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REVISION HISTORY

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1 EXECUTIVE SUMMARY

1.1 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 fuel economy, traffic safety and throughput. This will be demonstrated by driving up to seven differently branded trucks in one (or more) platoon(s) under real world traffic conditions across national borders. During the years, the project goals are:

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

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

1.2 Abstract of this Deliverable

This deliverable provides the definition of the requirements and specifications of the white-label multi-brand truck platooning concept to be implemented, tested and demonstrated with up to trucks of 6 different European OEMs. The white-label truck concept takes into consideration Platoon level A which will form the basis of the intended demonstration at the end of the project on public road. This report concentrates on the operational and tactical layer, but also identifies required interactions with the Strategic and Services Layers.

This deliverable serves as a starting point for the definition of requirements and specifications for the white-label multi-brand truck platooning by 6 European truck manufacturers and 7 automotive suppliers. D2.5 will further refine these requirements and specifications based upon learnings from development, testing and verification of these specifications in real trucks and functional safety and SOTIF activities.

Chapter 2 gives a background overview, aim and structure of this report; and relation to the other work packages.

Chapter 3 presents the ENSEMBLE white-label truck platooning layers and describes the modules of the tactical and operational layers as well as the communication modules via V2V and V2I in a nutshell. It provides for considerations to be taken during functional safety and also provides for the approach taken by the project to derive requirements and specifications.

Chapter 4 is describing the Tactical Layers modules and specifications. The tactical layer coordinates the actual platoon forming, both from the tail of the platoon in Platoon Level A and through merging in the platoon in further Platoon Levels to be elaborated in D2.5. The platoon system over the tactical layer will gather platoon status and data information and distribute this information over the platoon. The platoon system status information gathered by the tactical layer is updated cyclically.

Chapter 5 describes the communication modules for V2V and V2I which will enable the platoon to interact with the other vehicles and the infrastructure. For the communication module for V2V to facilitate the required interaction of the trucks in the platoon, a communication link must be established between the platoon participants. The decentralized tactical layer, running locally in the trucks, needs information from the other trucks. For the communication module for V2I, specifications have been developed for the definition of information needed to interact between the platoons and the infrastructure. The information that is needed is policy based on zone (zone policy or geofencing) and be constantly up to date with this information (refresh period to be defined) as well ensure information that is communicated via RSU is implemented by individual vehicles - for Platoon Level A, for safety purposes, this includes a validation by the driver.

Chapter 6 outlines Operational Layer modules and its related requirements for e.g. HMI, Longitudinal Control and Sensors. The common HMI-logic should function as the “lowest common denominator” for each OEM’s HMI-design for platooning, regardless truck brand. The purpose of the common HMI-logic is to provide a structure for coherent interactions between the driver and the platoon system and still allow for OEM specific solutions. Longitudinal control requirements are divided among requirements for how the minimum inter vehicle time gap is selected, requirements for safely handling braking in the platoon, requirements for how to increase the inter vehicle time gap in a safe way and requirements for how to close gaps and keep the platoon together. The latter one describing the platoon 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. As regards sensing specifications, this report focuses on the sensor data and associated sensors required for a white-label solution to assess the environment and which are specific for platooning. For the platooning demonstration it is planned to use the actuators which are present in state-of-the-art vehicles. Thus, there are no specific requirements for the time being. This could change over time once the results of the HARA and SOTIF analysis are available. The communication requirements are already documented in the deliverables D2.6 and D2.8 for V2I and V2V respectively.

Chapter 7 summarises the findings and formulates conclusions and next steps for the follow-up: D2.5 Functional specification for white-label trucks (Operational & Tactical layers). D2.5 will develop requirements and specification for the further Platoon levels operational and tactical layer stemming from the definitions and use cases which are going to be further detailed in D2.3.

D2.4 provides the specified functionalities for WP3 to implement. During WP5, the verification and validation phase the functionality of the equipped vehicles will be verified against the specifications and the developed functionality will be compared to the intended multi-brand functionality as presented in D2.4 to validate the results. In WP4 a list of KPIs on e.g. impact of platooning on traffic flow, bridges, other road-user's behaviour, impact on the environment, possible business cases will be mapped against D2.4 requirements. In WP6 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.

2 INTRODUCTION

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

2.1.1 Relation to ENSEMBLE work packages

As per 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).

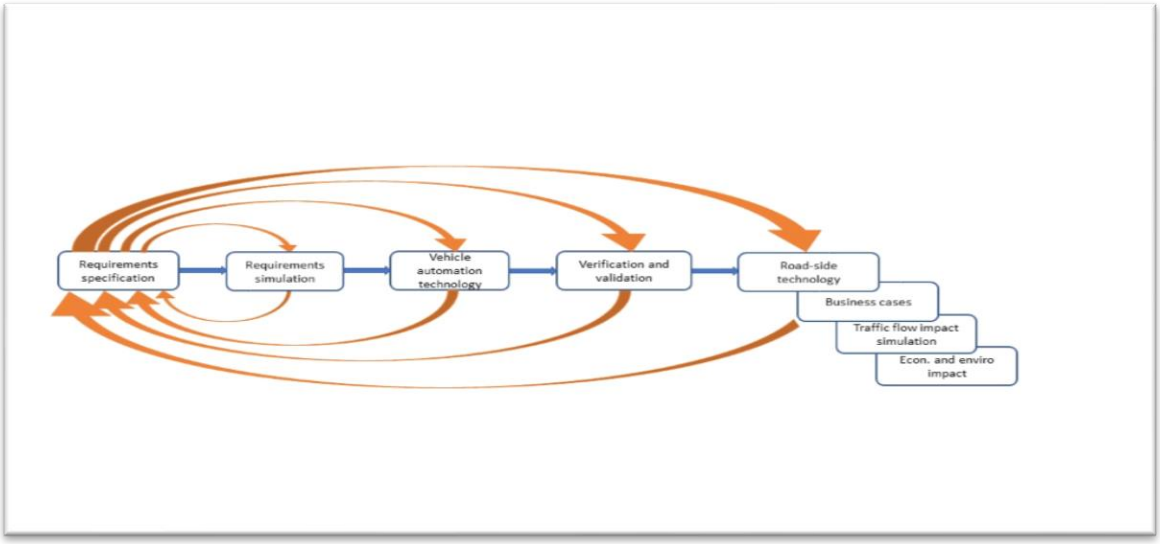


Figure 1: Evolution cycles for the derivation of the relevant requirements for multi-brand truck platooning

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. In order to perform a reality check on the feasibility and the relevance of the requirements specifications, first-principles simulations are performed. This deliverable concentrates on the operational and tactical layer, but also identifies required interactions with the higher layers (Strategic and Services Layers). Please note that Chapter 3 will describe in more details the different platooning layers. Thus, in WP2 focus is on Platooning Level A for implementation in the trucks.

WP3 - This work package implements the requirements and the specifications of WP 2 into demonstrator trucks (i.e. comprising hardware and software). This implementation includes the operational and the tactical layer, as well as the interface to the strategic layer. The implementations will be verified in WP5 against the specifications and requirements given in WP2. The design and implementation process may result in change requests on the specifications and requirements, which will be collected in WP2 and comprised in D2.5, an update of this deliverable.

WP4 - In this WP, business cases and economical and environmental impact analyses will be performed., The non-vehicle-based requirements as considered in D2.4, will also link to a list of KPIs like e.g. in impact of platooning on traffic flow, bridges, other road-user's behaviour, impact on the environment, possible business cases, etc. These will be verified through testing with the equipped vehicles and through simulations.

WP5 - During the verification and validation phase the functionality of the equipped vehicles will be 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. Regarding other road user's behaviour and acceptance of platoons, a set of recommendations will be added to the requirements (e.g. information given by roadside or by special signals on the platoon).

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.

2.1.2 Relation to stakeholder needs

ENSEMBLE intends to take advantage of the existing relationships between the project members and the European Truck Platooning Challenge (ETPC) community in order to achieve a high degree of adoption of the results beyond the project. With this intention, ENSEMBLE has the ambition to cooperate with a large community of EU stakeholders, including the ETPC, road authorities and private stakeholders, especially for validation of the requirements and specifications. Feedback has been gained through dedicated meetings held together with the ETPC network (November 2018). In addition, regulation and requirements by the road authorities and member states might also generate additional requirements and might impact testing and verification of truck platooning systems on the roads. In the second quarter of 2019, the project also foresees to organize a common workshop among the

European Truck Platooning challenge (ETPC), C-Roads Platform, CONCORDA, CEDR in order to validate the ENSEMBLE specifications and to ensure convergence and agreement on the V2I topic and to suggest a unique proposal for the European Commission.

2.2 Aim of the deliverable

This deliverable provides the definition of the requirements and specifications of the white-label multi-brand truck platooning concept to be implemented, tested and demonstrated with trucks of the 6 OEMs. This deliverable concentrates on the operational and tactical layer, but also identifies required interactions with the higher layers (Strategic and Services Layers).

2.3 Structure of report

This deliverable is structured into 9 chapters:

- Chapter 1 provides with the executive summary;
- Chapter 2 gives a background overview, aim and structure of report;
- Chapter 3 presents the ENSEMBLE white-label truck platooning layers and modules; considerations for functional safety and the approach taken for deriving requirements and specifications
- Chapter 4 is describing the Tactical Layer modules and specifications;
- Chapter 5 describes the communication modules for V2V and V2I
- Chapter 6 outlines Operational Layer modules and requirements for e.g. HMI, Longitudinal Control and Sensors;
- Chapter 7 summarises the findings and formulates conclusions and next steps for the follow-up: D2.5 Functional specification for white-label trucks (Operational & Tactical layers).

3 ENSEMBLE WHITE-LABEL TRUCK FUNCTIONAL ARCHITECTURE

This chapter 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 Level A.

3.1 Platooning Layers

The concept of the ENSEMBLE platooning system consists of a hierarchical system, with interacting layers. The envisioned concept is presented in Figure 3 different layers have the following responsibilities:

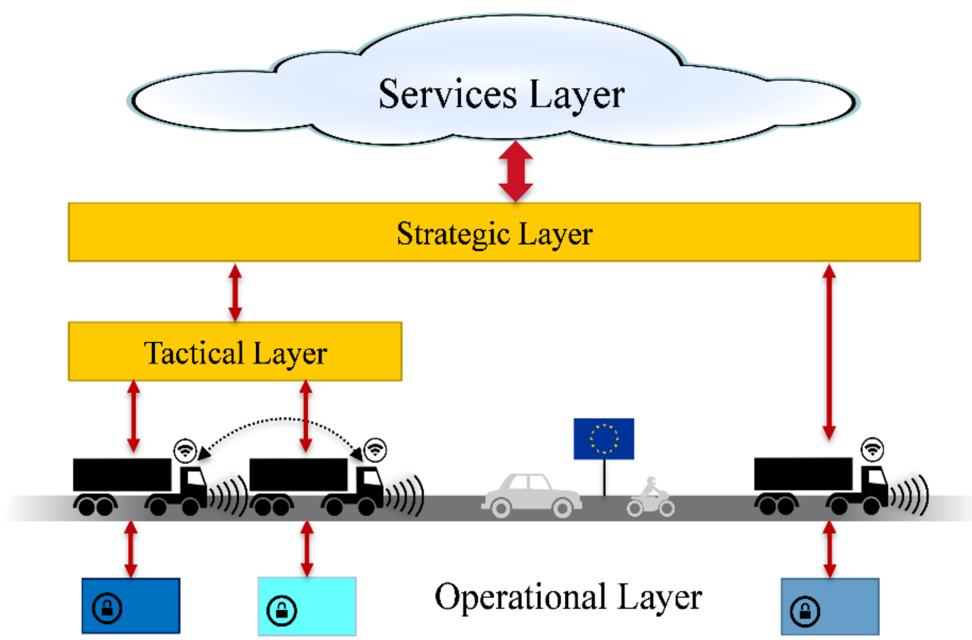


Figure 2: ENSEMBLE Platooning Layers

- 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.

3.2 White-label truck platooning functional modules

The white-label truck concept encompasses all layers, but specifications are made only for the tactical (this deliverable) and the strategic layer, because these are common to all brands. Requirements are formulated for the operational layer (this deliverable), as it will be brand specific.

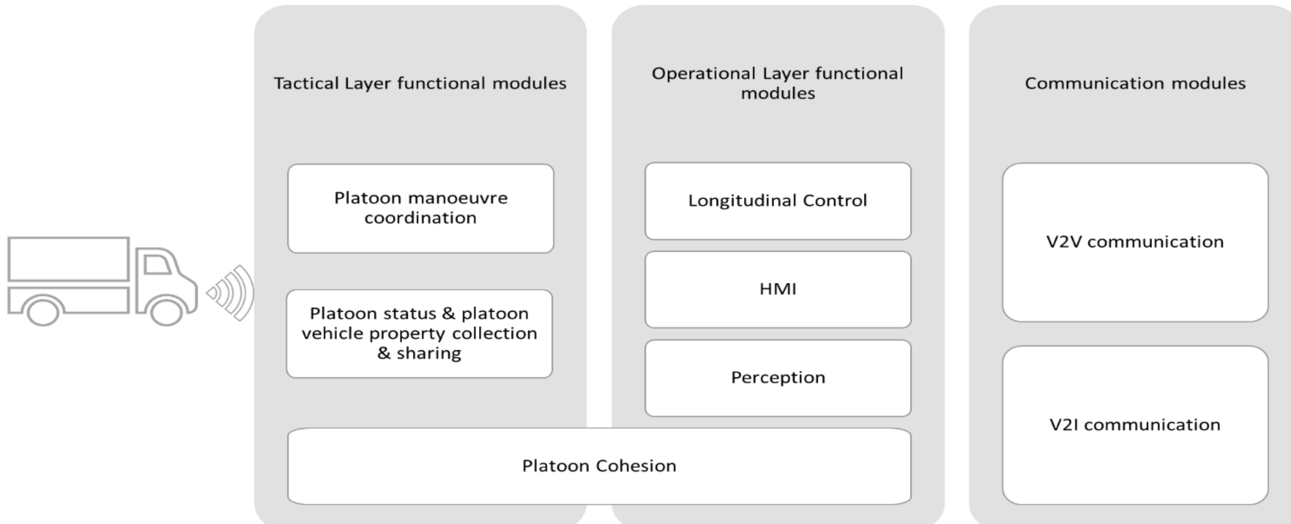


Figure 3: Platooning functional modules of the white-label truck (high-level view)

Figure 3 gives a high-level overview of the platooning functional modules of the white-label truck. The white-label truck represents a brand-less truck that has all the described specifications of this report D2.4 (functional requirements and specifications for the operational and tactical layer respectively), D2.6 (connection to the intelligent infrastructure), D2.8 (platooning protocol definition and communication strategy) and the safety mechanisms (D2.10, D2.12 and D2.14).

