailing traffic, increasing the risk of a collision of the following traffic with the trailing vehicle. and force a subsequent strong acceleration which reduces fuel efficiency. Hence, when the intention is to increase the time gap to the preceding vehicle in the platoon, the system shall be restricted in how to do.

PSF_Long_Control_008: When the intention is to increase the time gap to the preceding vehicle in the platoon the relative speed compared to the lead vehicle shall be maximum 10 km/h and the maximum deceleration shall be 0.5 m/s². The requirement on relative speed does not apply to look ahead functionality (that for example is increasing the time gap before a downhill in order to use a higher rolling speed to close the gap again).

Note: The maximum allowed deceleration requirement is to avoid harsh braking in normal driving for the platoon.

Platoon cohesion

Situations will occur in which the platoon has difficulties keeping together as intended. For example, when a gap was opened between two platoon vehicles (because of an intruder vehicle or platoon gap adaptation), it might not be possible to close the gap when the platoon is traveling at the speed limit. Unintended large gaps may also occur because a platoon vehicle has lower speed or acceleration capabilities than the preceding vehicles in hilly road segments or when the platoon is increasing speed. In such situations, there is a need for functionality to keep the vehicles together in order to keep platooning benefits such as reduced air drag, etc. The necessity of keeping the platoon together depends on the mission of the platoon and is a strategic decision coming from e.g. business logic. For the requirements this means that a required reaction is not stated, because the functionality can be brand specific and the driver may be able to activate/deactivate such cohesion functionality. Only the possibility to communicate a (potential) cohesion issue is specified.

Below the cohesion functionality is summarized in two requirements, where the first requirement is aiming for solving an existing cohesion issue, whereas the second requirement is about avoiding cohesion issues to occur.

PSF_Long_Control_009: The system shall be able to inform the preceding vehicle that it cannot reach the intended time gap i.e. the gap is too large by communicating a desired maximum speed request.

Note: The preceding vehicle can then choose to lower the speed (either automatically by the system or with a recommendation to the driver). In addition, the preceding vehicle can choose to send this request forward in the platoon. In this way, the maximum speed request might eventually be received by the platoon leader. This requirement describes how a cohesion issue can be solved that originates from an already opened gap between two platoon vehicles (because of an intruder vehicle or platoon gap adaptation).

PSF_Long_Control_010: The system shall be able to inform the preceding vehicle about its performance limitations by communicating a desired maximum acceleration request and a desired maximum speed request.

Note:

- *The preceding vehicle can then choose to consider these limitations for its own acceleration and speed (either automatically by the system or with a recommendation to the driver). In addition, the preceding vehicle can choose to send a similar request forward in the platoon, while accounting for its own performance limitations. In this way, the minimum maximum acceleration request and the minimum maximum speed request might eventually be received by the platoon leader.*
- *This requirement describes a method to avoid having cohesion issues introduced in the platoon by the platooning vehicles itself. The aim is to achieve a driving behaviour (acceleration, speed) of the platoon that does not cause vehicles in the platoon reaching their performance limitations. The basic idea is to avoid that vehicles cannot keep up instead of reacting to a too large gap as result of vehicles that cannot keep up.*
- *The maximum acceleration request is the main parameter. It is a positive value and is a real-time prediction of the maximum acceleration capability of the vehicle multiplied with a robustness factor to avoid reaching the performance limitations. It is not the intention to use this parameter for a slowdown request.*
- *Both maximum acceleration and velocity requests are considered to allow the longitudinal control to decide on the acceleration profile to reach the desired velocity. Compare this to a cruise control functionality with a set speed and a desired way to reach the set speed (i.e. acceleration profile).*

2.5.5 Sensing technology module

A state-of-the-art truck already contains countless sensors to assess the vehicle status, the driver status and the environmental status. Modern ADAS sensors are the basis for such valuable functions like automatic emergency brake assistant and lane departure warning, both of which are already mandatory modules in heavy duty trucks in Europe. Positioning sensors are used in numerous systems such as navigation, toll collection and fleet management. Speed and acceleration sensors are used for a wide range of powertrain and braking control algorithms.

The focus of this chapter will be to highlight the sensing requirements which will enable a white label solution to assess the environment and which are specific for platooning. Initially the chapter will describe the environmental sensing tasks/requirements which need to perform for the Platooning Support Function. Subsequently the requirements will be linked to the defined platooning use cases and values will be given to them. By way of disclaimer, this chapter will not recommend a specific technology, the number of sensors or their positions. The topic of sensor fusion is also out of scope as the possible use thereof need to be decided by the OEM partner.

Mandatory

1. It could be argued that the most important environmental data is the distance from a following vehicle to a leading vehicle and the rate of change of this distance. This information is vital to maintain the safe distance between vehicles. It is also highly desirable to detect the position of vehicles in adjacent lanes in to enable early detection of cut-in movement.

2. Geolocation of a vehicle in latitude and longitude helps vehicles which are willing and capable of platooning to find each other. This location is also required to determine the position on a highway and whether the current and upcoming segments of highway are suitable for platooning.
3. The speed and acceleration values shall be available and shared over V2V.

Optional

1. Position of a vehicle with respect to left and right lane markings and rate of change of these distances is very important in case lane keeping of a following vehicle is desired.
2. Detection of vehicles ahead and whether they are in the ego lane or not.

For (1) there are multiple technologies - radar, lidar, camera or V2X. Fundamentally new sensor technology is not expected in the next years. The table below shows suitability of the individual technologies for the tasks in platooning

	Radar	Camera	Lidar	V2X	GPS+
Distance	++	o	++	O	+
Velocity	++	0	++	-	o

Table 6: Sensors suitability for platooning

For (2) there is currently only one viable technology which is satellite based GNSS, something which is sufficiently well known. The only open question is where from where to get this data. The positioning data could also come from a navigation system as well as V2X solution. It is up to the individual manufacturer to define this. The accuracy of the positioning data should be in the range of 1m. The data should be available up to every 0.1s. Those necessities are linked to the Platooning Partner Identification procedure in Section 2.3.3. If the Platooning Partner Identification procedure will be updated during the project, the accuracy and frequency of availability of the positioning data will change. Fundamentally new sensor technology is not expected in the next years. Since this is the case the data required for platooning must be captured with the technology mentioned previously.

The sensors for (3) are already in all state-of-the-art vehicles. Each of these sensors has an output which is usually specific for a vehicle manufacturer or even a vehicle type. Inside a vehicle this is fully acceptable since the characteristics of the output signals are known to the manufacturer. The characteristics of data received by a following vehicle must in some way be standardized, so that there is enough certainty about the quality of the data and thus no ambiguity as to its meaning

The environmental sensing must fulfil certain minimum functionality in the use cases irrespective of technology. Below is a list of sensing requirements which are aligned to the use cases formation, engaging, platooning and disengaging. Several parameters mentioned in the sensing requirements are currently aligned to state-of-the-art adaptive cruise control systems for the Platooning Support Function level. These parameters will change when later moving to the Platooning Autonomous Function level.

PSF_SENS_001: The ego vehicle shall detect preceding vehicles and measure the distance of these with a range and accuracy in accordance with ISO 15622 (ISO, 2018)
PSF_SENS_002: The ego vehicle shall detect its own speed
PSF_SENS_003: The ego vehicle shall be able to detect an emergency brake manoeuvre (deceleration <-4m/s2) of the preceding vehicle in the platoon
PSF_SENS_004: The ego vehicle shall be able to measure its lateral and longitudinal position to an accuracy of 1m with a frequency up to 10Hz.
PSF_SENS_005: The ego vehicle shall detect whether the proceeding vehicle is in the ego path or not in accordance with ISO 15622

3 REFLECTIONS ON SPECIFICATIONS FOR THE PSF AFTER 7-BRAND TESTING

3.1 Introduction

This chapter details the technical lessons learnt from testing the Platooning Support Function (PSF) as specified in:

- D2.3 - V2 “Platooning use cases, scenario definition and platooning levels” (Willemsen, 2022)
- D2.5 – Final version “Functional specification for white-label trucks (operational & tactical layers)” – this deliverable
- D2.8 – V2 “Platooning protocol definition and communication strategy” (B. Atanassow, 2022a)
- D2.9 – “Security framework of platooning” (B. Atanassow, 2022b)

Deliverables D2.6 (Villette, 2018) and D2.7 (C. Villette, 2022) add further details regarding the communication with infrastructures and possible services enabled by I2V.

Deliverable D6.15 (Sjoberg, 2022) details what will be brought into standardization in terms of the platooning protocol and compile all feedback stemming from the implementation work in the ENSEMBLE project. The test sessions performed during the project is tabulated in Table 7.

Table 7 - Test sessions during the ENSEMBLE project

#	Date	Location	Testing partners
1	March 9-12, 2020	AstaZero, Sweden	MAN, Scania, Volvo Group
2	September 14-16, 2020	Helmond, The Netherlands	DAF, Daimler, ZF/Wabco
3	March 23-25, 2021	Aldenhoven, Germany	DAF, IVECO, MAN (communication only)
4	June 14-18, 2021	AstaZero, Sweden	Scania, Volvo Group
5	June 21-25, 2021	Papenburg, Germany	DAF, Daimler, IVECO, MAN
6	July 20-22, 2021	Helmond, The Netherlands	DAF, Daimler
7	August 16-20, 2021	AstaZero, Sweden	Scania, Volvo Group
8	August 23-27, 2021	Jeversen, Germany	Daimler, IVECO
9	September 6-23, 2021	IDIADA, Spain	DAF, Daimler, IVECO, MAN, Scania, Volvo Group

Due to the pandemic situation, the last testing session in Spain was the first time all seven truck brands met to test the platooning support function. This session was also the final testing and demonstration. There have been test sessions between brands geographically co-located, see Table 7. There was a test session planned with all brands before the final event in Spain, but this had to be cancelled due to COVID-19 restrictions on travels, which of course lead to extra time spent on testing and harmonization at the final event.

3.2 V2V protocol

3.2.1 *KeyUpdate* and *PlatoonStatusSharingContainer*

During the final event, there was an inconsistency discovered among the implementations of the protocol defined in Deliverable D2.8. The inconsistency turned out to be when to update the *PlatoonPosition*, and *NumberOfTrucks* in the *PlatoonStatusSharingContainer* which is transmitted in the Platoon Control Message (PCM). This inconsistency, led to two different interpretations on when to update this information:

1. As soon as the information is received through the *KeyUpdate* message when propagated backwards in the platoon. The update of the *PlatoonStatusSharingContainer* is done in the PCMs that are still being sent with the old encryption key (i.e., the group participant key, GPK).
2. The update of the *PlatoonStatusSharingContainer* is done only after switching to the new encryption key (i.e., the group participant key, GPK). The *KeyUpdate* message has reached the last vehicle in the platoon and the last vehicle starts to transmit PCMs with updated *PlatoonStatusSharingContainer*, which is propagated towards the front of the platoon.

When finalizing D2.5 (this deliverable) and D2.8 (B. Atanassow, 2022a), no conclusion had been reached on how to address this, but this will be planned to be solved in standardization see Deliverable D6.15 (Sjoberg, 2022). This issue was solved temporarily at the final event, to facilitate the final successful demonstration of 7-brand platooning and it did not in the end affect the overall PSF.

3.2.2 Pseudonym change

For real-world deployment, the authorization tickets (AT) used for signing and verifying all messages at the networking & transport layer by the *GeoNetworking* protocol will be changed during the driving of a vehicle to preserve privacy. C2C-CC has specified a pseudonym change algorithm based on driven distance and time in the Basic System Profile (BSP) (CAR2CAR, 2018). In the ENSEMBLE project, there was no pseudonym change algorithm implemented. When the AT is changed also the *StationID* will be changed. The platooning protocol needs to be robust to handle these changes.

3.2.3 Acknowledgements

An acknowledge after joining/leaving the platoon may be needed (especially when no encryption is used). This would provide clear information on whether the functionality is active or not during a leave or a join. However, the caveat with acknowledgements is that they might not be successfully received (i.e., corrupted by the channel) and timeouts need in all cases to be present. The addition of acknowledgements can speed up the join/leave procedure and thereby, increase efficiency.

3.2.4 Lifetime of messages

An additional requirement might be needed to ensure consistency of values for lifetime of messages as mentioned in the *GeoNetworking* header.

3.2.5 Timestamps in V2X messages

The signals in the V2X messages contain measurement values from different data sources having different refresh cycle times. For instance, most data from the vehicle CAN have a much shorter refresh cycle than measurements of a GNSS receiver. An additional requirement might be needed to define multiple timestamps separated for groups of signals having similar refresh cycles.

3.2.6 Communication timeout and fail-safe operation

In the communication protocol (B. Atanassow, 2022a) timeouts are defined for the reception of cyclic messages. The PCM has, e.g., a 150 ms timeout. With a cycle time of 50 ms, this means that 3 messages can be missed before the timeout is activated. Hence, missing 2 messages can happen without triggering of a timeout, and thus the information that should have been sent/received through these messages is lost. When then certain information is only sent once, e.g., the *SplitStatus* (containing information such as request for a back split), this can be missed without any warning. Additional requirements may be needed to ensure a fail-safe operation for message losses that do not trigger a timeout. This may, e.g., lead to holding certain values during consecutive message cycles, instead of sending it only once.

3.3 Security

3.3.1 Encryption

Regarding encryption, partners remarked that the protocol should be designed to be clear about the operability with or without encryption. At the moment, the ENSEMBLE Communication Protocol is normally encrypted but can also be used without encryption by filling the encryption keys with dummy values.

On this topic following feedbacks have been received:

- When encryption is an integral part of the V2X protocol, meaning that V2X communication is not working without encryption, it would be beneficial to also specify a consolidated mechanism/approach for testing. For instance, logging of negotiated encryption keys should be required during testing to enable real-time debugging by eavesdropping and decryption of the communication.

- When there is a strict separation of the security layer in the V2X protocol such that encryption can be enabled or disabled without the need for exception handling in the functional layer/logic of the V2X protocol, it might be beneficial to specify an additional message besides the *KeyUpdate* message such that the *KeyUpdate* exclusively contains signals required for encryption and, in case of disabled encryption, can be dropped without any impact on the functional layer.

3.4 Implementation

3.4.1 Using redundant communication channels

In the case of using a redundant communication channel (e.g., each message is sent twice), depending on the timing of transmitter and receiver in handling a *JoinRequest* message the following can happen:

1. As a result of the first message the receiving truck (i.e., that is being joined) creates a new *PlatoonID* and a new encryption key. These *PlatoonID_1* and *PlatoonKey_1* are sent to the joining truck (with the redundant communication) as part of the *JoinResponse* message.
2. Although the receiving truck is then in the platooning state, the second *JoinRequest* message is received and processed and *PlatoonID_2* and *PlatoonKey_2* are created. These values are not sent out by some mechanism but are used internally in the receiving truck.
3. The joining truck will use *PlatoonKey_1* to encrypt the PCMs. This key is known by the receiving truck so the PCMs can be decrypted.
4. The receiving truck, when also being the trailing truck, will then start to use *PlatoonKey_2* to encrypt the PCMs. This key is, however, not known by the joining truck so the PCMs cannot be decrypted anymore.

In general, this can be solved by implementing a message filter. For CAMs and PMMs the *GenerationDeltaTime* field can be used for the detection of the same message. For the PCM, the *SequenceNumber* field can be used for the detection of the same message. The use of redundant transmission should be taken into account, also looking forward towards the Platooning Autonomous Function. Hence, it is important to have the design freedom to choose how many antennas are on the vehicle, and where they are placed. This should include the freedom to have more than one transmitter, to avoid signal attenuation from having to use very long cables to other antennas. Therefore, it is important to support receiving the same message multiple times.

3.5 Further observations for future implementations

Signing and verification appeared to be computationally demanding. PCMs are currently signed, verified and encrypted. Encryption is relatively computationally cheap. It is probably sufficient from a security perspective to only encrypt PCMs and skip the signing and verification or do the signing and verification with a lower rate. It is even questionable to what extend the current solution is scalable with state-of-the-art communication hardware. Some stress testing revealed that 20 Hz PCM communication was affected when having a platoon of 8 trucks using the V2X communication implementations of two OEM partners.

Concerning security, a possible attack vector is identified as a vehicle joining the platoon only to leave directly after. This vehicle will then have the encryption keys and will be able to decrypt all information sent within the platoon for one minute (until the security key is updated). The attacker could then simply repeat the attack pattern again.

4 PLATOONING AUTONOMOUS FUNCTION (PAF)

4.1 Introduction

The Platooning Autonomous Function (PAF) is the second and most advanced platooning level identified in the ENSEMBLE project. It has been defined in D2.3 (Willemsen, 2022), where also the use cases have been identified. This work is based on theoretical considerations. An actual implementation was not validated, as certain autonomous driving pre-requirements are not available today.

In this section of D2.5 for the PAF, an introduction will provide further details on the functionality and its sub-functions, also comparing that with the Platooning Support Function and a stand-alone SAE L4 vehicle.

In the following chapters, the requirements and specifications derived from the use cases are described.

4.2 Approach – Platooning Autonomous Function

The process that defined the Platooning Autonomous Function has been impacted by the COVID-19 pandemic and the partial availability of some partners at the beginning of the pandemic. In order to gather the set of requirements and specifications for the PAF the following steps have been followed, with the purpose to gather and validate the information provided by the WP2 partners, even when temporarily not available.

- Spring 2020 – Definition of the Platooning Autonomous Function (PAF) level (Willemsen, 2022)
- Summer 2020 – Definition of the Use Cases of the PAF (Willemsen, 2022)
- ENSEMBLE GA 2020 (Online – 8/9 October 2020) – Presentation to all WP2 members of the PAF level and first draft of Use Cases
- Autumn 2020 – Review of the Use Cases (Willemsen, 2022)
- Winter 2020/2021 – Approval of the Use Cases (Willemsen, 2022)
- Spring 2021 – First draft of requirements and specifications
- Summer 2021 – Section of D2.5 on PAF drafted
- Autumn 2021 – Review of the entire D2.5 (PSF + PAF)
- Winter 2021 – Final approval of D2.5 (PSF + PAF)

Red squared tables throughout the deliverable are defining a unique Requirement/ Specification.

The format is PAF_yy_00X, where:

- *PAF* identifies that the specification/requirement holds for the Platooning Autonomous Function

- *yy* identifies the domain function of the tactical, operational layer and the communication functional modules (e.g. 'Tactical layer').
- *00X* identifies the number of the requirement within the domain.

PAF_Plan_Dec_001: The system shall generate the desired trajectory to follow the preceding truck in the platoon.

