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

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Revision history

Version	Date	Author	Summary of changes	Status
0.1	14/1/2021	Antoine Schmeitz (TNO)	Updated the document to include the description and use cases for the Platooning Autonomous Function. Included comments from WP leader (CLEPA) and partners.	Draft
0.2	20/10/2021	Antoine Schmeitz, Dehlia Willemsen (TNO)	Updated document after comments from partners on the Autonomous Function use cases. Added the platooning formation use cases to the Support Function	For approval by WP2 partners
0.3	17/11/2021	TNO	Updated document after comments from partners	For approval by WP2 partners
1.0	31/01/2022	TNO	Updated document on referencing, punctuation, language, etc.	For approval by WP leader
1.1	31/01/2022	CLEPA	Approved by WP Leader	For approval by coordinator
2.0	16/02/2022	TNO	Approved by coordinator	Submitted to EC

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EXECUTIVE SUMMARY

Context and need of a multi brand platooning project

Context

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

Project scope

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

- Year 1: setting the specifications and developing a reference design;
- Year 2 and 3: implementing this reference design on the OEM own trucks, as well as performing impact assessments with several criteria;
- Year 4 (due to COVID-19): focus on testing the multi-brand platoons on test tracks and public road.

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

Abstract of this Deliverable

This deliverable consists of 2 parts:

- Platooning levels
- Use cases

This document is the final version of D2.3 "V2 Platooning use cases, scenario definition and Platooning Levels". The previous version has been published as D2.2 V1 Platooning use-cases, scenario definition and Platooning Levels (Vissers, 2018). After first publication of the Platooning levels and use cases (D2.2, Vissers, 2018), a review towards implementation in the demonstration

trucks and a preliminary safety analysis (Dhurjati, 2019) were performed. This revealed that some safety issues were present in the previous defined platooning levels of D2.2. In this regard, new platooning levels have been defined:

- Platooning Support Function (PSF): here the driver is responsible for the driving task,
- Platooning Autonomous Function (PAF): the driver of the following trucks is not responsible anymore, the system performs the complete driving task within the specified operational design domain. A lead tuck with a driver responsible for the driving task remains.

The first level is implemented and demonstrated in the project. Changes encountered in the use cases during implementation and testing of the PSF-functionality in WP3 and WP5 are incorporated in this final version of D2.3.

This deliverable also includes the use cases for the envisioned Platooning Autonomous Function. In contrast to the Platooning Support Function, implementation of the Platooning Autonomous Function is not part of the ENSEMBLE project and the specification of the Platooning Autonomous Function and its use cases is solely done on theoretical considerations to sketch a future perspective of platooning. The latter is also due to the low technology readiness level (TRL) of certain required autonomous driving subfunctions at the time of writing.

The main properties of the Platooning Support Function are based on Adaptive Cruise Control (ACC) as defined in (ISO 15622, 2018):

- The driver is responsible for the full driving task, in line with the current state of the art support functions, and this will be clearly indicated via the HMI,
- Longitudinal coordinated automated control for the complete speed range from 0 (brake to standstill; acceleration from standstill optional) to maximum cruise speed (depending on country regulations and OEM implementations),
- Following distances according to ACC (OEM specific) with minimum distances ranging between 1.4 s and 1.6 s. The driver selects the following distance,
- Limited accelerations (>-3.5 m/s^2),
- Under adverse conditions like bad weather, slopes, etc. the drivers have the responsibility to increase the time gap or disengage platooning completely.

The high-level use cases for the Platooning Support Function are detailed. First the methodology how the use cases were derived, is defined and after that the high level use cases for the Platooning Support Function and additional one-lines / assumptions are added. The main high level use cases of the Platooning Support Function are:

- Engaging to platoon
  - Join from behind: either by single vehicle or existing platoon
  - Merge in-between by single vehicle in existing platoon
- Platooning
  - Steady state platooning
  - Follow to stop
  - Emergency braking
  - Platoon gap adaptation:
    - I2V interaction
    - Cut-in
    - System status (e.g. packet loss)
  - Cohesion request
- Disengage platoon
  - Leave
  - Split
  - Leave by steering away

On the other hand, the main idea of the Platooning Autonomous Function is having autonomous following vehicles (manned or unmanned), but also a driver in the lead truck. When engaged, the Platooning Autonomous Function performs the entire dynamic driving task for the following vehicles. The driver in the lead truck has the responsibility to guide the platoon through traffic, but is not responsible for the (operational and functional) safety of the entire platoon. This also implies that the lead truck driver has the responsibility to obey the rules of the road (i.e. laws and informal rules). In other words, the lead truck driver is 'driving' a 'long truck' consisting of electronically coupled automated following vehicles. It is believed that this type of autonomous platooning could be an earlier deployable (and a less costly) step on the roadmap of automated long-haul freight transport, because of potentially less complex technical challenges.

The main properties of the Platooning Autonomous Function are:

- A lead truck with a driver, who is responsible for performing part or all of the dynamic driving task.
- Following trucks are driverless when these start platooning at a hub, as the system will be able to handle all situations autonomously within the limited ODD (including faults by being fault tolerant and SOTIF situations like cut-ins, weather, etc.).
- Envisioned ODD of the platooning function is hub-to-hub highway driving on selected driving routes important for long-haul freight transport.
- The ODD of the following vehicles is additionally limited by 'being part of the platoon', which means that these vehicles are designed to follow the lead -, or other following vehicles autonomously as part of the platoon (also called "follow-me" or "auto-follow" functionality).

The identified high level use cases of the Platooning Autonomous Function are:

- Platoon formation
  - Formation of driverless platoon in dedicated area (Orchestrated non real-time)
- Engaging to platoon
  - Join a stationary platoon/vehicle from behind at the hub
  - Join from behind by a manned, single vehicle on the highway
- Platooning
  - Platooning between the hub and the highway
  - Platooning in lane on the highway
  - Entire platoon starting from a standstill
  - Emergency manoeuvre
  - Cut-in
  - Maintaining Platoon cohesion
  - Lane change triggered by Leading truck
  - Lane change triggered by Following or Trailing truck
  - Lane merge
  - Entering highway via an onramp
  - Highway offramp
  - Platooning on a connection between two different highways
  - Road Works/Construction zone
  - Traffic signs handling
  - Toll gates
  - Traffic lights on highways
  - Traffic lights on intersections
  - Roundabouts
  - Resting Areas/Parking lots
  - Parking
  - Border Crossing
- Disengage platoon
  - Drop-off area at the destination hub
  - Leave (while platooning, with a manned trailing truck)
- Safe state
  - Safe state evaluation and reaching (nearest parking area)
  - Safe state evaluation and reaching (hard shoulder/emergency lane)
  - Safe state evaluation and reaching (stop in lane)

Since the following trucks may not have full SAE level 4 capability without being part of the platoon, a platoon split may lead to enter a safe state, which can affect the traffic flow. Potential threats that can lead to a split have been identified and solutions are suggested, e.g. in the context of adapting (digital) infrastructure and traffic rules.

1. INTRODUCTION

1.1. Background

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

Following objectives are defined:

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

The concept of the envisioned technology to implement above objectives, consists of a hierarchical platooning system with interacting layers. The envisioned concept is presented in Figure 1-1.

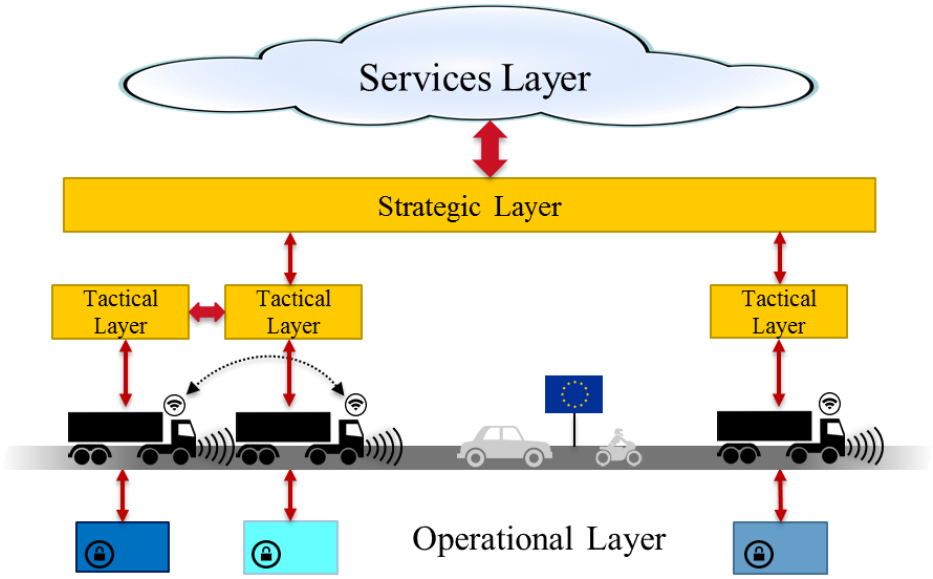


Figure 1-1: Layered concept of ENSEMBLE.

The different layers have the following responsibilities:

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

relative to the lane or to the preceding vehicle. Key performance requirements for this layer are vehicle-following behaviour and (longitudinal and lateral) string stability of the platoon, where the latter is a necessary requirement to achieve a stable traffic flow and to achieve scalability with respect to platoon length, and the short-range wireless inter-vehicle communication is the key enabling technology.

Furthermore, the concept provides a staged introduction of platooning along different platooning levels, which have been defined in the course of the project. The definition of “platooning levels of automation” will comprise elements like e.g. the minimum time gap between the vehicles, whether there is lateral automation available, driving speed range, operational areas like motorways, etc.

1.2. Aim of ENSEMBLE

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

1.3. Aim and structure of this report

The objective of this document is to describe the final version of platooning levels and use cases. These can then form the basis of possible further standardisations. The first platooning levels and use cases were defined in D2.2 (Vissers, 2018), pending the safety evaluation of the proposed, high level, functionality. The preliminary safety analysis (Mengani, 2019), however, revealed that the original Platooning Level A as defined in the D2.2 is ASIL D, when having the driver responsible while having time gaps of 0.8 s. For this reason, strict safety requirements were needed that were not in line with the aims of a “first” platooning level that could be deployable on short term considering the readiness level of the required technology and the existing regulatory framework. Hence, after thorough review with the project partners, new levels were defined and documented in the first version of this deliverable (now Chapters 3 and 4):

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

In this final version of the report, the use cases regarding the Platooning Support Function have been updated based after reviews, developing the Platooning Support Function in WP3 and testing the functionality in WP5. These use cases form the basis for the reviewed specifications and requirements reported in D2.5 (Mascalchi, 2022).

Besides the updated use cases of the Platooning Support Function, this document includes the identified use cases for the envisioned Platooning Autonomous Function. In contrast to the Platooning Support Function, implementation of the Platooning Autonomous Function has not been part of the ENSEMBLE project and the specification of the Platooning Autonomous Function and its use cases has solely been done on theoretical considerations to sketch a future perspective of platooning. The latter is also due to the low technology readiness level (TRL) of certain required autonomous driving subfunctions at the time of writing.

For the interested reader, related requirements and specifications are listed in D2.5 (Mascalchi, 2022). Additional details on the Communication protocol can be found in D2.8 (Atanassow, 2022a) and D2.9 (Atanassow, 2022b). Furthermore, the Safety of the intended functionality (SOTIF) analysis of both levels can be found in D2.13 (Dhurjati, 2022b). The Functional Safety analysis can be Found in D2.14 (Pezzano, 2022). Finally, the Item Definition can be found in D2.15 (Dhurjati, 2022a).

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

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

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

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

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

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

The contents of this deliverable are as follows. First the platooning levels are discussed in Chapter 2. The Platooning Support Function is detailed in Chapter 3. Next, Chapter 4 defines each use case of the Platooning Support Function. Chapter 5 is devoted to detailing the Platooning Autonomous Function and Chapter 6 describes each use case of it. Finally, Chapter 7 summarises and concludes this report.

2. PLATOONING LEVELS

The platoon as a whole can be seen as a system of interconnected vehicles with specific requirements. Originally, three platooning levels were defined in D2.2 (Vissers 2018), that are separate from the SAE (Society of Automotive Engineers) levels of automation, basically because platooning also heavily depends on communication capabilities. These platoon levels were defined pending the safety evaluation of the proposed high level system. The preliminary safety analysis (Mengani 2019), however, revealed that the original Platooning Level A, as defined in the D2.2, is ASIL (Automotive Safety Integrity Level) D, as defined by ISO 26262 (ISO 26262, 2018). This ASIL D originated from the requirement of having the driver responsible, while having time gaps of 0.8 s. For this reason, strict safety requirements for the system would be needed. These safety requirements were not in line with the aims of a “first” platooning level that could be deployable on short term considering the readiness level of the required technology and the existing regulations framework.

Three aspects were identified as key challenges:

1. Driver as a backup: having the driver as a back-up means giving enough time to the driver to react,
2. Brake performance estimation: to be able to calculate the (minimum) safe following distance, each platoon member needs to know its own and its predecessor’s immediate braking performance,
3. Localisation: to be able to identify the communication partner, at least localisation with lane accuracy is needed for platooning.

Taking this into consideration, two levels of platooning have finally be defined with the driver responsibility as the key difference:

1. **Platooning Support Function (PSF)**: the driver is responsible for the driving task. Hence (s)he is also responsible to choose a safe following distance and monitor the system e.g. whether the right platooning partner is being followed (though supported by the system as much as possible). To give the driver sufficient time to react, minimum time gaps around 1.5 s have to be respected. The Platooning support function is a longitudinal control function, but lateral driver assistance systems, such as e.g. lane centring, might be optionally available as well.
2. **Platooning Autonomous Function (PAF)**: The lead truck has a driver responsible for the driving task, but the following trucks are fully automated, i.e. the system performs the complete driving task within the specified (limited) operational design domain. Here, the driver is out-of-the-loop, however (at least) the first two aforementioned technical challenges need to be solved before this implementation can be introduced to the market. Moreover, not having a driver as backup also means that time gaps might be

reduced to 0.5 s, depending on the system response time and accuracy of e.g. the brake force estimation.

Table 2-1 summarises the high-level properties of these two platoon levels.

Table 2-1: High-level properties of the Platooning Support and Autonomous Functions.

	Platooning Support Function	**Platooning Autonomous Function**
Lead truck driver responsibility for the driving task	Yes, for the leading truck	Yes, for the leading truck and also for guiding the platoon through traffic.
Following / trailing truck driver(s) responsibility for the driving task	Yes	No
Lead truck system responsibility for the driving task	No	No
Following / trailing truck system responsibility for the driving task	No	Yes, but only for safety and optionally for traffic rules
Lead truck control	Optional longitudinal and lateral driver support	Optional longitudinal and lateral driver support
Following / trailing truck control	Longitudinal driver support, optional lateral driver support	Both longitudinal and lateral automation
Time gaps	~ 1.5 s	~ 0.3 to 1.2 s (dry weather conditions)
Focus	Quick deployment on road	Limited ODD: first in dedicated areas, then gradually increase ODD. Paving the way to full autonomous trucks with a follow-me functionality.
Main benefits	Improved safety and efficiency due to earlier anticipation possibilities V2V offers for following trucks.	Improvement in driver productivity and possible solution for current driver shortage problem. Potential decreased time gaps improve efficiency and road capacity. Safety not depending on driver behaviour for the following trucks.

The Platooning Support Function is implemented and demonstrated in the project. Changes encountered in the review of the use cases during implementation of the functionality and testing in WP3 and WP5 are incorporated in this final version of D2.3.

In contrast to the Platooning Support Function, implementation of the Platooning Autonomous Function is not part of the ENSEMBLE project and the specification of the Platooning Autonomous Function and its use cases is solely done on theoretical considerations to sketch a future perspective of platooning. The latter is also due to the low technology readiness level (TRL) of certain required autonomous driving subfunctions at the time of writing.

The Platoon Support Function is further detailed in Chapter 3 and its use cases are defined in Chapter 4. Chapter 5 is devoted to further discuss and define the Platooning Autonomous function and its use cases are described in Chapter 6.

3. PLATOONING SUPPORT FUNCTION (PSF)

To describe the Platooning Support Function (PSF) more in detail, following clusters are used:

- Platoon characteristics,
- Relevant high-level manoeuvres,
- Driver interaction,
- Operational design domain and vehicle configuration.

3.1. Platoon characteristics

There is no limitation regarding the vehicle configuration foreseen, as long as the ego vehicle fulfils the minimum platooning capabilities. The decision if a truck could become a platoon candidate or a leader remains at the OEM.

Basis for the Platooning Support Function is Adaptive Cruise Control (ACC) as defined in (15622, 2018). Hence, **the driver is responsible for the complete driving task**. The longitudinal control is automated with limited accelerations (>-3.5 m/s^2) by means of decentralized controllers, using platoon-wide information. Lateral control (steering) remains at the driver and is thus not coordinated on a platoon level. The driver may turn on steering assist or active steering based on local sensors in the truck, if available (not mandatory for PSF).

The **time gap** is conform current ACC time gaps. Depending on the brand, the minimum gap ranges between 1.4 s and 1.6 s. Furthermore, the actual time gap can depend on OEM strategies for different conditions like e.g. downhill driving, optimal driving, string stability. Last, but not least, the time gap is also a driver preference.

The **speed range** of the Platooning Support Function is from zero to the maximum speed of the truck (again OEM specific). It is the responsibility of the driver to set the speed, according to the allowed speed of the specific country the truck is driving in. Engaging or formation of the platoon application may only be possible above a certain speed, similar to ACC (and will thus be OEM specific). In a Stop and Go situation the braking can go below a speed of 30 km/h; accelerating again may require manual intervention (depending on brand/truck).

The **leading truck** has the option to control the vehicle speed/acceleration by advanced driver support systems (like ACC, CC, …) or manually.

The **maximum number of trucks in a platoon** considered in ENSEMBLE for the Platoon Support Function is seven. In practise, this means that for simulation and testing purposes a maximum number of seven will be considered. In general, the technical choices will be made using scalability as a requirement. The actual number of trucks in a platoon on the road may be different due to legal, road authority or technical restrictions.

With respect to the **location** where the function can be activated, each driver is responsible to adhere to the local rules and guidelines and thus only activates the platooning function on allowed highways and released roads. Received road restriction (e.g. received through I2V communication) are included in this responsibility.

Specific situations the function must be able to handle are:

- cut-in and cut-through situations and react in a safe manner to these,
- when a truck in the platoon performs full braking (either by a support system (e.g. AEBS) or by the driver (overrule)).

Finally, all members of the platoon shall, of course, be equipped with wireless V2V communication and environmental perception sensors. All members of the platoon shall also be able to perform each role (leading, following, trailing) in a platoon (see Figure 3-2).

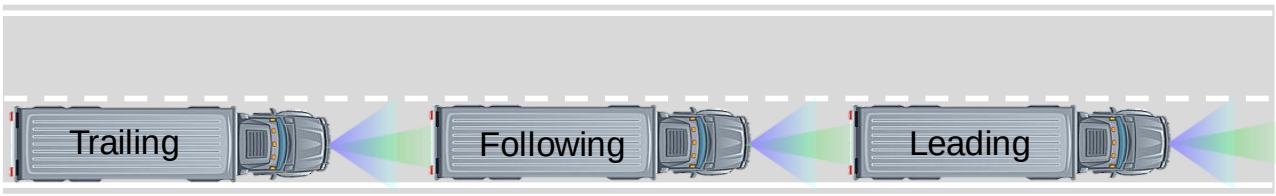


Figure 3-2: Definition of leading, following and trailing vehicles in a 3-truck platoon.

3.2. Relevant high-level Manoeuvres

Following high-level manoeuvres have been identified for the Platooning Support Function:

- Platoon Formation
- Platoon Engaging
- Platooning
- Platoon Disengaging

The high level manoeuvres are placed in context of each other. For the manoeuvres already specific use case examples are given that will be detailed in this report and further specified (functionality) in D2.5 (Mascalchi, 2022) and D2.6 (Villette, 2018).

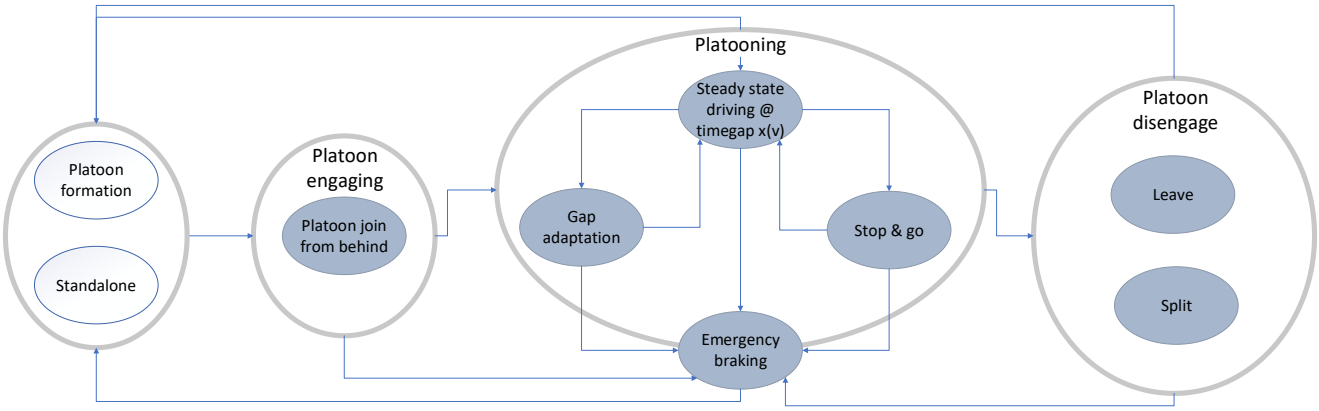


Figure 3-3: High level manoeuvres interaction.

3.3. Driver interaction

The HMI should reflect the high level manoeuvres. In this way the transition from manually driving to automated driving and vice versa needs to be transparent to the driver. Hence:

- The HMI should provide the possibility to switch the platooning function on and off (sending announcement via V2V to the platoon neighbours if switched on).
- Accept or deny Platoon formation / Engaging is processed in an automated way without driver confirmation.
- Driver has the possibility to leave the platoon (platoon → standalone)
- The HMI may have different information shown on the display depending on the truck's position in the platoon.
- Changes that do not require input or actions from the drivers may also be indicated in the HMI, e.g. new leading truck, ego-vehicle's (new) position in the platoon, in order to keep the driver in-the-loop.

In case of a failure, depending on the safety assessment, some dedicated requirements may be defined. Intentional driver overruling by braking is handled in the same way as for ACC. Steering away (exits, change lanes) will be handled upon agreed specifications as specified in the use cases (section 4.4.4).

3.4. Operational design domain and vehicle configuration

The Operational Design Domain (ODD) is the definition of where (what road types speeds, etc.) and when (under what conditions, such as day/night, weather limits, etc.) an automation function is designed to operate.

Due to the definition of the first level of platooning as a support function, the driver is in charge of ODD monitoring and may decide when it is not safe anymore to platoon / if the time gap needs to be adapted (if available). Moreover, the basis for the ODD is ACC.