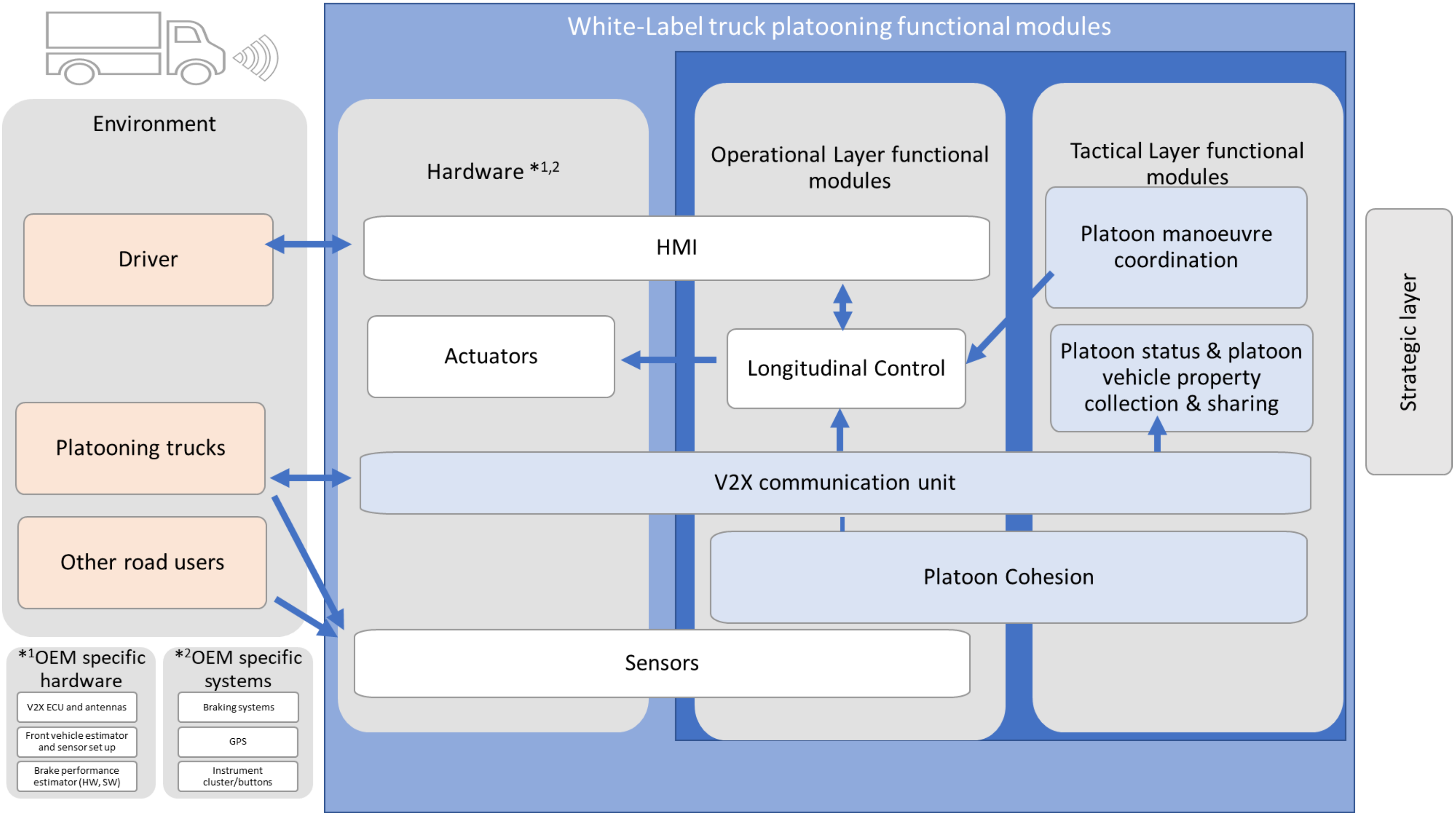


Figure 4: Platooning modules of the white-label truck (detailed view)

Figure 4 describes a more detailed description of the 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 are described in D2.8).
- Platooning information 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 this deliverable).
- Platoon manoeuvre coordinator: this is a module that coordinates specific manoeuvres that need a cooperative approach rather than an individual one (specified in this deliverable).
- 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. (specified in this deliverable).

For the white blocks in Figure 4 requirements have been formulated for the operational Layer which are OEM specific.

- HMI: this module provides the required logic for the interfacing to the driver. (specified in this deliverable).
- Sensors: this software module provides the host vehicle environmental perception and localisation based on vehicle-mounted sensors
- Longitudinal control: this module contains the control algorithms for automatically executing vehicle acceleration and deceleration, e.g. to drive at a certain seed, to maintain a desired inter-vehicle gap or to perform emergency braking. (specified in this deliverable).

Related to the environment, communication modules need to be established with other road users, platooning trucks (V2V), infrastructure (V2I) and the driver (HMI) to provide the necessary information and interact with the platoon.

The parts that are more OEM specific are:

- V2xX Antennas
- Front vehicle estimator and sensor set up
- Brake performance estimator (HW and SW)

Finally, these are the systems that probably need no direct change, but only a different (extra) interface:

- Braking system
- GPS
- Instrument cluster / Buttons

3.3 Functional Safety considerations

The definition of the specifications of the whole multi-brand truck platooning concept need to be put in relation to the functional safety analysis and SOTIF to be developed in D2.12 in order to assure that the white-label truck platooning modules can function safely during normal operations and system failures. Since these activities will not only define requirements to deal with hazards arising from E/E malfunctions but also address hazards resulting from performance limitations or insufficiencies of the function itself, the safety activities carried out for the project are considered comprehensive enough to have safe platooning deployment on public roads. Platoon Level A final definition will include all these outcome and results and delivered in D2.5. Requirements specified in the upcoming sections are yet to be analysed from a safety perspective. Safety analysis of the platoon Level A specification is progressing in parallel to specifications definition and will be released in the form of deliverables D2.12: Hazard Analysis and Risk Assessment and Functional Safety Concept and D2.14: SOTIF Safety Concept.

Since safety impacts all the platooning layers, the ENSEMBLE project implements two different facets of safety for completeness:

- Functional Safety: Functional safety aims to ensure absence of unreasonable risk due to hazards caused by malfunctioning behaviour of Electrical/Electronic systems. The malfunctioning behaviour can be any failure or unintended behaviour of a function with respect to its design intent at the vehicle level
- Behavioural Safety: Also known as Safety of the Intended Functionality (SOTIF) aims to ensure absence of unreasonable risk due to performance limitations or insufficiencies of the function itself. In addition, reasonably foreseeable misuse by the drives, which could lead to potentially hazardous system behaviour, is also considered as part of SOTIF analysis.

For functional safety, the work products and the process defined in the international standard "ISO 26262: Road vehicles – Functional safety" will be followed. The work products of the concept phase, which include the Item Definition, the Hazard Analysis and Risk Assessment and the Functional Safety Concept, will be developed jointly by all the partners to have a common set of functional safety requirements for the platoon. Once the common safety concept is defined, each OEM will have the liberty to meet these functional safety requirements with their own technical safety requirements and system design. Typical functions to be considered for functional safety in platooning include malfunctions arising from communicating erroneous data to other vehicles of the platoon.

For behavioural safety, Unlike Functional Safety, SOTIF does not deal with hazards arising from E/E malfunctions It examines unsafe triggering events originating either from external factors like environment, infrastructure, etc. or due to driver misuse. Typical triggering events to be considered for SOTIF in platooning include situations of emergency braking, Cut-in by external vehicles, platooning in bad weather conditions, entering tunnels, obstacles in the lane, un-informed steering by the lead vehicle (driver misuse), etc.

3.4 Approach

In order to gather the common set of requirements and specifications a 6-steps' approach was introduced, with the purpose to gather and validate the information provided by the WP2 partners.

- Step 1: Initially a structured template for the collection of requirements and specifications was created.
- Step 2: This template was validated by the WP2 partners.
- Step 3: After its validation, this template was circulated to all D2.4 partners, for them to record the specific requirements and specifications per layer.
- Step 4: All partners provided the WP2 leader with the template filled-in with the specific inputs needed. A mapping between use cases, modules and requirements and specifications of the tactical and operational layer was then developed.
- Step 5: The input of these templates was discussed and validated in several workshops and conference calls chaired by the WP2 leader.
  - Meetings and workshops
    - 28-29 June, 11-12 September, 4 December, 09 January 2019/ WP2 workshops
    - 24 July, 13 November, 11 October, 10 January 2019 / D2.4 workshops
    - 27 November / HMI Workshop, 5 December / Longitudinal workshop
  - Conference calls
    - 18 July, 30 August, 17 January, 28 January / D2.4 Conference calls
    - 12 individual conference calls with each chapter owner
- Step 6: Finally, CLEPA consolidated all final inputs, as provided by all the D2.4 partners, and prepared Deliverable (D) 2.4.

In Appendix G, an example of D2.4 template for requirements and specifications is presented. These templates will also be followed when it comes to defining the further Platoon Levels in D2.5.

In addition, for each use case the intention was to derive the relevant modules needed to perform this use case.

	Operational layer	**Tactical layer**	**Strategic layer**	**Service layer**
Engaging to platoon	**x**	**x**		
Platooning	**x**	**x**	**x *****	**x ***
Disengage platoon	**x**	**x**	**x *****	

Platoon formation	**x ****	**x ****	**x**	**x ***

Table 1: Use cases and involved layers

** service modules can only be partially identified from the existing high-level use cases. Services from a logistic perspective will be further analysed in WP4.*

*** The involvement of the Operational layer and tactical layer is limited in platoon formation. E.g. only a certain speed advice will be given to the tactical layer which the tactical layer will forward and send to the operational layer.*

**** During these use cases the strategic layer is mainly involved by receiving information from the tactical layer such that services can be deployed.*

Red squared tables throughout the deliverable are defining a unique Requirement/ Specification satisfying the modules of the tactical, operations layers and the communication modules V2V and V2I against the use cases developed.

The format yy_00X, where:

- *yy* identifies the domain function of the tactical, operational layer and the communication modules provided (e.g. Tactical layer) from the use cases in D2.2:
- *00X* identifies the number of the requirement within the domain.

e.g. Tactical_layer_001: The platoon system has awareness of the status of the coordinated gap opening on platoon level through a specific signal (0: no coordinated gap opening, 1: coordinated gap opening in progress)

A Traceability Matrix is provided in APPENDIX A depicting the requirements/specifications against use cases. Please note that this document serves as a starting point on the development of the described modules and its related requirements and specifications to be finalised in WP3.

4 TACTICAL LAYER MODULES & SPECIFICATIONS

The tactical layer is one of the four layers defined for the hierarchical platooning system architecture. 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 enables platoon cohesion in several scenarios (e.g. driving on hilly roads, varying platoon's speed in certain ranges), and advices 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 on the order of the vehicles within the platoon due to vehicle compatibility.

The needed functionality in the tactical layer is captured by 4 functional modules which will be detailed further in this chapter, being:

- Platoon Manoeuvre coordination module (section 4.1)
- Platoon Cohesion (section 4.2)
- Platoon status & platoon vehicle property collection & sharing modules (section 4.3)

The tactical layer modules, especially the "Platoon status & platoon vehicle property collection & sharing" can be mapped to all use cases as described in D2.2. For the other modules the most relevant use cases are: 2.1, 3.1, 3.4.1, 3.4.2 and 3.4.3.

4.1 Platoon manoeuvre coordination module

The purpose of this functional module is to coordinate the manoeuvres on platoon level. For platoon level A the coordination of the manoeuvres (e.g. the join action) is relatively straightforward and it is expected that the coordination will be done by means of rules on vehicle level. For the details regarding this, the reader is referred to section 5.1.1. Some more complex manoeuvres (e.g. coordinated gap opening) need coordination on platoon level for which initial solutions are described below.

Coordinated gap opening

Use case 3.4.1 *Platoon gap adaptation because of I2V interaction* is about platoon gap adaptation for all vehicles in the platoon, initiated by a request from the infrastructure, e.g. to avoid damage to a bridge. The goal of the platoon manoeuvre coordination module is to define rules which allow coordination on platoon level to assure a safe and efficient way for the platoon and the surrounding traffic to adapt the gaps between the vehicles within the platoon. Different simulations are performed to analyse the effect of certain basic strategies.

First, simulations are performed to show the effect if there is no coordination on platoon level, but a basic rule to limit the relative speed difference to the vehicle in front of (maximum) 3 km/h. This simulation starts with 7 trucks, platooning at 80 km/h at 0.8 s time gap. Then all trucks perform a gap opening action (of 10 m additional gap distance) at the same moment in time. Note that the maximum speed of the trucks is assumed to be limited to 85 km/h. The main results are shown in below figures.

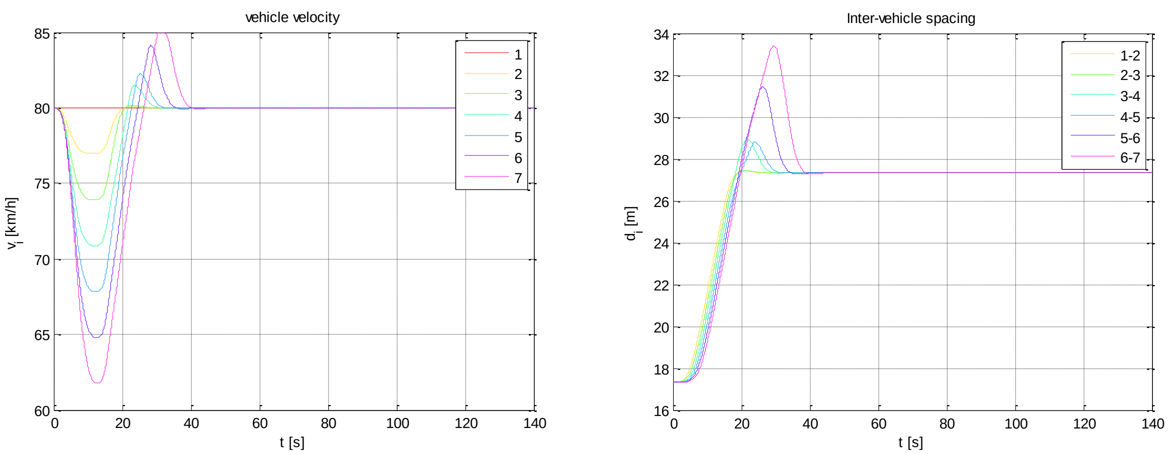


Figure 5: Time versus relative speed & gap for simultaneous gap opening

The conclusion of this simulation with simultaneous gap opening by 7 trucks is that this strategy results in a fast opening of the gap, i.e. in 40 s the gaps are opened. However, a large speed difference at the end of the platoon (>15 km/h) and large gap errors (>5m) occur. Moreover, the gap errors are amplified towards the back of the platoon. Such behaviour is likely to negatively affect traffic flow and safety (large speed difference to e.g. passenger vehicles driving typically at 120 – 130 km/h). Therefore, this strategy is suitable for emergency situations in which fast gap openings have highest priority, but in normal situations coordination is desired to avoid a negative impact on the traffic flow and safety. As this strategy for emergency opening does not require further coordination on platoon level (emergency gap opening is operational strategy) this is not further discussed here.