4.3 The Platooning Autonomous Function functionality

In this introduction chapter the PAF functionality and sub-functions are described and compared with the Platooning Support Function (PSF) and a stand-alone SAE L4 (SAEJ3016, 2014) truck. As defined in D2.3 (Willemsen, 2022), the PAF puts itself in the middle between the PSF and a SAE L4 (SAEJ3016, 2014) truck. Being defined as a "follow me" functionality (i.e. having a human driving in the lead vehicle with the other vehicles following it in an autonomous way), this function can be easier and quicker to achieve compared to a full autonomous stand-alone vehicle (SAE L4 (SAEJ3016, 2014)).

In order to further explain the functionality and its sub-functions of the PAF, three diagrams with different level of detail have been drafted, starting from the higher and more general level and after that diving into the details.

The first diagram, see Figure 6, shows the interactions between various layers of the platooning function. This layered structure of the platooning function is common for both the PSF and the PAF and it has been defined as a basis for ENSEMBLE in D2.3 (Willemsen, 2022).

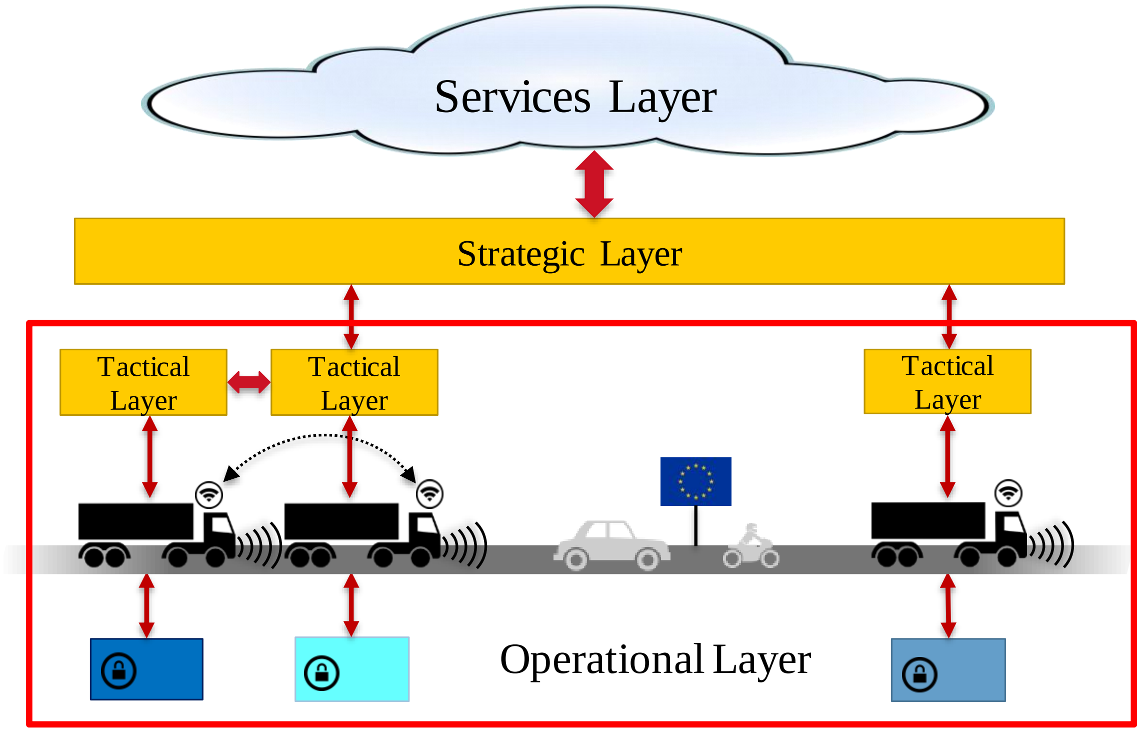

Figure 6 - Platooning Layers

Figure 7 shows the interactions between driver and the vehicle, and between the vehicles using V2V communication for the red square in Figure 6 above.

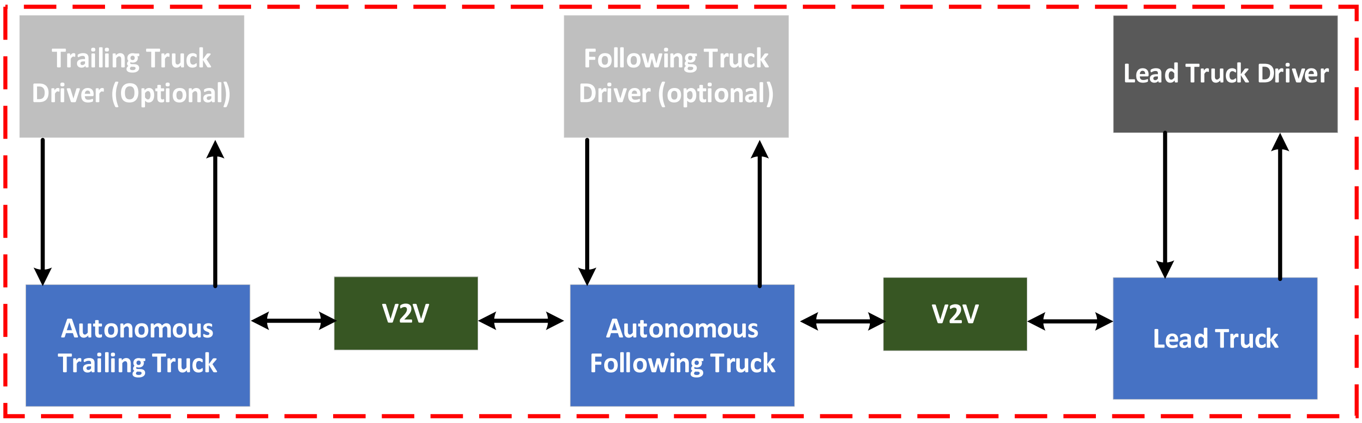

Figure 7 - PAF - Interactions driver/truck and truck/truck in the platoon

The next two diagrams (Figures 8 and 9 that further detail Figure 7 above) focus on the functions implemented at vehicle level. The PAF consists of the lead vehicle, an (optional) following vehicle, and the trailing vehicle. This is because the maximum number of vehicles in the platoon is currently set to three.

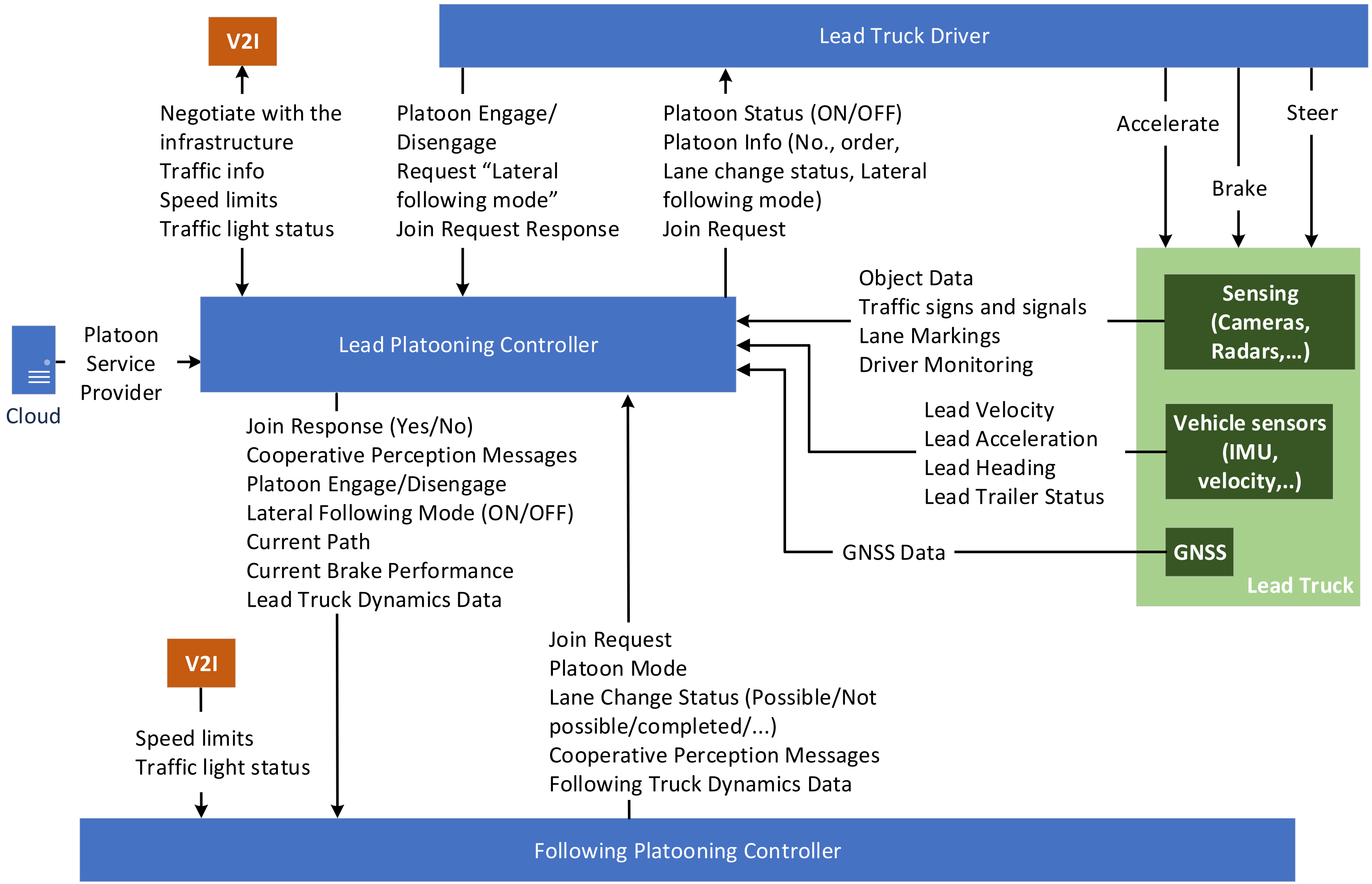

Figure 8 - PAF - Detailed diagram of interactions between driver and system (a)

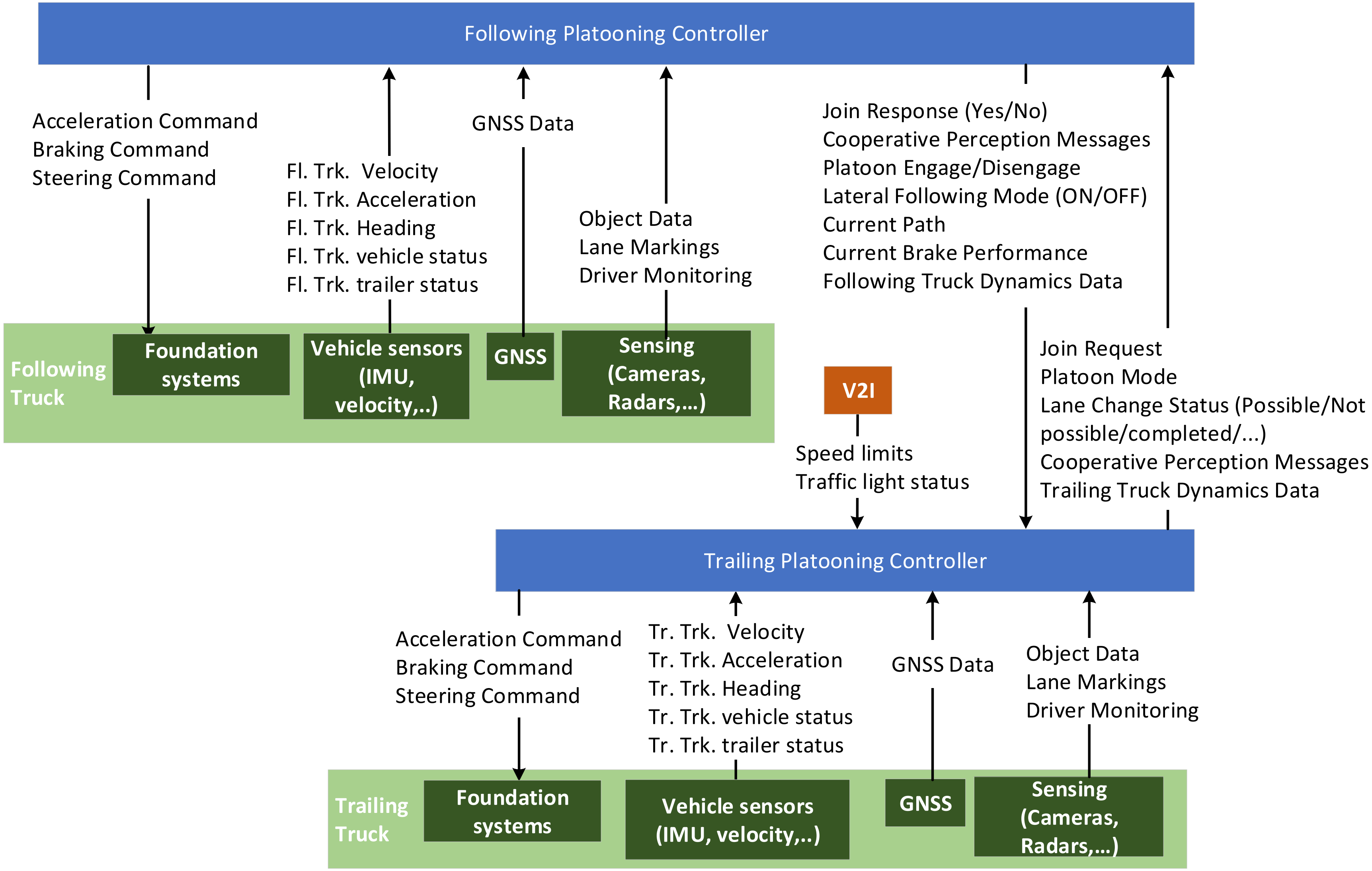

Figure 9 - PAF - Detailed diagram of interactions between driver and system (b) (Fl.Trk.: following truck, Tr.Trk.: trailing truck)

Lead truck driver: The lead truck driver is mandatory and is responsible to guide the entire platoon through the traffic while respecting the traffic rules. The PAF does not automate the dynamic driving task of the lead truck. The leading truck driver can be supported by ADAS systems of this vehicle.

Lead platooning controller: The lead truck platooning controller is responsible for guiding the following trucks to follow the lead vehicle. This is done by sending essential information like current route, platoon status and other vehicle related data like speed, acceleration, etc. via V2V communication.

Following platooning controller: The following truck platooning controller is responsible to autonomously control the truck to follow the route provided by the lead vehicle. Even though the path comes from the forward truck, the following truck is responsible to follow the path safely. Therefore, the task of object and event detection and response solely falls on the following truck. The following truck platooning controller is also responsible to send similar information as received from the lead truck to the trailing truck. Furthermore, information about its own and the platoon status will be shared with the lead platooning controller.

Trailing platooning controller: The trailing platooning controller has the same responsibilities as the following truck controller except that it does not need to transmit route and other vehicle behaviour related information.

Looking again at Figure 7, one vehicle in the platoon can be further detailed, as highlighted in purple in Figure 10 below.

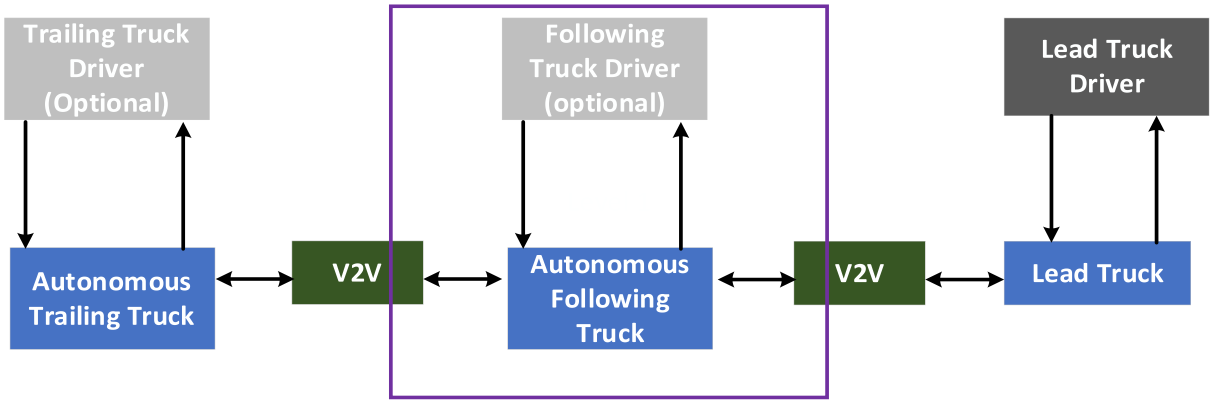

Figure 10 - PAF - Interactions driver/truck and truck/truck in the platoon – focus on following vehicle

Since the main automation of the PAF resides in the following trucks, the third diagram (that further details the purple rectangle in Figure 10, focuses on this (Figure 11 below). The trailing truck has the same features as the following truck; hence it is not repeated.