4. USE CASES PLATOONING SUPPORT FUNCTION (PSF)

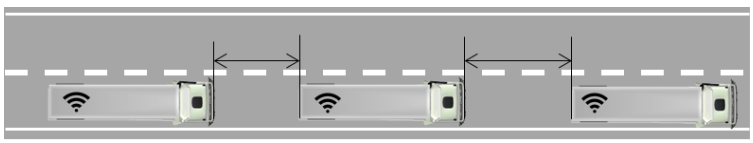
4.1. Introduction

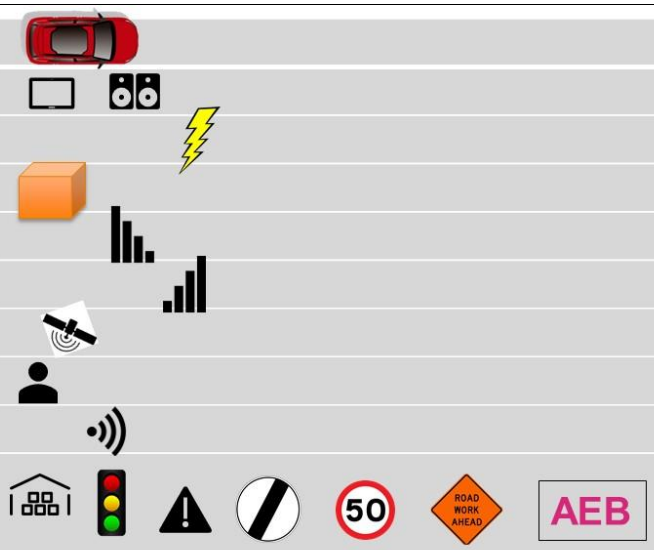
To derive use cases, more specifically the high level use cases, a methodology has been followed to assure a level of completeness. In this section, the methodology to derive a use case from a scenario is discussed.

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.

The goal of the use cases is to be able to derive the functionalities (and related requirements) as needed for the ENSEMBLE project which will be further specified in the deliverable D2.5 (Mascalchi, 2022) and 2.6 (Villette, 2018).

The template that will be used for the use cases in this document is the following.

ID	Unique identifier.
Name	Name of the use case.
Story	Short description of the use case
Initial condition	State of the environment (infrastructure & vehicles), system (vehicle, platooning system, …) & driver (in each vehicle).
Trigger	E.g. Driver pushes the platoon system activation button on the HMI
Sequence	Sketch:  Legend of the sketch icons:

	Other vehicle HMI Fault / failure Stand still object Decreasing speed Increasing speed "Cloud" / Service Driver V2X Other  Sequence in time: *Bullet points* 1. *A* 2. *A* 3. *A*
Final condition	State of the environment (infrastructure & vehicles), system (vehicle, platooning system, …) & driver (in each vehicle).

As a result, a use case is a detailed scenario including the manoeuvres, ODD and events (Figure 4-4).

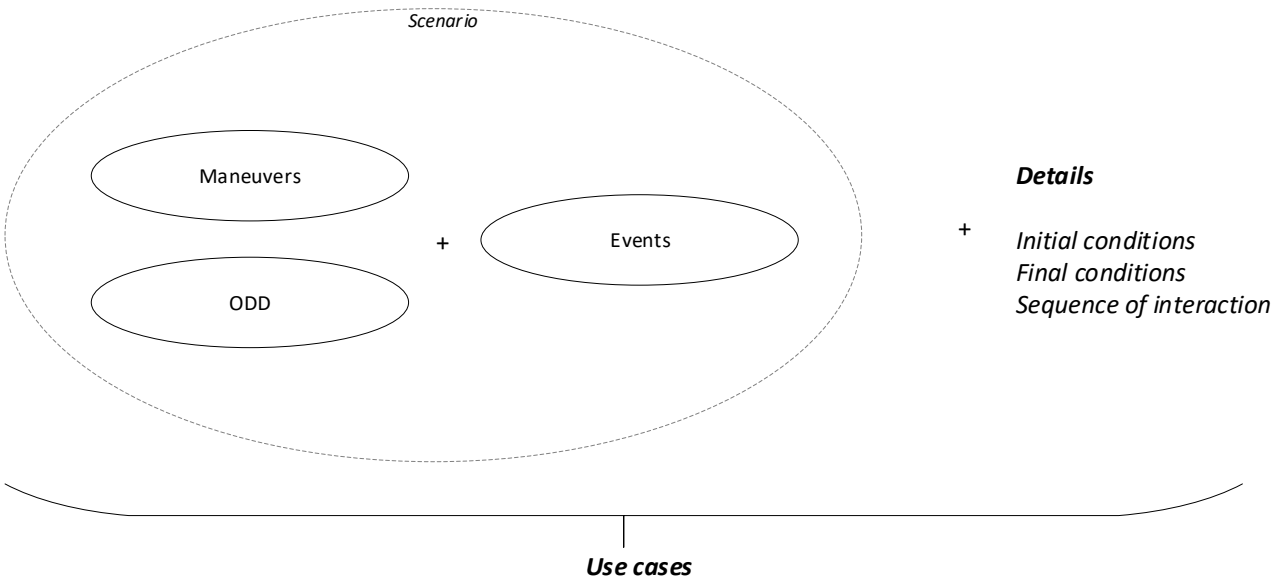


Figure 4-4: Use cases comprehend a scenario (manoeuvres, ODD and events) and details.

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.

In ENSEMBLE, scenarios will mainly be used for scenario-based assessment. Scenarios will be described not as an entity for the development process, but will be described by the following parts:

- manoeuvre (“activity”),
- operational design domain (ODD),
- events.

The scenarios will be extended towards use cases 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) where necessary.

4.2. Manoeuvre

4.2.1. Introduction to Manoeuvre

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 as a manoeuvre.

The manoeuvres are on a high level comparable to what can be presented to the user on e.g. the HMI considering the “mode” of the system so that he is informed.

4.2.2. Platooning Support Function manoeuvres

The platoon behaviour, both orchestrated platooning and ad-hoc platooning can be described by four manoeuvres. The manoeuvres are the result from the works as described in the state of the art documentation (Willemsen, 2018).

Reflecting to orchestrated and ad-hoc platooning, the main difference between ad-hoc platooning and orchestrated platooning is the involvement of a platoon formation process for orchestrated platooning to strategically find platoons / vehicles that can platoon together (Figure 4-5 and Figure 4-6):

- Platoon formation
- Platoon engaging
- Platooning
- Platoon disengaging

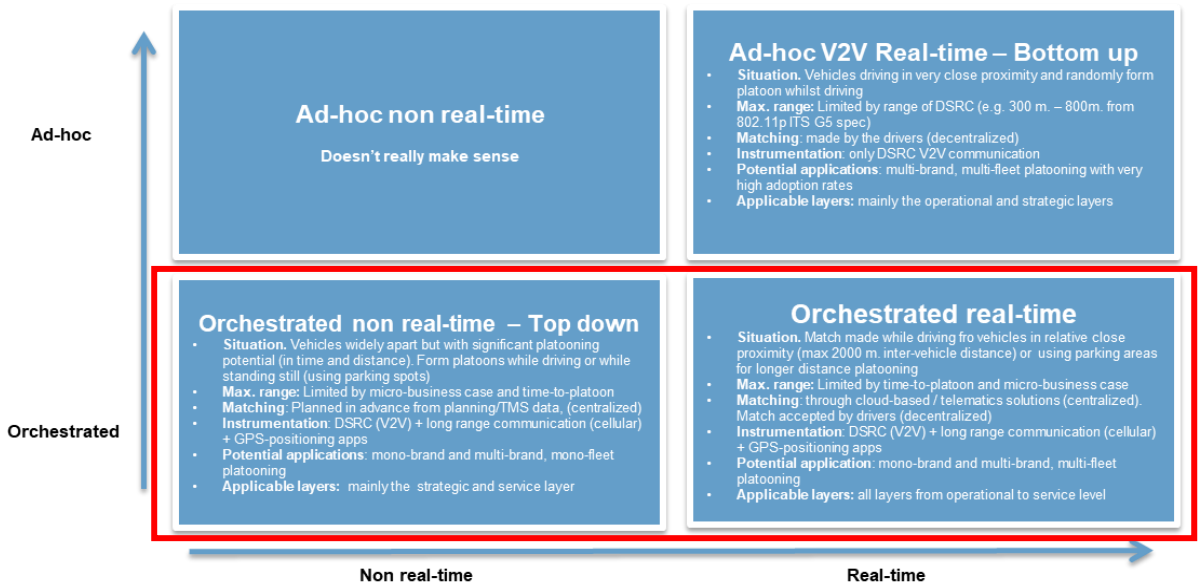


Figure 4-5: Platoon formation (red box) (Burgmeijer, 2017).

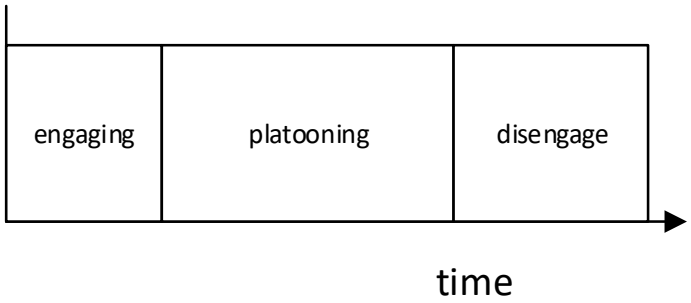


Figure 4-6: Manoeuvre example in a time sequence for ad-hoc platooning.

For each of the manoeuvres a definition will be given in Table 4-2 below.

Table 4-2: Manoeuvres of Ensemble for the Platooning Support Function.

ID	Manoeuvre name	Description
M1	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 orchestrated real time or non-real time. 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.
M2	Platoon engaging	Using wireless communication (V2V), the Platoon Candidate (single vehicle or existing platoon) sends an engaging request to the platoon target (single vehicle or existing platoon) in front. When conditions are met, the system starts (if needed) to decrease the time gap between the trucks to the platooning time gap.
M3	Platooning	A group of two or more automated cooperative vehicles are in line, maintaining a close distance using wireless communication (V2V). Typically this is 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.
M4	Platoon disengage	The ego-vehicle can decide to leave the platoon or to split the platoon into 2 new platoons (only a following truck can perform this action). When conditions are met the truck(s) starts (if needed) to increase the gap between the trucks to a safe (non-platooning/standalone) gap. The disengaging is completed when the gap is large enough which depends on the operational safety based on vehicle dynamics and human reaction times is given.

4.3. Event

4.3.1. Introduction

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 state.

Helpful here is to look at the interfaces that the “system” has with external context (Figure 4-7). If we consider here the strategic, tactical and operational layer as the “system” (as the service layer will only be implemented with an “example application” and see the infrastructure which is studied in ENSEMBLE as input/output) then the following main interfaces will be there for the system:

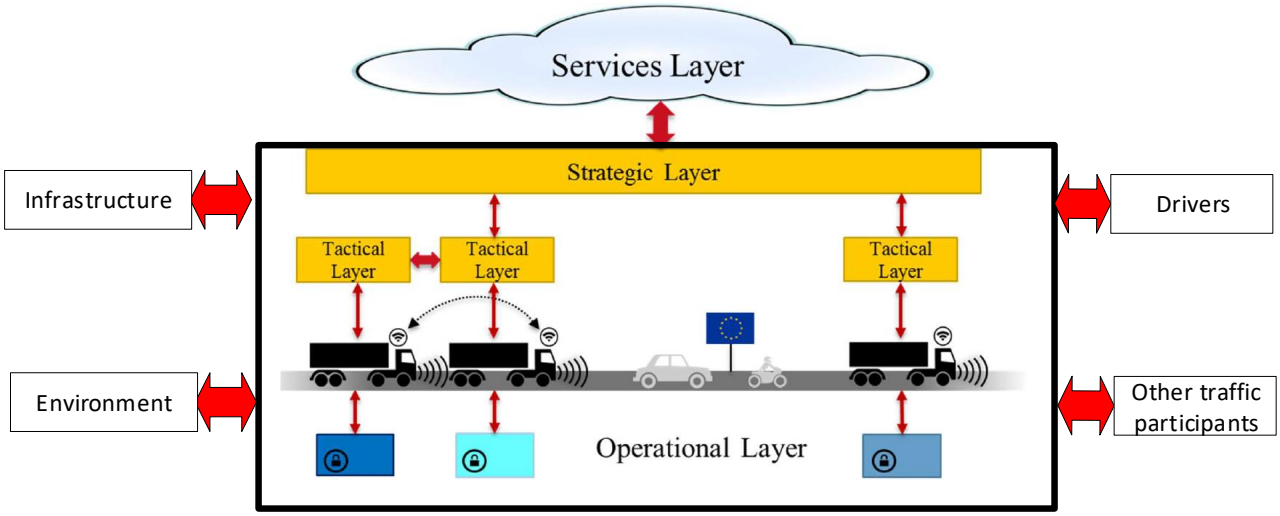


Figure 4-7: Main interfaces.

It can be observed that interaction with the driver, other traffic participants, the environment (e.g. visible lane markers and weather conditions), the platoon service provider (I2V/IOT) and the infrastructure (via I2V or road sign recognition) is included.

4.3.2. Platooning Support Function Events

Below a list with obvious events is defined which will be used to derive the high level use cases in this document. The list is a set which contains the most important external events and is based on experience from the state of the art as described in D2.1 (Willemsen, 2018).

Table 4-3: Events of Ensemble.

ID	Event name	Description
E1	Cut-in	The cut-in object (car, motorcycle, truck) can cut-in anywhere in the platoon and also the duration may vary. Once the cut-in vehicle leaves the platoon this is called a cut-out action. Depending on the duration of the cut-in the reaction of the system may vary.
E2	Normal braking vehicle (to stop) in front of the leader	This is a typical event which happens in dense traffic when approaching a traffic jam. The vehicle in front of the platoon slowly decelerates because of the traffic jam. The platoon system has to handle this situation in a safe way.
E3	Emergency braking by a platoon truck (either by driver or AEB system)	Both the AEB system and the driver may cause full braking (maximum braking) which is an event that shall be handled in the platoon.
E4	Limit received via I2V	Via I2V certain limits can be received (e.g. gap, speed) which are relevant for a special zone on the road (e.g. at a bridge).
E5	Failure of the system / system status (e.g. packet loss)	Because of a system failure or limited performance of system components (e.g. packet loss) a certain reaction of the platoon system may be required. Some options are handover to the driver (transition of control) or gap adaptation.

4.4. Platooning Support Function use cases

Here the high level use cases, that form the basis to derive the technical specifications as reflected in e.g. D2.5 (Mascalchi, 2022) and D2.6 (Villette, 2018), are given. The goal of the use cases is to describe the required, application level, behaviour of the whole platooning system.

The high level use cases are derived from the manoeuvres and events earlier defined:

- Platoon formation
  - Platoon formation based on generic match making (Orchestrated non real-time)
  - Platoon formation based on just extended awareness (Orchestrated real-time)
- Engaging to platoon
  - Join from behind
  - Merge in between by single vehicle in existing platoon
- Platooning
  - Steady state platooning
  - Follow to stop

- Emergency braking
- Platoon gap adaptation
    - I2V interaction
    - Cut-in
    - System status (e.g. packet loss)
- Cohesion Request

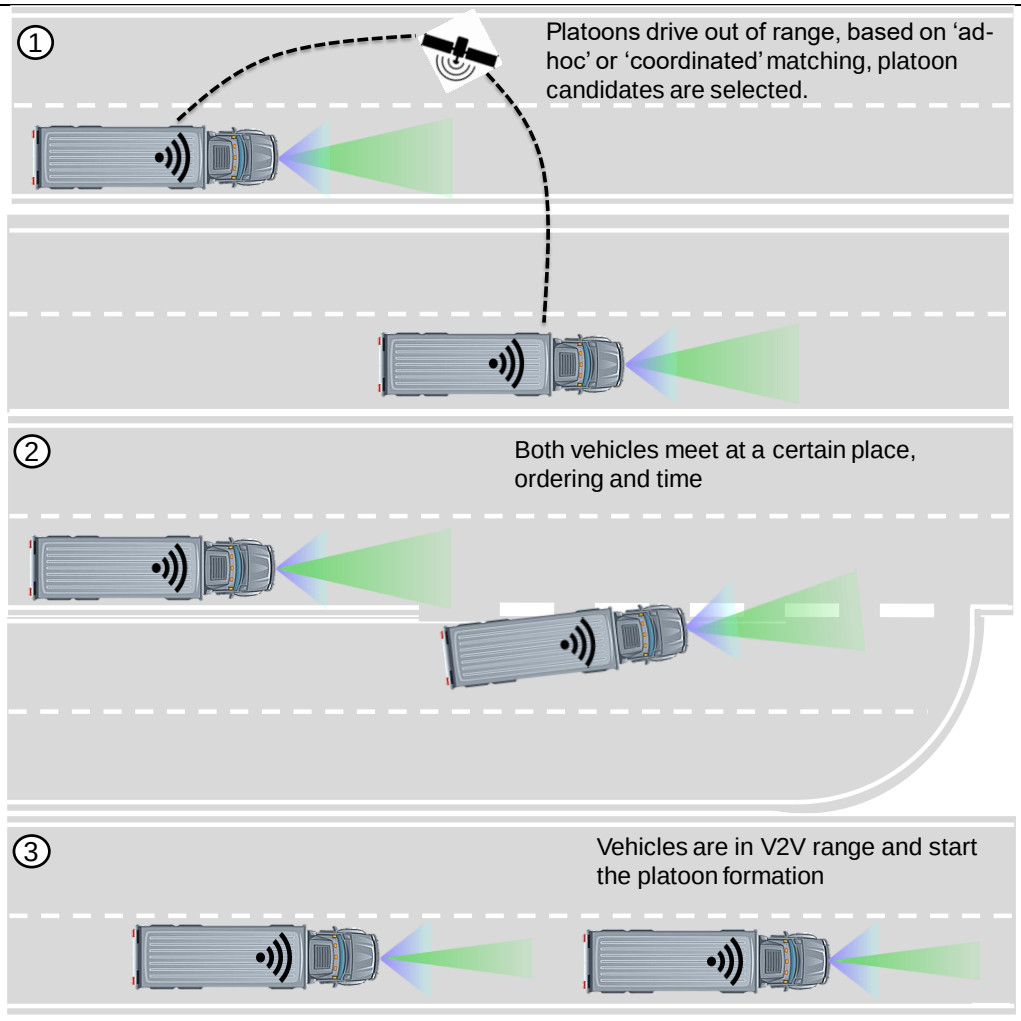
- Disengaging platoon
    - Leave
    - Split
    - Leave by steering out

The use cases reflect the minimum implementation to make the function work therefore the generic match making is excluded from platoon formation. For this reason, the platoon formation use cases have not been tested. However, these use cases were added to provide input to Task 4.2, which is about service and strategic layer design. Optimisation features, i.e. aimed at optimising the behaviour, will be elaborated in D2.5. An example is an advice system to the driver, displaying what the advised current cruise speed is. This would optimise the platoon speed while still having the possibility to be engaged by a new truck.

4.4.1. Platoon formation

Platoon formation based on generic match making (Orchestrated non real-time)

<table>
<tr><td>ID</td><td colspan="2">PSF_1.1</td></tr>
<tr><td>Name</td><td colspan="2">Platoon formation – based on generic match making (Orchestrated non real-time)</td></tr>
<tr><td>Story</td><td colspan="2">At least two separate trucks have active subscriptions to a platoon enabler service.
The platooning enabler service will give a recommendation based on some business logic that the two vehicles should form a platoon at some location and at some time in the future. The rendezvous could be in a few seconds or in a few days.
Information about the planned platoon along with a ticket valid for the platoon is sent from the offboard system to the vehicles. An offboard service can help with platoon awareness to help coordinate vehicles to the rendezvous.
At the rendezvous the two vehicles and/or drivers identify and authorize each other with help of the platooning ticket. After this an engage procedure can start.</td></tr>
<tr><td>Initial condition</td><td colspan="2"><table>
<tr><td>Operation area:</td><td>Any of the operational area inside the ODD for the platooning support function</td></tr>
<tr><td>Environmental conditions:</td><td>Positive conditions for platooning, other conditions detected either by driver or system.</td></tr>
<tr><td>Target vehicle(s):</td><td>Truck or active platoon registered with the platoon enabler.</td></tr>
<tr><td>Ego vehicle (s):</td><td>Truck or active platoon registered with the platoon enabler.</td></tr>
</table></td></tr>
</table>

	Application status target vehicle(s):	Steady state platooning (active platoon) or standalone (single vehicle)
	Application status Ego vehicle	Steady state platooning (active platoon) or standalone (single vehicle)
	Driver status target vehicle(s):	Aware
	Driver status Ego vehicle	Aware
	System status	No failure
Trigger	Active subscriptions to a platoon enabler service	
Sequence	 1.1 The platooning enabler (offboard service) matches some vehicles by sending a recommendation to form a platoon. The recommendation is based on the business logic of that service and may take into account as much information as the fleet owner is willing to share with that service (no need to standardise) [Optional] Example remote Fleet Management System (rFMS) connection to enable live matching.	

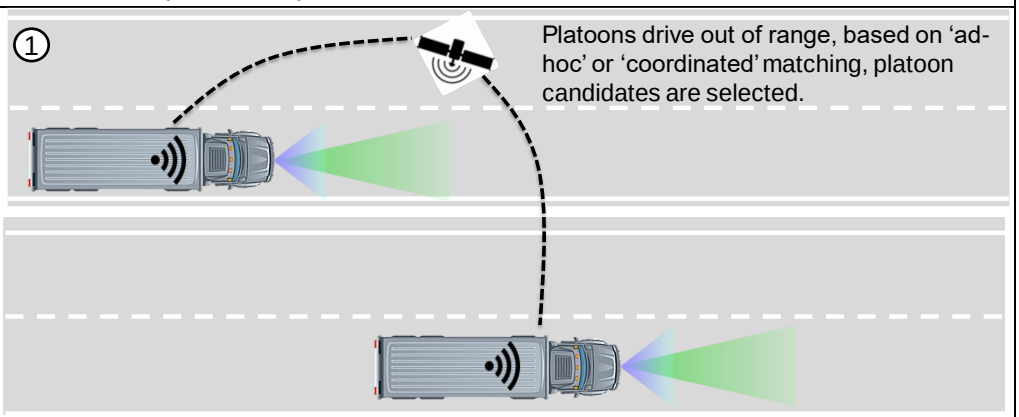
<table>
<tr><td></td><td>1.2 The platooning enabler sends information to the two vehicles about the platooning opportunity. This may be done just before they should start or well in advance. Information in the platooning opportunity may include
▪ Recommended rendezvous point and time
▪ Opportunity duration
▪ Recommended split point
▪ Platooning Ticket for identification and authorization
▪ What service it originated from (The vehicle may be connected to several platoon enablers)
▪ Validity parameters (e.g. time, location, valid vehicles, …)
▪ Recommended platoon configuration e.g. vehicle order (this could be put in a driver app as well and then needs no standardisation)
1.3 When the recommendation is accepted and conditions are met the drivers activate platooning.
1.4 [Optional] Relay ego vehicle information to planned partners via the platooning enabler service (extended platoon awareness). Standardisation needed.
1.5 [Optional] Service specific extended platoon awareness e.g. driver apps that relays information to each other. No standardisation needed as it does not interact with the vehicle.