The idea behind the first method is that the ego vehicle only starts enlarging the gap when the preceding vehicle has finished opening its own gap. The role of the tactical layer is here to assure that this information is shared between the trucks together with the information that a coordinated gap opening is ongoing. The actual gap opening per vehicle, including the related requirement (e.g. maximum relative velocity, maximum duration, maximum deceleration) is managed on operational level. The typical response following this specification is shown in the figure below.

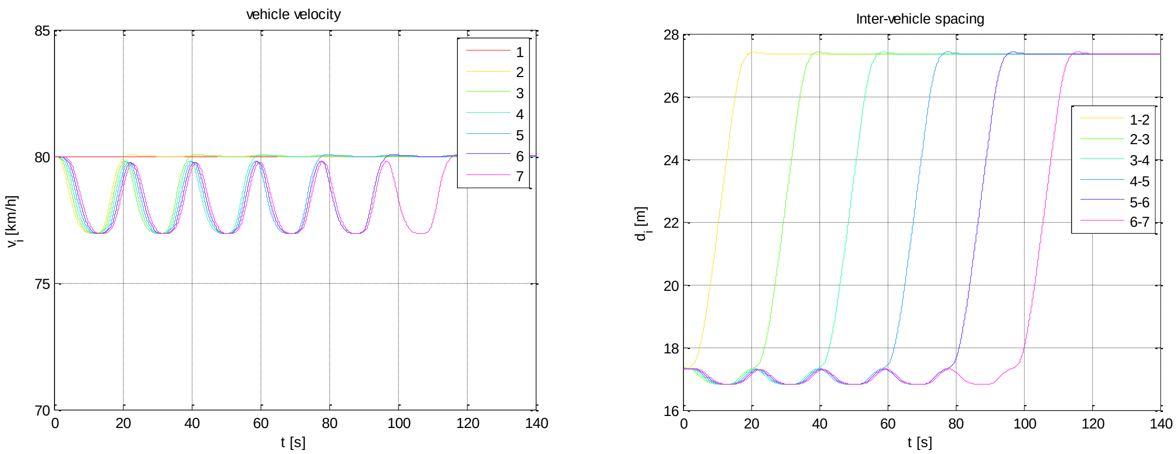


Figure 6: Time versus relative speed & gap for coordinated gap opening based on REQ: Tactical_layer_001

The second method implements a maximum speed difference with respect to the lead vehicle. After the trigger, each platoon member will start to try to open the gap but is limited by this maximum speed difference and hence only the second vehicle in the platoon will start opening the gap (to the lead vehicle). When this second vehicle has finished the gap openings and thus is speeding up again to attain the platooning speed, the second gap towards the third vehicle is opened etc. (see figure 8, below).

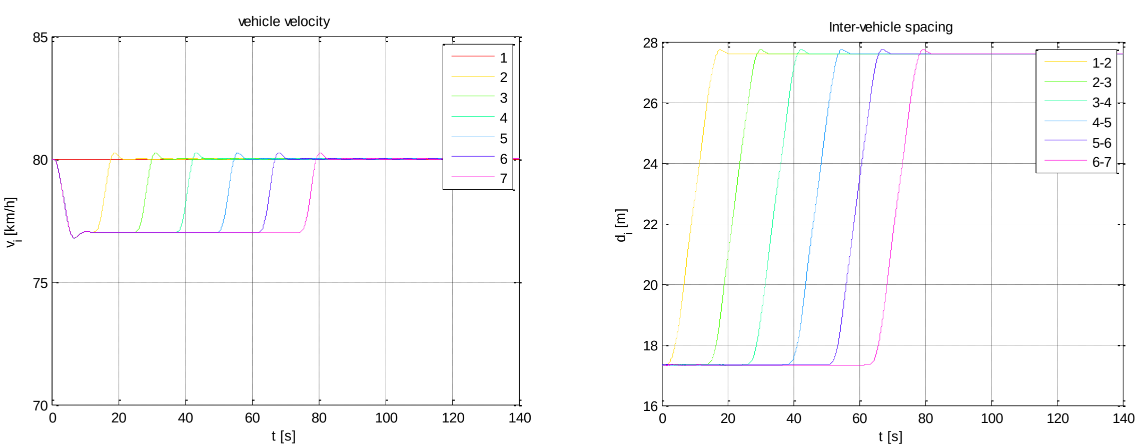


Figure 7: Time versus relative speed & gap for coordinated gap opening based on REQ: Tactical_layer_002

Comparing the methods, the benefit of method 1 is the robustness and the ease of implementation, only requiring the communication of the gap opening status together with the information that a coordinated gap opening is ongoing on platoon level. The benefit of method 2 is the reduced time it takes to open the coordinated gap, but this comes with a cost of a possibly more complex implementation of the gap opening control on operational level (e.g. considering the maximum relative velocity to the leader). During the project both methods will be implemented and further analysed and tested.

4.2 Platoon status, platoon vehicle property collection and sharing modules

Platoon status & sharing

The required platoon status & data information is gathered from requirements from HMI and the strategic & service layer functionalities. 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	Cut-in vehicle in the platoon	HMI
PS_004	Platoon set speed	HMI
PS_005	Platoon leader vehicle actual speed	Coordinated gap opening

Table 2: platoon status & data information

It must be remarked that not all information is specified in detail and Table 2 will be updated in D2.5.

The intention is to update and share the information on platoon level with a much lower rate than used for the control messages. Since this information is not time critical, the update frequency can be chosen substantially lower compared to control related V2V information. As a first guess a rate of 1 Hz is proposed.

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, Cut-in vehicle in the platoon, Platoon set speed and Platoon leader vehicle actual speed) and distribute this information over the platoon.

Tactical_layer_002: The platoon system status information gathered by the tactical layer is updated cyclically. Since this information is not time critical, the update frequency can be chosen substantially lower compared to control related V2V containers.

Note: The update frequency is initially defined to be 1 Hz. The definition of the final value will be the object of further investigations.

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.

Tactical_layer_003: The platoon system status information within the tactical layer is shared between the trucks.

Vehicle property collection & sharing

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

1) Send relevant truck information to the service & strategic layer

2) 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 and will be further explored in WP4. This list is not detailed here.

For point 2, the relevant information that needs to be shared comes from vehicle item 003 (e.g. desired maximum platoon speed).

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 3: Vehicle property collection & sharing

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

Tactical_layer_004: The platoon system over the tactical layer shares the vehicle property information (Maximum acceleration request (to the platoon), Desired maximum platoon speed), in an equal method within the platoon as the platoon status information.

One possible option 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. The current intention is to update the information on platoon level with 1 Hz.

Tactical_layer_005: The platoon system property information gathered by the tactical layer is updated cyclically. Since this information is not time critical, the update frequency can be chosen substantially lower compared to control related V2V containers.

Note: The update frequency is initially defined to be 1 Hz. The definition of the final value will be the object of further investigations.

5 COMMUNICATION MODULES & SPECIFICATIONS

5.1 Communication module via V2V

In order to implement the use-cases defined in deliverable D2.2 section 4.5 `Platooning level A use-cases' coordination of vehicle manoeuvres on a platoon level is required. This can be achieved by defining in-vehicle platoon roles and states which define the coordinated manoeuvres on a vehicle level to be performed by the platooning controller at the operational layer. In this section only, Platoon Level A implementations are considered, therefore the platoon roles and states lead to defined references for longitudinal control, which are described in detail in section 6.2.

A proposal for the coordination of vehicle level manoeuvres by management of platoon states and roles can be achieved by a state machine, which is introduced in the following section. Further information to this state machine (state-role mapping, state and role transition matrix) can be found in Appendix C.

In order to allow an interaction between the trucks within the platoon, a communication link must be established between the platoon participants. The decentralized tactical layer running locally in the trucks needs information from the other trucks. In this section, information is gathered, which must be communicated via V2V in order to conduct the use-cases defined in deliverable D2.2 section 4.5 'Platoon level A use-cases'. Whereas the reader should refer to deliverable 2.8 for a detailed specification of the V2V interface. The statements and requirements regarding V2V in this chapter mainly serve the purpose of the clarification of functional interaction.

All requirements listed below reflect the current state of discussion in the consortium and will be further refined in course of the project.

5.1.1 Vehicle State Machine considerations

A possible consideration for solving the coordination of vehicle level manoeuvres by management of platoon states and roles can be achieved by a state machine. This section describes considerations for state machine and a role (property) based on the position of the vehicle in the platoon. The state and role characterise the relation of the vehicle with respect to the next forward vehicle in the platoon and the next backward vehicle in the platoon. They define the desired control action in each scenario.

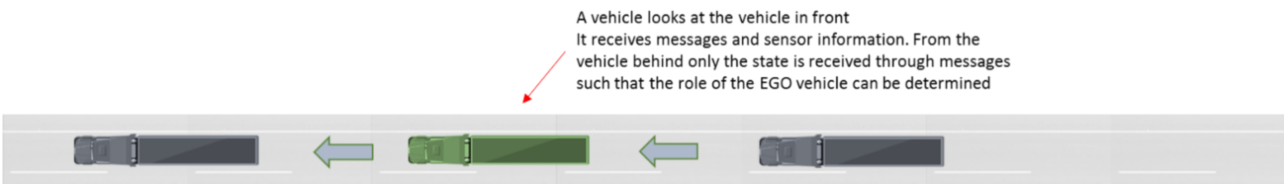


Figure 8: Vehicle platoon level - relations

Using the relation to the forward platooning vehicle (if existing) and the backward platooning vehicle (if existing) the role of the vehicle can be determined:

- Platoon candidate: not platooning with either a forward or backward vehicle
- Leader: platooning with a backward vehicle
- Trailing: platooning with a forward vehicle
- Following: platooning with a forward and backward vehicle

The states related to the main manoeuvres at vehicle level can be maintained on this level. Figure 9 provides a schematic view of the state machine containing the main states, roles and transitions. The state machine contains the following states:

- Standalone & platoon formation
- Join from behind
- Normal platooning
- Platooning standby with cut-in
- Emergency braking
- System Issue leave ("fast" gap opening towards front & backward vehicle, continue standalone if gaps are opened)
- Normal leave (gap opening towards front & backward vehicle, continue standalone)
- Normal split (gap opening towards front vehicle only, continue as leader)

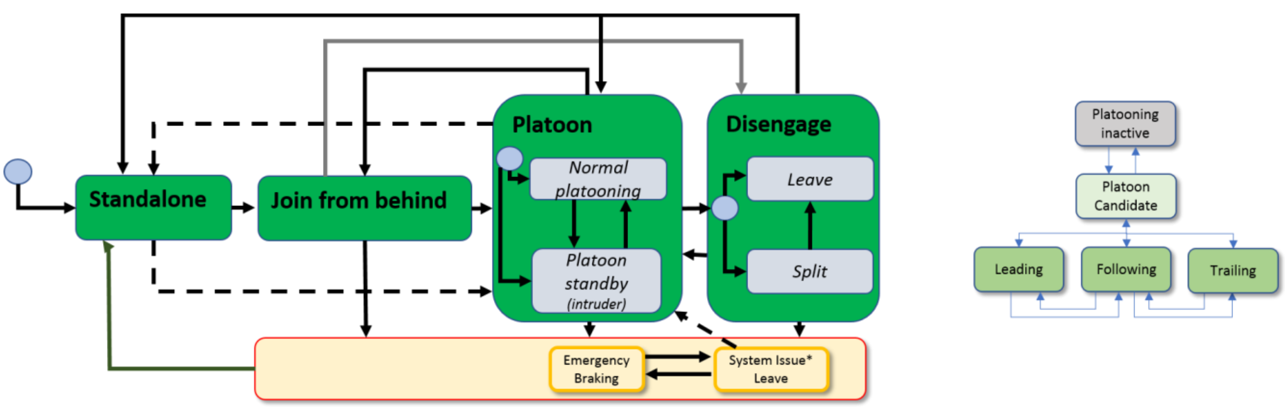


Figure 9: Platoon state machine on vehicle level

ENSEMBLE

The coordination of in-vehicle manoeuvres to perform the use-cases results from the combination of in-vehicle states and roles within the ego vehicle. In some cases, this requires different control actions corresponding to one state with respect to the current platoon role – or the position within the platoon respectively. The mapping between role and allowed states is given in Table 7 in Appendix C. It is assumed that there is at least a direct V2V communication between the ego vehicle and its next neighbouring preceding and following vehicle (see also deliverable D2.8). Furthermore, it is assumed, that by activating the platooning function the driver agrees to all role and state changes during activation and each driver can leave the platoon via HMI interaction at any time as it is described in section 6.1. Therefore e.g. in case of a change from follower to leader role no driver confirmation of the driver is necessary.

Remarks:
The coordination of vehicle specific manoeuvres to implement platooning use-cases is obtained by the interaction of decentralised in-vehicle state-machines, where platooning states and platooning roles at a vehicle level are defined and the transitions between those states and roles define the corresponding control action of each vehicle.

The interaction of in-vehicle state machines required for manoeuvre coordination is based on direct V2V communication between the ego vehicle and (if available) the next preceding platoon vehicle and (if available) the next following platoon vehicle. The required communication is based on the signals defined for CAM+, PCM and PMM messages (see Deliverable D2.8). For interactions that require awareness of information in the whole platoon additional signals are defined

The manoeuvre coordination based on in-vehicle state machines considers the driver's HMI inputs. By activating the platooning system, the driver agrees to all future state and role changes during activation time, but each driver can switch off platooning via HMI interface at any time.

As the ego vehicle joins a platoon in follower or trailing truck position, the gap to the preceding vehicle will switch from a safe gap for standalone operation to the target gap for platoon control. If there are no driver overrides take-over events between driver and platoon, driver control shall take place only after the safe gap has been restored by automatic control.

Depending on the position of the ego vehicle relative to surrounding platoon candidates and/or members, the in-vehicle platoon role can switch between the roles 'Platooning inactive, 'Platoon candidate', 'Leading', 'Following' and 'Trailing'.

5.1.2. Specifications linked to use cases

As it is described in the previous section the implementation of the use-cases described in deliverable D2.2 section 4.5 'Platoon level A use-cases' requires coordination of vehicle manoeuvres by means of interaction between in-vehicle state-machines using V2V-communication. In this section different use-cases are described with focus on this information exchange in order to specify the required V2V information flow by explicitly defining the content and sending direction of the information in each case. The general description in this section is complemented by more detailed list of contents including sender and receiver in the tables in Appendix D. This information should be understood complementary to the V2V requirements specification in deliverable D2.8.

Platooning

Among the use-cases listed in deliverable D2.2 the use-case platooning contains 2 sub use-cases, namely the 'Steady state platooning' (use-case ID 3.1), and the emergency braking use-case (use-case ID 3.2.1) which are linked to the modules and specifications.