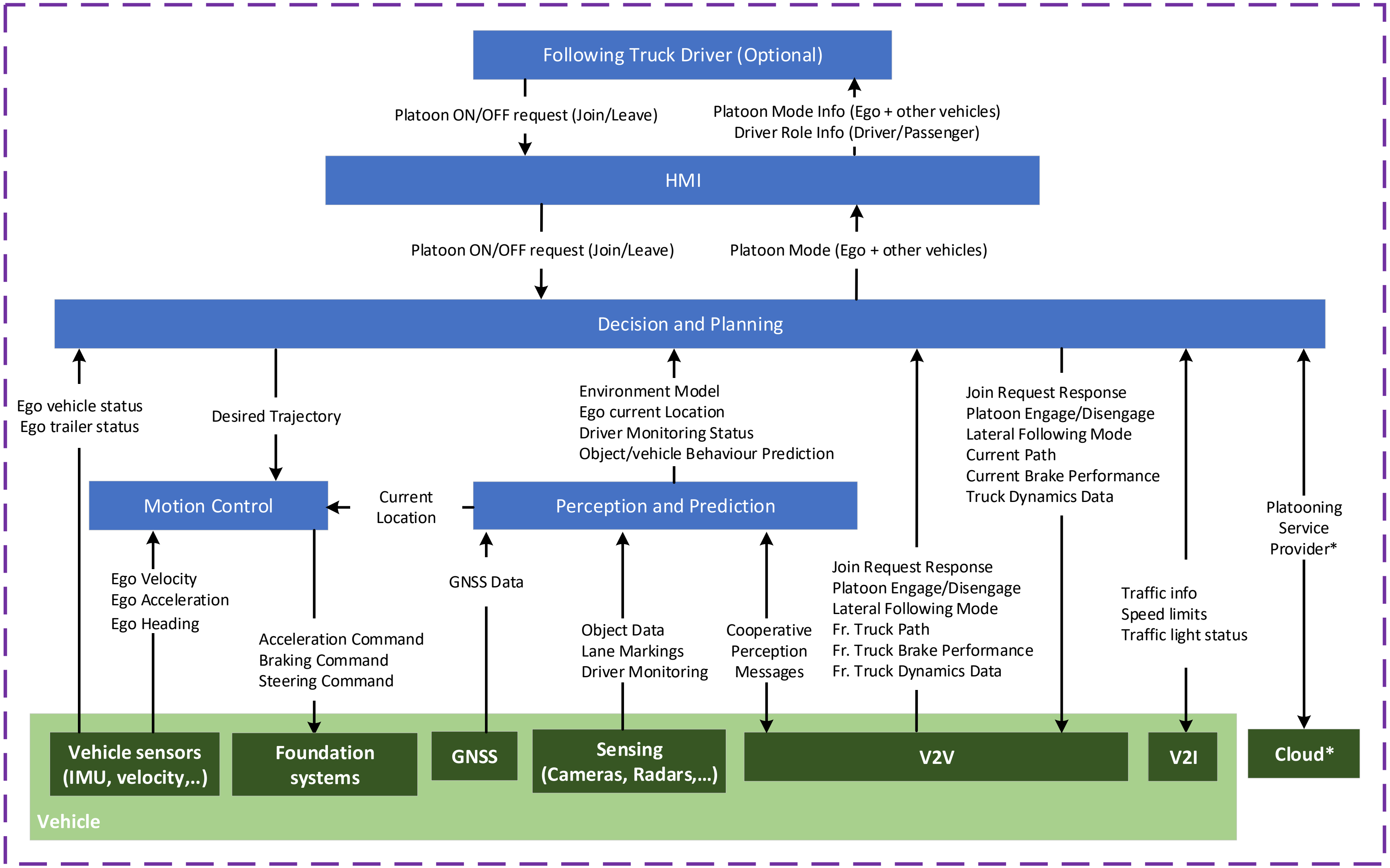

Figure 11 - PAF - Detailed diagram of the following truck functionalities

Below, a description of the various modules in Figure 11 is provided:

Vehicle: The vehicle consists of all the sensors and actuators to drive the vehicle autonomously. This includes foundational systems like the steering, braking and propulsion as well as sensors specific to autonomous driving such as cameras, radars, lidars, GNSS, V2V and V2I modules. The perception sensors are expected to have a 360-degree view of vehicle's surroundings.

Perception and prediction module: The perception module processes the data from the onboard sensors and the data received from the V2V and V2I (optional) modules to extract useful information required to understand the surroundings. This includes subfunctions like localisation, lane detection, objects detection and tracking, free space detection and behaviour prediction (refer to table 8 for the details on each of these sub functions).

This information is used by the decision and planning module and the motion control module.

Decision and planning module: The decision and planning module is responsible for defining the trajectory to be followed by the truck. The trajectory is defined based on the information received from the forward truck, the perception and prediction data from the perception and prediction module and the inputs received from the lead truck function. The trajectory data typically contains a time sequence of waypoints which thus also includes the desired vehicle speed (refer to table 8 for the details on each of these sub functions).

Motion control module: The motion control module sends acceleration, braking and steering commands to the vehicle. Its main task is to ensure that the vehicle follows the path/trajectory provided by the planning module.

HMI module: The HMI module in the following and the trailing truck is mainly used for joining and leaving the platoon. Once platooning is initiated, the HMI provides the status of the platoon to the occupant, if present.

Following truck driver (Optional): Once the platoon is engaged, the driver is merely an occupant in the vehicle with no dynamic driving tasks (DDT) responsibilities. He/She might take back the task of driving by request to leave.

In order to highlight how the PAF is a functionality that, in terms of complexity, stays in the middle between the PSF and a stand-alone SAE L4 (SAEJ3016, 2014) truck, a comparison has been made.

Starting from the PSF, Figure 12 shows the functionality for a following truck, as it has been done in Figure 11 for the PAF.

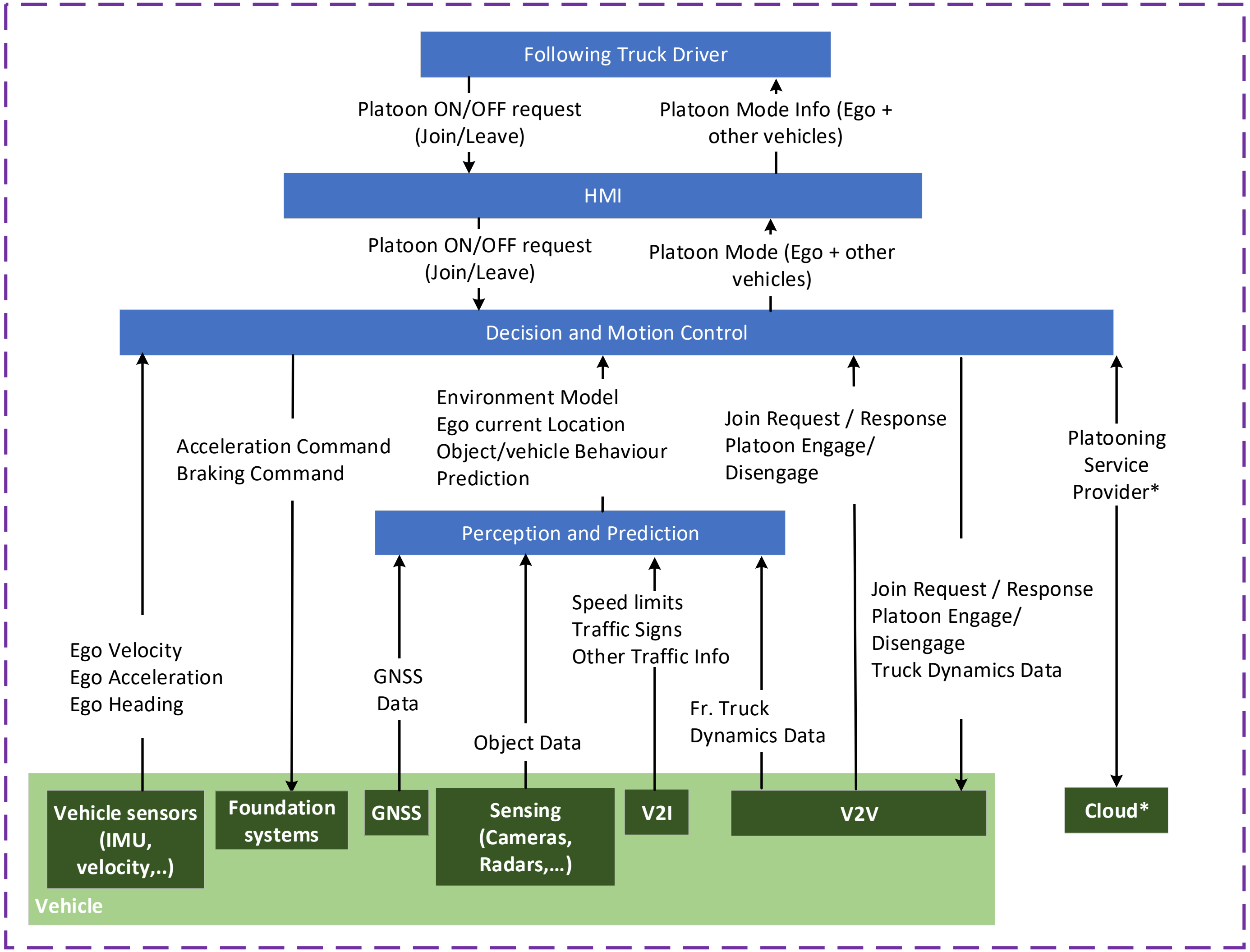

Figure 12 - PSF - Detailed diagram of the following truck functionalities

Below it is possible to find the description of the various modules in Figure 12.

Vehicle: The vehicle consists of all the sensors and actuators to automate the longitudinal control. This includes foundational systems like braking and propulsion as well as sensors specific to ADAS systems like cameras, radars, GNSS, V2V and V2I modules.

Perception and prediction module: The perception module processes the data from the onboard sensors and the data received from the V2V and V2I modules to extract useful information required to understand the surroundings. For the support function this mainly involves objects detection and tracking. This module is mainly required to handle cut-in situations and other situations that arise from actors outside the platoon safely. The perception sensors are expected to have, at least, a view of the scene in front of the vehicle.

Decision and motion control module: This module is responsible to implement the platooning function based on the inputs received from the driver and the forward truck. This includes taking decisions during platoon formation, engaging, platooning and disengaging. Based on the decisions, it sends acceleration and braking commands to the foundational systems in the vehicle and informs the driver of the current status of the platoon through the HMI.

HMI module: The HMI module is mainly used for joining and leaving the platoon and informing the driver about the status of the platooning function.

Following truck driver: Drivers are mandatory in all the vehicles. Since only the longitudinal control is automated, the drivers are responsible for steering in all driving conditions. And, since this is a support function, the driver is the fallback for the Dynamic Driving Tasks (DDT) in all driving conditions.

Finally, Figure 13 shows the diagram of a general SAE L4 function for a stand-alone vehicle.

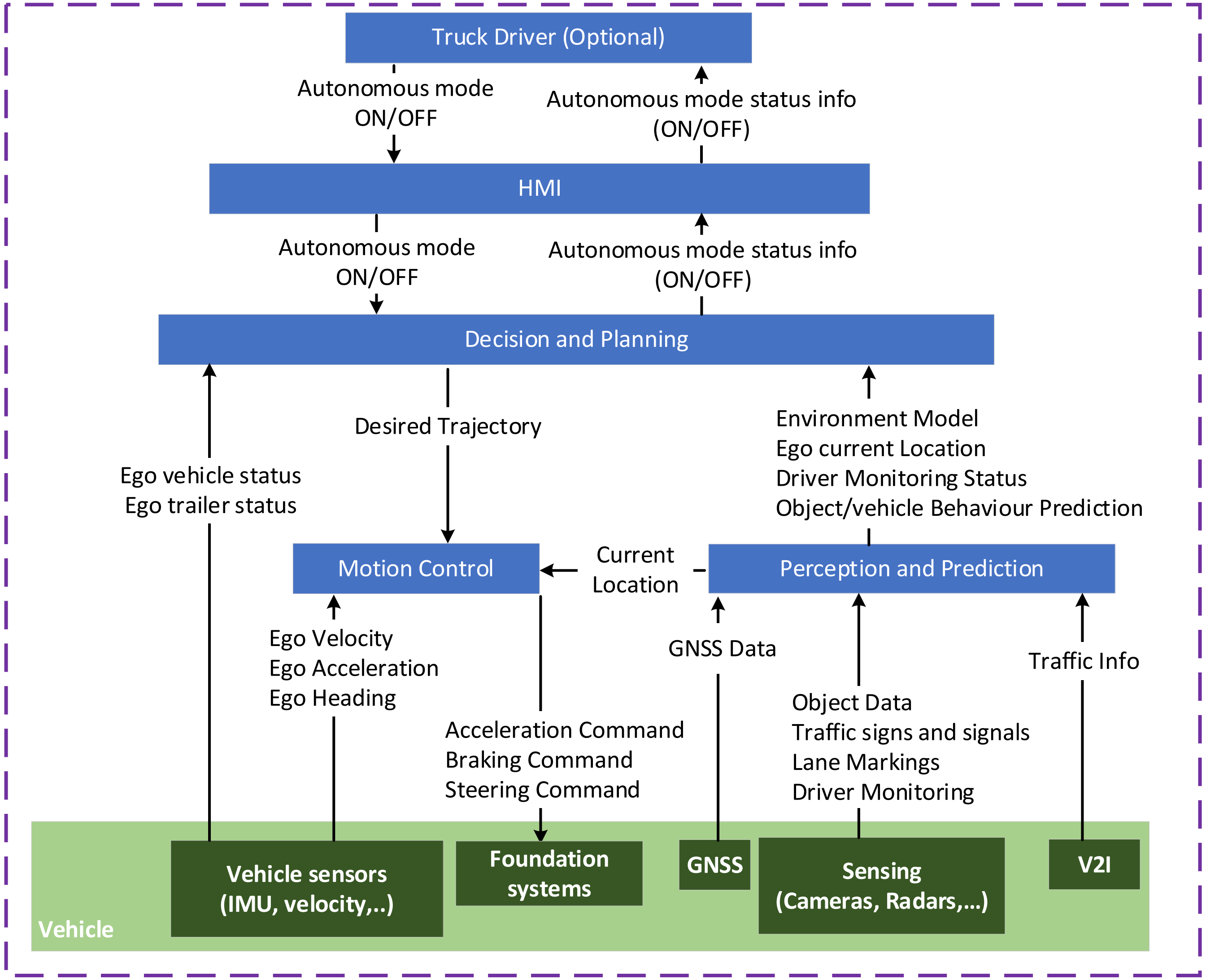

Figure 13 - SAE L4 Standalone Vehicle - Detailed diagram of the following truck functionalities

Unlike the following trucks in the PAF, an independent L4 system cannot depend on following a preceding vehicle (with a human decision maker behind the steering wheel) that exchanges specific information via V2V in a specific way. This requires additions on the Perception and Prediction as well as on the Decision and Planning subfunctions for e.g. path planning, traffic lights detection and classification, traffic signs detection and classification.

Table 8 provides an overview of the various functions, subfunctions and the required complexity:

Table 8 - Comparison between PSF/PAF/SAE L4 Standalone vehicle

Modules	Sub-modules	Description	Platooning Support Function	Following truck Platooning Autonomous Function	Generic L4 Truck
Perception and prediction	Sensors	HW components that gather data about the surroundings (Lidar, radar, camera, GNSS).	X_1	X	X
	Precise localisation	Module to determine the precise location of the vehicle.	0	X	X
	Lane detection	Module that detects lanes on the roads	0	X	X
	Traffic light detection and classification	Module that detects and classifies the traffic lights. V2I communication can also be used to meet this requirement.	0	0	X
	Traffic sign detection and classification	Module that detects and classifies the traffic signs. These include speed limits, special zones, road works, toll gates, speed limits, etc. V2I communication can also be used to meet this requirement.	0	0_1	X
	Object detection and tracking	Module that detects objects on the road like vehicles, VRUs and debris. This module also estimates useful data of the objects of interest like their type, position, velocity, acceleration, etc.	X	X	X
	Free space detection	This module detects the free space available to driver around the ego vehicle. This is used as an input for behaviour planning.	0	X	X

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Modules	Sub-modules	Description	Platooning Support Function	Following truck Platooning Autonomous Function	Generic L4 Truck
	Prediction	Based on the perception data, this module predicts the manoeuvres other objects on the road is most likely to take in the near future.	X	X	X
Decision and planning	Route planning	High level path of the vehicle between two points on a map. This is similar to features found in typical mobile apps or onboard navigation systems in a vehicle.	0	0_2	X
	Behaviour planning	Module that decides which manoeuvre to perform next, taking into account the estimates from prediction. This includes actions like change lanes, stop at a traffic light, exit the highway, etc.	X_2	X_3	X*
	Tactical layer	Module that coordinates the platoon formation, cohesion and dissolution. This is achieved by implementing inter vehicle communication amongst the vehicles of the platoon.	X	X	0_3
	Trajectory planning	Based on the information received from the behaviour planning, this module generates the precise time sequenced path for the vehicle to follow. This path is based on the information received from the behaviour planning module.	0	X	X*

Modules	Sub-modules	Description	Platooning Support Function	Following truck Platooning Autonomous Function	Generic L4 Truck
Motion control	Motion control	The motion control module sends acceleration, braking and steering commands to the vehicle. Its main task is to ensure that the vehicle follows the path/trajectory provided by the planning module.	X[4]	X	X
HMI	HMI	The HMI module in the following and the trailing truck is mainly used for joining and leaving the platoon. Once platooning is initiated, the HMI provides the status of the platoon.	X[5]	X[6]	X

Table 9 - Explanation of Table 8

X_1	The sensors for the support function are limited to the ones required for typical SAE L1/L2 ADAS systems.
X_2	Behaviour planning is limited to maintaining a set time gap to the forward vehicle.
X_3	Behaviour planning need not consider traffic rules as the lead truck is responsible for this.
X_4	Motion control does not include steering. And the deceleration is limited to ACC levels.
X_5	HMI lets the driver take back control of the vehicle and leave the platoon at any point while driving.
X_6	Only the trailing truck is allowed to leave a platoon, if manned
0_1	The lead driver is responsible for the traffic rules for the entire platoon.
0_2	The route is decided by the driver of the lead vehicle
0_3	A generic L4 truck might use V2V communication to exchange information with other vehicles, but is not part of a dedicated platoon
X*	Asterisk indicates functions that are assessed more complex for a generic L4 truck, as it cannot rely on following a trusted preceding vehicle with a human driver.

Following an analysis of the Use Cases in D2.3 (Willemsen, 2022), a list of functionalities linked to the PAF have been identified. These functionalities allow the PAF to fulfil each Use Case in an efficient and safe way. These functionalities have been linked to each module defined above.