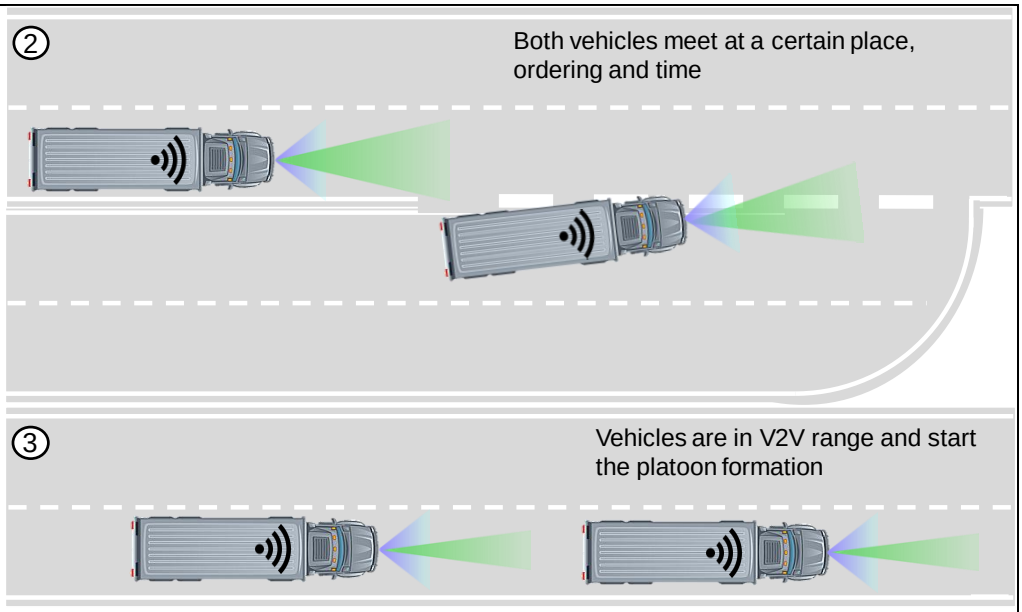
2 Vehicles are in V2V range of each other and each identify its partner
[Optional] Drivers manually arrange vehicles in right order

3 Vehicles start “Platoon engage”-use case with optional authentication and authorization parameters set.</td></tr>
<tr><td>Final condition</td><td>
<table>
<tr><td>Operation area:</td><td>Any of the operational area inside the ODD for the platooning support function</td></tr>
<tr><td>Environmental conditions:</td><td>Positive conditions for platooning, other conditions detected either by driver or system.</td></tr>
<tr><td>Target vehicle(s):</td><td>Truck or active platoon within V2V range of ego vehicle(s)</td></tr>
<tr><td>Ego vehicle (s):</td><td>Truck or active platoon within V2V range of target vehicle(s).</td></tr>
<tr><td>Application status target vehicle(s):</td><td>Steady state platooning (active platoon) or standalone (single vehicle)</td></tr>
<tr><td>Application status Ego vehicle</td><td>Engaging possible</td></tr>
<tr><td>Driver status target vehicle(s):</td><td>Aware</td></tr>
<tr><td>Driver status Ego vehicle</td><td>Aware</td></tr>
<tr><td>System status</td><td>No failure</td></tr>
</table>
</td></tr>
</table>

Platoon formation based on just extended awareness (Orchestrated real-time)

ID	PSF_1.2
Name	Platoon formation – based on just extended awareness (Orchestrated real-time)
Story	At least two separated trucks have active subscriptions to a platooning enabler service. The platooning enabler service will give a recommendation based on some business logic that the two vehicles should form a platoon at some location and at

<table>
<tr><td></td><td>some time in the future. This may be a dynamic point that is real time communicated to the vehicles.
Information about the planned platoon along with an optional ticket valid for the platoon is sent from the offboard system to the vehicles. An offboard service will help with platoon awareness to help coordinate vehicles to the rendezvous. Optionally, at the rendezvous, the two vehicles identify and authorize each other with help of the platooning ticket. After this: normal engage procedure.</td></tr>
<tr><td>Initial condition</td><td>
<table>
<tr><td>Operation area:</td><td>Any of the operational area inside the ODD for the platooning support function</td></tr>
<tr><td>Environmental conditions:</td><td>Positive conditions for platooning, other conditions detected either by driver or system.</td></tr>
<tr><td>Target vehicle(s):</td><td>Truck or active platoon registered with the platoon enabler.</td></tr>
<tr><td>Ego vehicle (s):</td><td>Truck or active platoon registered with the platoon enabler.</td></tr>
<tr><td>Application status target vehicle(s):</td><td>Steady state platooning (active platoon) or standalone (single vehicle)</td></tr>
<tr><td>Application status Ego vehicle</td><td>Steady state platooning (active platoon) or standalone (single vehicle)</td></tr>
<tr><td>Driver status target vehicle(s):</td><td>Aware</td></tr>
<tr><td>Driver status Ego vehicle</td><td>Aware</td></tr>
<tr><td>System status</td><td>No failure</td></tr>
</table>
</td></tr>
<tr><td>Trigger</td><td>Active subscriptions to a platoon enabler service</td></tr>
<tr><td>Sequence</td><td> 
</td></tr>
</table>



1.1 Driver activates platooning (enters driving alone state)
1.2 The platooning enabler (offboard) service matches some vehicle with a recommendation to form a platoon together. The recommendations is based on the business logic of that service and may take into account as much information as the fleet owner is willing to share with that service (no need to standardize). Both vehicles have an rFMS connection to the platooning enabler to enable live matching
1.3 [Optional] The platooning enabler sends information to the two vehicles about the platooning opportunity. Information in the platooning opportunity may include:
- 1.3.1 Recommended rendezvous point and time
- 1.3.2 Opportunity duration
- 1.3.3 Recommended split point
- 1.3.4 Platoon Ticket for Identification and authorization
- 1.3.5 What service it originated from (The vehicle may be connected to several platoon enablers)
- 1.3.6 Validity parameters (e.g. time, location, valid vehicles, …)
- 1.3.7 Recommended platoon configuration e.g. Vehicle order (this could be put in a driver app as well, then no standardization needed)

1.4 Relay ego vehicle information to planned partners via the platooning enabler service (extended platoon awareness). (Standardisation needed)
1.5 [Optional] Service specific extended platoon awareness e.g. driver apps that relays information to each other. No standardisation needed as it does not interact with the vehicle.

2 Vehicles are in V2V range of each other and each identify its partner
2.1 [Optional] Drivers manually arrange vehicles in right order

3 Vehicles start “Platoon engage”-use case (Optionally uses a platooning ticket to identify and authorize the join to make sure they are the planned platoon and belong to the same service)

Final condition	Operation area:	Any of the operational area inside the ODD for the platooning support function
	Environmental conditions:	Positive conditions for platooning, other conditions detected either by driver or system.
	Target vehicle(s):	Truck or active platoon within V2V range of ego vehicle(s)
	Ego vehicle (s):	Truck or active platoon within V2V range of target vehicle(s).
	Application status target vehicle(s):	Steady state platooning (active platoon) or standalone (single vehicle)
	Application status Ego vehicle	Engaging possible
	Driver status target vehicle(s):	Aware
	Driver status Ego vehicle	Aware
	System status	No failure

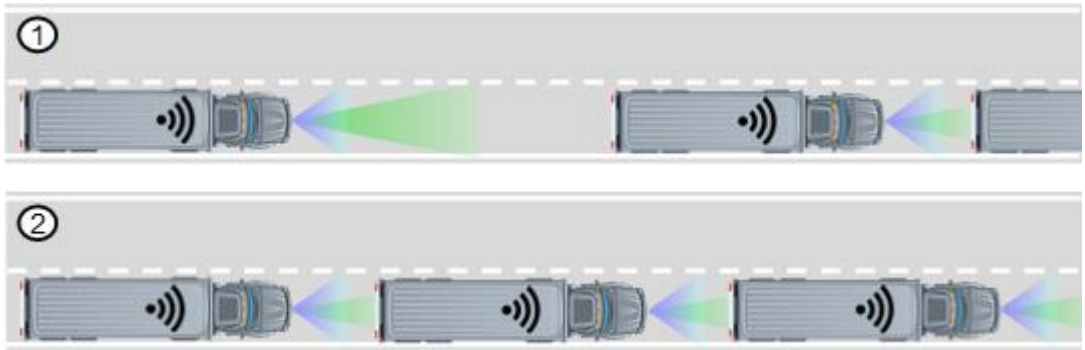
4.4.2. Engaging to platoon

The “engage to platoon from behind” use case is for adding one more vehicle to the platoon. The use case joining an existing platoon by another platoon from behind is from a technical perspective similar, so here the focus is describing how a single vehicle joins a platoon or single platoon candidate vehicle from behind.

After the use case join from behind by single vehicle, the use case merge in-between by single vehicle is described.

Join from behind

ID	PSF_2.1	
Name	Join from behind	
Story	Using wireless communication (V2V), the Platoon Candidate (single vehicle or existing platoon) sends an engaging request to the platoon target (single vehicle or existing platoon) in front. When conditions are met the system starts to decrease the time gap between the trucks to the platooning time gap (if needed).	
Initial condition	Operational area:	Any of the operational area inside the ODD for the platooning support function
	Environmental conditions:	Positive conditions for platooning, other conditions detected either by driver or system.

<table>
<tr><td></td><td><table>
<tr><td>Target vehicle(s):</td><td>Steady state platoon or a single platoon candidate that can accept to be extended with one more vehicle (i.e. is ‘joinable’). The platoon is signalling that the platoon is joinable by the trailing truck.</td></tr>
<tr><td>Ego vehicle (s):</td><td>Driven at a safe distance behind the last vehicle of the platoon:
Single platoon candidate or last vehicle in platoon must be within sensor view and in lane.
Single platoon candidate or last vehicle in platoon must be within V2V range (able to communicate reliably). Not necessary to have V2V contact with other vehicles in the platoon.
No intruder between Ego and target vehicle.
Speed within platooning range.
The platooning capability and conditions are verified to be positive.
Advanced driver assistant system (e.g. ACC) activated.</td></tr>
<tr><td>Application status target vehicle(s):</td><td>Platooning
HMI: Platooning status on HMI.</td></tr>
<tr><td>Application status Ego vehicle</td><td>Advanced assist system (e.g. ACC) activated
HMI: Platooning candidate</td></tr>
<tr><td>Driver status target vehicle(s):</td><td>Aware</td></tr>
<tr><td>Driver status Ego vehicle</td><td>Aware</td></tr>
<tr><td>System status</td><td>No failure of internal systems and communication (V2V) is online. Sensor characteristics required for platooning ok.</td></tr>
</table></td></tr>
<tr><td>Trigger</td><td>The ego vehicle and the platoon is in ‘Joinable’ mode.
The ego vehicle detects an ‘is-joinable’ announcement through V2V communication.</td></tr>
<tr><td>Sequence</td><td><u>Use case sequence:</u>
 
1.1 The ego vehicle sends a request to join to the target vehicle.
1.2 The platoon system of the target vehicle evaluates the join request and accepts the request. The trailing vehicle can perform this automated action using the shared platoon state of the platoon.
1.3 The V2V platooning communication channel is setup with security enabled.
1.4 Both ego and target vehicles start the platoon communication.
1.5 [Optional] Both vehicles report the join event to their respective platoon enablers (offboard). To be detailed by task 4.2 of the project.</td></tr>
</table>

	2.1 If needed the ego vehicle keeps the distance same as the platooning distance. 2.2 Once the platooning distance gap is reached the platoon is in steady platooning state and if needed the speed is increased to the speed of the platoon.
Final condition	

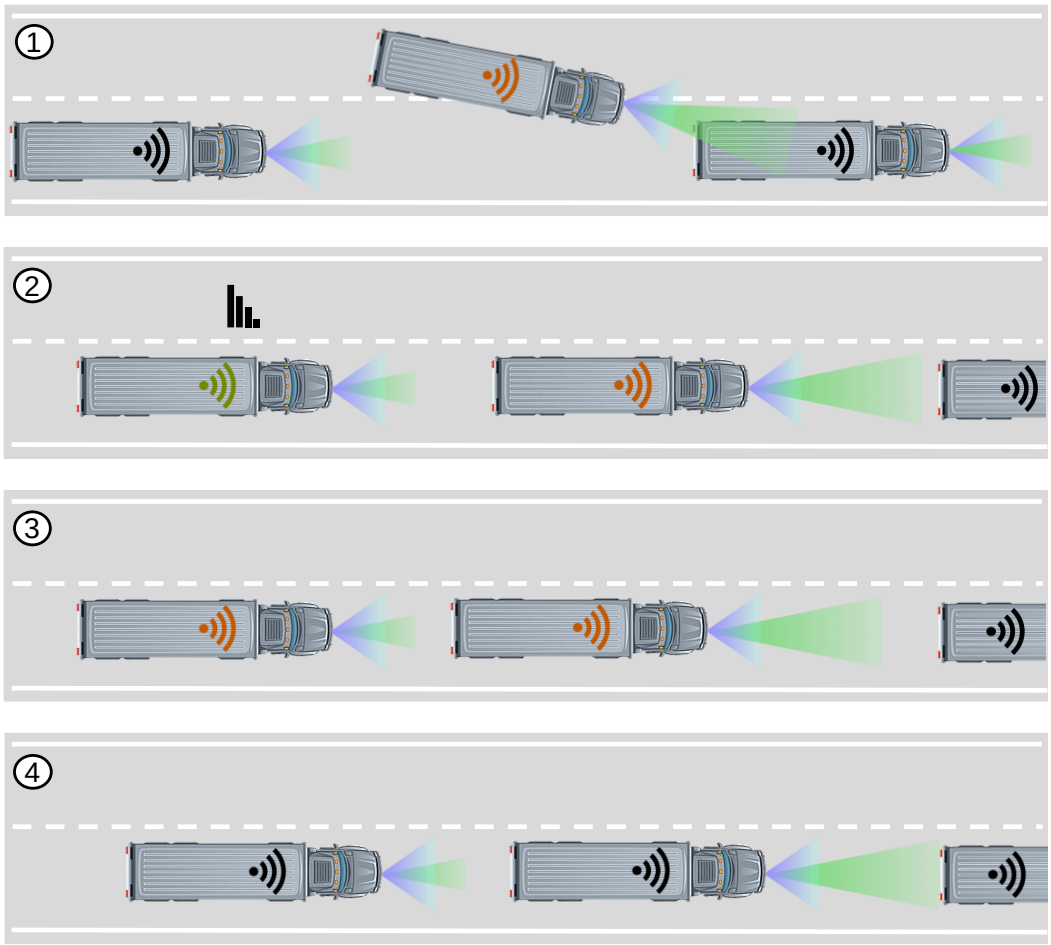
Operational area:	Any of the operational areas inside the ODD for the platooning support function
Environmental conditions:	N/A
Target vehicle(s):	Steady state platooning with now the newly added truck being the new trailing truck.
Ego vehicle (s):	Steady state platooning as the trailing truck.
Application status target vehicle(s):	Platooning Shows platooning status on HMI
Application status Ego vehicle	Platooning Shows platooning status on HMI
Driver status target vehicle(s):	Aware
Driver status Ego vehicle	Aware
System status	Steady state platooning

Merge in-between by single vehicle in existing platoon

This use case is actually a combination of other use cases.

ID	PSF_2.2
Name	Merge in-between by single vehicle in existing platoon
Story	A joinable vehicle cuts in in an established, steady state driving, platoon. Then the vehicle behind this cut-in vehicle will issue a split (see use case 4.2) from the original platoon and then join the vehicle in front (use case 2.1). The vehicle in front can then join the platoon in front (use case 2.1), if/when it is directly in front.
Initial condition	

Operational area:	Any of the operational area inside the ODD for the platooning support function
Environmental conditions:	Positive conditions for platooning, other conditions detected either by driver or system.
Target vehicle(s):	A single platoon candidate that can accept to be extended with one or more vehicle (i.e. it is 'joinable').
Ego vehicle (s):	Driven at a safe distance behind another vehicle of the platoon: • Single platoon candidate that cuts in, must be within sensor view and in lane. • Single platoon candidate that cuts in, must be within V2V range (able to communicate reliably). • No intruder between Ego and cutting in platoon candidate. • Speed within platooning range. • Platooning
Application status target vehicle(s):	Manually driving or using advanced driver assistant system (e.g. ACC) HMI: Platooning candidate.
Application status Ego vehicle	Platooning HMI: Platooning status on/active

	Driver status target vehicle(s):	Aware
	Driver status Ego vehicle	Aware
	System status	No failure of internal systems and communication (V2V) is online. Sensors characteristics required for platooning ok.
Trigger	• The target vehicle cuts in (e.g. at a highway entrance) • The target vehicle is joinable • The ego vehicle detects the joinable signal viaV2V communication.	
Sequence	Use case sequence:  1. A single vehicle cuts in into the platoon 2. The ego vehicle detects the cut-in vehicle and reduces speed to increase the distance to this vehicle. The platoon system of the ego vehicle detects that the cut-in vehicle is joinable and splits from the former platoon (front split). 3. Two scenarios are possible: a) The ego vehicle joins the cut-in target vehicle and a new platoon is established (depicted) b) The cut-in vehicle joins the vehicle/platoon in front (alternative, not depicted) 4. A new platoon is established, if vehicles are within sensor and communication reach and there is no other cut-in vehicle. This can be achieved in two ways, corresponding to what is described with a) and b) above: a) The newly established platoon joins the vehicle/platoon in front (depicted)	

	b) The ego vehicle joins the cut-in vehicle, which is the trailing vehicle of the established platoon of 1.3 b) (alternative, not depicted).	
Final condition	Operational area:	Any of the operational areas inside the ODD for the platooning support function
	Environmental conditions:	N/A
	Target vehicle(s):	Steady state platooning with now the newly added truck.
	Ego vehicle (s):	Steady state platooning.
	Application status target vehicle(s):	Platooning Shows platooning status on HMI
	Application status Ego vehicle	Platooning Shows platooning status on HMI
	Driver status target vehicle(s):	Aware
	Driver status Ego vehicle	Aware
	System status	Steady state platooning

4.4.3. Platooning

Steady state platooning

The “steady state platooning” use case is the main use case for platooning and describes a platoon running at an “ACC” distance/time in an efficient formation within the longitudinal control limits described for steady state platooning.

ID	PSF_3.1	
Name	Steady state platooning	
Story	A group of two or more cooperative vehicles are in line, maintaining a typical low ACC distance (driver input) using wireless communication (V2V) which potentially enables increased traffic safety by use of additional ADAS-technology.	
Initial condition	Operational area:	Any of the operational areas inside the ODD for the platooning support function
	Environmental conditions:	Positive conditions for platooning, other conditions detected either by driver or system.
	Target vehicle(s):	Steady state platoon • Vehicle in front within sensor view, except for the leading truck. • Vehicle in front within V2V range for the following truck. Reception from at least 1 closest vehicle in front and to the back is required. • Vehicle in front within V2V range for the trailing truck. Reception from at least 1 closest vehicle in front is required. Control messages over V2V are sent according to specification.
	Ego vehicle (s):	Steady state platoon • Vehicle in front within sensor view, except for the leading truck.

<table>
<tr><td></td><td><table>
<tr><td></td><td>• Vehicle in front within V2V range for the following truck. Reception from at least 1 closest vehicle in front and to the back is required.
• Vehicle in front within V2V range for the trailing truck. Reception from at least 1 closest vehicle in front is required.
Control messages over V2V are sent according to specification.</td></tr>
<tr><td>Application status target vehicle(s):</td><td>Platooning
HMI: Platooning status</td></tr>
<tr><td>Application status Ego vehicle</td><td>Platooning
HMI: Platooning status</td></tr>
<tr><td>Driver status target vehicle(s):</td><td>Aware</td></tr>
<tr><td>Driver status Ego vehicle</td><td>Aware</td></tr>
<tr><td>System status</td><td>All systems are ok.</td></tr>
</table></td></tr>
<tr><td>Trigger</td><td>Transition to steady state platooning because relative speed and relative distance between the trucks within steady state tolerances.</td></tr>
<tr><td>Sequence</td><td><u>Use case sequence:</u>
 

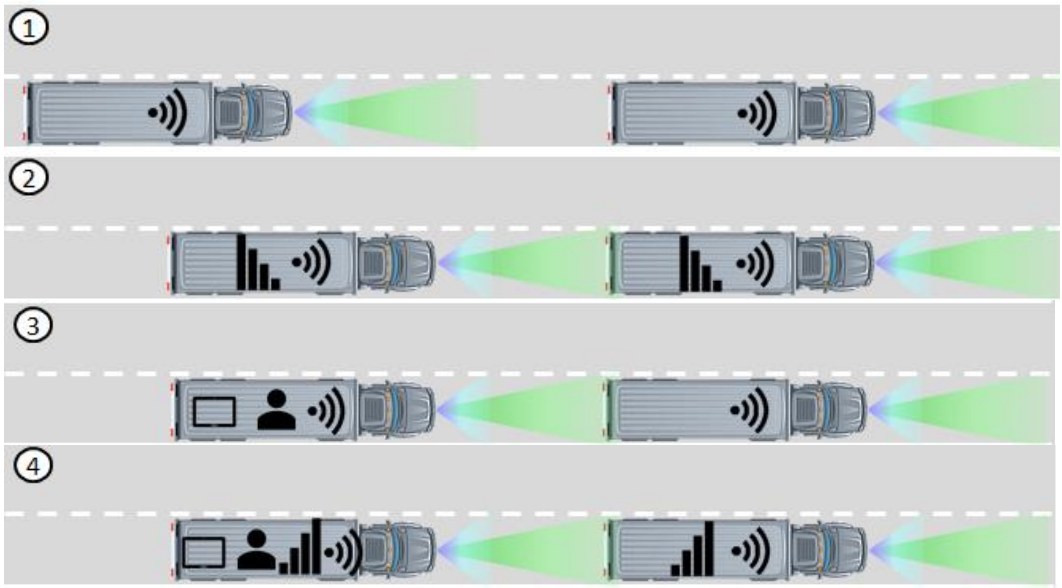
1.1 The ego vehicle is receiving platooning information via V2V from vehicles in the platoon. At least from the one in front for the trailing truck and from the one to the back for the leading truck.
1.2 The ego vehicle is broadcasting information on V2V to be consumed by the other platoon members.
1.3 The ego vehicle regulates platooning distance and speed based on V2V, sensor and vehicle internal information.
1.4 [Optional] The ego vehicle sends information to off board services. To be detailed by task 4.2 of the project
1.5 [Optional] The ego vehicle listens to Off Board signals (e.g. to receive platoon formation suggestion). To be detailed by task 4.2 of the project
1.6 Following traffic regulations is the responsibility of each driver.
1.7 When the ego vehicle cannot keep up or close a gap it sends a cohesion request to the vehicle in front.</td></tr>
<tr><td>Final condition</td><td><table>
<tr><td>Operational area:</td><td>Any of the operational areas inside the ODD for the platooning support function</td></tr>
<tr><td>Environmental conditions:</td><td>Positive conditions for platooning, other conditions detected either by driver or system.</td></tr>
<tr><td>Target vehicle(s):</td><td>Steady state platooning:
• Vehicle in front within sensor view, except leading truck.
• Vehicle in front within V2V range for the following truck. Reception from at least 1 closest vehicle in front and to the back are required.</td></tr>
</table></td></tr>
</table>

		• Vehicle in front within V2V range for the trailing truck. Reception from at least 1 closest vehicle in front is required. Control messages over V2V are sent according to specification.
	Ego vehicle (s):	Steady state platooning: • Vehicle in front within sensor view, except leading truck. • Vehicle in front within V2V range for the following truck. Reception from at least 1 closest vehicle in front and to the back are required. • Vehicle in front within V2V range for the trailing truck. Reception from at least 1 closest vehicle in front is required. Control messages over V2V are sent according to specification.
	Application status target vehicle(s):	Platooning HMI: Platooning status
	Application status Ego vehicle	Platooning HMI: Platooning status
	Driver status target vehicle(s):	Aware
	Driver status Ego vehicle	Aware
	System status	All systems are ok.

Follow to stop

For the “Follow to stop” use case, it is specified that at least each platooning system should be able to follow the front platooning partner to a full stop. The continuation of this use case is specific for each OEM and will probably depend on the ACC capabilities of the specific truck.