Steady state platooning

The first use-case which will be dealt with, is the use-case of steady state platooning derived from deliverable D2.2 section 4.5.3 'Steady State Platooning'. In the first sequence of this 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). If the ego vehicle is the leading truck, it shall at least receive V2V messages from the first following vehicle or trailing truck in case of a two-vehicle platoon. In case of the trailing truck, the ego vehicle shall receive platooning information at least from the neighbouring preceding platoon vehicle. If the ego vehicle is a following truck, it shall receive V2V information at least from next preceding and the next following platoon member. For a more detailed description of the information flow in this use-case refer to Table 10 in Appendix D.

Interaction_of_the_trucks_001: The platoon system in the ego vehicle shall receive platooning information via V2V needed to maintain the platooning time gap, for platoon cohesion and for platoon standby from vehicles in the platoon.
(At least from the one in front for the trailing truck and from the one to the back for the leading truck and the one in front and to the back for the following truck)

Interaction_of_the_trucks_002: The platoon system in the ego vehicle shall broadcast the platooning information via V2V, which is needed by the other platoon members' control system.

Emergency braking

In addition to the information to be transmitted during steady-state platooning as described in the previous section and Table 10, in an emergency braking situation all following platoon members with respect to the vehicle initiating the emergency braking should be aware of the ongoing braking manoeuvre. Therefore at least the actual and intended brake deceleration must be broadcasted. This way each vehicle can detect an emergency braking manoeuvre by comparing the received deceleration value to a (still to be defined in course of the project) certain threshold. Furthermore, as the ego vehicle needs to brake at least equally strong, it must broadcast its own actual and intended deceleration to its followers. A list containing the information transmitted between the vehicles via V2V in this use-case is contained in Table 11.

Interaction_of_the_trucks_003: The platoon system in the ego vehicle shall be informed in case of emergency braking events of the preceding platoon vehicle(s). Therefore at least the requested and actual acceleration value of the preceding platoon vehicle must be received and to be compared with a defined acceleration threshold of -4 m/s².

Further project activities as e.g. functional safety analysis will show whether an additional emergency braking flag is needed.

Interaction_of_the_trucks_004: The platoon system in the ego vehicle shall broadcast its actual and intended acceleration via V2V to enable following vehicles to detect emergency braking events.

Further project activities as e.g. functional safety analysis will show whether an additional emergency braking flag is needed.

Leave by trailing truck

While the Platoon is active, the ego vehicle starts the leaving procedure. The system broadcasts its intention to leave the platoon via V2V and increases the inter-vehicle time gap to a safe gap towards the preceding vehicle and, when it is reached, gives back the control to the driver. The safe gap shall not necessarily be understood as “legal safe gap” as there are different regulations in different countries. The definition of this value will be an objective of functional safety analysis (see D2.5). The completion of the disengagement is broadcasted, before afterwards platoon messaging is stopped. More detailed information regarding the V2V information flow in this use case is provided in Table 12 (Appendix D).

Interaction_of_the_trucks_005: The platoon system of the ego vehicle shall broadcast its intention of leaving the platoon through V2V communication.

Interaction_of_the_trucks_006: When the ego vehicle has reached the safe gap in the disengagement procedure, the platoon system in the ego vehicle shall broadcast this information.

Interaction_of_the_trucks_007: When the disengagement procedure is finished, the platoon system of the ego vehicle shall disconnect the platooning specific communication.

Leave by leading truck

If the leading vehicle's driver decides to leave the platoon, the leading vehicle's platooning system broadcasts its intention to leave at first. The first following vehicle system then increases the inter-vehicle time gap towards the leading vehicle until the safe gap is restored. The following vehicle confirms the completion of gap opening via V2V. The former leading vehicle continues to drive in standalone state and disconnects the platoon specific communication. Without any further HMI interaction, the former first following vehicle becomes the new leading vehicle. It is to be clarified in course of upcoming project activities whether this leading vehicle change requires re-negotiating keys or changes in V2V channels. A detailed list of the V2V information flow in this use case is contained in Table 13 (Appendix D)

Interaction_of_the_trucks_008: When the first following vehicle has reached the safe gap (SG) in the disengagement procedure, the platoon system of the ego vehicle shall receive this information from the first following vehicle.

Meanwhile the other truck platooning members continue as a new platoon, where the first following vehicle takes over the role of the leading truck in the platoon.

Interaction_of_the_trucks_009: When the disengagement procedure is finished the remaining platoon continues with the former first following vehicle becoming the new leading vehicle.

Note: Implications on V2V keys and channels must be clarified in future project activities.

Leave by following truck

In this use case the leaving vehicle first broadcasts its intention to leave. It automatically enlarges the gap towards the platooning vehicle ahead, while the next following vehicle increases the gap to the leaving vehicle. When the SG is restored towards both directions the leaving vehicle can disconnect from platooning specific communication and continue driving in standalone state. This use-case is completely covered by the requirements derived for the two preceding use cases (see sections 0 0). Nevertheless, in Appendix D Table 14 the V2V information flow in this use case is given to provide a better understanding.

Split (following truck) and Cut-In (long time)

In the split use-case one of the follower vehicles (not the leader nor the trailer vehicle) starts the split procedure. One possible trigger can be an external demand (e.g. by the strategic layer). With respect to the V2V information flow this use-case is very similar to the 'Leave by following truck' use case. The main two differences are, that only the ego vehicle needs to enlarge the gap after broadcasting its intention to leave, and that after completion of "disengagement" the ego vehicle cannot disconnect from platooning specific communication since it continues operating as the leading vehicle of the second part of the initial platoon. Furthermore, in this use case the split procedure is broadcasted as reason to leave to allow the following vehicle to recognize that there is no need to enlarge the gap towards the ego vehicle. This starting of the splitting procedure must be broadcasted to the truck in front. For a more detailed summary on the information flow in this use-case refer to Table 15.

Interaction_of_the_trucks_010: The platoon system of the ego vehicle shall broadcast the start of the splitting procedure. This request must be distinct from a following vehicle's leave request to make sure the next following vehicle does not enlarge the gap towards the ego vehicle.

Note: Implications on V2V keys and channels due to switching leaders of the remaining platoon must be clarified in future project activities.

Another possible trigger for an automatic platoon splits by an intruder event, although this is not yet definitely specified. Possible trigger conditions could be a communication loss due to an intruding vehicle or exceeding an intruder lifetime limit. In this case the split procedure follows the description above, the only difference is that the ego vehicle must broadcast the existence of the intruder (including its distance, relative speed) in order to obtain awareness of the other drivers.

Interaction_of_the_trucks_011: The platoon system in the ego vehicle shall broadcast a cut-in when detected.

5.2 Communication modules via V2I

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 provide data from the infrastructure to keep platoons together as much as possible, and to keep all vehicles safe (platoons and vehicles surrounding them). Because not all OEM's have virtual maps systems and because in level A the platooning cloud back end, Road Side Unit have been selected for the implementation of infrastructure communication for the ENSEMBLE project for Platoon Level A. The first set of requirements is related to communication between the platoons and the road side units.

5.2.1 Specifications linked to use cases

Linking to D2.2, these requirements align with use case ID 3.4.1 (Platoon gap adaptation) and with considering event type E4 (Limit received via I2V).

Zone policy publication

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)

The objective is to be able to communicate limitations / advices on driving policies such as maximum speed and inter distance between vehicles based on real-time data (traffic conditions, traffic incidents, weather information, road conditions). Potential additional information on vehicle trajectory and lateral displacement can be progressively added with platoons beyond level A. This requirement is for example valid for toll zones: in this case, the objective is to get the pre-information by positioning the RSU in advance, to plan properly the reduction of power and avoid emergency breaking at the toll zone.

Zone policy update

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).

The objective is to ensure that the information communicated via RSU is up to date (refresh period to be defined). The second set of requirements is related to implementing the outcomes from the previous communication by individual vehicles.

Implementation by the platoon: update of maximum speed

The objective is to ensure that the information communicated via RSU is implemented by individual vehicles - for Level A, for safety purposes, this includes a validation by the driver.

REQ: Interaction_with_Infrastructure_003: Ability for the individual vehicles of the platoon to adjust speed based on zone policy. For level A, this will be implemented by a display on the HMI

Implementation by the platoon: update of inter-distance

The objective is to ensure that the information communicated via RSU is implemented by individual vehicles - for Level A, for safety purposes, this includes a validation by the driver.

REQ: Interaction_with_Infrastructure_004: Ability for the individual vehicles of the platoon to adjust interdistance based on zone policy. For level A, this will be implemented by a display on the HMI

6 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 Level A 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 Level A 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 Platoon Level A 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 the state machine will be described below in subsections 6.2, 6.3, 6.4 and 6.5 respectively.

For the platooning testing and demonstration, it is planned to use the actuators which are present in state-of-the-art vehicles. Thus, there are no specific requirements for the time being. This could change over time once the results of the HARA and SOTIF analysis are available from D2.12: Hazard Analysis and Risk Assessment and Functional Safety Concept and D2.14: SOTIF Safety Concept. The communication requirements are already documented in the deliverables D2.6 and D2.8 for V2I and V2V respectively.

6.1 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 E) were developed to complement the of 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 E. Based on these three steps a first draft of a common HMI-logic was developed following the main functionalities in the Use Cases in and was circulated to the partners in ENSEMBLE for input and further discussed in three Skype meetings. The HMI-logic was thoroughly discussed and reviewed in two-day face-to-face workshop with ENSEMBLE partners in the HMI-group.

6.1.1. 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 platoon system and still allow for OEM specific solutions. The common HMI-logic for platoon level A should function as the “lowest common denominator” for the HMI-design for platooning, regardless truck brand.

The HMI logic for platoon level A in the tables below consists of three items:

1. The HMI-logic described in terms of Driver input (buttons, levers and other driver control devices etc.) and System Output (displays, icons, text messages etc.) in specific use cases (see also Table 5).
2. HMI requirements (in the red boxes)
3. Generic graphical user interfaces (GUI)- Figure 11 showing how the Driver input (touch) and System Output can be represented. Please note, the GUI is not OEM-representative.

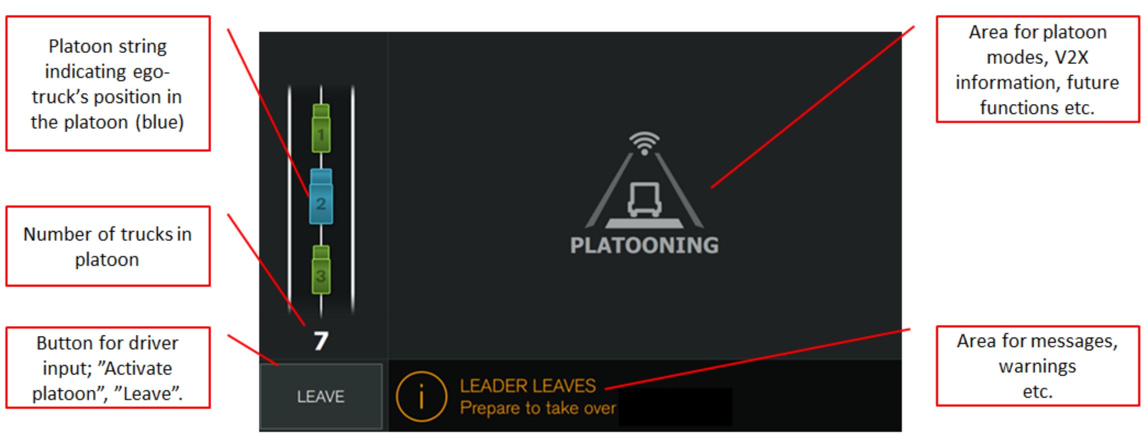


Figure 10: The generic graphical user interface

Driver Input (to the system)	Comment
Manual lateral control	The driver is in lateral control, i.e. steering.
Activate system longitudinal control	The driver activates the longitudinal control, which is a prerequisite for platooning.
Activate platoon	The driver activates the platoon mode which starts the *Platoon Formation process*
Leave platoon	The driver leaves the platoon deactivates the platoon mode
Gap adjustments	The driver can change the gap to the vehicle in front (not shorter than the safe distance defined by the platoon system).
System Output (to the driver)	**Comment**
Number of trucks in the platoon	Information about the size of the whole platoon. Important aspect of being part of a platoon and to understand the behaviour of the platoon.
Ego-truck position in the platoon	Information to the driver to understand the roles and tasks in the platoon.
Cut-in indicator	Information about other vehicles that cut in in the platoon and when these vehicles leave the platoon. The cut-ins affect the speed and gaps.
Gap adjustments	Changes in gaps, e.g. due to Cut-ins. Important information to keep the driver in-the-loop.
On-going platoon mode, for example: • Formation • Engage • Steady state • Cut-in/out • Leave	information about the current mode to keep the driver in-the-loop and to maintain mode-awareness.
Messages to the driver e.g. • Take over manual control • Emergency brake • Warning messages	Information to keep the driver in-the-loop and to maintain role & task awareness.

Table 4: Overview of the main modules in the common HMI-logic, platoon level A.

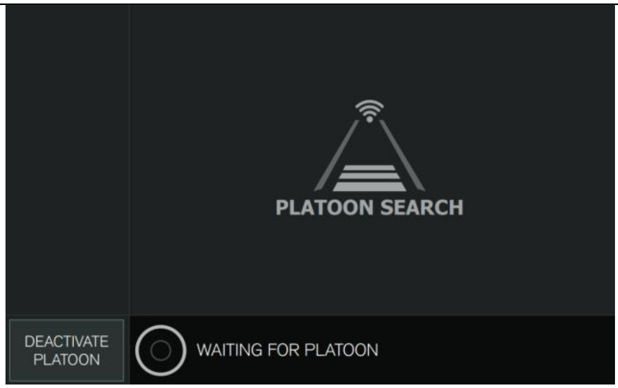
The HMI-logic for platooning level A and the connected HMI-requirements should be regarded as a working document and subject for changes as knowledge and experience are gained in the field of platooning, Moreover, The HMI-logic does not specify:

- Which or what kind of devices, displays, interaction modes etc. for driver input and for System output to the driver
- Placement of driver input and system output to the driver, for example buttons, stalks, instrument cluster, secondary displays etc.
- Specific symbols, messages, colour schemes, arrangements of information to the driver

Linked Use Case	Driver input (to the system)	System output (to the driver)	Generic Example
1.1 Platoon formation		Truck specified for platooning	

HMI_001: The driver in a platoon should be able to recognize that the ego-truck has a platoon feature.