Table 10 - PAF - List of Functionalities with link to the Use Cases

Functionality	Functionality description	Linked Use Case
Platooning enabler service subscription [Platooning Service Provider]	Function to match the platooning vehicle according to business logic, up to the fleet owner [topic of project task 4.2]	Platooning formation
Cloud-to-Truck communication	Function to inform the involved platooning vehicles/driver about the new platooning info [topic of project task 4.2]	Platooning formation
Platooning partner identification	Function to identify platooning partners in V2V range	Platooning formation
Platooning info	Convoy correct ordering information to the drivers	Platooning formation
Platooning info	Platooning activation, convoy correct ordering check + join request, join status info	Join a stationary platoon/vehicle from behind at the hub
Platoon joining	Communication among vehicles: stand-still joining	Join a stationary platoon/vehicle from behind at the hub
Cloud-to-Truck communication	Function to report the correct joining to the offboard service	Platooning Formation Join a stationary platoon/vehicle from behind at the hub Join from behind by a

Functionality	Functionality description	Linked Use Case
		manned single vehicle on the highway
Time gap evaluation, selection and sharing	Target Time Gap (TTG) evaluation based on brake distance estimation (that considers perception info); when available, the TTG is shared among the platooning vehicles and visualised on the HMI	Join a stationary platoon/vehicle from behind at the hub Join from behind by a manned single vehicle on the highway Platooning between the hub and the highway Platooning in lane on highway
Platooning info	Platooning activation, partner identification, join request, request acceptance, join status, target time gap	Join from behind by a manned single vehicle on the highway
Gap closing	Function that allows the joining truck to reach the TTG	Join from behind by a manned single vehicle on the highway Cut-in
TTG keeping	Vehicle, using the information available, maintains the TTG	Join from behind by a manned single vehicle on the highway Platooning between the hub and the highway Platooning in lane on highway
Transition of control	Function meant to perform the transition of control from the driver to the system and vice versa	Join from behind by a manned single vehicle on the highway Leave (while platooning, with a manned trailing truck)
Mission information	Optional info on route to be communicated to the leading vehicle	Platooning between the hub and the highway
Forward vehicle following	Unmanned trucks follow the truck in front, making use of the platoon information (especially from the vehicle in front) and their own sensors	All Platooning use cases like e.g. Lane change triggered by leading/following truck, entering/leaving the highway, road works/construction zone, toll gates, etc.. (see D2.3 section 6.2.3).
VRUs recognition/intention prediction	Function to detect VRUs around the vehicle, optionally highlighting the ones that can produce a risk (multiple sensor information fused) (optional)	Platooning between the hub and the highway Entire platoon starts from standstill Resting area / parking lots

Functionality	Functionality description	Linked Use Case
Manoeuvring	Function that allows to control the vehicle longitudinally and laterally, to be ready to react to unexpected events (e.g. VRUs or obstacles on the road)	Platooning between the hub and the highway Platooning in lane on highway Entire platoon starts from standstill Resting area / parking lots Parking Drop-off at the destination hub
Platooning info	Function to visualise platooning related information	Platooning between the hub and the highway Platooning in lane on highway Entire platoon starts from standstill Resting area/Parking lots Leave (while platooning, with a manned trailing truck)
Driving readiness (unmanned trucks)	Ego vehicle checks the surrounding environment with its own sensors (or with the support of V2X information) and communicates to the leading vehicle if it is ready to move or not.	Entire platoon starts from standstill
Hazardous event mitigation/avoidance	Making use of all the available information, the vehicle evaluates the minimum risk manoeuvre to mitigate/avoid the collision (EB and ES included)	Emergency manoeuvre
Intruder recognition/intention prediction	Making use of the available sensors, the vehicle recognises that an intruder entered or is entering the Platooning driving lane	Cut-in
Safe gap handling	Function to recover a safe distance with respect to a non-platoon vehicle	Cut-in Leave (while platooning, with a manned trailing truck)
Time gap over time evaluation	Function that, evaluates if the system is keeping the TTG within a range	Maintaining Platoon cohesion
Maximum speed capability evaluation	Making use of the available sensors, the vehicle identifies the maximum speed it is able to drive	Maintaining Platoon cohesion
V2V speed application	Leading truck receives the requested cohesion speed and automatically applies it when it is below its own set speed	Maintaining Platoon cohesion
Lane change evaluation (following vehicles)	Making use of all the available information, the following trucks evaluate the possibility to make a lane change	Lane change triggered by Leading truck Lane change triggered by Following truck

Functionality	Functionality description	Linked Use Case
Lane change information (Leading vehicle)	Display the readiness of the following trucks and that they have changed lanes to the driver(s)	Lane change triggered by Leading truck
Lane change request	Follower truck requests to change lane to the Leading truck driver.	Lane change triggered by Following truck
Lane change information (Followers)	Display lane change request of follower truck and offer possibility to accept/deny.	Lane change triggered by Following truck
Lane merge evaluation (following vehicles)	Making use of all the available information, the following trucks evaluate the possibility to negotiate a lane merge	Lane merge
Lane merge information	Display the readiness of the following trucks to negotiate a lane merge driver(s)	Lane merge
Traffic signs identification and application [optional]	Function that identifies the road prescription in the vehicle area and applies them	Traffic signs handling
Road works identification	Function that identifies when the vehicle enters and leaves the road works area	Road Works/Construction zone
Road works triggering	Function that allows the lead vehicle’s driver to activate or deactivate "Lateral Following" mode	Road Works/Construction zone
Toll gates zone identification	Function that identifies when the vehicle enters and leaves the toll gates area	Toll gates
Toll gates zone triggering	Function that allows the lead vehicle’s driver to activate or deactivate "Lateral Following" mode	Toll gates
Platooning vehicle lateral following	Function that allows the system to follow the vehicle in front without using the lane markers	Road works/construction zone Toll gates Roundabouts (with intelligent traffic lights)
Roundabout identification	Function that identifies when the vehicle is approaching a roundabout with an intelligent traffic light	Roundabouts (with intelligent traffic lights)
Roundabout communication	Function that negotiates with intelligent traffic lights	Roundabouts (with intelligent traffic lights)
Standby mode	Function that puts the platooning on hold.	Parking Drop-off area at the destination hub
Border crossing identification	Function that allows the vehicle to identify the country in which it is driving	Border crossing
Traffic light identification	Function that identifies when the vehicle is approaching an intelligent traffic light	Traffic light on highway Traffic light on intersection Roundabouts (with intelligent traffic lights)

Functionality	Functionality description	Linked Use Case
Traffic light communication	Function that negotiates with intelligent traffic lights	Traffic light on highway Traffic light on intersection Roundabouts (with intelligent traffic lights)
Trigger a leave by the driver	Function that allows the driver to deactivate the platooning functionality	Drop-off area at the destination hub
Trigger leave by the driver (following vehicle)	Function that allows the driver to deactivate the platooning functionality	Leave (while platooning, with a manned trailing truck)

For each functionality, and linked use case, a list of requirements and specifications have been derived.

4.4 Decision and Planning – Motion Control modules

This subsection describes the minimum requirements needed for safe and fuel-efficient vehicle control in the platooning autonomous function while still leaving room for flexibility and vehicle/OEM specific control strategies.

The most important goals for the Platooning Autonomous Function driving platform are to assure that the transported goods reach the destination hub in the most safe and efficient way, considering fuel saving and driver cost that is strictly linked to the function. The Platooning Autonomous Function driving platform includes Decision and Planning and the interface with the Motion Controller module (see also Figure 11).

The unmanned vehicles are designed to avoid collisions within the platoon, and to not disturb or cause safety issues for trailing and surrounding traffic. Additionally, the platoon, created at the hub, must ensure the cohesion among its members as much as possible.

In order to allow the vehicle to be part of an Autonomous Platoon, a minimum set of vehicle performances will be defined, e.g. minimum braking capability, sensors, etc. Since this set will mainly depend on the available technology in the next years, this topic is not analysed in this deliverable and it could be subject of future discussion.

4.4.1 Decision and planning module

This subsection describes the minimum requirements needed for this module in the Following and Trailing vehicle.

Platooning vehicle following

To be able to follow the platooning vehicle in front, the following requirements must be fulfilled.

PAF_Plan_Dec_001: The system shall generate the desired trajectory to follow the preceding truck in the platoon.

This desired trajectory will then be sent to the "Motion Control" module to evaluate the needed actions to guide the vehicle along the trajectory.

PAF_Plan_Dec_002 (Optional): The system shall obey the traffic rule(s).

The PAF foresees that the following and trailing trucks can be responsible for traffic rules. This is, however, not mandatory. As a summary two different situations can occur:

- Plan_Dec_002 not implemented – Following and trailing trucks are only responsible for their own safety (leaving the responsibility to obey traffic rules only to the lead truck driver);
- Plan_Dec_002 implemented – Following and trailing trucks are both responsible for respecting traffic rules and their own safety.

PAF_Plan_Dec_003: The system shall maintain a dynamic time gap (avoiding any collision within the platoon) with respect to the vehicle in front.

The need of maintaining the Target Time Gap (TTG) is the results of several possible evaluations based on safety, fuel efficiency and business requirements.

Concerning the "Safety", the TTG value is evaluated taking into account the estimated braking performance calculated by a Brake Performance Estimator module. This represents the minimum time gap to be kept to avoid collisions within the platoon. The TTG is usually kept constant (longitudinally) and the vehicles are aligned (laterally) to optimise efficiency. The higher fuel efficiency is then realised by aerodynamic drag reduction. This effect increases when reducing the gap between the trucks. Finally, as for business requirements, maintaining the TTG as much as possible allows the trucks to respect the mission and to keep the platoon coherent.

PAF_Plan_Dec_004: The system shall generate the desired trajectory, considering the need to maintain a certain lateral displacement within a range, during in-lane driving on straight highway with respect to the platoon member in front.

Keeping a lateral displacement within a certain range will help the platoon to save fuel thanks to beneficial air flow around the truck.

PAF_Plan_Dec_005: The system shall generate the desired trajectory to be followed to stay inside the target lane, unless a situation requires otherwise, e.g. during a lane change/merge, safety related manoeuvres or the absence of lane information.

The need of keeping the lane is the basic strategy in lateral control, mainly to avoid attenuation of lateral tracking errors. However, manoeuvres and the absence of lane information require other strategies.

Braking performance estimation and Target Time Gap calculation

To prevent cut-ins from other cars into the platoon, it could be favourable to have a short inter-vehicle distance in normal driving and open the gap for different situations like short on-ramps at highway entries. Short gaps between the trucks may also improve efficiency and road capacity. This will be investigated in WP4 of ENSEMBLE.

To be able to *safely* keep a close distance to the preceding vehicle, the system needs to know the maximum braking capabilities of its own and of the preceding vehicle.

Therefore, estimating this property is considered required.

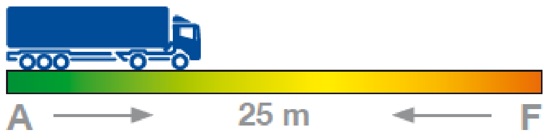
PAF_Plan_Dec_006: The system shall estimate its dynamic braking performance taking into account its state and the prediction of the road conditions ahead.

The dynamic braking performance is used for safety evaluation and to define the TTG to be kept. Currently no sensors or algorithms, that reliably estimate the brake performance, are available.

The Table 11 comprises the most important parameters that influence the brake performance of a truck and, therefore, the minimum distance required to achieve a full stop.

Table 11 - most important parameters that influence the brake performance of a truck

Item	Description	Unit	Parameter dynamic
Brake temperature	Temperature of brake disks and pads. This can cause brake fade (loss of performance due to high temperature).	Celsius	Medium
Wear of pads/disks	Pads/Disks performances are influenced by wear.		Low
Brake pressure gradient	Change of brake pressure with time.	Bar/s	High
Installed brake force	The legal limit for the brake capabilities of a truck are 5 m/s^2. This provides a minimum boundary for the installed brake force. On heavy trucks, the installed brake force might not be sufficient to lock the wheels, which		None

	means that the tyre-road friction is not the only limiting factor.		
Type of tyre	Different types of tyres are available on the market (e.g. summer tyres, winter tyres, 4 seasons). Performance change depending on the type of tyre and related environment where it is supposed to work (weather conditions, temperature, etc.). In the EU, tyre labels are used to classify the wet grip or braking performance on a wet road. A = shortest braking distance and F = longest braking distance; class G will not be used for truck tyres. According to Goodyear (Goodyear, 2015), in case of full braking, the difference between A-class and F-class, means for a typical truck with semi-trailer operating at 40 tonnes Gross Trailer Weight (GTW) driving at 80 km/h, up to 25 m shorter braking distance.  In terms of time gap, this means that already at least 1.2 s are needed to bridge the gap between (new/non-worn) A- and F-class tyres to allow full braking without collision when the truck with F-class tyres needs to react on a full braking preceding truck with A-class tyres on a wet road. In terms of requirements for Autonomous Platooning, this strongly gives rise to reduce the allowed tyre classes, e.g. to only A and/or B, to homogenise vehicle performance.	No Unit	None
Tyre tread wear	Tyre tread wear can change the braking performance, in particular in wet or slippery conditions. In particular, worn tyres can increase the risk of (partial) aquaplaning. Although tread wear is slow, it can result in large performance differences on wet surfaces between seemingly identical vehicles under further identical operating conditions.	mm	Low
Tyre Inflation Pressure	Inflation pressures that are different from the optimal one (higher or lower) affect the performance of the tyre and its optimal wear.	Bar/psi	Low
Tyre Size	Size of the tyre, usually indicates the width, shoulder and dimension.	No Unit	None
Tyre Performance change over lifetime	How the performance is influenced by the age of the tyre (e.g. modifications in the chemical/mechanical properties).	%	Low

Axle loads (including centre of gravity height)	Load on each axle of the truck. This is influenced by the total load and its distribution. Centre of gravity height influences the load transfer during braking.	Tons	None
Brake supply pressure	Trucks use air brakes. Compressed air is stored in the vehicle's supply or "wet" tank and the dual service (primary and secondary) air tanks. It is unsafe to drive a vehicle when the air pressure is outside the normal operating range.	kPa/psi	Medium
Weight	Weight of the truck and total load	Tons	None
Road surface	The type of road surface. Macro and micro roughness of the road surface affect the coefficient of friction between the tyres and the road.		Low – High
Road surface condition	The condition of the road surface comprises e.g. is it dry, damp, wet, icy, snow-covered, etc. and further details like water layer depth, type of snow and ice, etc. Furthermore, contamination of the road surface affects grip, e.g. oil, sand, dust, rubber particles, (wet) leaves, etc. It must also be remarked that the combination of road surface and condition is important, i.e. a wet rough surface has a significant higher friction coefficient than a wet smooth surface. Additionally, the roughness of the road surface also changes with wear.		Medium – High
Tyre and road surface temperatures	Grip is related to the visco-elastic properties of rubber. These are temperature dependent. The temperature of the tyre tread is affected by the ambient temperature, the road surface temperature and the tyre (historical) loading conditions, e.g. slip encountered during braking, cornering.	K	Medium
rolling radius / brake effective radius	These determine the relation between the applied brake moment (Mb) to the wheel and the brake force (Fb) between tyre and road: Mb = Fb * r.	m	Low
Number of braking wheels per axle		-	None
Road slope	Inclination of the road surface with respect to the horizontal line.	Degrees	Low
Other braking contribution	E.g. Internal Combustion Engine contribution, retarder, etc.		None

This can be summarised in five main sources of influencing parameters:

- the braking system(s): these are truck/trailer dependent values.
- brake states: available brake pressure, brake temperature, disk/pad wear. Some of these values may change rather quickly but may also be measurable.
- the tyres: as for the braking system(s), these come with the involved truck/trailer. Many conditions influence the tyre performance: tyre temperature, loading condition, inflation pressure, tyre wear, and typically most of these values only change over time slowly and may also be measurable.
- the road/weather conditions: these are external factors that may change very quickly. Mostly these will change for the whole platoon as the vehicles are driving closely together and thus experiencing the same weather/road conditions. However, grip implies contact between tyres and the road. Therefore, different tyres will react differently to changing road/weather conditions.
- total mass of the vehicle and load distribution: this changes each drive but may be measurable.

The tyres and braking system are mentioned above as one of the main sources of influencing parameters. In the text below further information is provided on potential issues and current technologies that can support the Brake Performance Estimation for these parameters.

Brake failure detection to increase safety

The functional safety, according to the ISO 26262 standard, does not take into account mechanical failures, being focused on electronic and software systems, sub-systems and components.

It is assumed that mechanical components are already designed, validated and maintained according to know-how and standards, and thus sufficient and robust.

For these reasons, mechanical failures are not part of the safety analysis carried out in the ENSEMBLE project. However, maintenance can’t be guaranteed and disc wear may lead to failure, thus creating the need for disc wear monitoring.

When platooning at short distances with loaded trucks, these kind of failures may result in accidents with the worst severity possible. For this reason, increasing the safety of mechanical safety components such as brake rotors is a possible way to improve the overall safety concept even though it is outside the scope of the standard.

Sensors integrated in the rotors to detect cracks at early stages have already been patented and research is ongoing. This kind of device will help to detect possible failure of the component before it really occurs and to safely trigger earlier maintenance or a limp-home mode to maintenance centers avoiding possible accidents.

Fade detection

The braking performance, defined as the maximum deceleration that the braking system can develop, when the road adherence is not the limiting factor, may be limited by the pad friction coefficient in a phenomenon called “fade” or “fading”. Then the pad friction coefficient drops due to disc and pad overheating. When this occurs, the pressure must increase to ensure the requested level of deceleration is reached; when the maximum pressure is reached before reaching this deceleration, the braking capability (in terms of deceleration) is limited.

This performance characteristic is highly affected by the temperature reached by the pads, which in turn is, a.o., a function of the ventilation of the braking system. The aerodynamic flow around the truck due to platooning (good for fuel consumption) may result in a lower ventilation for the following vehicles, increasing discs and pads temperatures and worsening braking performances.

Physical models may be implemented in feed-forward to understand if the mission is too critical and the risk of fading is real. These models shall take into account:

- Braking system sizing
- Brake events history
- Vehicle load
- Road slope
- Platooning information (role in the platoon, number of vehicles, distance)
- Ambient temperature

This monitoring can also be done as a feedback, by comparing the deceleration developed with the braking pressure, the latter increasing above standard levels when the fading condition is beginning.

Finally, precise measurement of pads or discs temperature can be acquired through dedicated sensors.

Information from control systems like ABS and traction control

The essence of the underlying friction estimation problem is to detect the maximum tyre-road friction, while not using it. Estimating the tyre-road friction when it is used is rather straight-forward and is done in state-of-the-art ABS and traction control systems. However, when the friction potential is fully used, it means that the vehicle is already performing the emergency braking and further control is not available anymore, i.e. the vehicle cannot brake harder when it concludes it should to avoid a collision. Nevertheless, information of ABS and traction control systems can be shared via V2X with other vehicles to warn/inform these about friction conditions. Note that especially in winter conditions, the maximum friction potential is often reached in “normal” driving conditions.

Apart from estimating the maximum friction, ABS wheel speed sensor information is also often used in an attempt to estimate friction at low slip levels (i.e. yet far from the slip level associated with the maximum friction level). Reliability of these methods is, however, low as typically slip stiffness is estimated instead of friction and the correlation between slip stiffness and friction is not yet fully understood.

Smart tyres

The latest developments in tyre technology integrate sensors to supply useful information to the vehicle. This information is related to the tyre type, inflation pressure, temperature and more. Furthermore, as described for the brake failure sensors, the wear or even a puncture of a tyre can be monitored to trigger earlier maintenance or limp-home modes, increasing overall platoon and road safety.

More advanced solutions for passenger cars can even detect the aquaplaning condition and interact with the control systems to keep the vehicle stable. Also this kind of information can be used by the platoon to warn and adjust the distance between the trucks accordingly.