ID	PSF_3.2	
Name	Follow to stop	
Story	In an established steady state platoon; the leader is reducing the speed (<30 km/h) due to a ‘normal event’ (traffic jam, toll gate…). The following vehicles will follow the deceleration request. Once the leader is accelerating again, then it is OEM specific if and how the following vehicle will react.	
Initial condition	Operational area:	Any of the operational areas inside the ODD for the platooning support function
	Environmental conditions:	Any environmental condition inside the ODD for the platooning support function
	Target vehicle(s):	Steady state platooning
	Ego vehicle (s):	Steady state platooning
	Application status target vehicle(s):	Platooning Shows platooning status on HMI
	Application status Ego vehicle	Platooning Shows platooning target active on HMI

	Driver status target vehicle(s):	Aware
	Driver status Ego vehicle	Aware
	System status	No failure of internal system
Trigger	Leading truck brakes till < 30 km/h	
Sequence	<u>Use case sequence:</u>  1 Initial state: steady state platooning 2 Target vehicle brakes to speed <30 km/h and even to a full stop, follower follows brake action 3 (OEM specific continuation: e.g. driver confirmation required for drive off) 4 (OEM specific continuation: e.g. accelerate again to follow target vehicle)	
Final condition	Operational area:	Any of the operational areas inside the ODD for the platooning support function
	Environmental conditions:	Any environmental condition inside the ODD for the platooning support function
	Target vehicle(s):	OEM specific
	Ego vehicle (s):	OEM specific
	Application status target vehicle(s):	Aware
	Application status Ego vehicle	Aware
	Driver status target vehicle(s):	No failure of internal system
	Driver status Ego vehicle	Depends on OEM specific implementation
	System status	Depends on OEM specific implementation

Emergency braking

<table>
<tr><td>ID</td><td>PSF_3.3</td></tr>
<tr><td>Name</td><td>Emergency Braking</td></tr>
<tr><td>Story</td><td>
All trucks in the platoon are equipped with an Automatic Emergency Braking System (AEBS) according to Regulation No 131 of the Economic Commission for Europe of the United Nations (UN/ECE) (UN R131, 2014). According to this regulation, a warning is provided not later than 1.4 s before the start of the emergency braking phase. For state-of-the-art AEBS systems, a sensor system (e.g. containing radar, accelerometers), which is installed on the ego truck, and calculations (e.g. time-to-collision) are used to determine the desired start of the emergency braking phase. ‘Emergency braking phase’ means the phase starting when the AEBS emits a braking demand for at least 4 m/s^2 deceleration to the service braking system of the vehicle.

Detecting deceleration of a preceding vehicle with a vehicle based sensor system involves a certain delay, as the system reacts on the evaluation of the motion of the preceding vehicle using the sensor system, which has its own delay as well. When the vehicle is part of a platoon, all trucks in the platoon send a desired acceleration via V2V. This desired acceleration is the acceleration demand requested to the ego truck’s braking system. As this demand is earlier than the realisation of the vehicle’s deceleration, it enables following vehicles to anticipate on a braking action earlier. Note that the V2V communication delay is much smaller than the delay due to the vehicle longitudinal dynamics and the sensor system delay.

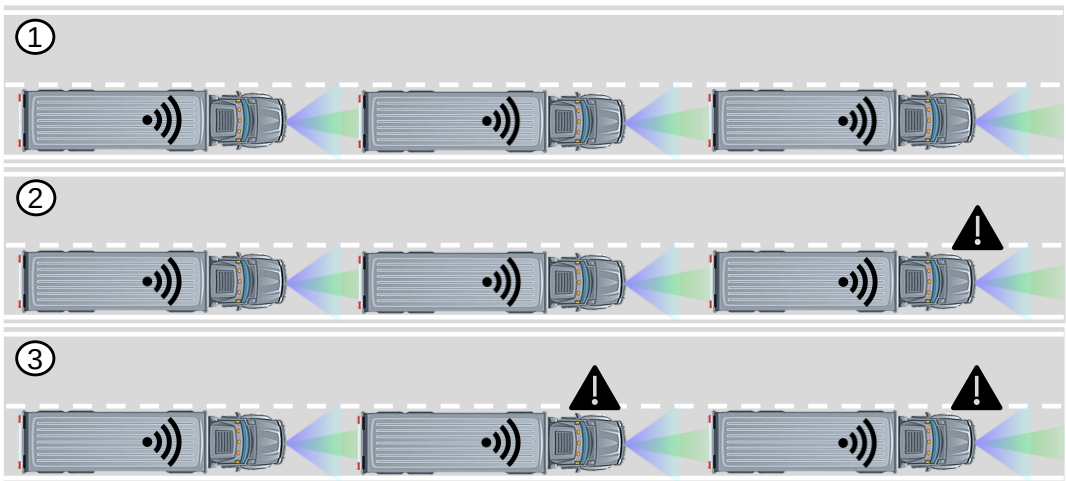
When the AEBS of the vehicle is kept unmodified, the (faster) detection of a strong braking of the preceding vehicle based on V2V communication will, if necessary, trigger a warning to the driver, while the platooning system already requests a maximum of 3.5 m/s^2. Strong braking is here defined as a deceleration of at least 4 m/s^2. The necessity for a warning to the driver is based on the evaluation whether the intervehicle distance is sufficient to avoid a collision, considering the maximum braking demand of 3.5 m/s^2 of the platooning system.

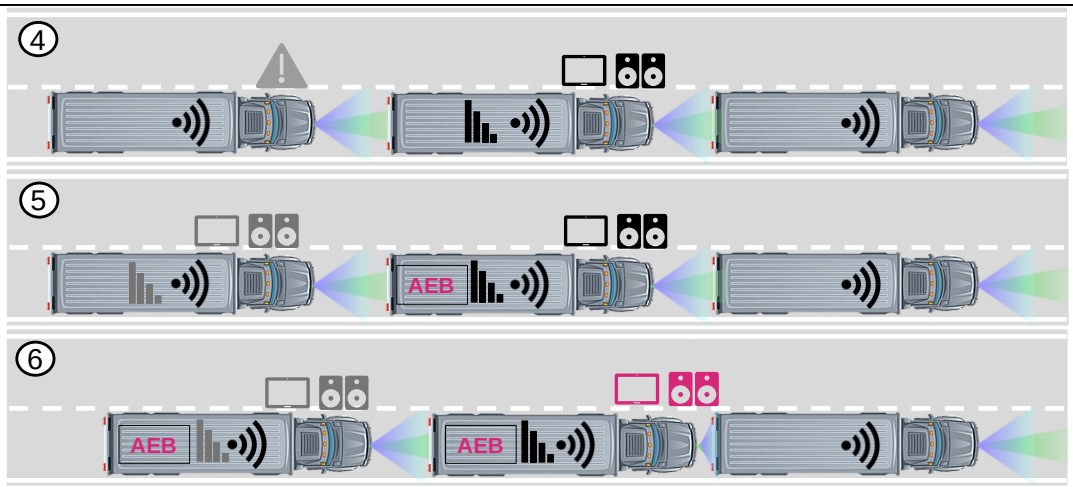
(OPTIONAL) Alternativeley the Platooning function has the AEBS functionality integrated: the AEBS warning is already on the basis of the (faster) V2V communication. The emergency braking action is only initiated after comfirmation of the onboard sensor(s). Hence, In this case, the emergency braking phase can start earlier (if assessed necessary by the system). During the confirmation period, the system will brake with a deceleration up to the system limit (up to 3.5 m/s^2).

The table below summarises the differences:
<table>
<tr><td>System</td><td>Advantages Platooning offers</td></tr>
<tr><td>Non-platooning, ACC and AEBS</td><td>-</td></tr>
</table>
</td></tr>
</table>

	Platooning and separate AEBS	Earlier detection of potential collision based on V2V, resulting in earlier braking of max. 3.5 m/s^2 and earlier warning of the driver.
	Platooning with AEBS integrated	Earlier detection of potential collision based on V2V, resulting in earlier braking of max. 3.5 m/s^2, earlier warning of the driver and earlier starting of the emergency braking phase.
Initial condition		

Operational area:	Any of the operational areas inside the ODD for the platooning support function
Environmental conditions:	Any environmental condition inside the ODD for the platooning support function
Target vehicle(s):	Leader or Follower of a Platoon
Ego vehicle (s):	Follower or Trailer of a Platoon at a given target time gap to the forward vehicle.
Application status target vehicle(s):	Any platooning state (so not in standalone state)
Application status Ego vehicle	Any platooning state (so not in standalone state)
Driver status target vehicle(s):	Aware
Driver status Ego vehicle	Aware
System status	No failure

Trigger	The truck in front of the ego vehicle initiates emergency braking, i.e. it performs braking with a deceleration (demand) that is larger than 4 m/s^2. This hard braking demand can be the result of an AEBS event or the driver is actuating the brakes.
Sequence	<u>Use case sequence:</u> 



1. Any platoon driving state
2. Target vehicle intends to perform an emergency braking action with a deceleration larger than 4 m/s^2.
3. Ego vehicle recognises the strong braking demand of the front vehicle via V2V informationand assesses the risk of a collision (OEM specific, e.g.using time-to-collision measures). Note: the risk of a collision also depends on the intervehicle distance (time gap).
4. Ego vehicle starts to decelerate with a maximum allowed deceleration of 3.5 m/s^2 and warns the driver if a risk of collision is determined.
5. The ego vehicle's separate AEBS also continuously assesses the necessity of an emergency braking using the onboard sensor(s).
6. When the AEBS has concluded the necessity of emergency braking, the full AEBS sequence is initiated, starting with the AEBS warning modes and, maximum 1.4 s later the start of the emergency braking phase. The AEBS executes emergency braking until the emergency situation is no longer present or the ego vehicle has stopped completely.

   OR (OPTIONAL): the platooning system (with AEBS integrated) uses the V2V communicated braking demand of the front vehicle in its algorithm to assess the necessity of an automated emergency braking. If the system decided that the emergency braking phase is necessary, it will start warning the driver no later than 1.4 s before the platooning functionality performs the emergency braking. The platooning function executes emergency braking until the emergency situation is no longer present or the ego vehicle has stopped completely.

Final condition

The final condition of the system depends on the exit speed of the ego-vehicle. Here we define 2 cases:

a. Vehicle moving with low speed (< 30 km/h) or in standstill condition
b. Vehicle moving with a speed above 30 km/h

In general: Drivers are responsible to resume in both cases.

Operational area:	Any of the operational areas inside the ODD for the platooning support function

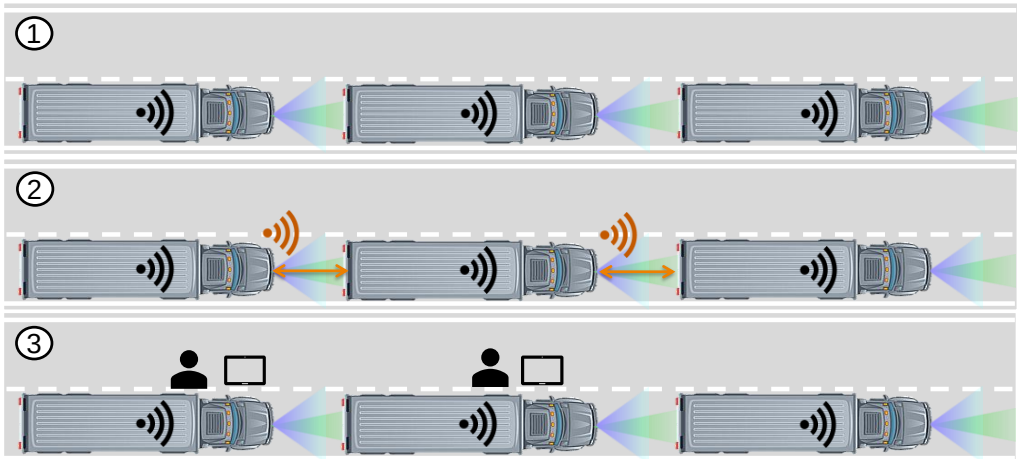
	Environmental conditions:	Any environmental condition inside the ODD for the platooning support function
	Target vehicle(s):	a. Vehicle moving with low speed (< 30 km/h) or in standstill condition b. Vehicle moving with a speed above the 30 km/h
	Ego vehicle (s):	a. Vehicle moving with low speed (< 30 km/h) or in standstill condition b. Vehicle moving with a speed above the 30 km/h
	Application status target vehicle(s):	a. Truck leaves platoon, continues as standalone b. HMI: Driver can resume platooning.
	Application status Ego vehicle	a. Truck leaves platoon, continues as standalone b. HMI: Driver can resume platooning.
	Driver status target vehicle(s):	Aware
	Driver status Ego vehicle	Aware
	System status	No failure

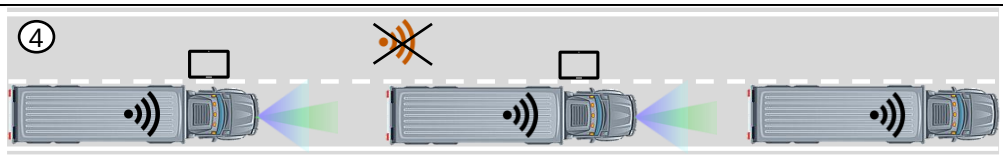
Platoon gap adaptation

I2V interaction

ID	PSF_3.4.1
Name	Platoon gap adaptation because of I2V interaction
Story	**Pre requisite**: guidelines for zone policy have been setup to take into account the time to arrival to the zone between notification and implementation to avoid high decelerations at the rear of the platoon. A platoon is driving in steady state platooning. I2V communication informs all vehicles in the platoon of a zone policy stating: increase distances between vehicles for a specific zone defined by (for example, but not limited to) GPS locations for start and end. (Other zone policies from V2I may be a specific speed, or lateral positioning, etc.). Upon receiving and reaching the designated area, each driver in the platoon applies the required zone policy. At the end of the zone, the drivers on the platoon can resume to the previous configuration.
Initial condition	

Operational area:	Any of the operational areas inside the ODD for the platooning support function
Environmental conditions:	Positive conditions for platooning, other conditions detected either by driver or system.
Target vehicle(s):	Steady state platooning: • Vehicle in front within sensor view, except leading truck.

<table>
<tr><td></td><td>
<table>
<tr><td></td><td>• Vehicle in front within V2V range for the following truck. Reception from at least 1 closest vehicle in front and to the back are required.
• Vehicle in front within V2V range for the trailing truck. Reception from at least 1 closest vehicle in front is required.
• Control messages over V2V are sent according to specification.</td></tr>
<tr><td>Ego vehicle (s):</td><td>Steady state platooning:
• Vehicle in front within sensor view, except leading truck.
• Vehicle in front within V2V range for the following truck. Reception from at least 1 closest vehicle in front and to the back are required.
• Vehicle in front within V2V range for the trailing truck. Reception from at least 1 closest vehicle in front is required.
• Control messages over V2V are sent according to specification.</td></tr>
<tr><td>Application status target vehicle(s):</td><td>Platooning
HMI: Shows platooning status: platooning active, platoon specific information and functions.</td></tr>
<tr><td>Application status Ego vehicle</td><td>Platooning
HMI: Shows platooning status: platooning active, platoon specific information and functions.</td></tr>
<tr><td>Driver status target vehicle(s):</td><td>Aware</td></tr>
<tr><td>Driver status Ego vehicle</td><td>Aware</td></tr>
<tr><td>System status</td><td>All systems are ok.</td></tr>
</table>
</td></tr>
<tr><td>Trigger</td><td>Reception of message from V2I (road side, off board or on board (map)) from the road operator indicating a recommended zone policy for distance for the platoon for a specific road section by all vehicles and reaching the zone.</td></tr>
<tr><td>Sequence</td><td><u>Use case sequence:</u>
 
</td></tr>
</table>



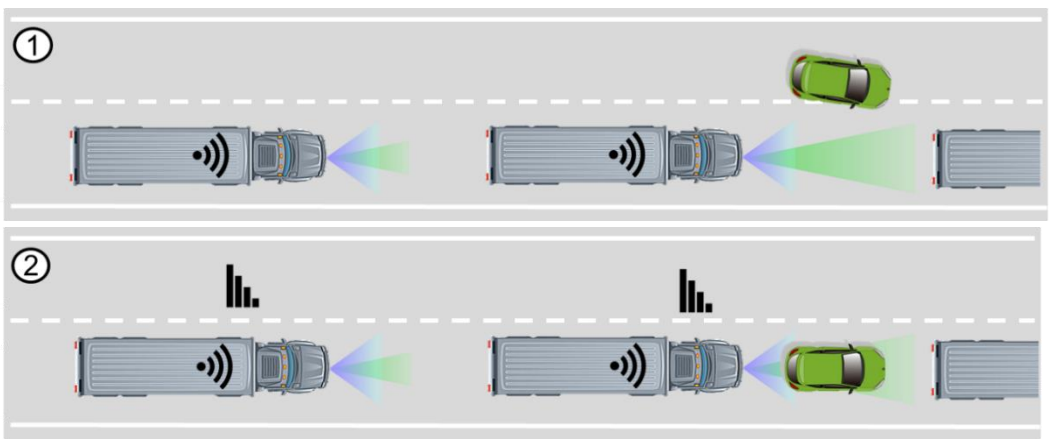
1. Any platoon driving state
2. All trucks in the platoon receive instructions from I2V to increase the distance to the vehicle ahead.
3. The drivers of the platooning vehicles are informed of the new (larger) required distance through HMI. The drivers set the new following distance to this required gap, or if not possible, the drivers stop platooning.
4. At the end of the section of infrastructure, the drivers are informed of leaving the restriction zone and may choose another gap setting, or join the platoon again.

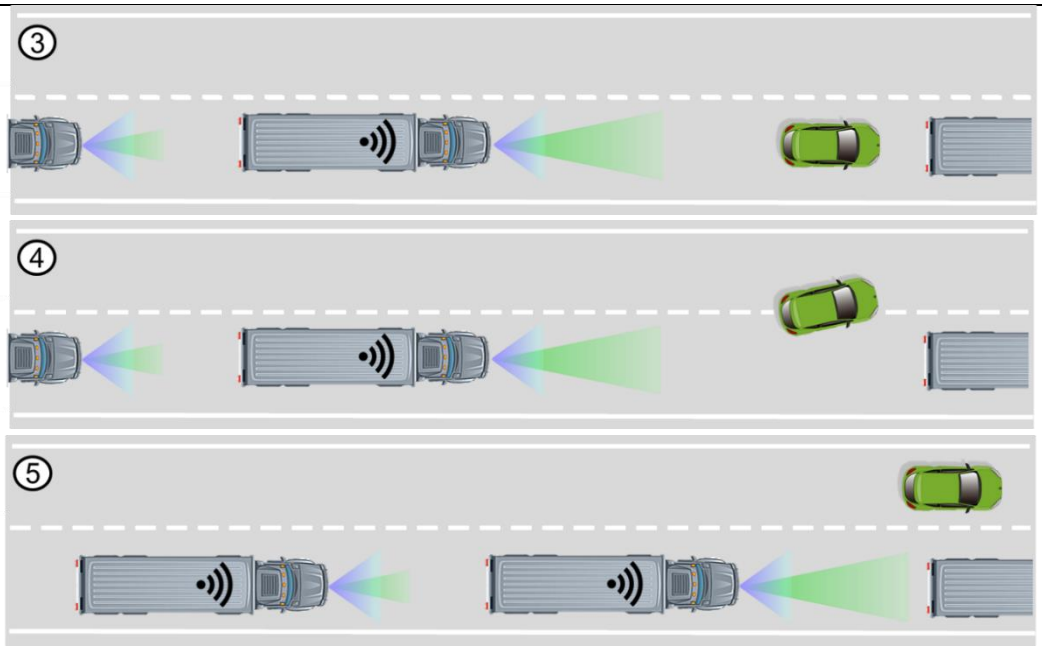
Final condition

Operational area:	Any of the operational areas inside the ODD for the platooning support function
Environmental conditions:	Positive conditions for platooning, other conditions detected either by driver or system.
Target vehicle(s):	Steady state platooning: • Vehicle in front within sensor view, except leading truck. • Vehicle in front within V2V range for the following truck. Reception from at least 1 closest vehicle in front and to the back are required. • Vehicle in front within V2V range for the trailing truck. Reception from at least 1 closest vehicle in front is required. • Control messages over V2V are sent according to specification.
Ego vehicle (s):	Steady state platooning: • Vehicle in front within sensor view, except leading truck. • Vehicle in front within V2V range for the following truck. Reception from at least 1 closest vehicle in front and to the back are required. • Vehicle in front within V2V range for the trailing truck. Reception from at least 1 closest vehicle in front is required. • Control messages over V2V are sent according to specification.
Application status target vehicle(s):	Platooning HMI: Shows platooning status: platooning active, platoon specific information and functions.
Application status Ego vehicle	Platooning HMI: Shows platooning status: platooning active, platoon specific information and functions.
Driver status target vehicle(s):	Aware
Driver status Ego vehicle	Aware
System status	All systems are ok.

Cut-in

Cut-in use case is described here only for cut-in between leader and following truck. The same sequence holds for cut-ins at other instances in the platoon.

<table>
<tr><td>ID</td><td colspan="2">PSF_3.4.2</td></tr>
<tr><td>Name</td><td colspan="2">Cut-in handling within the platoon. Cut in vehicle remains in the platoon for a certain period of time and then cuts out again.</td></tr>
<tr><td>Story</td><td colspan="2">Platoon members will adapt their speed and gap towards the cut-in vehicle and between the platoon members to assure safety (by onboard sensors only). The cut-in remains for an undetermined amount of time, possibly followed by a cut-out action. After a cut out, the platoon will automatically reduce the following distance (gap closing) to the rest of the platoon members and continue. Where needed the leader of the platoon will be supported to assist in the gap closing action by an advice to lower its speed during the gap closing action.</td></tr>
<tr><td>Initial condition</td><td colspan="2"><table>
<tr><td>Operational area:</td><td>Any of the operational areas inside the ODD for the platooning support function</td></tr>
<tr><td>Environmental conditions:</td><td>Any environmental condition inside the ODD for the platooning support function</td></tr>
<tr><td>Target vehicle(s):</td><td>Vehicle with equal speed to the platoon plans to cut in between the leading truck and following truck (ego vehicle in this use case) of the platoon. Vehicle is driving on the other lane.</td></tr>
<tr><td>Ego vehicle (s):</td><td>Steady state following truck of a platoon in steady state (see steady state use case).</td></tr>
<tr><td>Application status Ego vehicle(s)</td><td>Platooning
HMI: Shows platooning status</td></tr>
<tr><td>Driver status target vehicle(s):</td><td>Aware</td></tr>
<tr><td>Driver status Ego vehicle</td><td>Aware</td></tr>
<tr><td>System status</td><td>No failure of internal system and communication (V2V) is online</td></tr>
</table></td></tr>
<tr><td>Trigger</td><td colspan="2">Start of a cut-in is detected</td></tr>
<tr><td>Sequence</td><td colspan="2">Sketch:
 
</td></tr>
</table>



Sequence in time:

1 Ego vehicle is platooning
2 Vehicle cuts in in front of ego vehicle
3 1) Ego vehicle increases following distance (towards a safe following distance) towards cut-in vehicle by decelerating. The nominal longitudinal control of the ego vehicle will be performed using only local sensors.
2) HMI: Driver in Ego-vehicle and drivers of the platoon are informed about the cut-ins by means of the current platoon status.
4 Two different situations can occur (a/b):

a.1. The intruder performs a cut out before the ACC distance is reached (situation 5 in the sequence pictures)
a.2. Platoon automatically reduces the distance again to the desired platooning distance. If this is not possible, the cohesion functionality (use case ID3.4.4) will be used if active on the platoon vehicles.

b1. The intruder does not perform a cut out before the ACC distance is reached
b2. OEM specific continuation

Final condition

Operational area:	Any of the operational areas inside the ODD for the platooning support function
Environmental conditions:	Any environmental condition inside the ODD for the platooning support function
Target vehicle(s):	Vehicle driving by itself in another lane than the platoon
Ego vehicle (s):	Steady state following or trailing truck of a platoon in steady state (see steady state use case).
Application status Ego vehicle(s)	Platooning HMI: Shows platooning status
Driver status target vehicle(s):	Aware
Driver status Ego vehicle	Aware

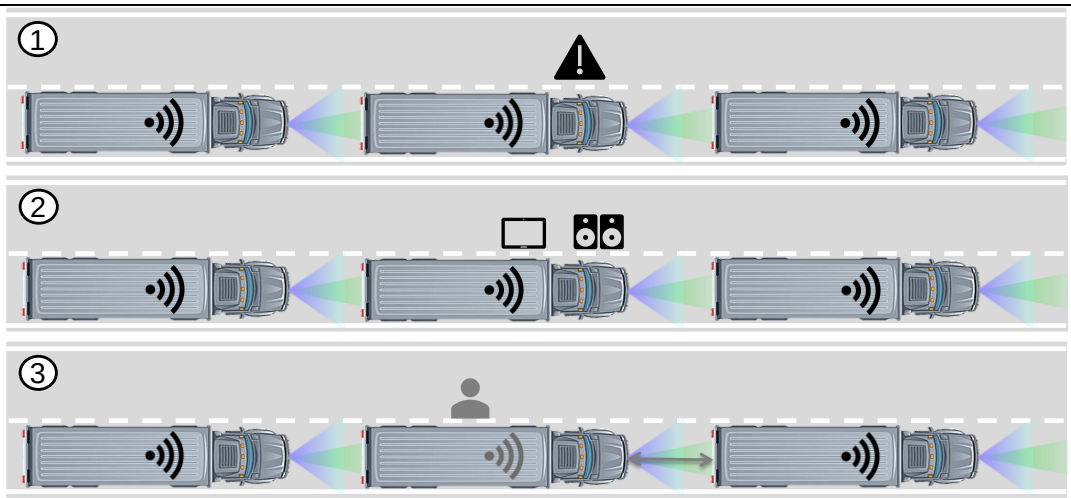
	System status	No failure of internal system and communication (V2V) is online

System status (e.g. packet loss)

ID	PSF_3.4.3
Name	Warning because of system status (e.g. packet loss)
Story	The vehicle detects that the platooning system is not performing as expected anymore (e.g. because of loss of too many packets). The driver will be warned on the status of the system. Optional: the target time gap between trucks is adapted to a new value.
Initial condition	Truck in steady state platooning, driving at a given target time gap from the preceding truck.