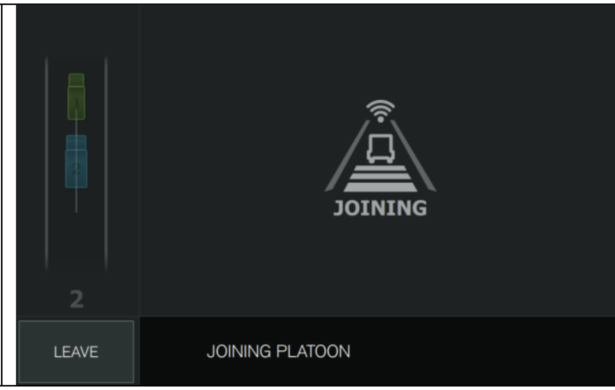
Linked Use Case	Driver input (to the system)	System output (to the driver)	Generic Example
1.2 Platoon formation	• Manual lateral control • Driver activates platoon mode. Two alternatives: 1. Driver activates ACC, which also activates the platoon mode. 2. Driver activates Platoon Mode (a button or similar) which also activates the CACC. • Cancel: The driver can cancel the ego-truck's formation process with a dedicated button-press or by inactivating the system longitudinal control (ACC).	• Ego-truck CACC, V2X status • Activate platoon • Platoon mode activated ⟶ Platoon system state: Formation in process; System searching for other platoon trucks. • When platoon truck found ⟶ Engage/Join Ego-truck Leave (button) • Deactivate platoon device, for example a button-press or with the system longitudinal control (ACC) device.	Driver activates Platoon mode 

			 Platoon mode activated

HMI_002: The driver in a platoon can activate the platoon mode at any time. The system determines *if* and *when* parameters are met to start the search for other platoon trucks.

HMI_003: The driver in a platoon can deactivate, cancel the formation and leave the platoon at any moment.

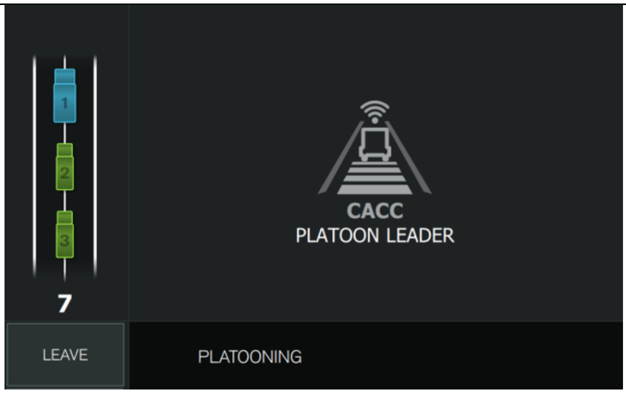
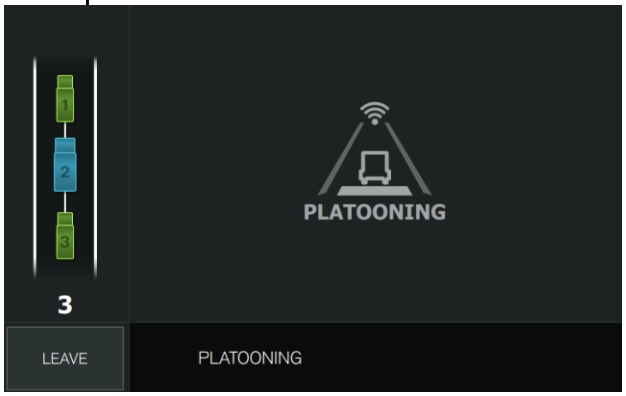
Linked Use Case	Driver input (to the system)	System output (to the driver)	Generic Example
2.1 Join from behind by single vehicle	• Manual lateral control. • Leave: The driver can always cancel the engaging process by pressing, for example a "Leave"-button.	• Ego-truck CACC, V2X status • Platoon System state: Platoon engage in in process • Platoon set speed • Ego-truck gap adjustments to truck in front (by the system). • Ego-truck Leave, for example a button	Platoon formation. Pending platoon-info

REQ_HMI_004: The driver in a platoon shall be informed about the reasons to the speed and gap adjustments.

inked Use Case	Driver input (to the system)	System output (to the driver)	Generic Example
2.2 Merge from behind by platoon	See UC 2.1	See UC 2.1	

Linked Use Case	Driver input (to the system)	System output (to the driver)	Generic Example
3.1 Steady state platooning	• Manual lateral control • Lead-truck: System longitudinal control (CACC) or manual	• Ego-truck CACC, V2X status • Platoon System state: Steady state (Platooning). • Number of trucks in the platoon	Platooning; Lead-truck, seven trucks in the platoon

	longitudinal control. • Follow-truck: System longitudinal control (CACC) • Follow-truck: Adjustments of the distance to the vehicle in front.	• Ego-truck position in the platoon • Ego-truck gap adjustments to truck in front (by the system). • Ego-truck Leave, for example a button	 Platooning; Follow-truck, Position 2, Three trucks in the platoon. 

HMI_005: The driver in a platoon shall be able to adjust the gap to the vehicle in front.

HMI_006. The driver in a platoon shall be informed about the ego-truck's position in the platoon.

HMI_007. The driver in a platoon shall be informed about the total number of trucks in the platoon.

HMI_008. The driver in a platoon shall be informed his role in the platoon driving as Lead-, Follow, or as Trailing driver.

HMI_009: The driver in a platoon shall be informed about the platooning active mode status in the ego-truck

HMI_010: The driver in a platoon shall be informed about platooning system failures and their causes.

HMI_011: The driver in a platoon shall be informed about imminent and on-going procedures in the ego-truck (Formation, Engage, Steady state, Speed and gap changes, Cut-ins, Emergency brake, System warnings)

Linked Use Case	Driver input (to the system)	System output (to the driver)	Generic Example
3.1.1 Follow to stop main flow	See Use Case 3.1	See Use Case 3.1 • Platoon System state: Information about the on-going process. • Information to driver if necessary, to take manual longitudinal control.	

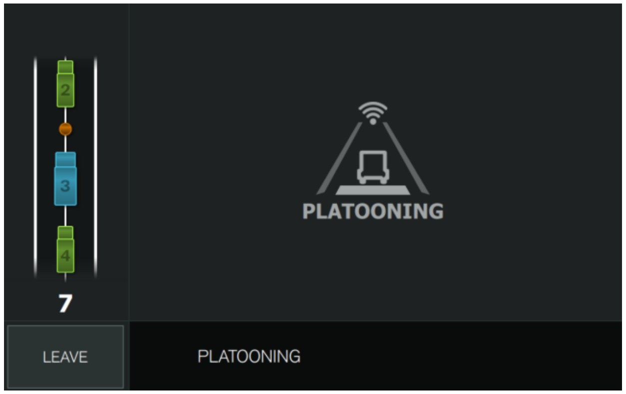
Linked Use Case	Driver input (to the system)	System output (to the driver)	Generic Example

3.2 Emergency braking	See Use Case 3.1 •In case of a false Emergency brake the driver can overrule. • The driver can resume platooning, see UC 1.2 Platoon Formation	See Use Case 3.1 • Platoon System state: Alert the driver about the Emergency braking. • Activate platoon device, for example a button	Message about on-going Emergency brake. Platoon system off (shadowed). Driver can resume platoon mode (“Activate platoon”) 

HMI_012: The Driver in the platoon shall be warned in case of an Emergency brake situation.

Linked Use Case	Driver input (to the system)	System output (to the driver)	Generic Example
3.3.1 Platoon gap adaptation because of I2V interaction	See Use Case 3.1 and 3.3.2	See Use Case 3.1, 3.3.4 • Platoon System state: Information about the on-going gap adjustments	

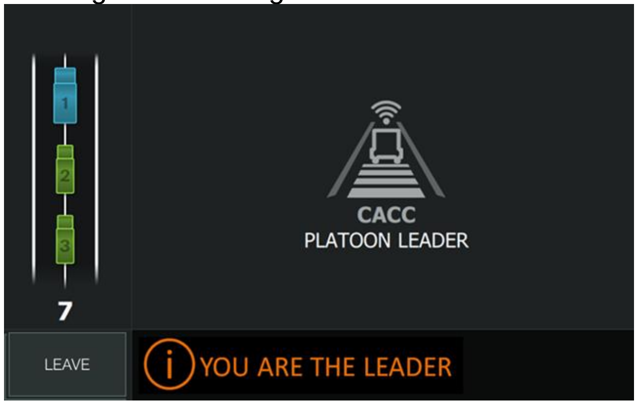
HMI_004: The driver in a platoon shall be informed about the reasons to speed and gap adjustments.

Linked Use Case	Driver input (to the system)	System output (to the driver)	Generic Example
3.3.3 Cut in vehicle remains for a short period (cut-out).	See Use Cases 2.1, 3.1 System output to driver: • Ego-truck: Cut-in indicator; position of the Cut-in in the platoon • Ego-truck Gap adjustments to truck in front (by the system).	See Use Case 3.1 • Platoon System state: Cut-in in process • Ego-truck CACC status, V2X status • Cut-in indicator; position of the Cut-in in the platoon. • Gap adjustments to vehicle in front (by the system). • Ego-truck Leave, for example a button	Cut-in Indicator 

HMI_013: The drivers in a platoon shall be informed about detection of incoming vehicle (cut-in).

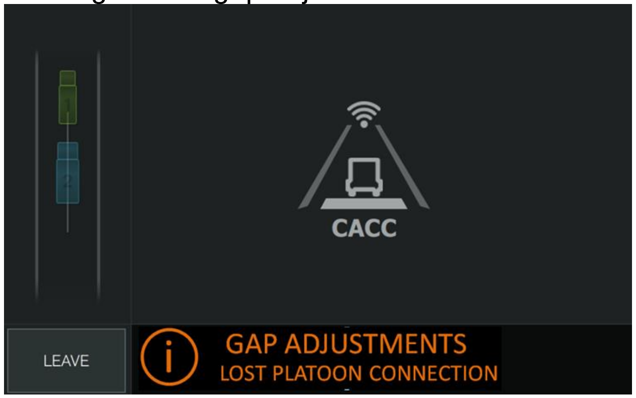
HMI_004: The drivers in a platoon shall be informed about the reasons to speed and gap adjustments.

Linked Use Case	Driver input (to the system)	System output (to the driver)	Generic Example

3.3.2 Cut in vehicle remains for a long period.	See Use Cases 2.1 and 3.1	See Use Case 3.1 • Platoon System state: "Long" Cut-in in process • Cut-in indicator • Gap adjustments by the system • First truck behind the cut-in: Info about becoming the new Lead-truck • New platoon configuration • Ego-truck Leave, for example a button	Message about being new Lead-truck 

HMI_013: The driver in a platoon shall be informed about detection of incoming vehicle (cut-in).

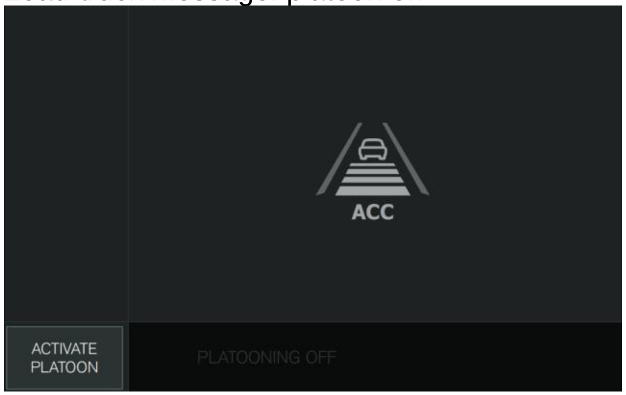
HMI_004: The driver in a platoon shall be informed about the reasons to speed and gap adjustments.

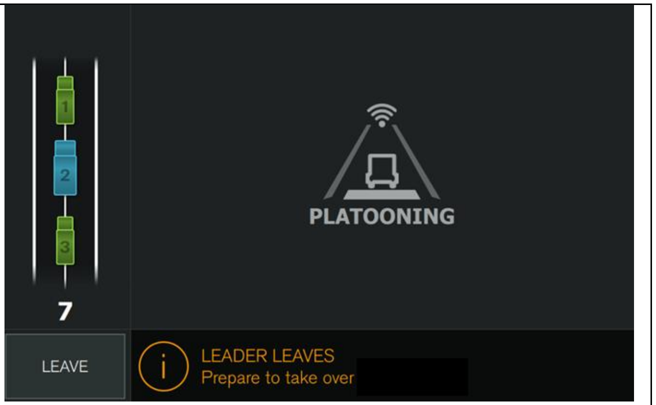
Linked Use Case	Driver input (to the system)	System output (to the driver)	Generic Example
3.3.4 Platoon time gap adaptation because of system status (e.g. packet loss)	See Use Case 3.1	See Use Case 3.1 • Platoon System state: Information about the reason for the gap adjustments, e.g. Loss of V2X • Information to driver if necessary, to take manual longitudinal control.	Message about gap adjustments 

REQ_HMI_004: The driver in a platoon shall be informed about the reasons to speed and gap adjustments.

REQ_HMI_009: The driver in a platoon shall be informed about the platooning active mode status in the ego-truck

Linked Use Case	Driver input (to the system)	System output (to the driver)	Generic Example
3.5.1 Leaving Platoon by trailing truck	**See Use Case 3.5.3**	**See Use Case 3.5.3**	

Linked Use Case	**Driver input (to the system)**	**System output (to the driver)**	**Generic Example**
3.5.2 Leaving Platoon by leading truck	• Manual lateral control • Leave, for example a button press	• Platoon System state: ego-truck Leaving in process • Ego-truck CACC status, V2X status • Ego-truck Leave (button) • Ego-truck: Feedback on the Leave press • Ego-truck Leaving truck: Platoon information off First Follow-truck: • Platoon System state: Lead truck Leaving in process • Ego-truck gap adjustments to vehicle in front (by the system). • First Follow-truck prepared to be new Lead-truck • New platoon configuration • Ego-truck Leave, for example a button	Lead-truck driver leaves the platoon  Lead-truck message: platoon off  First Follow-truck message → new Lead-truck

Linked Use Case	Driver input (to the system)	System output (to the driver)	Generic Example
3.5.3 Leaving Platoon by follower truck	• Manual lateral control • Leave, for example a button press	• Ego-truck CACC status, V2X status • Ego-truck: Feedback on the Leave press • Platoon set speed • Ego-truck: Gap adjustments by the system to vehicle in front. • Ego-truck Leave truck: Platoon information off. • Information to the truck behind the leaving about the "Leave" • New platoon configuration • Ego-truck Leave, for example a button	Follow-truck leaves 

6.1.2. Requirements related to driver and system roles and tasks

In a future scenario with platooning as an integrated part of the road transport system, truck drivers will face multiple roles; driving as a single individual driver (as today) and driving as part of a platoon either as a Lead-truck driver and/or as a Follow- truck driver. Based on the assumption that drivers will shift between these roles frequently during the same route, there should be from a cognitive point of view only minor and not critical differences between these roles and tasks required by the drivers. The reason is to avoid demanding and complex transitions between the roles and tasks. Major and frequent differences in the roles and tasks would require major changes in the drivers' mental models of driving, which would be cognitively demanding and cause role- and task confusion. In addition, minor differences in the roles and tasks are advantageous because it allows for consistent HMI for "regular" driving as well as for platoon driving. Driving in platoon involves two main driver roles:

- Lead-truck driver, who can use ACC or other longitudinal control provided by the platooning system in Steady State.
- Follow- and Trailer-truck driver, who needs to use the CACC or other longitudinal control provided by the platoon system.