Optical sensors

Also, optical sensors have been developed to real-time monitor road surface conditions. These sensors are typically used on both the infrastructure (e.g. at bridges, masts) and on special measuring vehicles of e.g. road operators. These optical sensors can measure the road condition (e.g. dry, wet, snow, ice, etc.), road surface and ambient temperatures, water film height, etc. and provide an estimate of the road friction. Such sensors could be part of the (digital) road infrastructure to inform vehicles via I2V about the road condition or developed into products that can be part of autonomous vehicles.

Sensor fusion and V2X

Although it is stated above that currently no sensors or algorithms, that reliably estimate the brake performance, are available, sensor fusion and data sharing (of maybe less reliable information) might improve future reliability. Nevertheless, the fundamental physical problem remains that each vehicle-tyre-road combination has a unique maximum friction.

Brake distance calculation

To give the reader an indication of how much the braking distance D may vary, only influenced by road friction, the following very basic equation is applied:

$$D = \frac{V^2}{2\mu g}$$

Where:

D = the braking distance in meters
g = constant of gravity
μ = tyre-road friction coefficient
V = vehicle initial speed in meters per second

Assuming a constant μ for a vehicle during braking, this equation is used to illustrate the effect of road condition (friction coefficient) on the braking distance in Table 12.

Table 12 - Examples of effect of road friction on braking distances

Type of condition	Typical friction coefficient [-]	Typical braking distance [m] from 80 km/h
Dry, bare surface	0.8 – 1.0	25.2 – 31.5
Wet, bare surface	0.7 – 0.8	31.5 – 36.0
Packed snow	0.20 – 0.30	83.9 – 125.8
Loose snow / slush	0.20 – 0.50	50.3 – 125.8
Black ice	0.15 – 0.30	83.9 – 167.8
Loose snow on black ice Wet black ice	0.15 – 0.25 0.05 – 0.10	100.7 – 167.8 251.7 – 503.4

Notes:

- As mentioned above friction coefficients vary with many factors, so the reported values in the table are just examples.
- Actual friction coefficients for truck tyres might be lower due to different rubber compounds.
- Wet grip may significantly vary with the road surface roughness and water layer depth. Friction coefficients could drop to 0.2 e.g. on a polished concrete surface with 2 mm water layer. In that case similar friction coefficients as on snow are reached.
- Obviously, the speed of 80 km/h is generally (too) high for winter conditions, as sudden situations could occur, e.g. sudden black ice.

Finally, in order to give to the reader an example of how the coefficient of friction is influenced by weather, in Figure 14 it is shown how these parameters change in the event of rain.

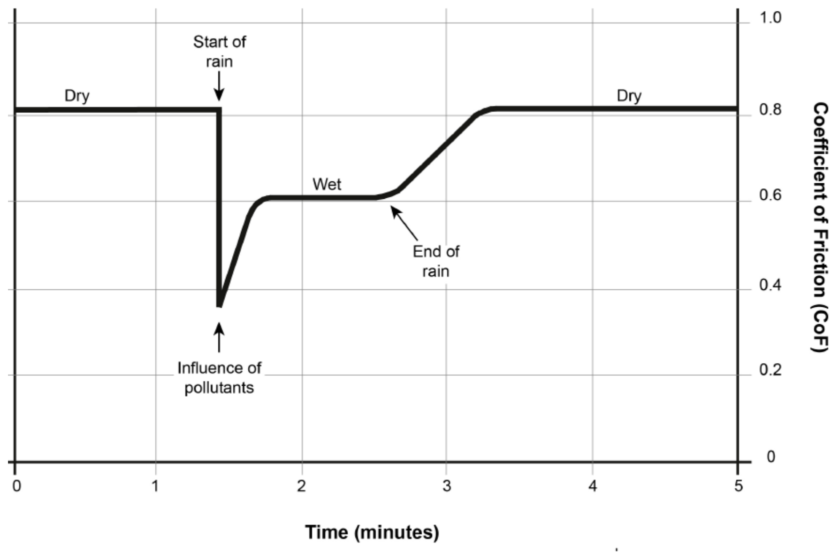


Figure 14 - Variation of the coefficient of friction versus time at a fixed location.

Once the braking performance has been calculated by Plan_Dec_006, it is then required to evaluate the correspondent time gap to ensure a safe and efficient platooning also being able to manage potential emergency braking situations.

PAF_Plan_Dec_007: Making use of the dynamic braking performance estimation information, the system shall evaluate the target time gap (TTG) with respect to the preceding platooning partner to be kept to safely drive in the platoon.

This evaluation of the TTG is done by taking into account the braking performances of the EGO vehicle and the vehicle in front.

In order to give to the reader an idea of the possible time gaps that the system can allow for safe and efficient platooning, a series of simulations have been made. These simulations are run through a script that plots the movement of vehicles in each scenario. As an example, a situation with dry road has been taken into account. In this case, the forward truck (Fw truck acc) has estimated its braking performance to have a value of –8 m/s² (requirement Plan_Dec_006). This is generally understood as the maximum braking performance of a truck. Simulations have then be made taking into account a potential estimated braking performance for the ego vehicle (EGO truck acc – in green) between –8 m/s² (maximum performance) and -1 m/s². It must be noted that –5 m/s² is the minimum performance legally allowed during a brake test inspection (under high-friction conditions; on a static brake testing machine or road test under dry conditions on a flat, straight road), see DIRECTIVE 2009/40/EC (2009/40/EC, 2009) on roadworthiness tests for motor vehicles and their trailers. Consequently, it might be expected that under 'normal' conditions –5 m/s² can be realised.

Note with regard to DIRECTIVE 2009/40/EC (2009/40/EC, 2009)*:*

The brake efficiency (z) must be at least 50 %, meaning that the total brake force between the vehicle's tyres and the road ($\sum F_b$) must be at least 50 % of the maximum allowed vehicle weight. This can be translated in a deceleration by the equation: $a_x = -\frac{\sum F_b}{m_{max}} = -\frac{z \cdot g}{100} \approx -5$ *m/s², where g is the constant of gravity and m_{max} the maximum allowed vehicle mass.*

Vehicle characteristics like weight distribution, centre of gravity, brake performance etc. are not taken into consideration for the simulation. It is assumed that any vehicle can reach the requested deceleration within 400 ms, this takes into account also 200 ms of V2X communication delay and 400 ms of brake ramp up.

The simulation calculates the changing speeds and distance between the vehicles based on:

- Initial speeds, initial time gap / clearance.
- Changes in accelerations: acceleration applied as exponential ramp-up (~ 400ms to reach the set value)

In the table below the resulting time gap can be found. It covers time gaps between 0.3 s and 1.2 s. Considering the (initial) speed of 90 km/h, this means (initial) clearances between 7.5 m and 30 m. Furthermore, the (final) clearance between the two vehicles when coming to a full stop, has also been included. As it is shown in Table 13, the calculated time gaps always result in (final) clearances between the two trucks of around 1 m and 2.5 m.

Table 13 - Minimum required time gap based on different brake performances of the vehicles under ideal road conditions .

Speeds (km/h)	Fw truck acc (m/s^2)	EGO truck acc (m/s^2)	**Time gap (s)**	Clearance when stopped (m)
90	-8	-8	**0.3**	2.48
90	-8	-7.5	**0.4**	2.37
90	-8	-7	**0.5**	1.9
90	-8	-6.5	**0.6**	0.96
90	-8	-6	**0.8**	1.96
90	-8	-5.5	**1**	2.2
90	-8	-5	**1.2**	1.54
90	-8	-4.5	**1.5**	2.12
90	-8	-4	**1.8**	0.94
90	-8	-3.5	**2.3**	2.28
90	-8	-3	**2.9**	2.4
90	-8	-2.5	**3.7**	1.57
90	-8	-2	**5**	2.82
90	-8	-1.5	**6.9**	1.01
90	-8	-1	**9.2**	1.68

As mentioned before, the braking performance and the corresponding safe time gap are influenced also by external parameters like the condition of the road surface. This means that the platoon needs to adjust the time gap timely in order to avoid situations where the time gap is not correct, considering the current brake performances. In order to do this, it is therefore necessary to predict the condition of the road ahead. To give a further example of how far ahead it is necessary to know the condition of the road Deliverable D2.4 (L. Konstantinopoulou, 2018) provides simulation results regarding the coordinated gap enlargement in the platoon (for the former Platooning Level A). These were the consideration made for the simulations:

- Maximum difference in speed allowed: 3 km/h
- Speed: 80 km/h ≈ 22.86 m/s
- Initial time gap: 0.8 s ≈ 18.29 m at 80 km/h (minimum time gap for the former Platooning Level A)
- Required time gap (after the enlargement): 10 m more ≈ 28.29 m ≈ 1.24 s

In the coordinated way (that means more efficiency), one of the ideas mentioned in D2.4 (figure 6) (L. Konstantinopoulou, 2018) is that the ego vehicle only starts enlarging the gap when the preceding vehicle has finished opening its own gap. In this case, the third truck (imagining a three truck platoon, as defined for the Platooning Autonomous Function) finishes the manoeuvre after around 40 seconds since the start of the gap enlargement. Given the speed of 80 km/h, this means that the entire gap enlargement for a three truck platoon requires around 915 meters. This means that the platoon, for a coordinated gap enlargement from 0.8 s to 1.24 s requires to get the information about a potential change in the road surface condition (that requires such change of time gap) at least 915 meters before.

In conclusion, for the PAF, since the driver is not considered a fallback anymore and the system is responsible for following trucks, it is then possible to achieve time gaps that are lower than the ACC ones defined for the PSF (between 1.4 s and 1.6 s). In order to do this in a safe way, it is required to have a clear understanding of the EGO Truck braking capabilities (Plan_Dec_006) and the corresponding time gap (Plan_Dec_007). In order to estimate the EGO Truck braking capabilities it is not only needed to be aware of the status of the vehicle itself (braking system, tires, load, etc.) but also the status of the road surface and other external conditions. Finally, , there is the need of predicting the conditions of the road ahead within a distance that enables to perform a coordinated gap enlargement to the safe time gap.

Manoeuvring

While driving, the system needs to react to several external and internal inputs. The reaction will not be always the same, but it will be based on the driving speed and on the scenario.

PAF_Plan_Dec_008: In nominal driving conditions, the system shall generate the desired trajectory to ensure a smooth vehicle behaviour.

The main objective of the functionality, in addition to the safety features, is to keep the fuel consumption as low as possible while reaching the destination point.

For this reason, all the manoeuvres done in nominal driving conditions will be designed to be as smooth as possible. This also benefits the passenger's comfort and the traffic flow in the vicinity of the platoon.

PAF_Plan_Dec_009: The system shall generate the desired trajectory to be followed, taking into account the possibility of unexpected events (e.g. VRUs or obstacles on road).

In case of unexpected events the system will give priority to the safety of the VRU(s) and of the vehicle itself, instead of considering the smoothness of the manoeuvre.

Hazardous events mitigation/avoidance

To be able to avoid collisions within the platoon and to react to hazards originating from other traffic, a platooning vehicle could use a so called Minimum Risk Manoeuvre (MRM) to avoid or mitigate further hazards.

PAF_Plan_Dec_010: The system shall identify the events chain or the scenario that could lead to a hazard for the platoon

The system must be able to identify an events chain or a specific scenario that is going to produce a hazard for the platoon. This evaluation is performed using the information available.

PAF_Plan_Dec_011: When an hazardous event is detected, the system shall generate the desired trajectory to perform the minimum risk manoeuvre (MRM) to mitigate/avoid the hazardous events.

The objective is to achieve a minimal risk condition.

Intruder handling

While driving on a highway, it is a common situation to have traffic participants that change lane. The platooning vehicle must be able to handle intruders changing lane into the platoon. Two different kinds of intruders are foreseen: cooperative and standard intruders.

A cooperative intruder is a vehicle that is equipped with a C-ITS system, able to communicate not only its presence on the road, but also its driven path and a prediction of its future trajectory.

A standard intruder, instead, is a traditional vehicle without a local connectivity possibility.

PAF_Plan_Dec_012: Once an intruder has been identified, the system shall generate the desired trajectory for itself to let the intruder enter the gap in front.

With a cooperative intruder, the system can calculate in advance its path since it is receiving predicted trajectory information via V2V and open-up the gap in a smoother way for the platoon and for the surrounding traffic.

With a standard intruder, instead, the system can evaluate the path of the intruder with local sensors only; for this reason, the manoeuvre could result in a more abrupt motion.

The system’s gap opening reaction is according to the intruder dynamic behaviour. When the intruder is, for example, performing a cut-through, the system reaction will not lead to recovering the safe gap with respect to the intruder. In cases in which the intruder will remain in the platoon, instead, the safe gap will be recovered.

Lateral following mode

The “Lateral following mode” is a particular state of the system, triggered by the leading truck driver in specific situations (e.g. at toll gates or roundabouts), in which the system is not using the lane detection as information to generate the trajectory anymore. This allows the following vehicles to strictly follow the behaviour of the leading vehicle, without lane constraints.

PAF_Plan_Dec_013: Once the "Lateral following mode" is enabled, the system shall generate the desired trajectory to follow the Leading truck, making use of V2V and local sensors information only (lane detection disabled).

Traffic lights

Looking into the future, more and more devices will be able to communicate with each other, exchanging relevant information and allowing a “monitoring”. In the transport sector, for example, the highways could use the information coming from “cooperative vehicles” (like platooning vehicles) to inform/warn other traffic participants or other convoys about upcoming situations.

One of the requirements on the infrastructure identified to enable PAF, is to have “smart” traffic lights, that are able to communicate with the convoy, e.g. through a C-ITS station.

In addition to that, an extension of the existing protocols is needed to allow negotiations between the vehicle and the traffic light in order to determine the trajectory to be followed.

PAF_Plan_Dec_014: The system shall generate the desired trajectory, negotiating with the "smart" infrastructure.

Lane change/merge

One of the most relevant situations while driving on road is represented by the platoon that needs to change or merge lane. This can happen for several reasons (e.g. road works with the driving lane closed, highway entry/exit, highway junctions, etc.). The related requirement is similar to the others above, but the decision on how to perform the manoeuvre is detailed more, since different strategies could be applied.

PAF_Plan_Dec_015: The system shall generate the desired trajectory to perform a lane change/merge when requested.

No simulations have been carried out in the project to propose a unique strategy, so the intention is to present some possibilities that do not limit future improvements.

The following strategies have been divided according to the situation: lane merge or lane change.

As for the lane merge, the leading truck driver should wait until the trailing truck acknowledges the manoeuvre, since when the leading truck enters the highway without waiting for the followers, it can happen that the platoon is disassembled due to upcoming other traffic participants. This could lead to a specific requirement to the infrastructure for having enough space in the entrance lane.

As for the lane change, two possible strategies are suggested as examples:

- Leading truck to change lane first – in this way the following trucks can follow the leading vehicle in the manoeuvre, but it could happen that an upcoming vehicle that was not detected cuts in, producing a disturbance that can break the platoon.
- Leading truck to change lane last – in this case, the manoeuvre is started by the trailing vehicle, that creates the space for the others, avoiding potential intruders to enter the platoon. A challenge in this strategy is that, for a certain period of time, the unmanned vehicle is controlling its dynamic behaviour without directly following a preceding platooning vehicle, which increases the risk of platoon break-up.

As already said, additional studies are needed to identify the best strategy to be used according to the situation, that should be a compromise between safety inside and outside the platoon.

Platoon cohesion

Situations will occur in which the platoon has difficulties keeping together as intended. For example, when a gap was opened between two platoon vehicles (because of an intruder vehicle or platoon gap adaptation), it might not be possible to close the gap when the platoon is traveling at the speed limit. Unintended large gaps may also occur because a platoon vehicle has lower speed or acceleration capabilities than the preceding vehicles in hilly road segments or when the platoon is increasing speed. In such situations, there is a need for functionality to keep the vehicles together in order to keep platooning as much as possible (since the unmanned vehicles cannot drive stand-alone) and to maintain benefits such as reduced air drag, etc.

Below, the cohesion functionality is summarized in two requirements, where the first requirement is aiming for solving an existing cohesion issue, whereas the second requirement is about avoiding cohesion issues to occur.

PAF_Plan_Dec_016: The system shall inform the preceding vehicle that it cannot keep the TTG (i.e. the gap with respect to the preceding platoon member is increasing over a threshold or it is already too large) by communicating a desired maximum speed request.

Note: If the preceding vehicle is not the leading vehicle, the request will be forwarded. The leading vehicle can then choose to lower the speed (either automatically by the system or with a recommendation to the driver).

PAF_Plan_Dec_017: The system shall inform the preceding vehicle about its performance limitations by communicating its torque use percentage and a desired maximum speed request.

Note:

- *When the preceding vehicle is not the leading truck, the request will be forwarded.*
- *The leading vehicle can then choose to consider these limitations for its own acceleration and speed (either automatically by the system or with a recommendation to the driver).*
- *The torque percentage is the main parameter. It represents the actual driving performance of the vehicle in driving condition and it is a clear indicator of the actual vehicle capability in continuing accelerating. It is not the intention to use this parameter for a slowdown request.*
- *Both torque percentage and speed requests are considered to allow the "Planning and motion control" module to decide on the trajectory profile to be followed to reach the desired velocity.*

4.4.2 Motion Control module

This subsection describes the minimum requirements needed for the Motion Control module, which logics are OEMs specific, to interact with the "Decision and Planning module", allowing the actuators control in the Platooning Autonomous Function.

The following requirements are meant to define the interface between "Motion Control" and the other modules according to the defined control structure (Figure 11).

PAF_Mot_Con_001: The system shall receive "desired trajectory" evaluated in the "Decision and Planning" module.

PAF_Mot_Con_002: The system shall receive current position information from the "Perception and Prediction" module to localise itself with respect to the desired trajectory.

PAF_Mot_Con_003: The system shall receive ego dynamic information from the local sensors of the vehicle platform.

Once the "Motion Controller" receives the required information, it regulates to follow the desired trajectory.

PAF_Mot_Con_004: Based on the communicated trajectory and vehicle own information (motion+position), the system shall control the *longitudinal* motion through acceleration and/or deceleration actuator interfaces.

PAF_Mot_Con_005: Based on the communicated trajectory and vehicle own information (motion andposition), the system shall control the *lateral* motion using the dedicated interfaces.

4.5 Perception

The purpose of this section is to describe a minimum set of perception functions and the associated minimum perception capability. As for the Platooning Support Function no mention will be made with what means/technology the perception function should be realized. This is the decision of the system developer.

In essence a platoon with driverless following vehicles must act as one vehicle. As such, sensor information must be transmitted to the leading vehicle for this to compile the aggregated sensor view around the platoon to enable any manoeuvre to be performed safely.