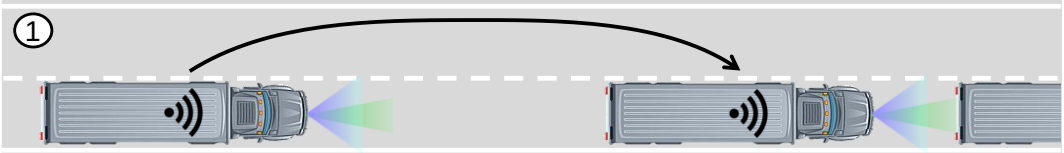
Operational area:	Any of the operational areas defined in the ODD for the platooning support function
Environmental conditions:	Any environmental condition inside the ODD for the platooning support function
Target vehicle(s):	Leader or follower of a Platoon driving at a given target time gap from preceding truck.
Ego vehicle (s):	Follower or trailer of a platoon driving at a given target time gap from preceding truck.
Application status target vehicle(s):	Platooning HMI: Shows platooning status: platooning active, platoon specific information and functions.
Application status Ego vehicle	Platooning HMI: Shows platooning status: platooning active, platoon specific information and functions.
Driver status target vehicle(s):	Aware
Driver status Ego vehicle	Aware
System status	Warning

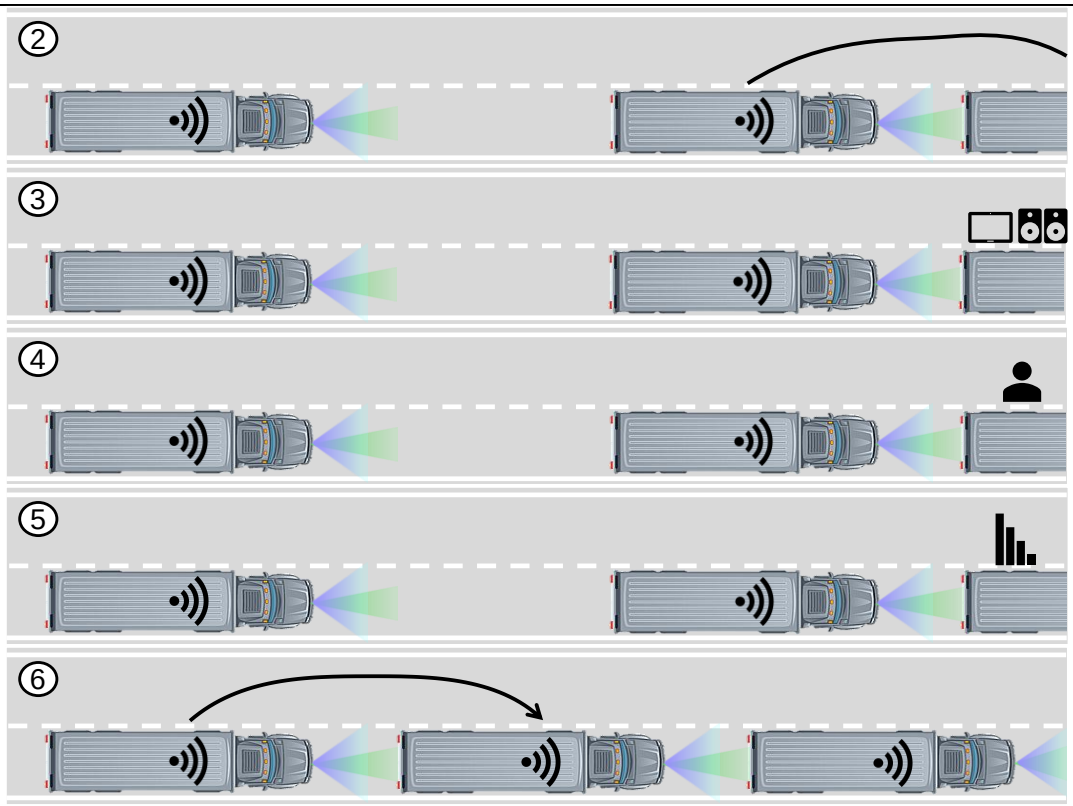
Trigger	Example triggers for system status • Geo Localisation lost/Low location accuracy • Abnormal situation finished (back to normal operation) • Sensor degradation or improvement (higher/lower uncertainty of sensors) • V2V packets lost within a certain timeframe

<table>
<tr><td>Sequence</td><td>


1. The vehicle detects that the platooning system status is not ok anymore.
2. The driver will be warned (HMI) on the status of the system.
3. Further actions may be performed:
a. Time gap may be adjusted based on the trigger event; some event may result in a faster system reaction and time-gap increase, whereas other events may result in smooth transition to prevent increased fuel economy and not create control disturbances.
b. HMI: the gap changes are communicated to the driver
c. In the event of too many V2V packets lost within a certain timeframe, the ego vehicle detects a loss of communication. When detected with respect to the platooning partner behind, the ego vehicle will trigger a back split. When the ego vehicle detects loss of communication with respect to the platooning partner in front, the ego vehicle starts a front split.
</td></tr>
<tr><td>Final condition</td><td>
<table>
<tr><td>Operational area:</td><td>Any of the operational areas defined inside the ODD for the platooning support function</td></tr>
<tr><td>Environmental conditions:</td><td>Any environmental condition inside the ODD for the platooning support function</td></tr>
<tr><td>Target vehicle(s):</td><td>Leader or Follower of a Platoon driving at a given target time gap from preceding truck.</td></tr>
<tr><td>Ego vehicle (s):</td><td>Following or Trailing truck of a Platoon driving at the given target time gap from preceding truck.</td></tr>
<tr><td>Application status target vehicle(s):</td><td>Platooning
HMI: Shows platooning status: platooning active, platoon specific information and functions.</td></tr>
<tr><td>Application status Ego vehicle</td><td>Platooning
HMI: Shows platooning status: platooning active, platoon specific information and functions.</td></tr>
<tr><td>Driver status target vehicle(s):</td><td>Aware</td></tr>
<tr><td>Driver status Ego vehicle</td><td>Aware</td></tr>
<tr><td>System status</td><td>Warning</td></tr>
</table>
</td></tr>
</table>

Cohesion request

<table>
<tr><td>ID</td><td colspan="2">PSF_3.4.4</td></tr>
<tr><td>Name</td><td colspan="2">Cohesion request</td></tr>
<tr><td>Story</td><td colspan="2">The aim of this use case is to keep the cohesion of the platoon (keep the platoon together) when desired.
A platoon is driving at e.g. 85 km/h (steady state platooning). The maximum attainable speeds of the platoon members are different, e.g. the lead vehicle can do 89.9 km/h and the first following vehicle only 85.0 km/h. The driver of the lead vehicle is informed about the lowest possible platoon speed (85.0 km/h in this example). The lead vehicle driver sets the set speed to this maximum speed to keep the platoon together.
Then a vehicle cuts through before the slowest vehicle (the second vehicle in the example) causing a gap in the platoon. This gap cannot be closed when the lead vehicle remains at the original maximum speed. Hence, the slowest vehicle requests a lower speed by changing the maximum attainable speed (for example 83 km/h) communicated to the vehicle in front (which forwards it to the vehicle in front until the request reaches the lead vehicle). The lead vehicle driver is informed of this change and lowers the set speed according to the request (83 km/h in this example). When the slowest vehicle has closed the gap, it changes the maximum attainable speed back to its maximum attainable speed as before the cut through situation (85.0 km/h in the example).</td></tr>
<tr><td>Initial condition</td><td colspan="2"><table>
<tr><td>Operational area:</td><td>Any of the operational areas inside the ODD for the platooning support function</td></tr>
<tr><td>Environmental conditions:</td><td>Positive conditions for platooning, other conditions detected either by driver or system.</td></tr>
<tr><td>Target vehicle(s):</td><td>Steady state platoon with “Cohesion” functionality active</td></tr>
<tr><td>Ego vehicle (s):</td><td>Steady state platoon with “Cohesion” functionality active</td></tr>
<tr><td>Application status target vehicle(s):</td><td>Platooning
HMI: Platooning status on HMI.</td></tr>
<tr><td>Application status Ego vehicle</td><td>Platooning
HMI: Platooning status on HMI.</td></tr>
<tr><td>Driver status target vehicle(s):</td><td>Aware</td></tr>
<tr><td>Driver status Ego vehicle</td><td>Aware</td></tr>
<tr><td>System status</td><td>No failure of internal systems and communication (V2V) is online. Sensor characteristics required for platooning ok.</td></tr>
</table></td></tr>
<tr><td>Trigger</td><td colspan="2">The system always sends the attainable maximum speed. If the vehicle is unable to close a gap, then the system automatically lowers this maximum speed.</td></tr>
<tr><td>Sequence</td><td colspan="2"><u>Use case sequence:</u>
 
</td></tr>
</table>



1. The ego vehicle (the slowest vehicle in the platoon) sends to the preceding the changed maximum attainable speed.
2. This information is forwarded to the lead vehicle
3. The HMI displays the maximum attainable speed to the driver of the lead vehicle
4. The driver of the lead vehicle lowers the set speed to just under this maximum requested speed (or, when driving manually, the driver drives slower than this speed).
5. The gap is closed
6. The slow vehicle changes the request back to its maximum attainable speed.

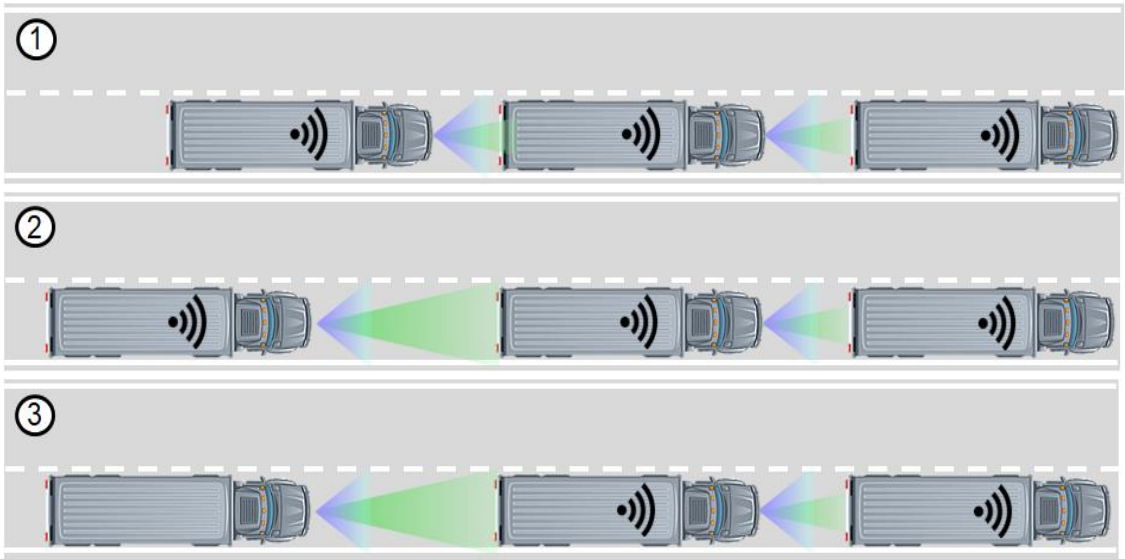
Final condition

Operational area:	Any of the operational area inside the ODD for the platooning support function
Environmental conditions:	Positive conditions for platooning, other conditions detected either by driver or system.
Target vehicle(s):	Steady state platoon with “Cohesion” functionality active
Ego vehicle (s):	Steady state platoon with “Cohesion” functionality active
Application status target vehicle(s):	Platooning HMI: Platooning status on HMI, showing the cohesion request.
Application status ego vehicle	Platooning HMI: Platooning status on HMI.
Driver status target vehicle(s):	Aware of the cohesion request
Driver status Ego vehicle	Aware

	Operational area:	Any of the operational area inside the ODD for the platooning support function	

4.4.4. Disengage platoon

Leave by trailing truck

ID	PSF_4.1.1	
Name	Leaving platoon by trailing truck	
Story	While the platoon is active, the ego vehicle starts the leaving procedure. The driver will be informed on the status of the system: platooning is switching off. Optionally, the system increases the inter-vehicle time gap in respect to the preceding one.	
Initial condition	Operational area:	Any of the operational areas inside the ODD for the platooning support function
	Environmental conditions:	Any environmental condition inside the ODD for the platooning support function
	Target vehicle(s):	Steady state following truck of existing platoon.
	Ego vehicle (s):	Steady state trailing truck of existing platoon.
	Application status target vehicle(s):	Platooning HMI: Shows platooning status: platooning active, platoon specific information and functions.
	Application status Ego vehicle	Platooning HMI: Shows platooning status: platooning active, platoon specific information and functions.
	Driver status target vehicle(s):	Aware
	Driver status Ego vehicle	Aware
	System status	No failure
Trigger	The ego driver starts the leaving procedure by pushing the leave button or pressing the brake pedal.	
Sequence	Use case sequence:  Sequence in bullet points:	

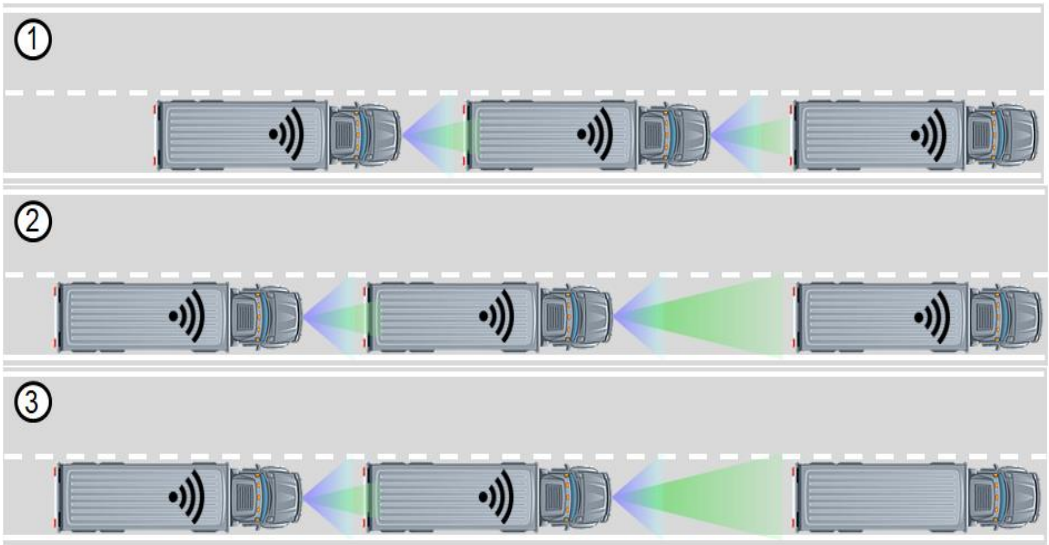
	1.1 The ego application enters “Leave” mode. 1.2 The start of the leaving procedure from the ego vehicle is broadcasted to the other platoon members through V2V communication (message to be inserted). 2 [Optional] The ego vehicle starts (if needed) to increase the inter-vehicle time gap with respect to the target vehicle 3.1 When the leave procedure is ended, the ego vehicle platooning communication is disconnected 3.2 When the leave procedure is ended, the ego vehicle HMI informs the driver that platooning support is no longer available 3.3 [Optional] The involved vehicles report the leave event to their respective platoon enablers (offboard). To be detailed by task 4.2 of the project. 3.4 When the leave procedure has ended, the platooning function is turned off. 3.5 When the leave procedure has ended, the other platoon members continue to platoon
Final condition	

Operational area:	Any of the operational areas inside the ODD for the platooning support function
Environmental conditions:	Any environmental condition inside the ODD for the platooning support function
Target vehicle(s):	Steady state following truck of platoon.
Ego vehicle (s):	Stand-alone state truck driving @ ACC following distance.
Application status target vehicle(s):	Platooning HMI: Shows platooning status: platooning active, platoon specific information and functions.
Application status Ego vehicle	Stand-alone (Stand-alone HMI, could be OEM specific)
Driver status target vehicle(s):	Aware
Driver status Ego vehicle	Aware
System status	Vehicle platform: no failure V2V: same as ”stand-alone” with platooning functionality active

Leave by leading truck

ID	PSF_4.1.2
Name	Leaving platoon by leading truck
Story	While the platoon is active, the leading vehicle starts the leaving procedure. The driver will be warned about the status of the system. Optionally, the first following vehicle system increases the inter-vehicle time gap in respect to the preceding one. When the leave procedure is ended, the leading vehicle continues as stand-alone truck, while the others continue as a new platoon; the first following vehicle takes over the role of the leading truck in the platoon.
Initial condition	

Operational area:	Any of the operational areas inside the ODD for the platooning support function
Environmental conditions:	Any environmental condition inside the ODD for the platooning support function
Target vehicle(s):	Steady state 1st following truck in existing platoon

<table>
<tr><td></td><td>
<table>
<tr><td>Ego vehicle (s):</td><td>Steady state leading truck of existing platoon.</td></tr>
<tr><td>Application status target vehicle(s):</td><td>Platooning
HMI: Shows platooning status: platooning active, platoon specific information and functions.</td></tr>
<tr><td>Application status Ego vehicle</td><td>Platooning
HMI: Shows platooning status: platooning active, platoon specific information and functions.</td></tr>
<tr><td>Driver status target vehicle(s):</td><td>Aware</td></tr>
<tr><td>Driver status Ego vehicle</td><td>Aware</td></tr>
<tr><td>System status</td><td>No failure</td></tr>
</table>
</td></tr>
<tr><td>Trigger</td><td>The ego driver starts the leaving procedure by pushing the leave button or pressing the brake pedal.</td></tr>
<tr><td>Sequence</td><td>Sketch:
 

1.1 The ego application enters “Leave” mode.
1.2 The start of the leaving procedure from the ego vehicle is broadcasted to the other platoon members through V2V communication (message to be inserted).

2 [Optional] The target vehicle starts to increase the inter-vehicle time gap in respect to the ego one

3.1 The target vehicle communicates being ready to continue as leading vehicle of the platoon to the ego one through V2V communication.
3.2 When the leave procedure is ended, the remaining platoon members shall assure that they can continue platooning (e.g. if needed re-negotiate the V2V encryption key)
3.3 When the leave procedure is ended, the ego vehicle HMI informs the driver that platooning support is no longer available
3.4 [Optional] The involved vehicles report the leave event to their respective platoon enablers (offboard). To be detailed by task 4.2 of the project.
3.5 The target vehicle becomes the new Platoon leader
3.6 The HMI of the target vehicle informs the driver about the new role in the platoon
3.7 The ego vehicle platooning communication is disconnected
3.8 The ego vehicle application enters “Stand-alone” mode</td></tr>
</table>

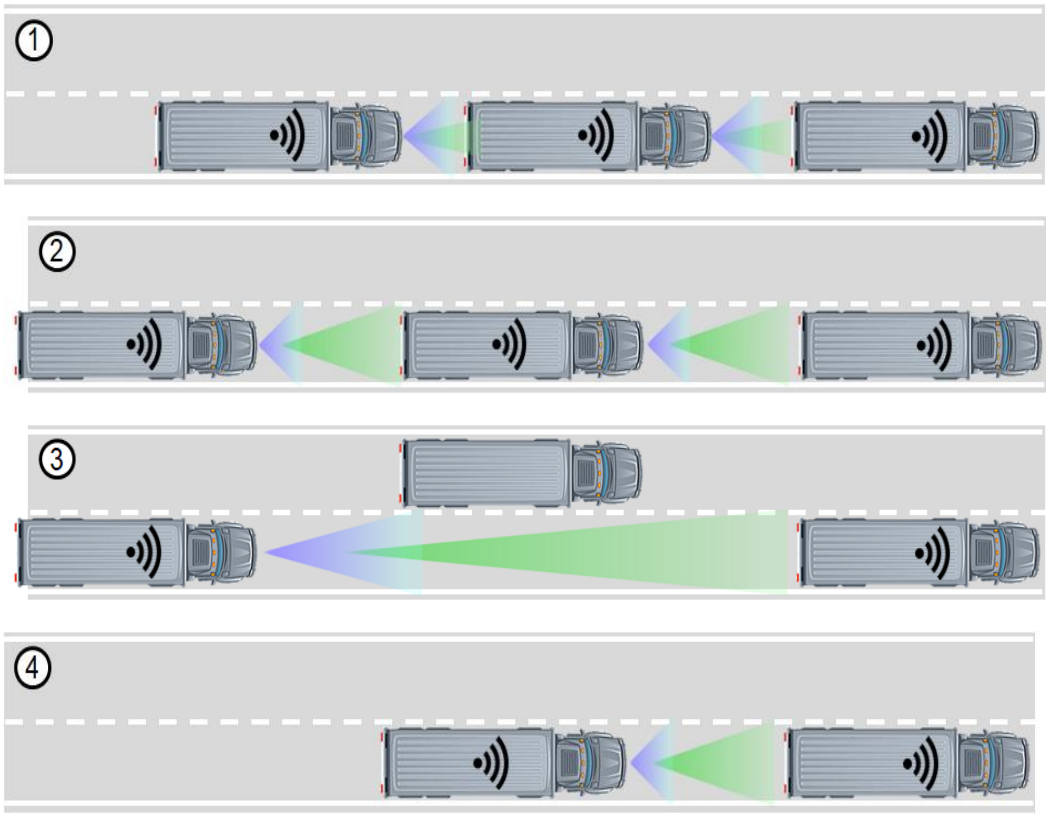
	3.9 HMI on for the remaining Platoon members is: see reference to “Steady-state” Platoon UC 3.10 The remaining Platoon members application is: see reference to “Steady-state” Platoon UC
Final condition	

Operational area:	Any of the operational areas inside the ODD for the platooning support function
Environmental conditions:	Any environmental condition inside the ODD for the platooning support function
Target vehicle(s):	Steady state leading truck of the new platoon.
Ego vehicle (s):	Stand-alone driving
Application status target vehicle(s):	Platooning HMI: Shows platooning status: platooning active, platoon specific information and functions.
Application status Ego vehicle	Stand-alone (Stand-alone HMI, could be OEM specific)
Driver status target vehicle(s):	Aware
Driver status Ego vehicle	Aware
System status	Vehicle platform: no failure V2V: same as ”stand-alone” with Platooning functionality active

Leave by following truck

ID	PSF_4.1.3
Name	Leaving platoon by follower truck
Story	While the platoon is active, one of the follower vehicles (not the leader nor the trailing vehicle) starts the leaving procedure. The driver is informed that the platooning system is switching off. Optionally, the first following vehicle system increases the inter-vehicle time gap in respect to the preceding one. Optionally, the ego-vehicle increases the inter-vehicle time gap in respect to the preceding one. When the leave procedure has ended, the driver of the ego-vehicle makes a cut-out action and continues as stand-alone truck. The remaining platoon members will close the gap after the cut-out has finished and will continue as one platoon.
Initial condition	

Operational area:	Any of the operational areas inside the ODD for the platooning support function
Environmental conditions:	Any environmental condition inside the ODD for the platooning support function
Target vehicle(s):	Steady state truck, successive to the ego, of existing platoon.
Ego vehicle (s):	Steady state follower truck of existing platoon.
Application status target vehicle(s):	Platooning HMI: Shows platooning status: platooning active, platoon specific information and functions.
Application status Ego vehicle	Platooning HMI: Shows platooning status: platooning active, platoon specific information and functions.