The drivers in platoon level A are driving under the same conditions as when not driving in platoon, for example to keep legal speed limits, adjust their driving to the current situation, be observant to the surrounding traffic and keep track the navigation/route to reach the destination etc. Driving as the Lead-truck driver should not include the task to safeguard the whole platoon. The platoon system for level A has the tasks to manage the functional safety of the longitudinal control and to prevent and mitigate critical events, e.g. by keeping ADAS active, defining threshold values that trigger distance and speed adjustments in the platoon, activating emergency brake etc.

6.1.3. Driver needs and challenges in platoon

A comprehensive understanding of driver needs and the challenges the drivers may face in platooning is important in order to develop an HMI-system that can support and enhance the usefulness, usability and safety of platoon driving. However, there is limited knowledge about driver needs regarding platoons as well as driver behaviour, acceptance, cognitive workload, situational awareness etc. connected to driving in platoons. Data from platooning is mainly gained from driving on test tracks and in driving simulators, while data from platooning in real traffic environments is scarce. This section presents a summary of the results from interviews with in total 20 test truck drivers driving in different platoons in real traffic environments These platoons had cruise speeds between 80 and 100 km/h, the gaps were around 1 s, driving with three trucks in the platoons and most of the time with system longitudinal control and manual lateral control. The information presented here should be regarded as insights and indications for future studies about platoon drivers' needs.

The drivers' first impressions often reflected their unfamiliarity with the platoon concept ("*Very different from what you are used to, "It was scary in the beginning", "You didn't know if you could trust the system")*. Later the drivers got more accustomed with driving in platoon ("*You* *got used to it", "You saw that it worked, which made you feel confident", "You got a sense of ease after a while".*

A key-factor for the drivers' acceptance of the platoon system was Trust, which was based on three elements:

1. The quality of the system, i.e. not malfunctioning, meeting expectations, working as intended
2. Time and mileage driven in platoon
3. Knowing your co-drivers in the platoon, e.g. how they handled cut-ins, how they did lane changes, how they communicate (via radio) etc.

Situations that were recognized as critical by the platoon drivers:

- Cut-ins
    - Other non-platooning trucks often remained in the platoon, presumably to take advantage of the benefits of the platoon (fuel savings), but without being a platoon truck.
    - Cars, but they left quite soon (they wanted to drive faster than the platoon). Cars overtaking in" sequences" caused series of cut-ins
- Short Entry/Exit:
    - Difficult to" synch" with other vehicles that entered the highway
    - Short exits were difficult to see due to the short gap between the trucks, ("*You need to synch to allow other vehicles to entry the highway").*
- Obstacles partly in the lane
    - For example, a follow-truck could not see a car standing close to the lane. The Lead-truck driver used the radio communication to alert the other drivers in the platoon.
- Dense traffic situations
    - Made all the situations mentioned above more critical.

Several platoon drivers had access to verbal communication with each other via radio. This communication was perceived as important for the safety of the platoon and to keep the platoon together. For example, the Lead-truck drivers informed about upcoming events (slow moving vehicles, queues, obstacles etc.) and the Follow-truck drivers informed about vehicles overtaking the platoon, cut-ins etc. The communication via the radio was also frequently used to inform each other about the route.

However, verbal communication between drivers in a platoon is probably not feasible in an international transport system, since drivers of different nationalities speaking different languages most likely have difficulties to understand each other. Therefore, the function of the verbal communication needs to be addressed with other means.

6.2 Longitudinal Control module

This subsection describes the minimum requirements needed for safe and fuel-efficient longitudinal control in a Level A platoon while still leaving room for flexibility and vehicle specific control strategies. The most important goal for the longitudinal control of the platoon vehicles in Level A is to assure safety. The system needs to be able to handle all foreseeable events regarding longitudinal control in a safe way. This above all means to be able 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.

6.2.1. Requirements linked to use cases

To being able to fulfil the use cases, several functionalities regarding longitudinal control have been addressed. See Table 2 for connection between use cases and needed functionalities. Requirements for the functionalities are described in the subsequent subsections.

Functionality	Functionality description	Linked Use Case
Time gap selection	Requirements for how the minimum inter vehicle time gap is selected	3.1 Steady state platooning 3.4.2/3.4.3 Cut in (long/short time) 3.4.4 Platoon time gap adaptation because of system status (e.g. packet loss)
Braking	Requirements for safely handling braking in the platoon	3.1 Steady state platooning 3.2 Follow to stop (&go) 3.3 Emergency braking
Time gap increase	Requirements for how to increase the inter vehicle time gap in a safe way	3.1 Steady state platooning 3.4.1 Platoon gap adaptation because of I2V interaction 3.4.4 Platoon time gap adaptation because of system status (e.g. packet loss) 3.5.1 Leaving platoon 3.5.2 Split platoon
Platoon cohesion	Requirements for how to close gaps and keep the platoon together	2.1 Join from behind by single vehicle/Merge from behind by existing platoon 3.1 Steady state platooning 3.4.1 Platoon gap adaptation because of I2V interaction 3.4.3 Cut in (short time) 3.4.4 Platoon time gap adaptation because of system status (e.g. packet loss)

Table 5: Longitudinal control functionalities and use cases mapping

Time gap selection

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

Long_Control_001: The system shall keep a time gap to the preceding vehicle such that it can avoid collision if the preceding vehicle is braking to standstill with its maximum deceleration capacity.

Long_Control_002: The system shall communicate the ego vehicle maximum brake deceleration capacity on dry asphalt* to the following vehicle. If the capacity is unknown, a value of 8 m/s² can be used instead.
**To be specified more in detail.*

Long_Control_003: The system shall never keep a closer time gap than 0.8 s to the preceding vehicle in the platoon. Time gap is here defined as the distance to the preceding vehicle divided by the ego vehicle speed.

Long_Control_004: 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.

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.

Long_Control_005: The system shall communicate the current brake acceleration of the ego vehicle and the current brake acceleration request actuated by the brake system, to the following vehicle. These shall always be communicated, irrespective whether the system or the ego vehicle driver is requesting the braking.

Note: Both requested and actual acceleration are needed in order to react quicker than with only sensor measurements during braking and get a better prediction of the preceding vehicle behaviour (for example if the requested acceleration differs from the actual acceleration).

Long_Control_006: 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.

Long_Control_007: The system shall not brake with a deceleration that is higher (stronger braking) than the maximum brake deceleration capacity communicated to the other platoon vehicles.

Time gap increase

Another safety issue to address is the increase of 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, increase 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.

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 3 km/h and the maximum deceleration shall be 3 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. The values for maximum relative speed and deceleration are to be evaluated at simulation, testing and safety analysis.

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.

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).

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).*

6.3 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 modules 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. 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 Level A platooning. 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 can also be useful in determining the position on a highway and whether the current and upcoming segments of highway are suitable for platooning.

Optional

a) 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.
b) 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**
Distance	++	o	++	o

Velocity	++	0	++	-

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 10m. The data is typically available every 0.5 - 1.0s. 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 table below highlights which technology offers the required data in the required accuracy

6.3.1 Requirements linked to use cases

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. The parameter mentioned in the sensing requirements are currently derived from state-of-the-art automatic emergency brake assistants since there is currently insufficient data available from actual platooning testing. These parameters could change over time as further platooning testing is done in this or other projects.

SENS_001: During platoon formation the platoon system vehicle shall detect preceding vehicles and measure the position of these with a longitudinal accuracy of 0.4m and a range of 100m

SENS_002: During engaging, platooning and disengaging the platoon system vehicle shall detect the preceding vehicle and measure the position of this with a longitudinal accuracy of 0.4m.

SENS_003: During platooning the vehicle shall detect cut in vehicles as these intrude in the direct path (width of path = vehicle width) of the ego vehicle at a minimum distance of 1m.

SENS_004: During all phases of platooning the platoon system vehicle shall measure the velocity of vehicles in the field of view with an accuracy of 0.4km/h with a range of +300…-90km/h

SENS_005: The cycle time of the velocity and distance measurements shall be 50ms

SENS_006: The platoon system vehicle shall be able to measure its lateral and longitudinal position to an accuracy of 10m

7 CONCLUSION AND NEXT STEPS

This deliverable set up the requirements and specifications for the white-label multi-brand truck platooning supported by the 6 European truck manufacturers and by the automotive European suppliers. The definition of the specifications of the whole multi-brand truck platooning concept need to be put in relation to the functional safety analysis and SOTIF to be developed in D2.12 in order to assure that the white-label truck platooning modules can function safely during normal operations and system failures. Since these activities will not only define requirements to deal with hazards arising from E/E malfunctions but also address hazards resulting from performance limitations or insufficiencies of the function itself, the safety activities carried out for the project are considered comprehensive enough to have safe platooning deployment on public roads. Platoon Level A final definition will include all these outcome and results and delivered in D2.5

As regards the tactical layer, the definition of activation conditions for coordinated gap opening is still open and needs to be further defined in the course of the ongoing project. The report describes two possible methods either by sequentially opening the gap while maintaining a maximum allowed delta speed with respect to the respective preceding vehicle, or by synchronously opening the gap between all vehicles while maintaining a maximum allowed delta speed with respect to the leading vehicle.

Regarding the communication module of V2V, implications on V2V keys and channels due to switching leaders of the remaining platoon needs to further be defined for the disengagement procedure (leave by leading truck, split and cut in use cases). Moreover, for the communication module of V2I, an important issue is that regulation and requirements by the road authorities and member states might also generate additional requirements and might impact testing and verification of trucks platooning systems on the roads. In the second quarter of 2019, the project has foreseen to organize a common workshop among the European Truck Platooning challenge (ETPC), C-Roads Platform, CONCORDA, CEDR in order to validate the ENSEMBLE requirements and to ensure convergence and agreement on the V2I message protocol set to be selected and ultimately suggest a unique proposal for the European Commission.

For Platoon level A, longitudinal control (incl. Emergency Braking) is currently managed by the function and the system has been designed to give the driver the choice of -a time gap setting with a minimum of 0.8s. The driver is responsible for monitoring the system and the driving environment and is fall back for performing the driving task in case of system failure. With the driver being responsible for longitudinal control in case of system failure, driver reaction time needs to be considered in case of malfunctions. In addition, the time gap can be increased by driver. Another safety issue to address is the inter vehicle distances in the platoon. The maximum allowed deceleration requirement is to avoid harsh braking in normal driving for the platoon. The values for maximum relative speed and deceleration are to be evaluated at simulation, testing and safety analysis.

As regards sensing module, the deliverable highlights the sensing requirements which enable a white label solution to assess the environment and which are specific for platooning. It describes the environmental sensing tasks/requirements which need to be performed for Level A platooning. The topic of sensor fusion is out of scope as the possible use thereof needs to be decided by the OEM partner. For the platooning demonstration it is planned to use the actuators which are present in state-of-the-art vehicles. Thus, there are no specific requirements for the time being. This could change over time once the results of the HARA and SOTIF analysis are available. The communication requirements are already documented in the deliverables D2.6 and D2.8 for V2I and V2V respectively.

The HMI-logic presented in this deliverable is based on the current knowledge from platooning and from general Human factors guidelines in the field of driver-automated vehicle interaction. The HMI-logic has not been evaluated and validated, for example in field tests or in simulator studies and, therefore, should be regarded as a draft and subject to changes as platoon systems are tested and evaluated from technical as well as from user (driver) point of view. Moreover, the HMI-logic is on a high level and does not stipulate specific messages, icons, symbols, colours or if and how multi-modal output (sounds and haptic) should be used to enhance the driver-platoon system interaction. These issues are important to investigate further once the overall HMI-logic is in place and be subject for standardization. The results from the interviews with platoon drivers indicated that the verbal communication (via radio) between the drivers was important to maintain the platoon and to handle situations, such as Cut-ins, obstacles ahead, traffic at exits and entries etc. However, it is most likely that drivers in future platoons speak different languages and don't understand each other. Therefore, the safety of a platoon should not be dependent on verbal communication between the drivers.

Another open issue is how drivers can recognize which truck(s) on the road are on the platoon. This is also the case while driving in a platoon, i.e. how to know that the truck in front of the ego-truck is part of the platoon (and not a cut-in). A subsequent question is if and how other co- road users need to be informed about platoon driving on the road. The term "responsibility" is deliberately not used, because "responsibility" infers legal matters and not HMI-matters. The responsibilities of the driver and the platoon system in different use cases and possible critical incidents should be investigated from a legal point of view (not from an engineering or HMI-point of view).

There are also long-terms effects of driving in platoons that are interesting for further investigations, for example:

- Acceptance and trust by drivers and by other road-users over time
- Drivers' compliance and coping strategies with gained experiences
- Misuse of platooning – by platoon drivers, by fleet management, by other vehicles
- Driver attention, distraction, fatigue, non-driving related tasks etc.
- How fleets can implement and manage platooning in their business to maintain efficient platoon driving from a safety point of view as well as from a fuel point of view

D2.4 provides the specified functionalities for WP3 to implement, during WP5, the verification and validation phase the functionality of the equipped vehicles will be verified against the specifications and the developed functionality will be compared to the intended multi-brand functionality as presented in D2.4 to validate the results. In WP4 a list of KPIs on e.g. impact of platooning on traffic flow, bridges, other road-user's behaviour, impact on the environment, and possible business cases will be mapped against D2.4 requirements. Finally, in WP6 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. The iteration process to validate and modify the specification during the whole project life-cycle is an essential part of the work, that is why this report can be regarded as a living document. An additional task for D2.5 is to develop requirements and specification for further Platoon Levels operational and tactical layer stemming from the definitions and use cases which are going to be further detailed in D2.3.