PAF_Perception_00: Each vehicle shall receive perception information from other vehicles in the platoon (cooperative perception)

It is vital that each vehicle can establish it precise position / location to an accuracy of 10 cm. In many use cases this information will be transmitted to other vehicles in the platoon enabling functions such as precise following of a leading vehicle's path.

PAF_Perception_01: The vehicle shall be able to determine its longitudinal and lateral position and match this onto a digital map	
ODD/Minimum Capability	10 cm accuracy

The dynamics of a truck change with each mission according to vehicle load, air resistance, and centre of gravity. They need to be known in order obtain a picture of the capabilities of the platoon. This is particularly relevant for platoon cohesion.

PAF_Perception_02: The vehicle shall be able to determine its longitudinal and lateral acceleration capability	
ODD/Minimum Capability	± 59 m/s^2 (aligned to state-of-the-art sensors specifications)

When a vehicle starts motion from standstill or is performing a low-speed manoeuvre it must establish that there are no objects in the vicinity which could cause damage to the vehicle or could be damaged by the vehicle. These objects can be stationary or in motion.

PAF_Perception_03: The vehicle shall be able to determine if a relevant object is in the front or side of the vehicle	
ODD/Minimum Capability	3.7 m front, 4.5 m to the side, 15 m behind (aligned to General Safety Regulation (GSR) specification for Moving Off Information System (MOIS) and Blind Spot Information System (BSIS)

It is important that vehicles shall be able to detect road lane markings in front of the vehicle to enable lane keeping. The field of view shall be such that lane keeping remains possible even when there is a platooning vehicle ahead at close separation which partly obstructs forward looking vision.

PAF_Perception_04: The vehicle shall be able to detect road lane markings of ego and adjacent lanes	
ODD/Minimum Capability	In front of vehicle 50 m range

For a wide range of manoeuvres, e.g. minimum risk manoeuvre, the vehicle must know the boundaries of the road. This also enables the vehicle to establish the boundaries of free space. Boundaries can be given by tunnel walls, guard rails, hard shoulders, pavement boundaries.

PAF_Perception_05: The vehicle shall be able to detect the boundaries of the road e.g., hard shoulder, guard rails…	
ODD/Minimum Capability	In front of vehicle 50 m range

If following trucks in the platoon are also responsible to follow traffic rules, each vehicle must be capable of detecting traffic signals and identifying the phase of the signals. Timely detection shall be possible even if there is a platooning partner directly in front.

PAF_Perception_06 (Optional): The vehicle shall be able to detect traffic lights and the signal phase thereof in time	
ODD/Minimum Capability	In front of vehicle 50 m range

If following trucks in the platoon are also responsible to follow traffic rules, each vehicle must be capable of detection and identify traffic signs to enable the safety of the individual vehicles in all modes. Timely detection shall be possible even if there is platooning partner directly in front.

PAF_Perception _07 (Optional): The vehicle shall be able to detect and identify all relevant traffic signs in time	
ODD/Minimum Capability	In front of vehicle 50 m range All European traffic signs

Forward-looking vehicle detection is a key requirement for platooning. First and foremostly this enables safe distance keeping to the vehicle ahead. Detection of (potential) cut-in vehicles is equally important. The field of view should be so that vehicles in ego lane as well as adjacent lanes are detected.

PAF_Perception_08: The vehicle shall be able to detect the position, category/type, and relative velocity of vehicles ahead of the ego vehicle	
ODD/Minimum Capability	In front of vehicle 100 m range

Lane changing and merging are complex manoeuvres for a platoon. To enable these, it is vital that the platoon has a complete picture of all relevant vehicles in the vicinity of the platoon.

PAF_Perception_09: The vehicle shall be able to detect the position, category, and relative velocity of vehicles in the immediate vicinity of the ego vehicle	
ODD/Minimum Capability	2 neighbouring lanes on either side

Detection of vehicles approaching from behind is mission critical for lane change and lane merge manoeuvres. These manoeuvres must be performed in such a manner that they do not unduly impair oncoming traffic i.e., the vehicle approaching from behind must be able to reduce speed in time and ideally without performing an emergency brake manoeuvre. Longer brake distances due to adverse weather condition must be considered.

To simplify this requirement, it is assumed that there is a speed limit for all vehicles of 130 km/h. Thus, vehicles approaching from behind with higher speeds are excluded as might be the case on Germans Autobahns.

PAF_Perception_10: The vehicle shall be able to detect the position, category, and relative velocity of vehicles approaching from behind the ego vehicle	
ODD/Minimum Capability	Behind the vehicle 200 m

Protection of vulnerable road users (VRU) is of paramount importance. Especially during low speed manoeuvring the vehicles must be able the detect any VRUs in the vicinity of the vehicle. In addition to their position, it is also important to estimate their intended path to be able to predict their future position. The detection range is aligned to the GSR specifications.

PAF_Perception_11: The vehicle shall be able to detect the position, category and relative velocity and estimate intended path of vulnerable road users in the immediate vicinity of the ego vehicle	
ODD/Minimum Capability	3.7 m front, 4.5 m sidewards, 15 m behind (aligned to General Safety Regulation (GSR) specification for Moving Off Information System (MOIS) and Blind Spot Information System (BSIS)

In cases such as a sharp turn or close following in construction sites, it is mandatory that any following trucks exactly follow the path of the preceding truck. Thus, the following trucks must by some means perceive the exact path of the preceding truck.

PAF_Perception_12: The ego vehicle must be able to perceive the path of the preceding truck. For sharp turns this implies that it should be able to perceive the swept path of the preceding truck.	
ODD/Minimum Capability	In front of vehicle

NOTE: The swept path is the envelope swept out by the sides of the vehicle body, or any other part of the structure of the vehicle.

At all times the vehicle needs to be able to detect relevant road infrastructure to be able to act in a correct manner thus enabling vehicle and road use safety. This includes all types of junctions, toll gates, bridges, tunnels, roundabouts etc. Timely detection shall be possible even when there is platooning partner directly in front.

PAF_Perception_13: The vehicle shall be able to detect and identify road infrastructure (toll gates, roundabouts, T-Junctions, etc.)	
ODD/Minimum Capability	In front of vehicle

In most cases it is assumed that following vehicles will be driverless. However, a vehicle with driver can join from behind. To be certain of the actual situation in the cabins, it is required to detect whether there is a person somewhere in the cabin. When a person is detected in the cabin, then the vehicle is not joinable, as described in Use Case Join from Behind by a manned single vehicle on the highway.

PAF_Perception_14: The ego vehicle shall be able to perceive the presence of a human in the cabin.	
ODD/Minimum Capability	Truck cabin

There may be transitions from autonomous driving to manual driving in the following vehicles. This is the case if a driver is present. Before returning to manual mode the vehicle must establish that a driver is present in the driving seat. The only hand over procedure defined in the Platooning Autonomous Function includes the passenger to perform a procedure in the HMI to take back control (and responsibility). For this reason, the requirement is optional.

PAF_Perception_15 (Optional): The vehicle shall be able to determine if a driver is sitting in the driver seat	
ODD/Minimum Capability	Truck cabin

Before transitioning from autonomous to manual driving mode, it is not sufficient to confirm that a driver is in the driver seat. It is equally important to confirm that the driver is awake, attentive, and not distracted. This rules out cases for instance when the driver is sleeping in the driver's seat, a case which is possible in an autonomous vehicle. The only hand over procedure defined in the Platooning Autonomous Function includes the passenger to perform a procedure in the HMI to take back control (and responsibility). For this reason, the requirement is optional.

PAF_Perception_16 (Optional): The ego vehicle shall be able to monitor the status of the humans in the vehicle, if any	
ODD/Minimum Capability	Truck cabin/attentiveness, pose, position

4.6 Tactical Layer

The tactical layer is one of the four layers defined for the hierarchical overall platooning system architecture. The tactical layer coordinates the actual platoon forming, potential partner identification and platoon dissolution. Furthermore, it ensures the autonomous dynamic driving task for following vehicles. This is achieved by gathering and distributing relevant information in the platoon. This information contains platoon status and data, vehicle property information and information about cooperative perception and decision-making.

The Tactical Layer is implemented through the execution of an interaction protocol using V2X communication. In fact, the interaction protocol is implemented by message sequences, initiating the manoeuvres that are necessary to identify a partner, to form a platoon, to perform manoeuvres such as lane changes, or to dissolve it and to share certain information in the platoon.

Platoon status and data information:

The required platoon status & data information is gathered from the strategic & service layer, the HMI (leading vehicle), perception and the safety channels. The following list in Table 14 is retrieved:

Table 14 - platoon status & data information ('platoon item table')

Platoon status item ID	Platoon status item description	Source requirements/specification
PS_001	Platoon creation info	Connectivity (strategic/service layer)
PS_002	Trucks ordering	Connectivity (strategic/service layer)
PS_003	Mission route	Connectivity (strategic/service layer)
PS_004	Number of trucks in the platoon	Connectivity (strategic/service layer)
PS_005	Intruder	Perception, Connectivity (V2X)
PS_006	Driving start readiness	Perception, Motion control (Operational layer)
PS_007	Platoon and Vehicle IDs	Connectivity (strategic/service layer)
PS_008	Platoon set speed	HMI
PS_009	Platoon health status	Safety

The following two requirements are formulated:

PAF_Tactical_Layer_01: The platoon system over the tactical layer will gather platoon status and data information (described but not limited into the platoon item table) and distribute this information over the platoon such that it is shared between all trucks in the platoon.

PAF_Tactical_Layer_02: The platoon system status information gathered by the tactical layer is updated cyclically. The update frequency is related to the priority of the information shared; it can be chosen substantially lower compared to operational control related V2V information.

Vehicle property information:

The four main purposes for the vehicle property collection and sharing are:

1. To share information about the brake performance to allow the following vehicle to maintain a safe time gap.
2. To exchange vehicle performance data to avoid cohesion problems and to report cohesion issues when these arise such that action can be taken by the operation layer.
3. To share relevant truck information between the trucks to enable optimization of e.g. operational modules.
4. To make relevant truck information available to the service & strategic layer.

Table 15 lists the identified vehicle property information.

Table 15 - vehicle property information ('vehicle item table')

Vehicle property ID	Vehicle property item description	Source requirements/specification
VP_001	Braking Performance	Actuators (Braking performance estimation)
VP_002	Cohesion information (e.g. maximum torque, maximum speed, etc.)	Motion control (Operational layer)
VP_003	Ego vehicle information (included in the platooning communication messages set)	Motion control (Operational layer)

The following two requirements are associated with the vehicle property information:

PAF_Tactical_Layer_03: The platoon system over the tactical layer will gather vehicle property information (described but not limited in the vehicle item table) and distribute this information over the platoon.

PAF_Tactical_Layer_04: The platoon system vehicle property information gathered by the tactical layer is updated cyclically. The update frequency is related to the priority of the information shared; it can be chosen substantially lower compared to operational control related V2V information.

Cooperative perception and decision-making information

To ensure the autonomous dynamic driving task for following vehicles the tactical layer gathers and distributes information about cooperative perception. In this way, the perception range of the platooning vehicles is increased and improved. Besides the perception information, information for cooperative decision making is gathered and distributed in the platoon.

Table 16 provides an overview of the identified information.

Table 16 - Cooperative perception and decision-making information

Cooperative ID	Item description	Source requirements/specification
Co_001	Sharing of perceived object information, e.g. other vehicles and VRUs.	Perception, Connectivity (V2X)
Co_002	Sharing of the vehicle's path history.	Perception, Connectivity (V2X)
Co_003	Sharing of perceived road information such as lane markings and boundaries.	Perception, Connectivity (V2X)
Co_004	Sharing of perceived traffic sign information.	Perception, Connectivity (V2X)
Co_005	Sharing of traffic light information.	Perception, Connectivity (V2X)
Co_006	Sharing of zone information, e.g. road works, toll gate area.	Perception, Connectivity (V2X)
Co_007	Platoon creation commands	Decision and planning
Co_008	Lane change status information, e.g. readiness to make a lane change, lane change progress.	Decision and planning
Co_009	Standby mode handling	Decision and planning
Co_010	Leave triggering by driver (leading truck or manned vehicles)	Decision and planning

The following requirement is formulated:

PAF_Tactical_Layer_05: The platoon system over the tactical layer will be able to ensure the autonomous dynamic driving task for following vehicles, gathering information about cooperative perception and decision-making and to distribute this over the platoon with the appropriate update frequency.

Partner identification:

The purpose of this functional module is to identify the correct vehicle to platoon with. The following two requirements are associated with the partner identification.

PAF_Tactical_Layer_07: The system shall be responsible for Partner Identification.

PAF_Tactical_Layer_08: The system shall be able to identify its platooning partner by using the available data from V2X, cloud and its own sensors.

4.7 HMI logic module

ENSEMBLE aims for multi-brand platooning which means that truck drivers should be able to drive in a platoon regardless of truck brand. This requires that the truck OEMs have a common HMI-logic for the main functionalities for platooning, for example how to join, drive in and leave a platoon in a safe and efficient way. Taking into account the experience gathered in the definition of the HMI requirements for the Platooning Support Function, a set of requirements for the Platooning Autonomous Function has been derived.

The main challenge of the HMI module in the Platooning Autonomous Function is related to the leading truck. Being the only one still driven by a human and considered that the platoon should be seen as a single entity, to give the right amount of information in an efficient way is essential. This will be done by a common HMI-logic as for the Platooning Support Function.

The purpose of the common HMI-logic is to provide a structure for coherent interactions between the driver and the Platooning Autonomous Function and still allow for OEM-specific solutions. The common HMI-logic should function as the “lowest common denominator” for the HMI-design for platooning, regardless truck brand.

The common HMI-logic for the Platooning Autonomous Function is specified in an implementation independent way, meaning that requirements will just provide an overview of the task that HMI system shall do without giving details on how this should be performed.

General

Obviously, a platooning function needs to be switched on and off. This is done in the vehicle HMI and leads to the following requirement:

PAF_HMI_01: The platooning function can be switched on/off by driver in the vehicle

Formation

Platoon formation requires that numerous information is provided to the driver to successfully rendezvous with the platooning partners. This includes rendezvous location, platoon destination, timing, schedule flexibility as well as information on the platooning partner. This information can be delivered directly to the vehicle or to a mobile device of the driver. The following requirements are associated with platoon formation.

PAF_HMI_02: The driver can switch on the formation service
PAF_HMI_03: A platooning opportunity is displayed to the driver
PAF_HMI_04: Other platoon partners are visualized to the driver
PAF_HMI_05: Required truck order is visualized to the driver

Engaging/Joining

The HMI is heavily involved when joining a platoon. All drivers, despite of the vehicle specific role, require support in setting up the platoon. The HMI will support as follows:

PAF_HMI_06: The driver can trigger engage function
PAF_HMI_07: The HMI visualizes the result of join procedure in joining vehicle
PAF_HMI_08: The HMI visualizes possible platooning partners in the vicinity
PAF_HMI_09: The driver can select platooning partner
PAF_HMI_10: The HMI visualizes a join request to LV (leading vehicle) driver
PAF_HMI_11: The HMI visualizes join acceptance / rejection to the joining driver
PAF_HMI_12: The LV driver can accept / reject join request
PAF_HMI_13: The HMI visualizes the result of join procedure to LV driver

Platoon Status

The platoon status must always be visible to the driver. Platoon status shall always be visualized in all vehicles while platooning. The status must be presented in such a way that it offers maximum information completeness with minimum effort to perceive and understand the content. The platoon status HMI shall contain the following information:

PAF_HMI_14: On/off status of platooning function
PAF_HMI_15: Role of the vehicle: LV or FV (following vehicle) /TV (trailing vehicle) and whether the vehicle is being controlled
PAF_HMI_16: Indication that an emergency manoeuvre is being executed (may need multiple modalities)
PAF_HMI_17: Lane change status

PAF_HMI_18: Indicate stop of FV/TV due to a pedestrian/obstacle in the vicinity
PAF_HMI_19: Number of vehicles in the platoon
PAF_HMI_20: Weight of each truck in the platoon

Platooning

In addition to displaying platoon status the HMI has further tasks specific to in lane platooning. These are:

PAF_HMI_21: LV driver can set and/or change set speed
PAF_HMI_22: The HMI visualizes 'ready to move or not'
PAF_HMI_23: The HMI visualizes in the FV/TV that cohesion request is ongoing to non-driver

Lane Change/Merge

A lane change/merge represents a significant challenge to the driver of the LV. To safely change lane, the driver requires clear information that a lane change/merge is possible. This is obviously based on perception information, which can be very complicated. The information thus must be presented in such a way that it is clear, concise, and condensed so that it leads to minimal time to comprehend.

PAF_HMI_24: The HMI visualizes the readiness to make lane change/merge to LV driver
PAF_HMI_25: The HMI visualizes the finishing of lane change/merge by all platooning partners to LV driver
PAF_HMI_26: The HMI visualizes lane change/merge request by platooning partner to LV driver
PAF_HMI_27: The LV driver can accept / reject lane change request

Road works

Road works pose a significant challenge to platoons, with their erratic road markings, narrow lanes, and variety of barriers. A special close following manoeuvre is foreseen to help following vehicles manage these critical situations in a safe manner. Hence special HMI requirements arise from this situation. These are as follows:

PAF_HMI_28: The HMI shall visualize upcoming road works
PAF_HMI_29: The HMI shall visualize that all platoon vehicles recognized the upcoming roadworks and switched to 'lateral following mode'
PAF_HMI_30: The LV driver can manually activate 'lateral following mode' in FV/TV
PAF_HMI_31: The HMI shall visualize that all platoon vehicles have left the roadworks
PAF_HMI_32: The HMI shall visualize that all platoon vehicles have switched off 'lateral following mode'
PAF_HMI_33: The LV driver can switch off 'lateral following mode' in FV/TV

Toll Gates

Toll gates pose a similar challenge as road works. Hence there are similar requirements as seen below:

PAF_HMI_34: The HMI shall visualize upcoming toll gates
PAF_HMI_35: The HMI shall visualize that all platoon vehicles recognized the upcoming toll gates and switched to 'lateral following mode'
PAF_HMI_30
PAF_HMI_37: The HMI shall visualize that all platoon vehicles have left the toll gates
PAF_HMI_32
PAF_HMI_33

Parking

The driver of the leading vehicle needs to take caution while parking the vehicle. Vulnerable road user, parked vehicles and other stationary object need to be avoided. The driver requires support from the HMI to aid him/her during the manoeuvre. This is covered in the previous section of this chapter. After parking the system can go into standby mode. This is realized as follows in the HMI:

PAF_HMI_40: The LV driver can switch on and off 'standby mode' in all trucks of the platoon
PAF_HMI_41: The HMI shall visualize that all trucks in the platoon are in 'standby mode'

Others

PAF_HMI_42: The HMI shall visualize traffic sign information

4.8 Communication

The PAF entails new requirements on information exchange compared to the PSF where all vehicles in the platoon contain a driver supervising the system. In PAF, only the first vehicle is driven by a human whereas the follower(s) can be unmanned or have a driver which turns into a passenger, i.e., no supervising task. The communication between vehicles, as clearly shown in the diagrams in section 4.3, is the enabler for the PAF to have unmanned autonomous following trucks. The vehicle-to-vehicle (V2V) module is then a fundamental part of the function. At the same time, the vehicle-to-infrastructure (V2I) module is also important to guarantee the correct exchange of information and negotiation with the infrastructure (e.g. intelligent traffic lights). The identified additional information exchange requirements are described herein. These address information exchange for both the vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications as well as with the offboard service situated on a remote server (cloud) using the vehicle-to-network (V2N) communication capability. The V2V/V2I communication for PSF is detailed in Deliverable 2.8 (B. Atanassow, 2022a).