	Driver status target vehicle(s):	Aware
	Driver status Ego vehicle	Aware
	System status	No failure
Trigger	The ego driver starts the leaving procedure by pushing the leave button or pressing the brake pedal.	
Sequence	Sketch:  Sequence in time as bullet points: 1. The ego application enters “Leave” mode. 2.1 The start of the leaving procedure from the ego vehicle is broadcasted to the other Platoon members through V2V communication (request back split and front split). 2.2 [Optional] The target vehicle starts to increase the inter-vehicle time gap with respect to the ego vehicle. 2.3 [Optional] The ego vehicle starts to increase the inter-vehicle time gap with respect to the preceding vehicle. 2.4 The target vehicle communicates being ready for the ego vehicle to leave (e.g. the gap has been increased) to the ego vehicle through V2V communication . 2.5 The ego vehicle communicates being ready to leave (e.g. the gap has been increased) to the preceding one through V2V communication. 2.6 The ego vehicle platooning communication is disconnected 2.7 The ego vehicle HMI informs the driver that platooning support is no longer available 2.8 [Optional] The involved vehicles report the leave event to their respective platoon enablers (offboard). To be detailed by task 4.2 of the project. 3 The platooning system of the ego vehicle is switched off	

	4.1 The remaining vehicles continue as standalone vehicles, or platooning vehicles depending on the configuration of the remaining vehicles. The new platoon configuration is visualised in all the remaining platooning trucks' HMI. 4.2 When the ego vehicle steers out of the platoon, the Join from behind use case applies and the remaining vehicles can close the gap and continue as a single platoon again
Final condition	

Operational area:	Any of the operational areas inside the ODD for the platooning support function
Environmental conditions:	Any environmental condition inside the ODD for the platooning support function
Target vehicle(s):	Steady state truck, of newly established platoon (4.b).
Ego vehicle (s):	Stand-alone state truck driving
Application status target vehicle(s):	Platooning HMI: Shows platooning status: platooning active, platoon specific information and functions.
Application status Ego vehicle	Stand-alone (Stand-alone HMI, could be OEM specific)
Driver status target vehicle(s):	Aware
Driver status Ego vehicle	Aware
System status	Vehicle platform: no failure V2V: same as "stand-alone" with Platooning functionality active

Split (following truck)

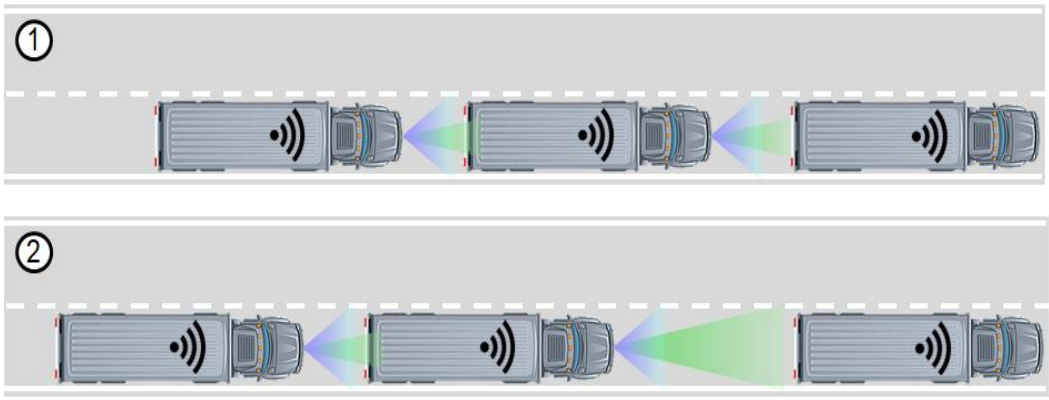
ID	PSF_4.2
Name	Split platoon by follower truck
Story	While the platoon is active, one of the follower vehicles (not the leader nor the trailer vehicle) starts the split procedure. Optional: the ego vehicle will increase the inter-vehicle time gap in respect to its preceding vehicle. The original platoon continues as 2 new platoons with the ego vehicle being the leading truck of one of the platoons.
Initial condition	

Operational area:	Any of the operational areas inside the ODD for the platooning support function
Environmental conditions:	Any environmental condition inside the ODD for the platooning support function
Target vehicle(s):	Steady state truck, preceding he ego, of existing platoon.
Ego vehicle (s):	Steady state follower truck of existing platoon.
Application status target vehicle(s):	Platooning HMI: Shows platooning status: platooning active, platoon specific information and functions.
Application status Ego vehicle	Platooning HMI: Shows platooning status: platooning active, platoon specific information and functions.
Driver status target vehicle(s):	Aware
Driver status Ego vehicle	Aware
System status	No failure

Trigger	The events that can trigger the Platoon split are:

<table>
<tr><td></td><td>

The target time gap increases up to the threshold the system split the platoon.
Loss of communication with the truck in front of the ego vehicle

</td></tr>
<tr><td>Sequence</td><td>
Sketch:


Sequence in bullet points:

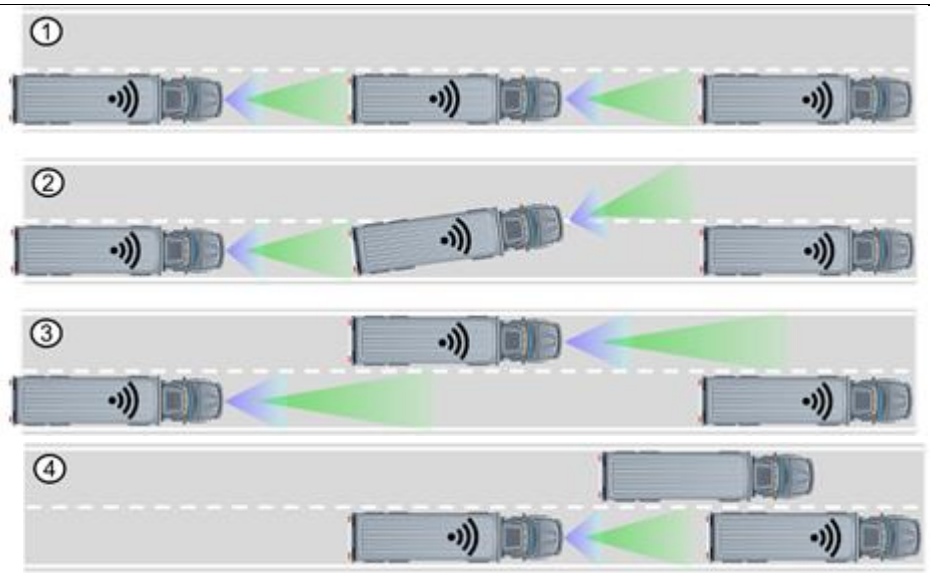
1.1 The ego application enters “Split” mode.
1.2 The start of the splitting procedure from the ego vehicle is broadcasted to the target one through V2V communication (message to be inserted).
1.3 [Optional] The ego vehicle opens the gap towards the target vehicle

2.1 The ego vehicle condition (ready to split, similar to ‘ready to leave’) is communicated through V2V communication (PCM).
2.2 The ego vehicle V2V communication (V2X-PCM) to the target vehicle is disconnected
2.3 The platoon is split in 2 branches
2.4 [Optional] The involved vehicles report the new situation to their respective platoon enablers (offboard). To be detailed by task 4.2 of the project.
2.5 The ego vehicle becomes the platoon leader of the new platoon
2.6 The HMI of the ego vehicle informs the driver about its new role in the Platoon
2.7 The new platoon configuration is displayed on the trucks’ HMIs
2.8 The two new platoons continue to platoon
</td></tr>
<tr><td>Final condition</td><td>
<table>
<tr><td>Operational area:</td><td>Any of the operational areas inside the ODD for the platooning support function</td></tr>
<tr><td>Environmental conditions:</td><td>Any environmental condition inside the ODD for the platooning support function</td></tr>
<tr><td>Target vehicle(s):</td><td>Steady state truck, trailing truck of one of the remaining platoon</td></tr>
<tr><td>Ego vehicle (s):</td><td>Leading ruck of one of the remaining platoons</td></tr>
<tr><td>Application status target vehicle(s):</td><td>Platooning
HMI: Shows platooning status: platooning active, platoon specific information and functions.</td></tr>
<tr><td>Application status Ego vehicle</td><td>Platooning
HMI: Shows platooning status: platooning active, platoon specific information and functions.</td></tr>
<tr><td>Driver status target vehicle(s):</td><td>Aware</td></tr>
<tr><td>Driver status Ego vehicle</td><td>Aware</td></tr>
<tr><td>System status</td><td>Vehicle platform: no failure</td></tr>
</table>
</td></tr>
</table>

Leaving by steering out as following truck

The “leaving by steering out as follower” use case is not a main use case for platooning, but will be a used case since it’s close to normal driving behaviours today. This will happen when taking exits or deciding to go faster than the platoon.

<table>
<tr><td>ID</td><td colspan="2">PSF_4.3.1</td></tr>
<tr><td>Name</td><td colspan="2">Leaving by steering out as following truck
.</td></tr>
<tr><td>Story</td><td colspan="2">A group of three or more vehicles are platooning. One of the follower trucks decides leave and steers out and takes an exit without using the leave button as for a normal leave.</td></tr>
<tr><td>Initial condition</td><td colspan="2"><table>
<tr><td>Operational area:</td><td>Any of the operational areas inside the ODD for the platooning support function</td></tr>
<tr><td>Environmental conditions:</td><td>Positive conditions for platooning, other conditions detected either by driver or system.</td></tr>
<tr><td>Target vehicle(s):</td><td>Steady state platooning:
• Vehicle in front within sensor view, except for leading truck.
• Vehicle in front & to the back within V2V range for the following truck. Reception from at least closest vehicle in front and to the back is required.
Control messages over V2V are sent according to specification.</td></tr>
<tr><td>Ego vehicle (s):</td><td>Steady state platooning:
• Vehicle in front within sensor view.
• Vehicle in front & to the back within V2V range for the following truck. Reception from at least 1 closest vehicle in front and to the back is required.
Control messages over V2V are sent according to specification.</td></tr>
<tr><td>Application status target vehicle(s):</td><td>Platooning
HMI: Platooning status</td></tr>
<tr><td>Application status Ego vehicle</td><td>Platooning
HMI: Platooning status</td></tr>
<tr><td>Driver status target vehicle(s):</td><td>Aware</td></tr>
<tr><td>Driver status Ego vehicle</td><td>Aware</td></tr>
<tr><td>System status</td><td>All systems are ok.</td></tr>
</table></td></tr>
<tr><td>Trigger</td><td colspan="2">The driver decides to steer out of the platoon.</td></tr>
<tr><td>Sequence</td><td colspan="2"><u>Use case sequence:</u></td></tr>
</table>



1. The trucks are platooning in steady state.

2.1 The driver in the ego vehicle (follower) steers out.
2.2 The ego vehicle detects that it's no longer following the vehicle in front and initiates a front split

3. The follower vehicle detects that it is no longer following the ego vehicle and initiates a front split.
4. New platoon configuration is negotiated.
   (Optional: the follower vehicle may join the platoon ahead)
   [Optional] The involved vehicles report the new situation to their respective platoon enablers (offboard). To be detailed by task 4.2 of the project.

Final condition

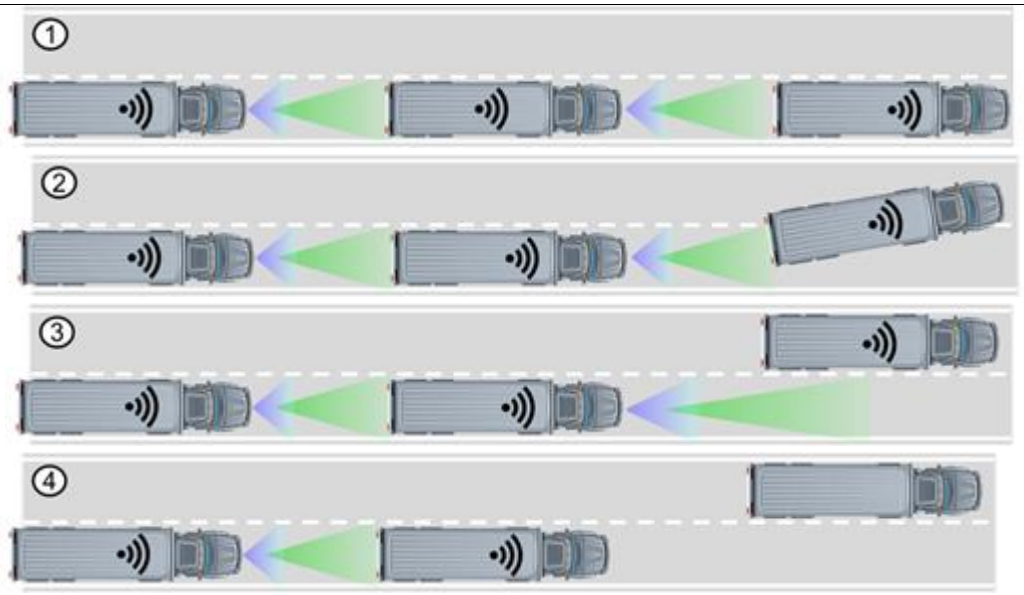
Operational area:	Any of the operational area inside the ODD for the platooning support function
Environmental conditions:	Positive conditions for platooning, other conditions detected either by driver or system.
Target vehicle(s):	The original front vehicle of the ego vehicle: equal to initial condition The original back vehicle of the ego vehicle is either platooning as a lead vehicle or driving alone.
Ego vehicle (s):	Driving alone
Application status target vehicle(s):	Platooning HMI: Platooning status
Application status Ego vehicle	Platooning HMI: Platooning status
Driver status target vehicle(s):	Aware
Driver status Ego vehicle	Aware

	System status	All systems are ok.	

Leaving by steering out as Leading truck

The “leaving by steering out as Leader” use case is not a main use case for platooning, but will be a used case since it’s close to normal driving behaviours today. This will happen when taking exits or deciding to change lane to pass other vehicles.

ID	PSF_4.3.2	
Name	Leaving by steering out as leading truck.	
Story	A group of three or more vehicles are platooning. The leader truck decides to leave and steers out by changing lane.	
Initial condition	Operational area:	Any of the operational areas inside the ODD for the platooning support function
	Environmental conditions:	Positive conditions for platooning, other conditions detected either by driver or system.
	Target vehicle(s):	Steady state platooning: • Vehicle in front and to the back within V2V range for the following truck. Reception from at least 1 closest vehicle in front and to the back is required. • Vehicle in front within V2V range for the trailing truck. Reception from at least 1 closest vehicle in front is required. Control messages over V2V are sent according to specification.
	Ego vehicle (s):	Steady state platooning: • Vehicle to the back within V2V range reception from at least closest vehicle to the back is required. Control messages over V2V are sent according to specification.
	Application status target vehicle(s):	Platooning HMI: Platooning status
	Application status Ego vehicle	Platooning HMI: Platooning status
	Driver status target vehicle(s):	Aware
	Driver status Ego vehicle	Aware
	System status	All systems are ok.
Trigger	The driver decides to steer out of the platoon.	
Sequence	<u>Use case sequence:</u>	



1. The trucks are platooning in steady state.

2.1 The driver in the ego vehicle (leader) steers out.
2.2 OPTIONAL: The ego vehicle detects that it's no longer following lane and initiates a leave.

3. The second vehicle (which has the intention to stay in the lane) detects that is no longer following the leader and initiates a split in front. The driver of the ego vehicle is informed about the system status: driving alone.

4.1 Leader is driving alone
4.2 New platoon configuration is negotiated
4.3 [Optional] The involved vehicles report the new situation to their respective platoon enablers (offboard). To be detailed by task 4.2 of the project.

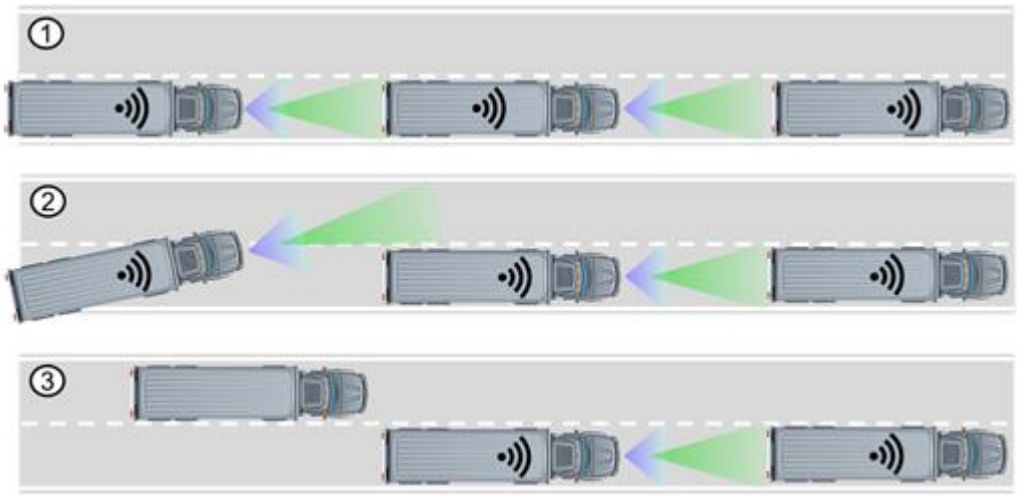
Final condition	Operational area:	Any of the operational areas inside the ODD for the platooning support function
	Environmental conditions:	Positive conditions for platooning, other conditions detected either by driver or system.
	Target vehicle(s):	Steady state platooning: • Vehicle to the back within V2V range reception from at least closest vehicle to the back is required. Control messages over V2V are sent according to specification.
	Ego vehicle (s):	Driving alone
	Application status target vehicle(s):	Platooning HMI: Platooning status

	Application status Ego vehicle	Platooning HMI: Platooning status
	Driver status target vehicle(s):	Aware
	Driver status Ego vehicle	Aware
	System status	All systems are ok.

Leaving by steering out as trailing

The “leaving by steering out as trailing” use case is not a main use case for platooning, but will be a used case since it’s close to normal driving behaviours today. This will happen when taking exits or deciding to go faster than the platoon.

ID	PSF_4.3.3	
Name	Leaving by steering out as trailing truck.	
Story	A group of three or more vehicles are platooning. The trailing truck decides leave and steers out e.g. by taking an exit without using the leave button as for a normal leave.	
Initial condition	Operational area:	Any of the operational areas inside the ODD for the platooning support function
	Environmental conditions:	Positive conditions for platooning, other conditions detected either by driver or system.
	Target vehicle(s):	Steady state platooning: • Vehicle in front within sensor view, except leading truck. • Vehicle in front and to the back within V2V range for the following truck. Reception from at least the closest vehicle in front and to the back is required. Control messages over V2V are sent according to specification.
	Ego vehicle (s):	Steady state platoon • Vehicle in front within V2V range for the trailing truck. Reception from at least 1 closest vehicle in front is required. Control messages over V2V are sent according to specification.
	Application status target vehicle(s):	Platooning HMI: Platooning status
	Application status Ego vehicle	Platooning HMI: Platooning status
	Driver status target vehicle(s):	Aware
	Driver status Ego vehicle	Aware

<table>
<tr><td></td><td><table><tr><td>System status</td><td>All systems are ok.</td></tr></table></td></tr>
<tr><td>Trigger</td><td>The driver decides to steer out of the platoon.</td></tr>
<tr><td>Sequence</td><td><u>Use case sequence:</u>
 

1. The trucks are platooning in steady state.

2.1 The driver in the ego vehicle (trailing) steers out.
2.2 The ego vehicle detects that it’s no longer following the vehicle in front, initiates a leave and informs the driver that the platooning system is now in ‘standalone’ mode (i.e. there are no other vehicles in the platoon).

3. New platoon configuration is negotiated
[Optional] The involved vehicles report the new situation to their respective platoon enablers (offboard). To be detailed by task 4.2 of the project.</td></tr>
<tr><td>Final condition</td><td><table>
<tr><td>Operational area:</td><td>Any of the operational area inside the ODD for the platooning support function</td></tr>
<tr><td>Environmental conditions:</td><td>Positive conditions for platooning, other conditions detected either by driver or system.</td></tr>
<tr><td>Target vehicle(s):</td><td>Steady state platoon
Vehicle in front within sensor view, except leading truck.
Vehicle in front within V2V range for the trailing truck. Reception from at least the closest vehicle in front is required.
Control messages over V2V are sent according to specification.</td></tr>
<tr><td>Ego vehicle (s):</td><td>Driving alone</td></tr>
<tr><td>Application status target vehicle(s):</td><td>Platooning
HMI: Platooning status</td></tr>
<tr><td>Application status Ego vehicle</td><td>Platooning
HMI: Platooning status</td></tr>
</table></td></tr>
</table>

		Driver status target vehicle(s):	Aware
		Driver status Ego vehicle	Aware
		System status	All systems are ok.

4.4.5. Other

For relevant environmental conditions where we expect specific system behaviour, a “one liner / assumption” with the desired reaction of the system is defined. This can form the basis for the detailing later in the specification phase of the project (D2.4/D2.5, D2.6/D2.7, D2.8, WP4 etc).

One liners / assumptions:

- On hilly roads it is desired that the platoon keeps its cohesion but this is user specific,
- In a tunnel (more in general, a longer section without GPS receival), we do not allow a platoon to engage unless technically possible without GPS receival (to be further investigated) and allowed by the regulations. Following the reason that engaging is not allowed, if engaging while entering a tunnel, engaging will be cancelled.
- In a tunnel (more in general a longer section without GPS receival), a cut-in causes that the platoon will be split in 2 branches, in line with the split use case.
- We expect the platoon to be able to perform the engaging, platooning and disengaging actions also on curved road with a curvature radius > 250m.
- When driving downhill, we expect the individual trucks to adapt the gap to the target in front (if needed) based on operational layer information (e.g. map data, brake system status).
- When, during engaging, a cut-in is performed within the platoon, the system will react equal as when the cut-in is performed in steady state.