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APPENDIX A. TRACEABILITY MATRIX

Category/number	Specifications	Use Case ID
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, Cut-in vehicle in the platoon, Platoon set speed and Platoon leader vehicle actual speed) and distribute this information over the platoon.	3.4.1
Tactical_Layer_002	The platoon system status information gathered by the tactical layer is updated cyclically. Since this information is not time critical, the update frequency can be chosen substantially lower compared to control related V2V containers.	3.4.1
Tactical_Layer_003	The platoon system status information within the tactical layer is shared between the trucks	3.4.1
Tactical_Layer_004	The platoon system over the tactical layer shares the vehicle property information (Maximum acceleration request (to the platoon), Desired maximum platoon speed), in an equal method within the platoon as the platoon status information.	3.4.1
Tactical_Layer_005	The platoon system property information gathered by the tactical layer is updated cyclically. Since this information is not time critical, the update frequency can be chosen substantially lower compared to control related V2V containers.	3.4.1
Interaction_of_the_trucks_001	The platoon system in the ego vehicle shall receive platooning information via V2V needed to maintain the platooning time gap, for platoon cohesion and for platoon standby from vehicles in the platoon.	3.1
Interaction_of_the_trucks_002	The platoon system in the ego vehicle shall broadcast the platooning information via V2V, which is needed by the other platoon members' control system.	3.1
Interaction_of_the_trucks_003	The platoon system in the ego vehicle shall be informed in case of emergency braking events of the preceding platoon vehicle(s). Therefore at least the requested and actual acceleration value of the preceding platoon vehicle must be received and to be compared with a defined acceleration threshold value.	3.3
Interaction_of_the_trucks_004	The platoon system in the ego vehicle shall broadcast its actual and intended acceleration	3.4.2

	via V2V to enable following vehicles to detect emergency braking events.	
Interaction_of_the_trucks_005	The platoon system of the ego vehicle shall broadcast its intention of leaving the platoon through V2V communication.	3.5.1.1
Interaction_of_the_trucks_006	When the ego vehicle has reached the safe gap in the disengagement procedure, the platoon system in the ego vehicle shall broadcast this information.	3.5.1.1
Interaction_of_the_trucks_007	When the disengagement procedure is finished, the platoon system of the ego vehicle shall disconnect the platooning specific communication.	3.5.1.1
Interaction_of_the_trucks_008	When the first following vehicle has reached the safe gap (SG) in the disengagement procedure, the platoon system of the ego vehicle shall receive this information from the first following vehicle.	3.51.2
Interaction_of_the_trucks_009	When the disengagement procedure is finished the remaining platoon continues with the former first following vehicle becoming the new leading vehicle.	3.51.2
Interaction_of_the_trucks_010	The platoon system of the ego vehicle shall broadcast the start of the splitting procedure. This request must be distinct from a following vehicle's leave request to make sure the next following vehicle does not enlarge the gap towards the ego vehicle.	3.5.1.3
Interaction_of_the_trucks_011	The platoon system in the ego vehicle shall broadcast a cut-in when detected.	3.5.1.3
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)	3.4.1
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).	3.4.1
Interaction_with_Infrastructure_003	Ability for the individual vehicles of the platoon to adjust speed based on zone policy. For level A, this will be implemented by a display on the HMI	3.4.1 (E4)
Interaction_with_Infrastructure_004	Ability for the individual vehicles of the platoon to adjust interdistance based on zone policy. For level A, this will be implemented by a display on the HMI	3.4.1 (E4)

Category/number	Requirements	Use Case ID
Long_Control_001	The system shall keep a time gap to the preceding vehicle such that it can avoid collision if the preceding vehicle is braking to standstill with its maximum deceleration capacity.	3.1, 3.4.2/3.4.3, 3.44
Long_Control _002	The system shall communicate the ego vehicle maximum brake deceleration capacity on dry asphalt* to the following vehicle. If the capacity is unknown, a value of 8 m/s^2 can be used instead.	3.1, 3.4.2/3.4.3, 3.44
Long_Control _003	The system shall never keep a closer time gap than 0.8 s to the preceding vehicle in the platoon. Time gap is here defined as the distance to the preceding vehicle divided by the ego vehicle speed.	3.1, 3.4.2/3.4.3, 3.44
Long_Control _004	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.	3.1, 3.4.2/3.4.3, 3.44
Long_Control _005	The system shall communicate the current brake acceleration of the ego vehicle and the current brake acceleration request actuated by the brake system, to the following vehicle. These shall always be communicated, irrespective whether the system or the ego vehicle driver is requesting the braking.	3.1, 3.2, 3.3
Long_Control _006	The system shall not brake more than needed to keep the selected time gap to the preceding vehicle.	3.1, 3.2, 3.3
Long_Control _007	The system shall not brake with a deceleration that is higher (stronger braking) than the maximum brake deceleration capacity communicated to the other platoon vehicles.	3.1, 3.2, 3.3
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 3 km/h and the maximum deceleration shall be 3 m/s^2. 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).	3.1, 3.4.1, 3.4.4, 3.5.1, 3.5.2
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.	2.1, 3.1, 3.4.1, 3.4.3, 3.4.4

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.	2.1, 3.1, 3.4.1, 3.4.3, 3.4.4
SENS_001	During platoon formation the vehicle shall detect preceding vehicles and measure the position of these with a longitudinal accuracy of 0.4m, a range of 200m and an opening angle of +/- 4° with an azimuth accuracy of 0.1°	1.1
SENS_002	During engaging, platooning and disengaging the platoon system vehicle shall detect the preceding vehicle and measure the position of this with a longitudinal accuracy of 0,5.	2.1
SENS_003	During platooning the vehicle shall detect cut-in vehicles in an opening angle of -75°...+75 and with a longitudinal accuracy of 0.1m and an azimuth accuracy of +/-1° up to 45° and +/-5° between 45° and 75°	3.1
SENS_004	During all phases of platooning the vehicle shall measure the velocity of vehicles in the field of view with an accuracy of 0.4km/h with a range of +400…+200km/h	3.1
SENS_005	The cycle time of the velocity and distance measurements shall be 50ms	?
SENS_006	The platoon system shall be able to measure its lateral and longitudinal position to an accuracy of 10m	
HMI_001	The driver in a platoon should be able to recognize that the ego-truck has a platoon feature.	1.1
HMI_002	The driver in a platoon can activate the platoon mode at any time. The system determines if and when parameters are met to start the search for other platoon trucks.	1.2
HMI_003	The driver in a platoon can deactivate, cancel the formation and leave the platoon at any moment.	1.2
HMI_004	The driver in a platoon shall be informed about the reasons to the speed and gap adjustments.	2.1, 3.3.1, 3.3.2, 3.3.3, 3.3.4
HMI_005	The driver in a platoon shall be able to adjust the gap to the vehicle in front.	3.1
HMI_006	The driver in a platoon shall be informed about the ego-truck’s position in the platoon.	3.1
HMI_007	The driver in a platoon shall be informed about the total number of trucks in the platoon.	3.1
HMI_008	The driver in a platoon shall be informed his role in the platoon driving as Lead-, Follow, or as Trailing driver.	3.1

HMI_009	The driver in a platoon shall be informed about the platooning active mode status in the ego-truck	3.1, 3.3.4
HMI_010	The driver in a platoon shall be informed about platooning system failures and their causes.	3.1
HMI_011	The driver in a platoon shall be informed about imminent and on-going procedures in the ego-truck (Formation, Engage, Steady state, Speed and gap changes, Cut-ins, Emergency brake, System warnings)	3.1
HMI_012	The driver in the platoon shall be warned in case of an Emergency brake situation.	3.2
HMI_013	The driver in a platoon shall be informed about detection of incoming vehicle (cut-in).	3.3.2

APPENDIX B. 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.
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

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

Term	Definition
	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	A requirement specifies a function a product or system must fulfil
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 specification describes or defines (a set of) requirement(s) for a product or system.
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.

Term	Definition
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 considering 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

Acronym / Abbreviation	Meaning
ADAS	Advanced driver assistance system
AEB	Autonomous 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
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
ETSI	European Telecommunications Standards Institute
EU	European Union
FCW	Forward Collision Warning
FLC	Forward Looking Camera
FSC	Functional Safety Concept
GN	GeoNetworking
GNSS	Global Navigation Satellite System
GPS	Global Positioning System

Acronym / Abbreviation	Meaning
GUI	Graphical User Interface
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
ITL	In-The_Loop
ITS	Intelligent Transport System
IVI	Infrastructure to Vehicle Information message
LDWS	Lane Departure Warning System
LKA	Lane Keeping Assist
LCA	Lane Centring Assist
LRR	Long Range Radar
MAP	MapData message
MIO	Most Important Object
MRR	Mid-Range Radar
OS	Operating system
ODD	Operational Design Domain
OEM	Original Equipment Manufacturer
OOTL	Out-Of The-Loop
PAEB	Platooning Autonomous Emergency Braking

Acronym / Abbreviation	Meaning
PMC	Platooning Mode Control
QM	Quality Management
RSU	Road Side Unit
SA	Situation Awareness
SAE	SAE International, formerly the Society of Automotive Engineers
SCH	Service Channel
SDO	Standard Developing Organisations
SIL	Software-in-the-Loop
SPAT	Signal Phase and Timing message
SRR	Short Range Radar
SW	Software
TC	Technical Committee
TOR	Take-Over Request
TOT	Take-Over Time
TTG	Target Time Gap
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)
WIFI	Wireless Fidelity
WLAN	Wireless Local Area Network
WP	Work Package

Appendix C. State Machine

I. State machine on vehicle level

To be more specific, the vehicle platoon role and vehicle platoon state will, as a combination, have a meaning for the operational action that is desired. It should be noted that when the vehicle is in a certain role, some states are not “available”. the following table shows an example with a platoon of size 3. Here the leading truck is truck 1, the following truck is truck 2 and the trailing truck is truck 3. In Table 7an overview is presented of the possible combined states and roles and resulting operational actions. Note that not all state and role combinations are possible; the impossibilities are indicated with a ‘-’.

State / role	*Platoon candidate*	*Leading*	*Following**	*Trailing*
Standalone	x	-	-	-
Join from behind**	-	-	x	x
Normal platooning	-	X Leading truck driver in control + optional ACC + optional platoon cohesion assist	X Coordinated automated longitudinal control (“CACC”)	X Coordinated automated longitudinal control (“CACC”)
Platoon standby	-	-	x	x
Leave	-	X Truck 2 requested (via V2V) to open the gap.	X Gap opened towards truck 1 and truck 3 requested (via V2V) to open the gap.	X Gap opened towards truck 2
Split	-	-	x ***	-
Emergency brake	-	X	x	x
System failure - leave	-	X Truck 2 requested (via V2V) to open the gap.	X Gap opened towards truck 1 and truck 3 requested (via V2V) to open the gap.	X Gap opened towards truck 2

Table 7: Possible combined states and roles of platoon state machine

** the following role only exists in a platoon with more than 2 trucks*
*** as soon as the engaging procedure starts the platoon candidate changes its role from a leading role to a following or trailing role*
**** split is only available for a following truck as this is a request to open the gap and to continue as a new platoon where the following truck will become the leading truck of the new platoon.*

Some triggers for transition between the states for the vehicle level are depicted in the following table. In the further course of the project the triggers listed in Table 8 will be further refined replacing general formulation of triggers by actual logical operations on specific input signals. A '-' means here that a transition is impossible.

From \ To	Standalone	Join from behind	Normal platooning	Platoon standby	Leave	Split	Emergency brake	System failure - leave
Standalone	0	PMM Join Response positive received	LV: Join Response positive transmitted → Leader	-	-	-	-	-
Join from behind	- *	-	Gap closing finished	Cut-in detected	Driver request, V2x request of target	Driver request, V2x request of target	Emergency trigger (local or target platoon vehicle)	Critical system fault detected
Normal platooning	- *	Existing platoon engage to new leader / existing platoon	0	FV/TV: Cut-in detected	Driver request, V2x request of target	FV: Driver request, V2x request of target	Emergency trigger (local or target platoon vehicle)	Critical system fault detected
Platoon standby	*-	-	Cut-out detected & platoon target in line of sight	0	Driver request, V2x request of target	Driver request, V2x request of target	Emergency trigger (local or target platoon vehicle)	Critical system fault detected
Leave	If gap opening is complete (by ego vehicle & backward vehicle)	-	Cancel leave	-	0	-	Emergency trigger (local or target platoon vehicle)	Critical system fault detected
Split	If gap opening is complete by ego-vehicle	*-	-	FV: Cancel split or become LV	-	FV: Driver request	0	FV: Emergency trigger (local or target platoon vehicle)
Emergency brake	If emergency is solved	-	-	-	-	-	0	Critical system fault detected

From \ To	Standalone	Join from behind	Normal platooning	Platoon standby	Leave	Split	Emergency brake	System failure - leave
System failure - leave	If gap opening is complete (by ego vehicle & backward vehicle)	-	Cancel leave and self-healing of critical issue	-	-	-	Emergency trigger (local or target platoon vehicle)	0

Table 8: Triggers for transition between the states for the vehicle level

**current assumption is that a “switch off” of the system by the driver or a “brake overrule” is always possible, the driver may take full control of the vehicle, but the system first goes via the disengaging state to assure that also the decoupling of the backward trucks is handled properly.*

II. Vehicle role and transition between roles

The role of a vehicle determines which operational actions should be performed in certain states of the state machine. The vehicles can only be in leading or trailing role when not in forming or standalone mode. Following table defines which transitions are possible.

From\To	Platoon deactivated	Platoon candidate	Trailing	Leading	Following
Platoon deactivated	0	When the driver activates the system I.e., he wants to be found for platooning	-	-	-
Platoon candidate	When the driver de-activates the system. I.e. he doesn't want to be found for platooning	0	When the vehicle joins a platoon (as a single vehicle only) or when a platoon is initiated with a vehicle in front. The ego vehicle is the last in the platoon	When another vehicle (or platoon leader) joins from behind. The ego vehicle becomes the leader of the newly formed platoon.	-
Trailing	When the driver leaves the platoon (or is forced to leave the platoon), and doesn’t want to be available for	When the driver leaves the platoon (or is forced to leave the platoon) but wants to be available for platooning with other vehicles.	0	-	When another vehicle joins the existing platoon from behind. I.e. it starts platooning behind the ego vehicle.

	platooning anymore				
Leading	When the driver leaves the platoon (or is forced to leave the platoon), and doesn't want to be available for platooning anymore	When the driver leaves the platoon (or is forced to leave the platoon) but wants to be available for platooning with other vehicles.	-	0	When the lead vehicle in a platoon joins another platoon from behind
Following	When the driver leaves the platoon (or is forced to leave the platoon), and doesn't want to be available for platooning anymore	When the driver leaves the platoon (or is forced to leave the platoon) but wants to be available for platooning with other vehicles.	When a vehicle following the ego vehicle leaves the platoon, the role changes from trailing to following.	When the platoon is split and **if the driver accepts to proceed as leader**.	0

Table 9: Vehicle role and transition between roles

Appendix D. Trucks interacting with the platoon

To detail the required V2V information, the following table lists the specific information, its inquirer and provider. As long as nothing else is stated each table contains additional input to Table 10.Table 10 lists the V2V information required to maintain steady state platooning including platoon cohesion functionality. Furthermore, the signals required for gap adaptation are contained.

Use-case: platooning – steady state platooning		
Required V2V information (cyclic)	**Inquirer**	**Provider**
System status is ok, positive conditions for platooning are met.	Ego vehicle	Truck in front
Information to calculate inter-vehicle (time) gap. These are informations enabling the system to evaluate braking and acceleration potential (e.g. power to mass ratio, brake capacity including quality measure as e.g. variance) (see Long_Control_002)	Ego vehicle	Truck in front
Driver awareness: Number of platoon members within the platoon (see HMI_007)?	Ego vehicle	Trailing truck
Position of the truck in front (see HMI_006)	Ego vehicle	Truck in front
Position of the ego truck (see HMI_006)	Truck to the back	Ego truck
Actual and/or requested acceleration and set speed as longitudinal control inputs (enables faster gap control at platoon time gap) (see Long_Control_005)	Ego vehicle	Truck in front
Desired maximum platoon/vehicle speed: communicate ego vehicle's performance limitations by providing maximum driveable vehicle speed and acceleration request (see Long_Control_010).	Ego vehicle	Truck in rear
Desired maximum platoon/vehicle speed: communicate ego vehicle's performance limitations by providing maximum driveable vehicle speed request (see Long_Control_010)	Truck in front	Ego vehicle
In case of gap adaptation: Awareness of ongoing gap adaptation, reason for gap opening (e.g. intruder with distance and relative	Truck in front, Truck behind	Ego vehicle

velocity incl. duration/lifetime, I2V request, technical reason), see HMI_016 and HMI_017 / IN_VEH_REQ_011.		