To describe the interaction between vehicles for the PAF mode, "roles" have been defined. The roles that the ego vehicle can have in the platoon are:

- **Platooning candidate**: a vehicle not platooning with either a forward or backward platooning partner, but it has the platooning capability enabled.
- **Leadin vehicle**: a vehicle platooning with at least one following vehicle and no vehicle ahead. The leading vehicle contains a driver supervising the system. A vehicle with a Leader role cannot join another platoon or platoon candidate.
- **Following vehicle**: a vehicle platooning with a forward and backward platooning partner. A following vehicle is driving inside a platoon and cannot join or be joined.
- **Trailing vehicle**: a vehicle platooning with at least one forward platooning partner (without a backward platooning partner). A trailing vehicle can be joined by another platoon or platoon candidate.

The platoon in PAF mode can consist of 2 or 3 vehicles. when the platoon consists of 2 vehicles then the platoon contains one leading and one trailing vehicle, which can accept one more platooning candidates. When the platoon consists of 3 vehicles then the platoon contains one leading, one following vehicle and one trailing vehicle, and no more platoon candidates are accepted.

In PAF, two ways to join a platoon are foreseen given that there are drivers in the vehicles or not:

1. *At the hub, the leading vehicle containing a driver initiates a join procedure with unmanned following vehicle(s) for hub-to-hub operation*

In this first case, the driver of the leading vehicle needs to arrange the other following truck(s) in the correct order, following the instructions provided by the offboard service. When the instructions are fulfilled, the vehicles will report the successful formation.

2. *A manned vehicle joins from behind a manned platooning candidate or an existing platoon of 2 vehicles on the highway.*

In this second option, which is very similar to PSF operation, a manned vehicle joins already a 2-vehicle platoon and once the vehicle is a platooning partner, the driver of this vehicle becomes a passenger (not supervising the platooning system).

Platoon candidate identification

To facilitate a platoon formation, the right platooning partner needs to be found. The identification of the right platooning candidates is supported by the strategic layer which resides offboard, hence, each vehicle shall be able to communicate with its corresponding offboard service layer. The information about a platooning opportunity may include rendezvous point and time, opportunity duration, disengage location, vehicle order etc.

PAF_COMM_1: The platooning system in the ego vehicle shall be able to communicate with an offboard service residing in the strategic layer using V2N communication.

PAF_COMM_2: The offboard service residing in the strategic layer shall be able to guarantee that platooning candidates fulfil all prerequisites for platoon engagement.

After the strategic layer has identified and negotiated the right platooning partner(s), the ego vehicle is informed. The ego vehicle will now need to identify the assigned platooning candidate(s) via V2V communication.

PAF_COMM_3: The platooning system in the ego vehicle shall be able to detect the assigned platoon candidates in the near vicinity using V2V communication.

Platoon formation hub-to-hub scenario

For the hub-to-hub scenario, the offboard service will provide information to all platoon candidates about which vehicles that will establish a platoon and it can contain either two or three vehicles. The driver of the leading vehicle will be notified about the platooning candidate(s) that will join the platoon.

PAF_COMM_4: The offboard service at the strategic layer provides information about platoon candidates to the platooning system onboard to all platoon candidates using V2N communication.

The onboard platoon system informs the driver in the proposed leading vehicle about the other platooning candidates.

PAF_COMM_5: The platoon system in leading vehicle shall inform the driver about the other platooning candidate(s).

PAF_COMM_6: The platoon system in the leading vehicle shall announce its platooning service on the V2V communication channel.

PAF_COMM_7: The following vehicle shall listen on the V2V communication channel for platooning service announcement from the leading vehicle. Once received, the following vehicle will initiate a join procedure.

If the platoon consists of two vehicles no more action is needed for the joining, the vehicles will now enter platooning mode and start transmitting platooning control messages.

If the platoon consists of three vehicles, the following vehicle shall announce its platooning capability for the trailing vehicle directly when it has established a connection to the platoon leader.

PAF_COMM_8: The following vehicle shall announce its platooning service on the V2V communication channel.

PAF_COMM_9: The trailing vehicle shall listen on the V2V communication channel for platooning service announcement from the following vehicle. Once received, the trailing vehicle will initiate a join procedure.

The vehicles will now enter platooning mode and start transmitting platooning control messages.

The platoon system onboard the leading vehicle will inform the driver when the platoon has been successfully established and the leading vehicle can leave the hub.

PAF_COMM_10: The platooning system onboard the leading vehicle shall inform the driver when the platoon has been successfully established through the V2V communication channel.

Platoon formation highway

In this scenario, a manned vehicle can join only from behind to an existing platoon or a stand-alone vehicle (becoming a trailing vehicle). This is possible only if there is a single vehicle or a platoon with an unmanned trailing vehicle (that becomes a following vehicle afterwards).. After a successful join, the driver will become a passenger in this scenario. Requirements COMM_4 and COMM_5 are also applicable in this scenario. The joining procedure follows the PSF. Once all vehicles are connected in the platoon, the onboard platooning system informs about the new status to the drivers.

PAF_COMM_11: The platooning system onboard shall inform the driver of the leading vehicle that all vehicles are connected in the platoon on the V2V communication channel.

PAF_COMM_12: The platooning system onboard shall inform the driver of the trailing vehicle that all vehicles are connected in the platoon on the V2V communication channel.

Since it is optional for following vehicles to be responsible for traffic rules and given the existence of specific speed limits depending on the weight of the vehicle, it is needed that each truck communicates this to all the partners in the platoon, such that the driver of the leading vehicle can take this into account.

PAF_COMM_13: The platooning system in the platoon partners shall communicate the weight of the vehicle.

Platooning

Once the platoon has been setup, either at the hub or on the highway, each vehicle in the platoon shall communicate its braking performance. This is used to estimate the target time gap TTG.

PAF_COMM_14: The platooning system in the ego vehicle shall communicate information about its braking performance to the other vehicles in the platoon on the V2V communication channel.

The trailing vehicle and the possible following vehicle shall perform the dynamic driving task (DDT) autonomously when in the platoon and connected to the vehicle in front with V2V connectivity. This means that the V2V communication is the enabler for achieving the PAF. The information needed to perform the DDT autonomously and in a safe way may also include:

- Sending/receiving the route path and vehicle behaviour (acceleration, speed, time gap, etc.)
- Sending/receiving a cohesion request
- Communicate that the ego vehicle is ready to move when starting from standstill
- Communicate that the ego vehicle is ready to change the lane in a safe way (including the lane merge use case)
- Sending request to the leading vehicle regarding changing the lane
- Sending/receiving triggers for the lateral following mode in the case of roadworks or toll gates.

PAF_COMM_15: The platooning system in the leading vehicle shall communicate information to the following vehicle and the possible trailing vehicle facilitating safe autonomous execution of the DDT.

The platoon containing vehicles performing the DDT autonomously shall be perceived as a single vehicle of “Station Type” platoon by other road traffic participants. The leader of the platoon may transmit collective perception messages (CPM) but it shall transmit CAM. The leader is responsible for communicating with smart road infrastructure on the V2V/V2I communication channel. The leading vehicle is responsible for disseminating information inside the platoon received from other road traffic participants which is necessary for upholding the autonomous DDT, i.e., the leading vehicle is filtering information.

PAF_COMM_16: The platooning system in the leading vehicle shall communicate necessary information received from communicating entities outside of the platoon to the trailing vehicle and the possible following vehicle in order for them to execute the autonomous DDT.

To support the driver in the leading vehicle, the platoon system shall provide information regularly about the current platooning driving mode in each platoon vehicle.

PAF_COMM_17: The driver of the leading vehicle shall regularly be updated on the current status of the following vehicle and the possible trailing vehicle.

Communication with smart road infrastructure while platooning

Requirements for the smart road infrastructure have been derived to avoid situations of splitting the platoon. These include, as an example, the presence of intelligent traffic lights that are able to communicate with the platoon. In the need of passing an intersection or a roundabout (both equipped with intelligent traffic lights) or another type of infrastructure (e.g. toll gates, highway ramps, tunnel or bridges) or even while crossing a border, the platoon needs to be able to communicate with smart road infrastructure, receiving information regarding speed or time gap adjustments as well as being able to negotiate manoeuvres. The smart road infrastructure can assure that the platoon is not split by e.g. adjusting the green phase of traffic lights and direct other traffic to other lanes to allow easy merging.

PAF_COMM_18: The leading vehicle shall be able to communicate its intention(s) to cross specific infrastructure (e.g. toll gates, intelligent traffic lights, roundabouts).

PAF_COMM_19: The leading vehicle shall be able to negotiate specific instructions with smart road infrastructure for the entire duration of the manoeuvre (e.g. crossing a traffic light).

The smart road infrastructure can also support the platoon by notifying important changes in the road condition or potential events ahead for safety and for taking decisions at platoon level with the right timing (e.g. enlarging the gap). The infrastructure can also communicate important information regarding traffic rules (e.g. traffic signs).

PAF_COMM_20: The leading vehicle shall be able to receive information from smart road infrastructure about changes in road conditions and potential events on the road ahead.

Cut-in

Cut-ins shall be communicated by all platoon partners using the V2V communication channel.

PAF_COMM_21: The platooning system of the platoon partners shall be able to communicate the presence of a cut-in vehicle in the platoon.

Lange change/merge

Lane changes can be triggered either by the leading vehicle or the following/trailing vehicles. The acknowledgement of a lane change is done by the driver of the leading vehicle.

PAF_COMM_22: All platoon partners shall be able to trigger a lane change request.

PAF_COMM_23: The decision about a lane change shall be taken by the driver of the leading vehicle.

Parking and resting areas:

When manoeuvring in low speed areas such as parking zones or resting areas, the trailing vehicle and the possible following vehicle need to be able to inform the leading vehicle that it had to stop and the reason why. This will ensure the cohesion of the platoon, avoiding a split. Reasons to stop may be:

- VRU in front
- malfunction
- obstacle

PAF_COMM_24: The platooning system in the trailing vehicle or the possible following vehicle shall be able to send information to the platoon partners about its intention to stop and the reason why.

When the driver of the leading vehicle wants to park at a resting area, this intention needs to be communicated to the whole platoon to enable the standby mode.

PAF_COMM_25: The platoon system in the leading vehicle shall be able to communicate the intention to park.

Disengaging:

Leaving can take place at the hub with unmanned vehicles or on the highway with manned vehicles. These two scenarios also apply for the disengaging procedures. In both cases, the platooning partners need to be able to communicate the intention to leave the platoon.

PAF_COMM_26: The platooning system onboard of the platoon partners shall be able to communicate its intention to leave the platoon.

In the case unmanned trucks arrived at the hub, the driver in the leading vehicle will request to leave the platoon. In this case, the request coming from the leading truck should result in the dissolution of the platoon (e.g. each vehicle will become a standalone one).

PAF_COMM_27: The intention to leave the platoon sent by the platooning system in the leading vehicle when at standstill, shall result in dissolving the platoon.

In the highway scenario, two leave situations can occur. In case of a 2-vehicle platoon when the trailing (manned) vehicle wants to leave, the platoon will be dissolved. In the case of a 3-vehicle platoon only the trailing vehicle can request to leave and the result will be a platoon of two vehicles and the leaving vehicle becomes standalone.

PAF_COMM_28: A 2-vehicle platoon shall be dissolved when the manned trailing vehicle wants to leave.

PAF_COMM_29: A 3-vehicle platoon shall become a 2-vehicle platoon when the manned trailing vehicle wants to leave.

4.9 Smart road infrastructure

This deliverable aims to define the requirements and specifications of the multi-brand truck platooning concept for a white-label truck. However, the autonomous platooning system needs infrastructure support to function. Requirements for communication with the smart/digital road infrastructure have been defined in the previous section, i.e. COMM_17, COMM_18 and COMM_19. Although formulating requirements for the infrastructure itself is strictly out of the scope of this deliverable, in this section reference is made to ongoing work about infrastructure characterisation for automated driving. In the Inframix EU-project, Infrastructure Support Levels for Automated Driving (ISAD) have been defined. These levels are shown in the Figure 15 below (Inframix, 2020).

	Level	Name	Description	Digital information provided to AVs			
				Digital map with static road signs	VMS, warnings, incidents, weather	Microscopic traffic situation	Guidance: speed, gap, lane advice
Digital infrastructure	A	Cooperative driving	Based on the real-time information on vehicles movements, he infrastructure is able to guide AVs (groups of vehicles or single vehicles) in order to optimize the overall traffic flow	X	X	X	X
	B	Cooperative perception	Infrastructure is capable of perceiving microscopic traffic situations and providing this data to AVs in real-time	X	X	X	
	C	Dynamic digital information	All dynamic and static infrastructure information is available in digital form and can be provided to AVs	X	X		
Conventional infrastructure	D	Static digital information / Map support	Digital map data is available with static road signs. Map data could be complemented by physical reference points (landmarks signs). Traffic lights, short term road works and VMS need to be recognized by AVs	X			
	E	Conventional infrastructure / no AV support	Conventional infrastructure without digital information. AVs need to recognise road geometry and road signs				

Figure 15: Levels of the Infrastructure Support for Automated Driving (ISAD Levels).

In the context of the Platooning Autonomous Function, a Digital Infrastructure with ISAD level B would be required that supports the functionalities described in the use cases of the Platooning Autonomous Function, such as intelligent traffic lights that can interact with the platoon.

5 CONCLUSION AND NEXT STEPS

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 has been demonstrated by driving up to seven differently branded trucks in one (or more) platoon(s) under real world traffic conditions. After demonstration, the technical results have been evaluated against the initial requirements. In the end, all activities in the project aim to accelerate the deployment of multi-brand truck platooning in Europe.

This deliverable provides the definition of the requirements and specifications of the multi-brand truck platooning concept. After first publication of the requirements and specifications (Konstantinopoulou, 2018), a review towards implementation in the demonstration trucks and a preliminary safety analysis (Dhurjati, 2019) were performed. This preliminary safety analysis revealed that the original Platooning Level A as defined in the D2.2 (Vissers, 2018) is ASIL D, when having the driver responsible while having time gaps of 0.8 s. For this reason, strict safety requirements would be needed that are not in line with the aims of a "first" platooning level that could be deployable on short-term considering the readiness level of the required technology and the existing regulations framework. Hence, after thorough review with the project partners, new levels were defined in D2.3 (Willemsen, 2022):

- **Platooning Support Function**: the driver is responsible for the driving task. Hence (s)he is also responsible to choose a safe following distance and monitor the system e.g. whether the right platooning partner is being followed (though supported by the system as much as possible). To give the driver sufficient time to react, minimum time gaps around 1.5 s have to be respected. The Platooning Support Function is a longitudinal control function (with decelerations limited to -3.5m/s^2), but lateral driver assistance systems, such as e.g. lane centring, might be optionally available as well

- **Platooning Autonomous Function**: The leading truck has a driver responsible for the driving task, but the following trucks are fully automated, i.e. the system performs the complete driving task within the specified (limited) operational design domain. Taking the driver(s) out-of-the-loop offers the possibility to reduce time gaps to a minimum of 0.3 s.

The Platooning Support Function has been implemented, tested and evaluated in the project.

The project also aims to provide a future vision of platooning to accelerate and initiate research and development into next levels of platooning and (digital) infrastructure, and to reflect on potential future needs for adaptation of regulations. For this reason, the second level, i.e. the Platooning Autonomous Function, has also been specified. However, the specification of the Platooning Autonomous Function and its use cases has solely been done on theoretical considerations to sketch a future perspective of platooning. The latter is also due to the low technology readiness level (TRL) of certain required autonomous driving subfunctions at the time of writing.

The white-label truck concept is a vehicle that collects all the common features among different OEMs. It is for this truck that the specifications are made; only for the tactical (this deliverable) and the strategic layer. Requirements are formulated for the operational layer (this deliverable), as the implementation will be brand specific.

The ENSEMBLE white-label truck platooning layers are presented and the modules of the tactical and operational layers as well as the V2V and V2I communication modules are described.

Since the Platooning Support Function has also been implemented and tested Change requests on the specifications and requirements from this design, implementation, testing and evaluation process have been collected in WP2 and are included as well.

Finally, the specification and requirements for the Platooning Autonomous Function are collected in this deliverable.

Apart from being a reference for the specifications and requirements of the white-label truck, this final deliverable is also an important input for WP6, where the requirements are consolidated towards pre-standards and recommendations and guidelines for future policy and regulatory frameworks for the wide scale implementation of multi-brand platooning.

Next to this, this deliverable also aims to provide input for future research. With regard to the Platooning Autonomous Function it is stated before that the technology readiness level (TRL) of certain required autonomous driving subfunctions at the time of writing is low. Most of the technical challenges for the Platooning Autonomous Function are also general challenges in the development of autonomous vehicles, such as precise localisation, perception, etc. However, one important challenge in the development of Autonomous Platooning that stands out is the development of a reliable brake performance estimation function. This function is the enabler for achieving smaller time gaps than 1.2 s and therefore offers typical platooning benefits like energy savings and improved road capacity. Furthermore, the smaller time gaps are an important strategy to discourage cut-in actions to happen that might split the platoon.