5. PLATOONING AUTONOMOUS FUNCTION (PAF)

5.1. Introduction

As mentioned in Chapter 2 and 3, two levels of platooning are defined in ENSEMBLE, i.e. platooning as a support function and as an autonomous function. The key difference between these two levels is the responsibility of the driver in the platooning function.

In contrast to the Platooning Support Function, implementation of the Platooning Autonomous Function is not part of the ENSEMBLE project and the specification of the Platooning Autonomous Function and its use cases is solely done on theoretical considerations to sketch a future vision of platooning. An actual implementation was not validated, as certain autonomous driving pre-requirements are not available today.

In case of the Platooning Support Function, the dynamic driving task (DDT) is the responsibility of the driver. In other words, the driver is still driving even when the Platooning Support Function is engaged – even if his/her feet are off the pedals and he/she is not steering. The driver must steer, brake or accelerate as needed to maintain safety. This holds for all vehicles in the platoon. In principle, the individual platooning vehicles can be classified as SAE Automation Level 1 or 2 vehicles (SAE J3016, 2021).

In contrast to this, only a driver in the first truck is required for performing the DDT for the Platooning Autonomous Function. When engaged, the Platooning Autonomous Function performs the entire DDT for the following vehicles. The driver in the first truck has a responsibility to respect the traffic rules (i.e. laws and informal rules) and to guide the platoon through traffic, but is not responsible for the (operational and functional) safety of the entire platoon. In other words, the lead truck driver is ‘driving’ a ‘long truck’ consisting of electronically coupled automated following vehicles. This section will not address situations where the driver does not respect the rules of the road. Responsibilities for the dynamic driving task are shown in Table 5-4.

Table 5-4: Truck responsibilities for the dynamic driving task for Platooning Autonomous Function.

Truck	Responsibilities
*Lead Truck **driver** responsibility*	- Responsible for following the traffic rules - Responsible for driving the platoon to the destination - Responsible for the safety of his/her own vehicle
*Lead Truck **system** responsibility*	- None
*Following / trailing truck(s) **driver** responsibility*	- None
*Following / trailing truck(s) **system** responsibility*	- Follow the lead truck to meet the traffic rules - Responsible for their own safety

This choice of Platooning Autonomous Function is motivated by the fact that the development of SAE Level 4 trucks that can be deployed in typical long-haul business, is not an easy task: substantial technical and non-technical challenges still need to be overcome (ERTRAC, 2019). In this respect, an autonomous platooning system that has a driver, who is driving the - for the rest-autonomous platoon, could be an earlier deployable (and a less costly) step on the roadmap of automated long-haul freight transport, because of potentially less complex technical challenges. As such, this autonomous platooning function can be seen as an important first step towards autonomous vehicles by shaping technology, regulation and public opinion (social acceptance). Moreover, having at least one driver who is supervising the platoon (and its cargo) is also seen as a benefit from a security perspective, compared to unmanned SAE Level 4 trucks.

From a multi-stakeholder benefits workshop held with the project partners, the following additional benefits were identified:

1. Improvement in traffic safety:
   - Safety is not dependent on platoon driver behaviour in the following vehicles anymore, so it becomes a design parameter.
2. Improvement in traffic flow:
   - Traffic flow with a higher density of trucks will be improved because of constant smaller following distance (i.e. 20 m) and smoother speed profiles
3. Improvement in driver productivity:

4. - Current driver shortage problem can be solved. Either because of an increase of productivity or no driver in the following truck.
5. Improvement in fuel consumption and consequently in emissions:
   - A positive effect on fuel consumption in real life conditions due to potential decreased headways. Because future truck configurations are unknown, an estimate cannot be given.

5.2. Platoon characteristics

The platoon consists of:

- A lead truck with a driver, who is responsible for performing part or all of the dynamic driving task (DDT).
- Following trucks that are driverless (but can be manned) as the system will be able to handle all situations autonomously within the limited ODD (including faults, by being fault tolerant and SOTIF situations like cut-ins, weather, etc.).

An essential part of the platooning system is V2V communication, which allows exchange of essential information between platoon members.

The main **ODD** of the platooning function is hub-to-hub highway driving on selected driving routes important for long-haul freight transport. The ODD of the following vehicles is additionally limited by 'being part of the platoon', which means that these vehicles are designed to follow the lead or other following vehicles autonomously as part of the platoon.

The agreed starting point in ENSEMBLE is to have a limited ODD that reduces complexity and focusses on the main part of the long-haul freight transport (i.e. highway driving) and could lead to a minimum viable product. In this way, the number of use cases can be kept small and important use cases can be worked out in detail. Later, the ODD can be further extended from this (viable) basis.

The function is initially designed to work on up to (about) 4 hour routes on the highways between transportation hubs that are considered as an important part of the current market (e.g. routes between warehouses). The hubs are located right next to the highways. The functionality is able to autonomously handle the short routes between the hub and the closest highway (If needed, drivers can bring the trucks to the hub and/or take them back to other (urban) locations). Requirements will be put on hubs and routes on the highway, which form part of the ODD in terms of what infrastructure they should have, what should be the maximum distance between them, fixed infrastructure that is allowed on the route (traffic lights, tunnels, construction zones, etc.), etc. External trucks with drivers can join (only from behind) or leave (from behind) a platoon on the highway (as long as an existing platoon has not reached the maximum number of trucks allowed by the function: currently 3). When joined, the drivers will become passengers of the autonomously driving truck and have no possibility to control the truck, other than pressing a "button" to leave the platoon. The limitation of 4 hour routes

has been introduced to initially not have to account for refuelling and lead truck driver resting s, as described in Regulation (EC) No 561/2006 (EC 561, 2006) to limit the ODD and use cases. Nevertheless, the possibility of having short breaks should be part of the ODD, implying that parking at different locations than the hub is included.

Longitudinal control

Longitudinal control of the following trucks is fully automated and covers the whole vehicle capability envelope. The platooning system can decelerate up to its maximum capability, enabling the system to perform emergency braking manoeuvres.

Time gap

As a first step, the platooning function maintains time gaps similar to state-of-the-art ACC systems (between 1.4 and 1.6 s) under steady-state driving conditions. Maintaining a particular time gap smaller than ACC gaps is not a strict requirement by itself, and therefore of lower priority. After the definition of the Braking Performance Estimation in D2.5 (Mascalchi, 2022), simulations showed that it is possible to achieve time gaps between 0.3 s and 1.2 s in dry conditions depending on the braking capabilities of the EGO truck and the vehicle in front. These smaller time gaps allow to have advantages like avoiding cut-in occurrences, energy consumption savings and decreased road occupation.

Lateral control

Lateral control of the following trucks is fully automated and offers both in-lane driving and lane change capabilities. Furthermore, lateral vehicle following is available when lane information is unavailable. Emergency steering (high lateral acceleration) is considered out of scope for the initial analysis.

Maximum number of trucks in a platoon

The maximum number of trucks in the platoon is initially limited to 3 trucks, but could be extended to more vehicles if it is proven that functionality and safety allow this. A platoon system of 3 trucks is considered sufficient to explore the required functionality.

Type of trucks

Following trucks can be automated trucks with driver cabin or potentially also unmanned vehicles without driver cabin. This makes no difference for the main hub-to-hub autonomous operation, but affects the platoon formation possibilities.

Key ENSEMBLE functions

To allow multi-brand platooning, common communication protocols and platoon coordination functions are required for e.g. join, leave, split, lane changes, V2V information exchange, etc.

5.3. Safety concept

To design a safe platooning function, two main aspects of safety will be considered during development: functional safety and safety of the intended functionality (SOTIF).

5.3.1. Functional safety

Functional safety corresponds to safely handling hazards that result from malfunctions in the system. These malfunctions including both hardware and software faults can result in unintended behaviour of the system.

The following vehicles in the platoon will be designed to remain operational in case of system faults, which means that both the primary functions (accelerating, braking and steering) for performing the task of driving and the platooning function will always be available, even in a degraded form.

The details of all the identified hazards and the corresponding safety mechanism can be found in deliverable D2.14 (Pezzano, 2022).

5.3.2. Safety of the intended functionality (SOTIF)

SOTIF corresponds to safely handling hazards that manifest in fault free systems due to performance limitations or insufficiencies of the functions that depend on situational awareness to drive safely.

The platoon function will be designed to safely handle external situations like cut-ins, emergency braking, tunnels, driving around emergency vehicles, driving in adverse weather conditions, construction zones, … .

The details of all the identified SOTIF situations and the corresponding safety concepts and requirements can be found in deliverable D2.13 (Dhurjati, 2022b).

5.4. Relevant high-level manoeuvres

The largest benefit for the specified autonomous platooning function is that long distances can be travelled with unmanned following vehicles. This is most efficient for cost reduction and dealing with driver shortage. Consequently, the main application domain is highway driving on selected driving routes limited by the functionality itself and important for long-haul freight transport.

When considering platoon manoeuvres, the primary focus is therefore on those manoeuvres that are required to drive on a highway from a starting point to a destination, or from one hub to another hub located next to the highway.

When platooning on the highway, the following manoeuvres shall be possible:

- In-lane driving;
- Lane changes limited to onramps, offramps, highway junctions and dealing with extraordinary circumstances (e.g. vehicle with breakdown, accident, object on the road, extremely slow driving vehicle, road works);
- Management of safe distance during cut-in and cut-through in the platoon;
- Maintaining platoon cohesion;
- Collision avoidance in emergency situations;
- Joining the rear of a platoon.

In addition to the aforementioned, platoon formation must be possible. This can be done in many ways, but may in first instance simply be done at standstill with drivers in the trucks at a hub or parking lot. These drivers manoeuvre the trucks to the starting position and then leave the following trucks before the autonomous function becomes active and the platoon commences. Alternatively, the arranging of the individual trucks can be done by the lead driver before the start of the drive. The same holds for disassembling the platoon at a hub or parking lot; drivers can get into the trucks to disengage the trucks from the platoon. In a later stage, the platoon might be assembled and disassembled in a fully automated manner.

5.5. Driver interaction

The driver in the lead truck is responsible for the dynamic driving task (DDT) of the lead truck AND for guiding the platoon through the traffic. This implies that the driver is facing additional responsibilities and tasks compared to driving a standalone truck. The driver is NOT responsible for the safety of the following trucks, as these trucks are performing the complete DDT autonomously in the ODD.

In addition, the autonomous platooning system also includes extra features designed to support the driver of the leading truck in supervising and controlling the unmanned following vehicles, which should be mandatory to use. In other words, the role of the driver now includes the role of being a platoon system operator who monitors the platooning system and takes actions in case of platoon manoeuvres.

Low driver distraction is a further mandatory safety criterion. The task of monitoring following vehicles shall be possible without significant distraction or engagement for a driver during SAE level 1 or 2 driving even while performing one of the aforementioned manoeuvres.

Managing such autonomous platoons could be an incremental qualification for a driver. It can be expected that initial driver training will be required to cope with the new driver interaction mechanisms and the additional tasks.

5.6. Operational design domain

5.6.1. Infrastructure

As mentioned above, the infrastructure for which the function is designed consists of selected driving routes on highways that are important for long-haul freight transport. These routes are selected on their suitability for autonomous platooning. The suitability is related to certain infrastructural properties that are required, but still have to be formulated when it is known what the technical capabilities and limitations of the autonomous platooning function are. As mentioned in the level definition it is important to highlight that the journey between the hub and the highway is foreseen to be short and therefore will include a limited amount of intersections and roundabouts.

Below, a first proposal is given for the ODD.

Road geometry

Typical EU highway network with main lanes, connector roads, onramps, offramps, junctions, toll gates.

Typical infrastructure between hub and highway, consisting of signalised intersections and roundabouts.

The following additional requirements apply, see section 6.3:

- All intersections in the ODD must have intelligent traffic lights that can interact with the platoon;
- All roundabouts in the ODD must have intelligent traffic lights that can interact with the platoon.

Road furniture and rules

The platoon should be able to handle all existing road furniture. The platooning vehicles must also follow the existing rules of the road.

Temporal modifications and events

The platoon must be able to handle road works and road accidents, break downs.

Digital information

Optional: up to date maps with sufficient precision/definition.

5.6.2. Moving objects

The platooning trucks shall be able to handle the full speed range of a highway in moving traffic and in stop- and go cases (0 km/h to 90 km/h). Setting the desired platoon speed is the responsibility of the lead truck driver.

The platoon operates in mixed traffic conditions on highways and between the hubs and the highways. This means that interaction with all kind of road users must be considered: cars, trucks, busses, motorcycles, cyclists, pedestrians, etc.

Furthermore, interaction with other moving objects such as deer crossing can occur.

5.6.3. Environmental conditions

Weather conditions

Since long-haul freight transport is the target application domain, the distances the platoon has to travel are long. This implies that the platoon must be able to deal with adverse weather conditions, as weather conditions are less unpredictable over longer distance and time.

Time of operation

Both daytime and night-time.

6. USE CASES PLATOONING AUTONOMOUS FUNCTION (PAF)

6.1. Introduction

In this chapter, the identified use cases of the envisioned Platooning Autonomous Function are drafted. A similar method as described in Chapter 4 for the Platooning Support Function has been followed to obtain the Platooning Autonomous Function use cases. Table 6-5, Table 6-6 and Table 6-7 summarise the manoeuvres, events and infrastructure characteristics of the Platooning Autonomous function, as these were initially identified. These tables formed the starting point for the description of the use cases. Consequently, these tables are not intended to be comprehensive in terms of details.

Table 6-5: Manoeuvres of ENSEMBLE for the platoon autonomous function.

ID	Manoeuvre name	Description
M1	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 is done orchestrated and non-real time. Platoon candidates may receive instructions during platoon formation (e.g. to park at a certain location) to allow the start of the engaging procedure of the platoon.
M2	Platoon engaging	Using wireless communication (V2V), the Platoon Candidate (single vehicle or existing platoon) sends an engaging request to the platoon target (single vehicle or existing platoon) in front. When conditions are met, the request is accepted by the platooning truck and platooning information exchange is started. Engaging can be done at standstill or while driving (for trucks joining with a driver).
M3	Platooning (autonomous)	A group of one or more, possibly unmanned, autonomous vehicles following a manned lead vehicle in a pre-defined order, maintaining contact with each other using wireless communication (V2V).
M4	Platoon disengaging	The vehicle(s) leaving the platoon, i.e. the platoon specific communication is stopped. Disengage can be done at standstill or while driving (only for manned following vehicles).

Due to the character of the system, where there may be no drivers in the following trucks and the fact that the following trucks may not have full SAE level 4 automation, some of the events may result in undesirable situations. In section 6.2 the so called ‘happy flow’ of the use cases are

described. Section 6.3 will detail potential issues, and suggest solutions for these (based on current knowledge), in the use cases connected to the events from Table 6-6.

Table 6-6: Events of ENSEMBLE for the platoon autonomous function

ID	Event name	Description
E1	Cut-in	The cut-in object (car, motorcycle, truck) can cut-in anywhere in the platoon and also the duration for which the vehicle remains amidst the platoon may vary. Once the cut-in vehicle leaves the platoon this is called a cut-out action. Depending on the duration of the cut-in the reaction of the system may vary.
E2	Emergency braking by a platoon truck (either by driver or AEB system)	Both the AEB systems of any of the trucks and the driver of the lead vehicle may cause full braking (maximum braking), which is an event that shall be handled in the platoon.
E3	I2V	The infrastructure may interact with the platoon, e.g. providing traffic signs, regulations. Additionally, I2V may enable or enhance e.g. crossing of intersections and roundabouts.
E4	Failure of the system / system status (e.g. packet loss)	Due to system failures or limitations in performance of the function, certain reactions by the platoon system may be required for safety. The system may need to go to a reduced performance (degraded) state or a safe state.
E6	Interactions with VRUs	Vulnerable Road Users (VRUs), such as pedestrians, may get in front of the trucks in parking areas, the hub or when driving between highway and hub. All the trucks (including the following ones) must recognise a possible collision with a VRU and try to avoid this.

Table 6-7: Infrastructure characteristics of ENSEMBLE for the platoon autonomous function

ID	name	Description
I1	Highway (main roads)	The highway main roads, between junctions and on/off ramps. Traffic lights can exist before certain elements, e.g. tunnels, bridges.
I2	Highway on ramps and off ramps	On and off ramps to enter or exit the highway
I3	Highway junctions	Junctions on the highway with merging traffic, or having to change lanes to follow the required route
I4	Highway connector roads	The connector roads connecting different main highway roads
I5	Platooning between the hub and the highway	All infrastructure elements between the hub and the highway, such as (signalised) intersections, roundabouts, etc.
I6	Resting Areas/Parking lots and hubs	Areas where vehicles or the platoon can park and manoeuvre.
I7	Road works	Any road works or construction zone.
I8	Toll gates	Toll gates on the highway network

6.2. Platooning Autonomous Function use cases

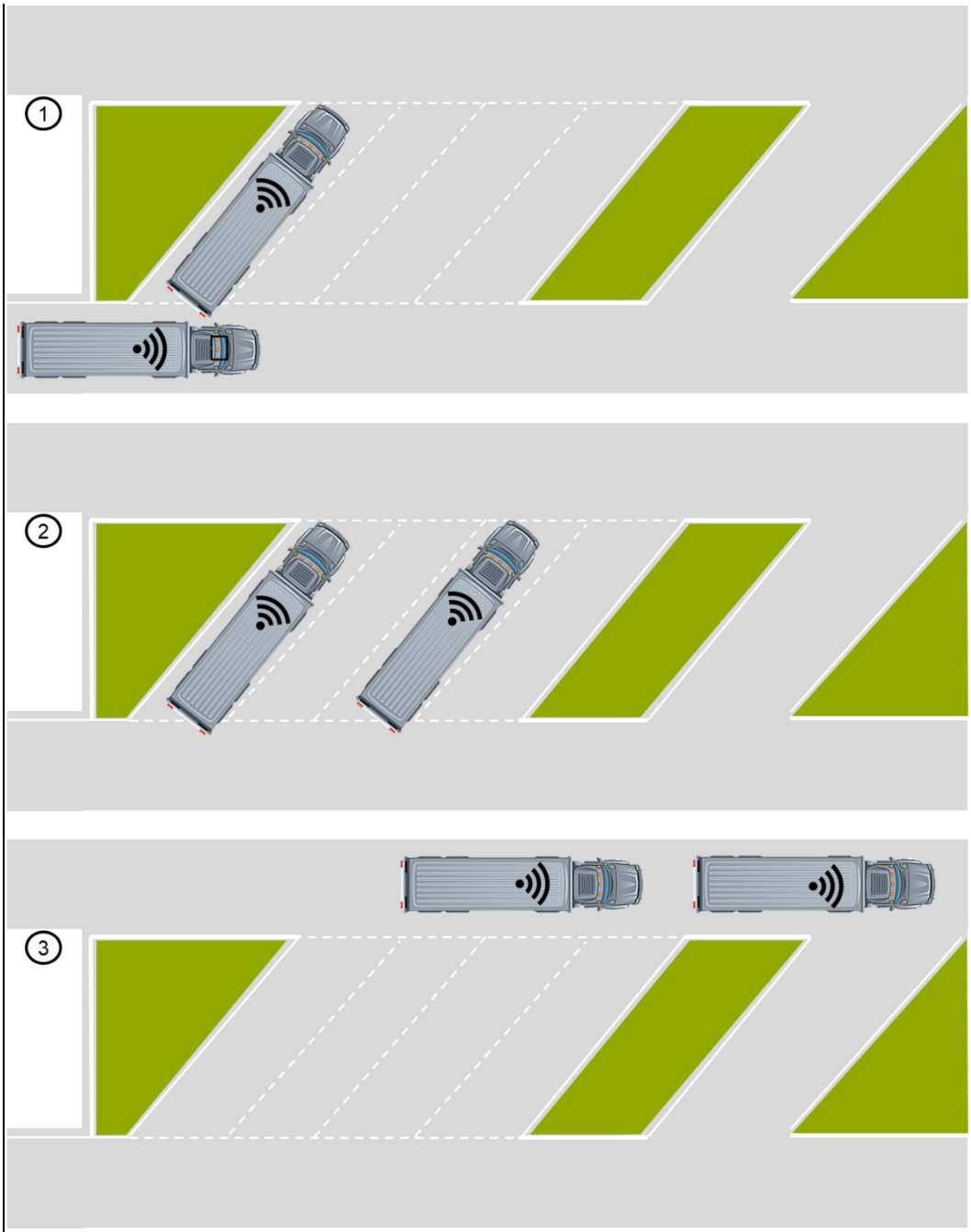
In this section, the high-level use cases are reflected. These form the basis to derive the technical requirements and specifications for the Platooning Autonomous Function to be reported in D2.5 (Mascalchi, 2022) and D2.8 (Atanassow, 2022a). The goal of the use cases is to describe the required behaviour of the whole platooning system at application level.