Table 10: steady state platooning incl. gap adaptation

Use-case: platooning – emergency braking		
Required V2V information	**Inquirer**	**Provider**
The preceding vehicle is currently performing an emergency braking (intended and current deceleration values including quality measure, as e.g. variance)	Ego truck	Truck in front
In-vehicle Platoon state during and after emergency braking (see Figure 9)	All trucks in platoon	Ego truck

Table 11: emergency braking

Use-case: disengage platoon – leave by trailing truck		
Required V2V information	**Inquirer**	**Provider**
Awareness of platoon status: trailing vehicle intends to leave platoon	Truck to the front	Ego truck (trailing truck)
Disengage is complete: this is communicated at least implicitly by the trailing vehicle stopping its WLAN connection or by a separate signal**)	All trucks in platoon	Trailing truck

Table 12: leave by trailing truck

**) This needs to be examined in later project activities

Use-case: disengage platoon – leave by leading truck		
Required V2V information	**Inquirer**	**Provider**
Awareness of platoon status: leading vehicle intends to leave platoon	Truck to the back	Ego truck
*New WLAN encryption key / channel**	*All trucks in remaining platoon (if >1)*	*First follower*

Disengage is complete: this is communicated at least implicitly by the leading vehicle stopping its WLAN connection or by a separate signal**)	First Follower	Leading truck

Table 13: leave by leading truck

*) Whether new WLAN encryption keys / channels are necessary in this use cases are still an open question and needs to be specified in the future.
**) This needs to be examined in later project activities

Use-case: disengage platoon – leave by following truck		
Required V2V information	**Inquirer**	**Provider**
Awareness of platoon status: following vehicle intends to leave platoon	Preceding vehicle, following vehicle	Ego vehicle (following vehicle)
Gap opening between next following vehicle and ego vehicle is complete: this is communicated by a separate signal	Ego vehicle (following vehicle)	Next following vehicle (vehicle behind)
Disengage is complete (SG is restored towards next following and next preceding vehicle): this is communicated at least implicitly by the following vehicle stopping its WLAN connection or by a separate signal**)	All vehicles in platoon	Ego vehicle (following vehicle)

Table 14: leave by following truck

**) This needs to be examined in later project activities

Use-case: Split including (long time cut-in)		
Required V2V information	**Inquirer**	**Provider**
Awareness of platoon state: following vehicle intends to leave preceding platoon	All platoon members ahead	ego vehicle (truck with intruder ahead)
Reason to leave (split)	All platoon members ahead	ego vehicle (truck with

		e.g. intruder ahead)
New WLAN encryption key / channel if needed (issue to be clarified in course of the project)	All trucks in remaining platoon (if >1)	First follower
Disengage is completed if gap between ego and first preceding vehicle is restored. This needs to be communicated by a message/signal in order to disconnect ego-vehicle from preceding platoon without having to stop platoon messaging completely since this is needed for platooning with the following platoon members..	Preceding vehicle	Ego vehicle

Table 15: Split including Cut-In- long time

APPENDIX E. HUMAN FACTORS GUIDELINES FOR PLATOONING

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 (see section 15.2.3 below) 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.

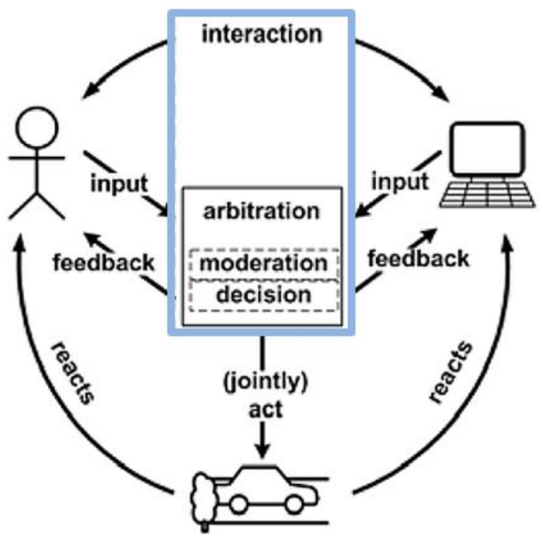

Figure 11: The relationships between the agents in a driver-vehicle-automation system.

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).

<table>
<tr><th>ID</th><th colspan="2">Name</th></tr>
<tr><td>P-HFR_Ag_ 1

P= Platoon

HFR= Human Factors Recommendation

Ag= Agent

Aw= Awareness

Arb= Arbitration

Act= Action</td><td colspan="2">"(Short name of the Recommendation)"</td></tr>
<tr><td>Platoon Level A</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

(Agent, Awareness, Arbitration, Action)</td></tr>
<tr><td colspan="3">Related Use Case:</td></tr>
<tr><td colspan="3">Human Factors challenge:</td></tr>
<tr><td colspan="3">Human Factors Recommendation/Guideline:</td></tr>
<tr><td colspan="3">Non-functional HF recommendations:</td></tr>
<tr><td colspan="3">Examples:

(Pictures and descriptions from real systems, prototypes, sketches, GUIs etc. or other examples that addresses the Human Factors Recommendation).</td></tr>
<tr><td colspan="3">References:

(References to papers, products, concepts, web-sites etc.)</td></tr>
</table>

Figure 12: The format of the table for the Human factors Guidelines for platooning.

<table>
<tr><th>ID</th><th colspan="2">Name</th></tr>
<tr><td>P-FR1Ag_1</td><td colspan="2">“Driver platoon knowledge”</td></tr>
<tr><td>Platoon Level A</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
Agent</td></tr>
<tr><td colspan="3">Related Use Case:
No specific Use case</td></tr>
<tr><td colspan="3">Human Factors challenge:
The drivers do not understand how to drive in a platoon in a safe and efficient way.</td></tr>
<tr><td colspan="3">Human Factors Guideline:
Driver training about platooning as a concept, how-to drive-in platoons and how to interact with the platoon system.</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>

ID	Name	
P-FR1Ag_2	“Verbal communication”	
Platoon Level A	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"	
Platoon Level A	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"	
Platoon Level A	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"	
Platoon Level A	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"	
Platoon Level A	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"	
Platoon Level A	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"	
Platoon Level A	Platoon Level B	Platoon Level C
x	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"	
Platoon Level A	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"	
Platoon Level A	Platoon Level B	Platoon Level C
x	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"	
Platoon Level A	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: 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"		
Platoon Level A		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"	
Platoon Level A	Platoon Level B	Platoon Level C
x	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"	
Platoon Level A	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"	
Platoon Level A	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:		

<table>
<tr><th colspan="2">ID</th><th colspan="2">Name</th></tr>
<tr><td colspan="2">P-FR1Act_2</td><td colspan="2">“Truck in front leaving the platoon, planned leave”</td></tr>
<tr><td colspan="2">Platoon Level A</td><td>Platoon Level B</td><td>Platoon Level C</td></tr>
<tr><td colspan="2">x</td><td>x</td><td>x</td></tr>
<tr><td colspan="4">Related to 4A-category
Action</td></tr>
<tr><td colspan="4">Related Use Case:
Steady state, Leave</td></tr>
<tr><td colspan="4">Human Factors challenge:
The driver ego-truck driver is affected by the truck in front is leaving the platoon.</td></tr>
<tr><td colspan="4">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).</td></tr>
<tr><td colspan="4">Non-functional HF recommendations:</td></tr>
<tr><td colspan="4">Examples:</td></tr>
<tr><td colspan="4">References:</td></tr>
</table>

ID	Name	
P-FR1Act_3	"Unexpected manoeuvre"	
Platoon Level A	Platoon Level B	Platoon Level C
x	x	x
Related to 4A-category Action		
Related Use Case: Steady state		
Human Factors challenge: Driver needs to make a sudden manoeuvre.		
Human Factors Guideline: The drivers in the trucks behind the acting truck are informed about changes in the platoon.		
Non-functional HF recommendations:		
Examples:		
References:		

APPENDIX F. TACTICAL LAYER – PLATOON SHARED MATRIX EXAMPLE

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. A possible method is to share a “matrix” in the platoon. Each vehicle on operational level knows with what vehicle it is platooning as a target vehicle (vehicle ID). This way the matrix can be extended by the platoon and vice versa be maintained / updated.

Vehicle ID	Platoon ID	Cut-in	Start platoon	Stop platoon	Platoon set speed
3	36	N	T: 10.10	GPS loc x	80
15	36	N	T: 10.10	GPS loc x	80
4	36	N	T: 10.15	GPS loc x	80
6	36	Y	T: 10.30	GPS loc x	80
12	36	N	T: 10.30	GPS loc x	80
35	36	N	T: 10.30	GPS loc x	80

In the order of the platoon, in this case vehicle 3 is leader

By means of this information the ***position*** *in the platoon and* ***size of the platoon*** *the can be visualized on the HMI*

If 1 vehicle reports a cut-in, this can then be visualized on the HMI of all if desired

Figure 13: Shared matrix example

For the platoon status information, the consensus is that a broadcasting method is not enough as truck 1 and 7 will most likely not be in range of each other. Therefore (an application based) hopping method is proposed. The proposal is to further detail the exact hopping method in WP3.1 and to align this with T2.3.

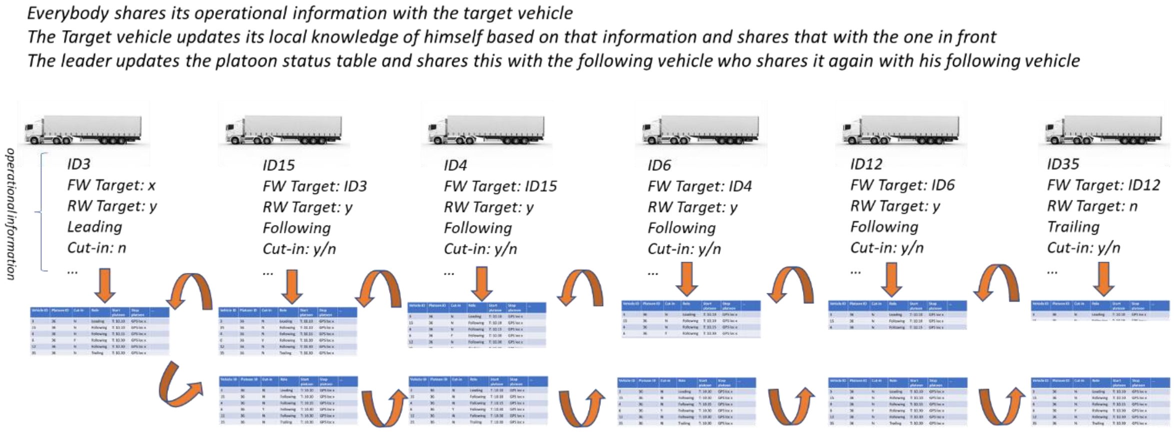

Figure 14: Shared matrix hopping implementation example

APPENDIX G. D2.4 REQUIREMENTS AND SPECIFICATIONS TEMPLATE

Linked Use case category	Linked Use case ID	Linked Use case name	Functions	Functional Requirements description	Parameters	Values	Actors involved	Enablers	Barriers	Comments/open issues for decision	Column1
Platoon formation	1.1	Platoon formation – based on generic match making (Orchestrated non real-time)	Speed advice	Speed advice to find platooning partner	Speed advice from strategic / services layer	To be calculated by service provider	ego truck service provider driver to follow speed advice	V2X communicatio n, traffc,	depends on traffic condition	Part of WP4?	
Platoon formation	1.2	Platoon formation – based on just extended awareness (Orchestrated real-time)	Speed advice	Speed advice to find platooning partner	Speed advice from strategic / services layer	To be calculated by service provider	ego truck service provider driver to follow speed advice	V2X communicatio n, traffc,	depends on traffic condition	Part of WP4?	
Engaging to platoon	2.1	Join from behind by single vehicle	Tactical layer, Platoon coordinator, Cohesion	It must be made possible for a truck to engage to the platoon in an efficent way. If the platoon is driving at a speed higher than or equal to the maximum speed of the engaing truck, the engaing will not be possible. Therefore, the lead truck must slow down sufficiently. Also the legal speed limit needs to be accounted for. It is undisirable to drive above the speed limit, but experience with structurally driving below the speed limit also shows negative impact on traffic flow because other trucks are then continuously overtaking the platoon. So either the lead truck slows down during engaging or the engaging	Speed of trailing vehicle in the platoon Speed of platoon leader Maximum speed the engaging vehicle can reach Legal speed limit Maximum acceleration the engaging truck can achieve (this indicates if or how fast the gap can be closed)	Values are not fixed, as these depend on road load, powertrain characteristics, vehicle mass, road and traffic rules, etc. This means values have to be continuously updated.	ego vehicle, trailing vehicle, leading vehicle	Tactical layer: awareness of platoon state, platoon information, V2V Operational layer: Estimators for acceleration capability and maximum speed	Driving above speed limit is illegal	With the current S4P communication protocol Platoon Awareness is not guaranteed; it is not certain that the lead truck is informed about a joining vehicle, or its capabilities.	
Engaging to platoon	2.1	Join from behind by single vehicle	Driver assistence system for lead truck driver, engage assist feature	The lead truck driver is informed about the engaging of a new vehicle to the platoon. In case of a cohesion issue (engaging truck is not able to join), the lead truck needs to slow down. This can be achieved in different ways: 1) Only via HMI: slow down recommendation, speed advice, etc. 2) Automatically by adjusting the speed setpoint (applicable to ACC or CC functions) In all cases: for platooning level A, it is the task of the lead truck driver to decide on any action taken (manually adjusting speed or overruling cruise control)	Speed advice (from Platoon Coordinator function) Information for showing on HMI (it must be clear to the driver what is happening; there must be at least awareness of the engaging action at the platoon leader; how this is best displayed is up to the HMI specialists)	Speed advice Engaging state General platoon information for HMI	Ego vehicle, leader vehicle, driver or leader vehicle	HMI display Cruise control (CC or ACC)		Need to decide on common, OEM specific or required/optional functionality. Meaning: the platoon awareness, required information exchange, etc. are common functionalities. The same holds for the basic slow-down-if-cannot-join functionality. How the speed is lowered on truck level could be truck specific, although it is maybe good to have reference implementations in ENSEMBLE as examples.	
				1) Vehicle automatically keeps a defined distance to the preceding vehicle in a safe and						Safe distance: The estimation of the braking distance of a truck in normal driving conditions is a technical	

Longitudinal Control

Figure 15: D2.4 template