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APPENDIX A. DEFINITIONS, ACRONYMS

I. Definitions

Term	Definition
Convoy	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
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 an acceleration of <-4 m/s2
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.
Fail-safe	A fail-safe in engineering is a design feature or practice that in the event of a specific type of failure, inherently responds in a way that will cause no or minimal harm to other equipment, the environment or to people.
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
Legal Safe Gap	Minimum allowed elapsed time/distance to be maintained by a standalone truck while driving according to Member States regulation (it could be 2 seconds, 50 meters or not present)

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	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. 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.
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	The ego-vehicle decides to disengage from the platoon itself or is requested by another member of the platoon to do so.

disengaging	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 (e.g. time gap of 1.5 seconds, which is depends on the operational safety based on vehicle dynamics and human reaction times is given). A.k.a. leave platoon
Platoon dissolve	All trucks are disengaging the platoon at the same time. A.k.a. decoupling, a.k.a. disassemble.
Platoon engaging	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. A.k.a. join platoon
Platoon formation	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. 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.
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.
Target Time Gap	Elapsed time to cover the inter vehicle distance by a truck indicated in seconds, agreed by all the Platoon members; it represents the minimum distance in seconds allowed inside the Platoon.
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	Description of system properties. Details of how the requirements shall be implemented at system level
Use case	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. 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 & alternative e.g. successful and failed in relation to activation of

	the system / system elements).

II. Acronyms and abbreviations

Acronym / Abbreviation	Meaning
ACC	Adaptive Cruise Control
ABS	Anti-lock Braking System
ACSF	Automatically Commanded Steering Function
ADAS	Advanced driver assistance system
ADR	Agreement concerning the International Carriage of Dangerous Goods by Road
AEB	Automatic Emergency Braking (System, AEBS)
ASIL	Automotive Safety Integrity Level
ASN.1	Abstract Syntax Notation One
BTP	Basic Transport Protocol
C-ACC	Cooperative Adaptive Cruise Control
C-ITS	Cooperative ITS
CA	Cooperative Awareness
CAD	Connected Automated Driving
CAM	Cooperative Awareness Message
CCH	Control Channel

CS	Cyber Security
CSF	Corrective steering functions
DEN	Decentralized Environmental Notification
DENM	Decentralized Environmental Notification Message
DITL	Driver-In-the-Loop
DOOTL	Driver-Out-Of-the Loop
DSRC	Dedicated Short-Range Communications
EC	European Commission
EMC	Electro Magnetic Compatibility
ESF	Emergency steering function
ESP	Electronic Stability Program
ETSI	European Telecommunications Standards Institute
EU	European Union
FAD	Fully Automated Driving
FCW	Forward Collision Warning
FLC	Forward Looking Camera
FSC	Functional Safety Concept
GN	GeoNetworking
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GRVA	Working Party on Automated/Autonomous and Connected Vehicles
GUI	Graphical User Interface
HAD	Highly Automated Driving
HARA	Hazard Analysis and Risk Assessment

HIL	Hardware-in-the-Loop
HMI	Human Machine Interface
HW	Hardware
I/O	Input/Output
IEEE	Institute of Electrical and Electronics Engineers
ISO	International Organization for Standardization
ITC	Inland Transport Committee
ITS	Intelligent Transport System
ITS-S	Intelligent Transport Systems Station
IVI	Infrastructure to Vehicle Information message
LDWS	Lane Departure Warning System
LKA	Lane Keeping Assist
LCA	Lane Centering Assist
LRR	Long Range Radar
MAP	MapData message
MIO	Most Important Object
MRR	Mid Range Radar
MVC	Modular Vehicle Combinations
OBD	On-Board Diagnostics
OS	Operating system
ODD	Operational Design Domain

OEM	Original Equipment Manufacturer
OOTL	Out-Of-The-Loop
OTA	Over the air
PAEB	Platooning Autonomous Emergency Braking
PMC	Platooning Mode Control
QM	Quality Management
RCP	Remote Control Parking
RSU	Road Side Unit
SAE	SAE International, formerly the Society of Automotive Engineers
SCH	Service Channel
SDO	Standard Developing Organisations
SIL	Software-in-the-Loop
SOTIF	Safety of the Intended Function
SPAT	Signal Phase and Timing message
SRR	Short Range Radar
SW	Software
TC	Technical Committee

TF	Task Force
TOR	Take-Over Request
TOT	Take-Over Time
TTG	Target Time Gap
UNECE	United Nations Economical Commission of Europe
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)
VECTO	Vehicle Energy Consumption Calculation Tool
VMAD	Validation Method for Automated Driving
WIFI	Wireless Fidelity
WP	Work Package
WP.1	Working Party 1 - Global Forum for Road Traffic Safety
WP.29	Working Party 29 - World Forum for Harmonization of Vehicle Regulations

APPENDIX B. HUMAN FACTORS GUIDELINES FOR PLATOONING SUPPORT FUNCTION

I. Introduction

The Human Factors Guidelines catalogue presented in this deliverable is structured in a similar way as the Human Factors Recommendations catalogue from the AdaptIVe project (Kelsch, J. et al., 2017) which covers a number of human factors challenges and recommendations in the field of automated vehicles. The catalogue presented here can be regarded as a complement to the AdaptIVe Human Factors catalogue with challenges and recommendations/Guidelines that are specific for platooning. The Guidelines are on a high-level and address functional matters, i.e. expressing what the system "*Should do*"

Please note, this is a first version of challenges and Guidelines for platooning. The current catalogue should be regarded as a working document. Challenges and guidelines will be added, revised and adjusted with increased experiences, gained knowledge and understanding of best practice for Platooning. Moreover, the current catalogue is only applicable for the work in the ENSEMBLE project.

II. Methodology

The first step was to go through the Human Factors recommendations for driver-automated vehicle interaction that were developed in AdaptIVe (Kelsch, J. et al., 2017). A conclusion was that these Human Factors recommendations are also applicable for platooning on general level and should be considered in HMI-development for platooning as well. However, the concept of platooning comprises specific situation that are not covered in these Human Factors recommendations. Therefore, the second step was to identify platoon specific challenges based on the State of Art, interviews with platoon drivers and in discussions with other truck OEMs. The third step was to formulate a high-level Human Factors Guideline for each platoon challenge. The fourth step was to categorize the high-level Human Factors Guidelines according to the Use Cases and to the 4A structure and to put them together in a catalogue. The high-level Human Factors Guidelines for platoon was circulated and discussed in workshops among the partners in ENSEMBLE. Further steps to complete the Human Factors Guideline catalogue are to add Non-functional recommendations/Guidelines, and examples of solutions related to each Guideline.

III. The 4A categories

Platoon systems can be regarded as multi-agent systems in which the driver, the (automation) system and the vehicle are interacting in an environment to achieve common goals (Figure 12). The four categories Agent state, Awareness, Arbitration and Action refer to the information processing in a cognitive system and are shortly explained below:

Agent refers the agents the driver, the automation, the vehicle, and the environment. The driver states are, for example level of knowledge, fatigue. The automation and the vehicle states are for example the technical parts of the system and the environmental states are for example traffic density and weather conditions.

Awareness refers to the perception, comprehension and projection of the situation, as well as the awareness of the current system modes, such as the platoon and automation levels, the awareness of roles and tasks between agents.

Arbitration is about the interaction and decision strategies between the agents. It includes how to coordinate the agents by different interaction modalities (haptic, acoustic, visual etc.). This category also addresses adaptation between the agents in the system.

Action refers to the actions performed by the agents including ergonomic matters, such as reachability, handling of input devices, visibility of output devices as well as the required skills and abilities to perform certain handlings. This category is also related to usability matters and vehicle control.

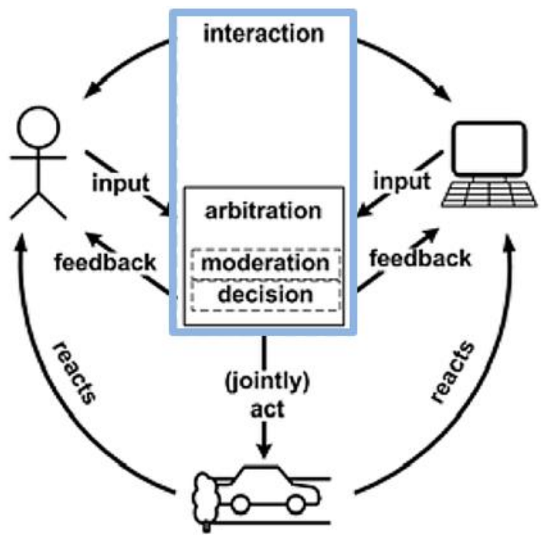

Figure 16: The relationships between the agents in a driver-vehicle-automation system.

IV. The Human Factors Guideline catalogue for platooning

The Human factors Guideline catalogue for platooning consists of 17 Guidelines. There is one table for each Human factors Guideline. Each table has an ID- code, short name, description of human factors challenges and the guideline, the related platoon levels, the 4A category and the related Use Cases. Examples of how to address the challenges and guidelines with non-functional recommendations and HMI solutions can be added based on best practices of platooning (Figure 14).

ID	Name	
P-HFR_Ag_ 1 P= Platoon HFR= Human Factors Recommendation Ag= Agent Aw= Awareness Arb= Arbitration Act= Action	"(Short name of the Recommendation)"	
Platoon Level A	Platoon Level B	Platoon Level C
x	x	x
Related to 4A-category (Agent, Awareness, Arbitration, Action)		
Related Use Case:		
Human Factors challenge:		
Human Factors Recommendation/Guideline:		
Non-functional HF recommendations:		
Examples: (Pictures and descriptions from real systems, prototypes, sketches, GUIs etc. or other examples that addresses the Human Factors Recommendation).		
References: (References to papers, products, concepts, web-sites etc.)		

Figure 17: The format of the table for the Human factors Guidelines for platooning.

ID	Name	
P-FR1Ag_1	"Driver platoon knowledge"	
Platooning Support Function	Platoon Level B	Platoon Level C
x	x	x

Related to 4A-category Agent
Related Use Case: No specific Use case
Human Factors challenge: The drivers do not understand how to drive in a platoon in a safe and efficient way.
Human Factors Guideline: Driver training about platooning as a concept, how-to drive-in platoons and how to interact with the platoon system.
Non-functional HF recommendations:
Examples:
References:

ID	Name	
P-FR1Ag_2	"Verbal communication"	
Platooning Support Function	Platoon Level B	Platoon Level C
x	x	x
Related to 4A-category Agent		
Related Use Case: Platoon formation, Steady state, Cut-in/out, Leave		
Human Factors challenge: Drivers speaking different languages have difficulties to understand each other.		
Human Factors Guideline: The safety of a platoon should not dependent on verbal communication between the drivers.		
Non-functional HF recommendations:		
Examples:		
References:		

ID	Name	
P-FR1Ag_3	"System limitations"	
Platooning Support Function	Platoon Level B	Platoon Level C
x	x	x
Related to 4A-category Agent		
Related Use Case: Steady state		
Human Factors challenge: Driver is not sure about the platoon system's capacity to handle different situations and conditions, for example bad weather, road conditions etc.		
Human Factors Guideline: The system should recognize non-platoon circumstances and communicate its limitations to the driver. See also AdaptIVe: FR1A_AUL		
Non-functional HF recommendations:		
Examples:		
References:		

ID	Name

P-FR1Ag_4	"Geo-fencing conditions"	
Platooning Support Function	Platoon Level B	Platoon Level C
x	x	x
Related to 4A-category Agent		
Related Use Case: Steady state		
Human Factors challenge: Geo-fencing conditions are not clear to the drivers.		
Human Factors Guideline: Geo-fencing conditions that affect the platoon are communicated to the drivers.		
Non-functional HF recommendations:		
Examples:		
References:		

ID	Name	
P-FR1Ag_5	"Understanding visual messages"	
Platooning Support Function	Platoon Level B	Platoon Level C
x	x	x
Related to 4A-category Agent		
Related Use Case: General. No specific Use Case. Platoon formation, Engage, Steady state, Leave, Cut-in, emergency brake, MRM		
Human Factors challenge: Drivers of different nationalities do not understand the text messages.		
Human Factors Guideline: Text messages should be written in a language that the driver can understand. Icons and symbols should be in accordance with ISO standards or with other established practices.		
Non-functional HF recommendations: Change languages in Settings.		
Examples:		
References:		

ID	Name

P-FR2Aw_1	"Position in platoon"	
Platooning Support Function	Platoon Level B	Platoon Level C
x	x	x
Related to 4A category: Awareness		
Related Use Case: Steady state		
Human Factors challenge: The driver does not know his/her position in the platoon.		
Human Factors Guideline: The ego-truck's current position in the platoon should be clearly displayed and communicated to the driver.		
Non-functional Factors Recommendation/Guideline:		
Examples:		
References:		

ID	Name	
P-FR2Aw_2	"Situational awareness 1"	
Platooning Support Function	Platoon Level B	Platoon Level C
x	x	x

Related to 4A-category

Awareness

Related Use Case:

Steady state, Leave, Cut-in, emergency brake, MRM

Human Factors challenge:

The driver loses situational awareness of the environment due to the limited field from driving close behind the truck in front.

Human Factors Guideline:

The system should provide adequate information to the driver about current and up-coming events that may affect the platoon.

Non-functional HF recommendations:

Examples:

References:

ID	Name	
P-FR2Aw_3	"Situation awareness 2"	
Platooning Support Function	Platoon Level B	Platoon Level C
	x	x
Related to 4A-category Awareness		
Related Use Case: Engage, Steady state, Leave, Cut-in, emergency brake, MRM		
Human Factors challenge: The driver does not understand the behaviour of the platoon.		
Human Factors Guideline: The system should provide enough and timely information about changes in the platoon.		
Non-functional HF recommendations:		
Examples:		
References:		

ID	Name	
P-FR2Aw_4	"Lost connection"	
Platooning Support Function	Platoon Level B	Platoon Level C
x	x	x
Related to 4A-category Awareness		
Related Use Case: Platoon formation, Engage, Steady state, Leave, Cut-in, emergency brake, MRM		
Human Factors challenge: Drivers are affected by the loss of or reduced V2V/X communication.		
Human Factors Guideline: The system should inform the drivers about lost or reduced V2V/X connection and provide adequate information about (i) what modules are affected and (ii) if any actions needed by the driver.		
Non-functional HF recommendations:		
Examples:		
References:		

ID	Name

P-FR2Aw_5	"Role confusion"	
Platooning Support Function	Platoon Level B	Platoon Level C
	x	x
Related to 4A-category Awareness		
Related Use Case: Steady state		
Human Factors challenge: Changing the roles from being a Follow-truck driver to be a Lead-truck driver, and vice versa, can lead to role confusion		
Human Factors Guideline: The drivers' roles and task should be clearly communicated to the drivers.		
Non-functional HF recommendations:		
Examples:		
References:		

ID	Name	
P-FR2Aw_6	"System strategy"	
Platooning Support	Platoon Level B	Platoon Level C

Function		
x	x	x
Related to 4A-category Awareness		
Related Use Case: Platoon formation, Engage, Steady state, Leave, Cut-in, emergency brake, MRM		
Human Factors challenge: The different modes (Manual, CC, ACC, CACC, Platoon levels A, B, C etc.) are not clear to the driver.		
Human Factors Guideline: The different modes should be clearly communicating to the driver to avoid mode confusion.		
Non-functional HF recommendations:		
Examples:		
References:		

ID	Name	
P-FR1Arb_1	"Cut-ins"	
Platooning Support Function	Platoon Level B	Platoon Level C
x	x	x
Related to 4A-category Arbitration		
Related Use Case: Cut-in		
Human Factors challenge: Cut-ins cause variations in speed and distances between the trucks in the platoon.		
Human Factors Guideline: The changes in the platoon caused by the cut-ins are communicated to the drivers.		
Non-functional HF recommendations:		
Examples:		
References:		

ID	Name	
P-FR1Arb_2	"Approaching ego-exit"	
Platooning Support Function	Platoon Level B	Platoon Level C
	x	x
Related to 4A-category Arbitration		
Related Use Case: Steady state, Leave		
Human Factors challenge: It is difficult for Follow-truck drivers to see their forthcoming ego-exits due to the limited field of view in close distances to the truck in front.		
Human Factors Guideline: The platoon system or other system, for example navigation system, inform the driver about the approaching ego-exits. The platoon system can adjust speed and distances to the truck in front prior the ego-exit.		
Non-functional HF recommendations:		
Examples:		
References:		

ID	Name

P-FR1Arb_3	"Obstacles in front"	
Platooning Support Function	Platoon Level B	Platoon Level C
x		
Related to 4A-category Arbitration		
Related Use Case: Steady State		
Human Factors challenge: Obstacles partly in the lane are difficult for the Follow-truck drivers to see and to avoid hitting.		
Human Factors Guideline: The platoon system informs the Follow-truck drivers about changes in speed and distances in accordance with the lead truck's actions. Exceeded threshold values (longitudinal) should also alert the Follow-truck drivers about the criticality.		
Non-functional HF recommendations:		
Examples:		
References:		

ID	Name	
P-FR1Act_1	"Manual lateral control behaviour"	
Platooning Support Function	Platoon Level B	Platoon Level C
x		
Related to 4A-category Action		
Related Use Case: Steady state		
Human Factors challenge: Difficult for follow-truck drivers to maintain correct manual lateral control over time.		
Human Factors Guideline: System detects and alerts the driver about erratic steering behaviour (by the driver). ADAS should always be active to mitigate the criticality.		
Non-functional HF recommendations:		
Examples:		
References:		

ID	Name

P-FR1Act_2	"Truck in front leaving the platoon, planned leave"	
Platooning Support Function	Platoon Level B	Platoon Level C
	x	x
Related to 4A-category Action		
Related Use Case: Steady state, Leave		
Human Factors challenge: The driver ego-truck driver is affected by the truck in front is leaving the platoon.		
Human Factors Guideline: The ego-truck driver is informed by the platoon system in advance about the truck in front forthcoming exit (leaving the platoon).		
Non-functional HF recommendations:		
Examples:		
References:		

<table>
<tr><th>ID</th><th colspan="2">Name</th></tr>
<tr><td>P-FR1Act_3</td><td colspan="2">“Unexpected manoeuvre”</td></tr>
<tr><td>Platooning Support Function</td><td>Platoon Level B</td><td>Platoon Level C</td></tr>
<tr><td>x</td><td>x</td><td>x</td></tr>
<tr><td colspan="3">Related to 4A-category
Action</td></tr>
<tr><td colspan="3">Related Use Case:
Steady state</td></tr>
<tr><td colspan="3">Human Factors challenge:
Driver needs to make a sudden manoeuvre.</td></tr>
<tr><td colspan="3">Human Factors Guideline:
The drivers in the trucks behind the acting truck are informed about changes in the platoon.</td></tr>
<tr><td colspan="3">Non-functional HF recommendations:</td></tr>
<tr><td colspan="3">Examples:</td></tr>
<tr><td colspan="3">References:</td></tr>
</table>