The high-level use cases are derived from the manoeuvres and events earlier defined:

- Platoon formation
  - Formation of driverless platoon in dedicated area (Orchestrated non real-time)
- Engaging to platoon
  - Join a stationary platoon/vehicle from behind at the hub
  - Join from Behind by a manned, single vehicle on the highway
- Platooning
  - Platooning between the hub and the highway
  - Platooning in lane on the highway
  - Entire platoon starting from a standstill
  - Emergency manoeuvre
  - Cut-in
  - Maintaining Platoon cohesion
  - Lane change triggered by Leading truck
  - Lane change triggered by Following or Trailing truck
  - Lane merge
  - Entering highway via an onramp
  - Highway offramp
  - Platooning on a connection between two different highways
  - Road Works/Construction zone
  - Traffic signs handling
  - Toll gates
  - Traffic lights on highways
  - Traffic lights on intersections
  - Roundabouts
  - Resting Areas/Parking lots
  - Parking
  - Border Crossing
- Disengage platoon
  - Drop-off area at the destination hub
  - Leave (while platooning, with a manned trailing truck)
- Safe state
  - Safe state evaluation and reaching (nearest parking area)
  - Safe state evaluation and reaching (hard shoulder/emergency lane)
  - Safe state evaluation and reaching (stop in lane)

6.2.1. Platoon formation

<table>
<tr><td>ID</td><td colspan="2">PAF_1.1</td></tr>
<tr><td>Name</td><td colspan="2">Formation of driverless platoon in dedicated area (Orchestrated non real-time)</td></tr>
<tr><td>Story</td><td colspan="2">At least two separated trucks have active subscriptions to a platoon enabler service. The platoon enabler service will give a recommendation based on a particular business logic that the two vehicles should form a platoon at a dedicated location/hub, at some time in the future and with a certain vehicle order. Information about the planned platoon is sent from the platoon enabler service to the carriers (owner of the vehicles), which in due course passes this on to the vehicles and drivers. Optionally, the platoon enabler service can help to coordinate vehicles to the rendezvous.
At the rendezvous, the two vehicles and/or drivers identify and authorize each other. After this, the normal engage procedure can start.
(Manoeuvre ID M1, Infrastructure characteristics I6)</td></tr>
<tr><td>Initial condition</td><td colspan="2"><table>
<tr><td>Operational area:</td><td>Not applicable as it can be done before actual platooning starts</td></tr>
<tr><td>Environmental conditions:</td><td>Not applicable as it can be done before actual platooning starts</td></tr>
<tr><td>Target vehicle(s):</td><td>Truck registered with the platoon enabler and capable of the platooning autonomous function. This vehicle can be a driverless following vehicle or a lead vehicle with a driver</td></tr>
<tr><td>Ego vehicle (s):</td><td>Truck registered with the platoon enabler and capable of the platooning autonomous function. This vehicle can be a driverless following vehicle or a lead vehicle with a driver.</td></tr>
<tr><td>Application status target vehicle(s):</td><td>Standalone (single vehicle)</td></tr>
<tr><td>Application status Ego vehicle</td><td>Standalone (single vehicle)</td></tr>
<tr><td>Driver status target vehicle(s):</td><td>Aware</td></tr>
<tr><td>Driver status Ego vehicle</td><td>Aware</td></tr>
<tr><td>System status</td><td>No failure</td></tr>
</table></td></tr>
<tr><td>Trigger</td><td colspan="2">Active subscriptions to a platoon enabler service</td></tr>
<tr><td>Sequence</td><td colspan="2"><u>Use case sequence:</u></td></tr>
</table>



1. The platoon enabler (offboard service) matches vehicles by sending a recommendation to form a platoon together. The recommendation is based on the business logic of that service and will take into account mission information provided by the carrier.
2. The platoon enabler sends information to the fleet owners about the platoon opportunity. This may be done just before they should start or well in advance. Information in the platoon opportunity may include:
   - Rendezvous point and time
   - Opportunity duration
   - Disengage location

<table>
<tr><td></td><td>

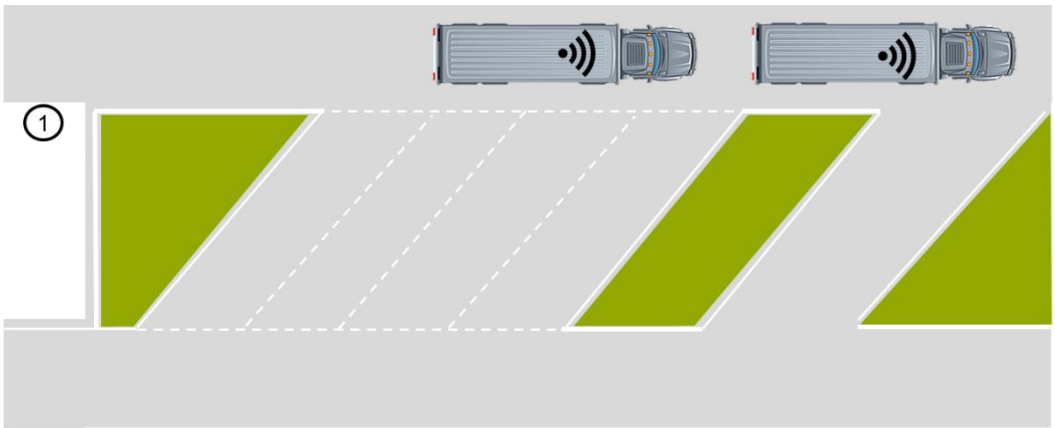
What service it originated from (The vehicle may be connected to several platoon enablers)
Vehicle order

3. The fleet owner/carrier passes the information to the drivers/vehicles in due time. The drivers/vehicles proceed to the rendezvous, where they activate platooning mode.
4. [Optional] Relay ego vehicle information to planned partners via the platoon enabler service (extended platoon awareness). Standardisation needed.
5. [Optional] Service specific extended platoon awareness e.g. driver apps that relay information to each other. No standardisation needed since it does not interact with the vehicle. It is up to each service.
6. Vehicles are in V2V range of each other and identify their partner.
7. Drivers manually arrange vehicles in line and in the right order.
8. Vehicles report successful formation and start “Platoon engage”- use case.
9. [Optional] Platooning enabler provides route information for leading vehicle.
</td></tr>
<tr><td>Final condition</td><td>
<table>
<tr><td>Operation area:</td><td>Hub or parking lot inside the ODD for the Platooning Autonomous Function</td></tr>
<tr><td>Environmental conditions:</td><td>Any environmental condition inside the ODD for the platooning autonomous function</td></tr>
<tr><td>Target vehicle(s):</td><td>Truck or active platoon within V2V range of ego vehicle(s)</td></tr>
<tr><td>Ego vehicle (s):</td><td>Truck or active platoon within V2V range of target vehicle(s).</td></tr>
<tr><td>Application status target vehicle(s):</td><td>Standalone (single vehicle)</td></tr>
<tr><td>Application status Ego vehicle</td><td>Engaging possible</td></tr>
<tr><td>Driver status target vehicle(s):</td><td>Aware</td></tr>
<tr><td>Driver status Ego vehicle</td><td>Aware</td></tr>
<tr><td>System status</td><td>No failure</td></tr>
</table>
</td></tr>
</table>

6.2.2. Engaging to platoon

Join a stationary platoon/vehicle from behind at the hub

<table>
<tr><td>ID</td><td>PAF_2.1</td></tr>
<tr><td>Name</td><td>Join a stationary platoon/vehicle from behind at the hub</td></tr>
<tr><td>Story</td><td>All vehicles are at standstill in the parking lot of a hub. Vehicles must be parked already in line and in the correct order. After verification, the platooning application of the lead vehicle sends a command to trigger the join request of the target vehicles, starting from the intended trailing vehicle, using wireless communication. When receiving the join request from the vehicle behind, the join is accepted by the target/ego vehicle by sending a positive join response if conditions are met. In this way, the platoon is set-up. The position in the platoon assigned to the platoon target equals to: (number of vehicles in the platoon) + 1.
(Manoeuvre ID M2, Infrastructure characteristics I6)</td></tr>
<tr><td>Initial condition</td><td>
<table>
<tr><td>Operational area:</td><td>Hub or parking lot inside the ODD for the Platooning Autonomous Function</td></tr>
</table>
</td></tr>
</table>

<table>
<tr><td></td><td>
<table>
<tr><td>Environmental conditions:</td><td>Any environmental condition inside the ODD for the platooning autonomous function</td></tr>
<tr><td>Target vehicle(s):</td><td>Follower is standalone at standstill
Vehicle is unmanned
Positioned in the desired order for platooning
Vehicle in front within sensor view
Vehicle in front within V2V range and reception of V2V from the closest vehicle in front</td></tr>
<tr><td>Ego vehicle (s):</td><td>Potential leader is standalone and at standstill
Vehicle manned
Vehicle in rear within V2V range and reception of V2V from the closest vehicle in the back</td></tr>
<tr><td>Application status target vehicle(s):</td><td>Standstill
If HMI available: show platooning status on HMI</td></tr>
<tr><td>Application status Ego vehicle</td><td>Standstill
HMI: Platooning Autonomous Function Activated
Platooning partner found</td></tr>
<tr><td>Driver status target vehicle(s):</td><td>Not present</td></tr>
<tr><td>Driver status Ego vehicle</td><td>Aware</td></tr>
<tr><td>System status</td><td>All systems are ok.</td></tr>
</table>
</td></tr>
<tr><td>Trigger</td><td>The lead truck driver verifies that the trucks are in the correct order and sends a command to trigger the join request for the target vehicles.</td></tr>
<tr><td>Sequence</td><td><u>Use case sequence:</u>
 

The lead truck driver, supported by the platooning application in the lead vehicle and the offboard service, verifies that the trucks are in the correct order.
After that, the lead truck driver uses the platooning application to send a command to trigger the join request, first to the follower, and, after the follower has joined, to the trailer. When a target vehicle receives the command, it will send a join request to the preceding vehicle after having performed a successful platoon partner identification step (i.e. target vehicle confirms that the received join request is indeed from the preceding vehicle). The platoon system of the preceding vehicle evaluates the join request and accepts the request if conditions are met.</td></tr>
</table>

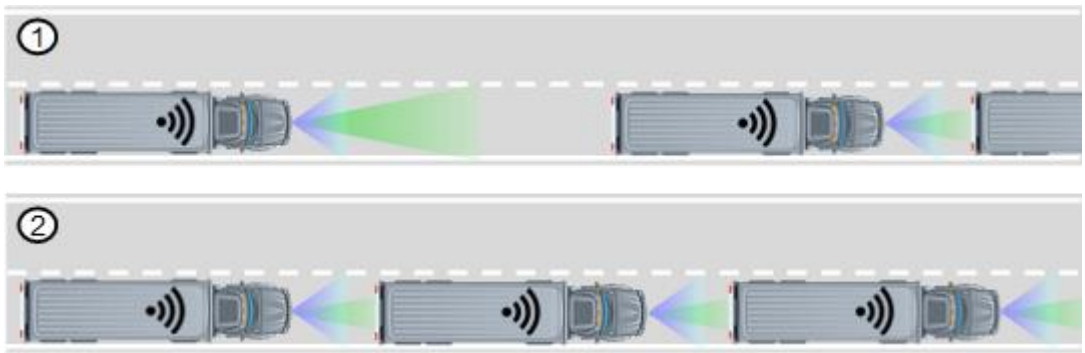
	3. The platooning application in the lead vehicle confirms the setup of the platoon and informs the driver about the (ongoing) process. 4. The V2V platooning communication is setup, including cyber-security features. The position in the platoon assigned to the platoon target equals to: (number of vehicles in the platoon) + 1. 5. Both ego and target vehicles start the platoon communication. 6. Both vehicles report the join event to the platoon enabler (offboard). To be detailed by task 4.2 of the project. 7. Trucks are all standstill, connected in a platoon, ready to depart from the HUB or to send another join request to another standstill truck, till the maximum number of vehicles is reached. 8. The driverless vehicles evaluate their (initial) minimum time gap based on their vehicle dynamic capabilities (brake performance, loading condition) and communicate this over V2V.
Final condition	

Operational area:	Hub or parking lot inside the ODD for the Platooning Autonomous Function
Environmental conditions:	Any environmental condition inside the ODD for the platooning autonomous function
Target vehicle(s):	Standstill platooning with the newly added truck being the new trailing truck.
Ego vehicle (s):	Standstill platooning as the leading truck.
Application status target vehicle(s):	Standstill Platooning If HMI available: show platooning status on HMI
Application status Ego vehicle	Standstill Platooning Shows platooning status on HMI
Driver status target vehicle(s):	Not present
Driver status Ego vehicle	Aware
System status	Standstill platooning

Join from behind by a manned single vehicle on the highway

ID	PAF_2.2
Name	Join from Behind by a manned single vehicle on the highway
Story	Using wireless communication (V2V), the Platoon Candidate (single vehicle, manned) sends an engage request to the platoon target in front. The platoon target can be a single vehicle or existing platoon with a trailing truck that is driverless. When conditions are met and the leader of the platoon accepted the request, the joining truck starts to decrease the time gap to the platoon to reach the Platooning Autonomous Function time gap. (Manoeuvre ID M2, Infrastructure characteristics I1)
Initial condition	

Operational area:	Any of the operational areas inside the ODD for the Platooning Autonomous Function on the main lane in the highway, i.e. joining should not be available on onramps, offramps, connector roads, junctions, etc.
Environmental conditions:	Any environmental condition inside the ODD for the platooning autonomous function

	Target vehicle(s):	Steady state platoon (with unmanned trailing truck) or a single platoon candidate that can accept to be extended with one more vehicle only (i.e. is 'joinable'). The trailing truck is signalling that the platoon is joinable. It must be within sensor view, V2V range and in lane of the ego vehicle. Not necessary to have V2V contact with other vehicles in the platoon.
	Ego vehicle (s):	Driven at a safe distance behind the last vehicle of the platoon, i.e. the target vehicle described above.
	Application status target vehicle(s):	**Leader:** Platooning , if single vehicle: joinable Advanced assist system (e.g. ACC and lane keeping) activated HMI: input requested, shows that new candidate wants to join **Following vehicle:** Platooning, joinable HMI: N/A
	Application status Ego vehicle	Platooning Autonomous Function Activated Advanced assist system (e.g. ACC and lane keeping) activated HMI: Platoon status, which is 'looking for a platooning partner', or 'joining a platoon'
	Driver status target vehicle(s):	Aware (if standalone vehicle) or not present if it is following truck
	Driver status Ego vehicle	Aware
	System status	All systems are ok.
Trigger	• The ego vehicle detects an 'is-joinable' signal through V2V communication. • The driver in the ego vehicle performs a join request on the HMI	
Sequence	<u>Use case sequence:</u>  1.1 The ego vehicle drives behind the target vehicle/platoon and sends a request to join the target vehicle/platoon. 1.2 The platoon system of the target vehicle evaluates the join request and accepts the request, if the conditions are met and the driver of the leading truck accepts the request as well. The trailing vehicle can perform this automated action using the shared state of the platoon.	

<table>
<tr><td></td><td colspan="2">1.3 The V2V platooning communication is setup, including cyber-security features, and both ego and target vehicles start the platoon communication.
1.4 [Optional] Both vehicles report the join event to their respective platoon enablers (offboard). To be detailed by task 4.2 of the project.
2.1 The ego vehicle closes the inter-vehicle distance to the Platooning Autonomous Function distance.
2.2 Once the platooning inter-vehicle distance is reached, the platoon is in steady state platooning.
2.3 The driver of the ego vehicle becomes a passenger only of the truck. He/she is out of the loop of the dynamic driving task (DDT) and HMI actions from the driver are not permitted (apart from leaving the platoon). Driver cannot control the truck in any way till he leaves the platoon (by pressing a dedicated button).</td></tr>
<tr><td>Final condition</td><td>Operational area:</td><td>Any of the operational areas inside the ODD for the Platooning Autonomous Function on the main travel lanes in the Highway</td></tr>
<tr><td></td><td>Environmental conditions:</td><td>Any environmental condition inside the ODD for the platooning autonomous function</td></tr>
<tr><td></td><td>Target vehicle(s):</td><td>Steady state platooning with now the newly added manned truck being the new trailing truck.</td></tr>
<tr><td></td><td>Ego vehicle (s):</td><td>Steady state platooning as the manned trailing truck.</td></tr>
<tr><td></td><td>Application status target vehicle(s):</td><td>Leader:
Platooning
Advanced assist system (e.g. ACC and lane keeping) activated
Following vehicle:
Platooning
If HMI available: show platooning status on HMI</td></tr>
<tr><td></td><td>Application status Ego vehicle</td><td>Platooning
Shows platooning status on HMI, informs the driver that (s)he now is not responsible for the driving task.</td></tr>
<tr><td></td><td>Driver status target vehicle(s):</td><td>Aware (if leader) or not present if it is a following truck</td></tr>
<tr><td></td><td>Driver status Ego vehicle</td><td>Not responsible for the DDT and out of the loop</td></tr>
<tr><td></td><td>System status</td><td>All systems are ok.</td></tr>
</table>

6.2.3. Platooning

Platooning between the hub and the highway

ID	PAF_3.1
Name	Platoon behaviour between the hub and the highway (Leader point of view)
Story	The Platoon was already formed at the hub; the Leader starts to drive from the hub exit, followed by the Follower and, if any, by the Trailer. Every vehicle shall be able to handle (by the driver on the Leading truck and by the system on the driverless trucks) any

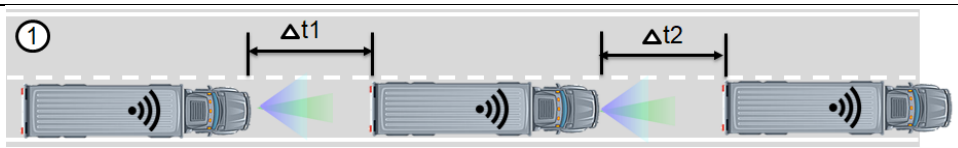
<table>
<tr><td></td><td>upcoming possible traffic situation, considering the road nature (e.g. VRUs, roundabouts, intersections, traffic lights, etc.)
(Manoeuvre ID M3, Infrastructure characteristics I1, I2, I3, I4, I5, I6, I7, I8, Events E1, E6)</td></tr>
<tr><td>Initial condition</td><td>
<table>
<tr><td>Operational area:</td><td>Any operational area between the hub and the highway inside the ODD for the platooning autonomous function</td></tr>
<tr><td>Environmental conditions:</td><td>Any environmental condition inside the ODD for the platooning autonomous function</td></tr>
<tr><td>Target vehicle(s):</td><td>Steady state Following and/or Trailing truck of a platoon</td></tr>
<tr><td>Ego vehicle (s):</td><td>Steady state Leading truck of a platoon</td></tr>
<tr><td>Application status target vehicle(s):</td><td>Platooning
If HMI available: show platooning status information</td></tr>
<tr><td>Application status Ego vehicle</td><td>Platooning
HMI: it displays Platooning status information</td></tr>
<tr><td>Driver status target vehicle(s):</td><td>Not present</td></tr>
<tr><td>Driver status Ego vehicle</td><td>Aware (Leader)</td></tr>
<tr><td>System status</td><td>No failure of internal systems and communication (V2V) is online.</td></tr>
</table>
</td></tr>
<tr><td>Trigger</td><td>• The Platoon exits from the hub</td></tr>
<tr><td>Sequence</td><td><u>Use case sequence:</u>

1 Optionally, the route to follow is communicated by the platooning enabler to the Platooning system and visualised on the vehicle’s navigation display.
2 The ego vehicle’s driver drives the vehicle in order to follow the intended route. The driver is supported by driver assistance or automated driving systems for longitudinal and lateral control.
3 The target vehicles, using their own sensor set and the established V2V communication with the vehicle ahead, follow the route, maintaining the lane centre and the time gap selected by the system after platoon formation.
4 If a lane change is needed to reach the right lane to the highway, see Lane change UC.
5 If the ego vehicle is approaching a junction, see Lane merge UC
6 The ego vehicle shall be able to recognise and automatically react to:
• VRUs
• Traffic signs (see traffic sign use case)
• Traffic lights (see Traffic light use case)
7 When the ego vehicle is approaching a roundabout, See roundabout use case.
8 If the highway entry ramp is reached, see Enter/exit highway UC.</td></tr>
<tr><td>Final condition</td><td>
<table>
<tr><td>Operational area:</td><td>Any operational area inside the ODD for the platooning autonomous function</td></tr>
<tr><td>Environmental conditions:</td><td>Any environmental condition inside the ODD for the platooning autonomous function</td></tr>
<tr><td>Target vehicle(s):</td><td>Steady state Following and/or Trailing truck of a platoon</td></tr>
<tr><td>Ego vehicle (s):</td><td>Steady state Leading truck of a platoon</td></tr>
<tr><td>Application status target vehicle(s):</td><td>Platooning
If HMI available: show platooning status information</td></tr>
</table>
</td></tr>
</table>

	Application status Ego vehicle	Platooning HMI: it displays Platooning status information
	Driver status target vehicle(s):	Not present
	Driver status Ego vehicle	Aware (Leader)
	System status	No failure of internal systems and communication (V2V) is online.

Platooning in lane on the highway

ID	PAF_3.2	
Name	Platooning in lane on the Highway	
Story	A group of two or more cooperative vehicles are in line and driving on a main travel lane of the highway, maintaining a short, but safe, inter-vehicle distance using wireless communication (V2V) which enables the following truck to be completely automated. (Ego vehicle is a leader) (Manoeuvre ID M3, Infrastructure characteristics I1)	
Initial condition	Operational area:	Any of the operational areas inside the ODD for the Platooning Autonomous Function on a main lane of the highway.
	Environmental conditions:	Any environmental condition inside the ODD for the platooning autonomous function
	Target vehicle(s):	Follower in a steady state platoon • Vehicle in front within sensor view • Vehicle in front within V2V range and reception of V2V from the closest vehicle in front Control messages over V2V are sent according to specification.
	Ego vehicle (s):	Leader in a steady state platoon • Vehicle in rear within V2V range and reception of V2V from the closest vehicle in the back Control messages over V2V are sent according to specification.
	Application status target vehicle(s):	Platooning HMI: N/A
	Application status Ego vehicle	Advanced assist system (e.g. ACC and lane keeping) activated HMI: Platoon status
	Driver status target vehicle(s):	N/A, or not needed to be aware.
	Driver status Ego vehicle	Aware
	System status	All systems are ok.
Trigger	Transition to steady state platooning on a main lane in the highway because relative speed and relative distance between the trucks are within steady state tolerances.	
Sequence	Use case sequence:	

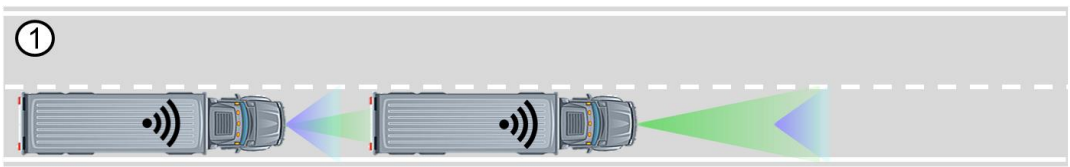


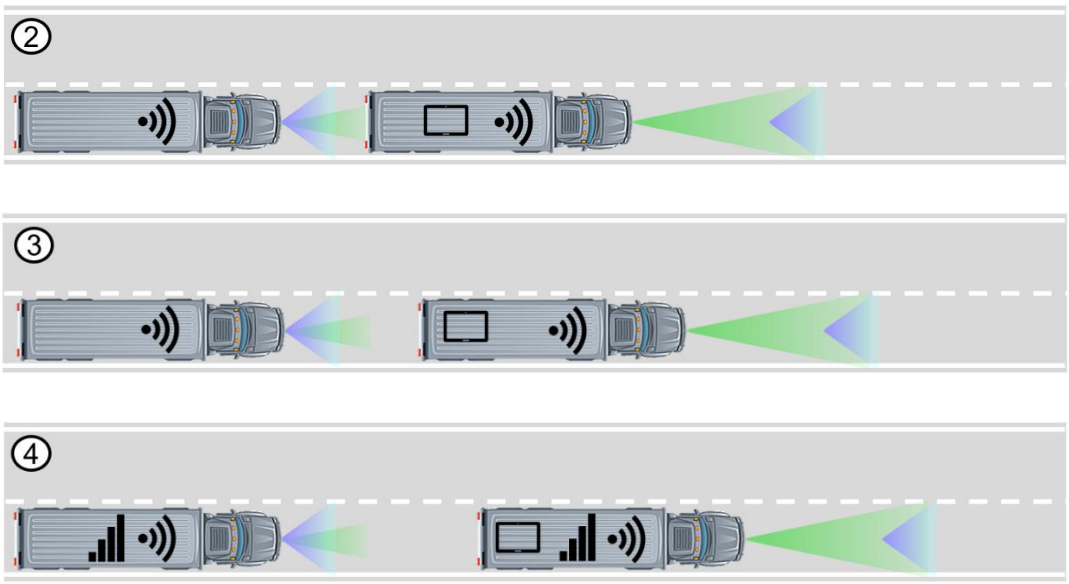
1.a Each vehicle in the platoon is receiving platooning information via V2V from vehicles in the platoon. At least from the one in front for the trailing and following truck and from the one to the back for the leading and following truck.
1.b The ego vehicle is broadcasting information on V2V to be consumed by the other platoon members.
1.c The target vehicle regulates its behaviour (both lateral and longitudinal control) based on V2V, sensor and vehicle internal information. Driver, if present, is out of the loop and is a passenger of the autonomous following truck.
1.d The lead vehicle is driven by a human, supported by driver assistance or automated driving systems.
1.d [Optional] Each vehicle in the platoon sends information to off board services. To be detailed by task 4.2 of the project.
1.e [Optional] Each vehicle in the platoon listens to Off Board signals (e.g. to receive platoon formation suggestion). To be detailed by task 4.2 of the project.
1.f Following traffic regulations is the responsibility of the leading truck's driver (ego truck) and the individual systems of the following trucks.
1.g If a following vehicle cannot keep up or close a gap it sends a cohesion request to the ego vehicle (leader). See UC (Maintaining Platoon cohesion).

Final condition	Operational area:	Any of the operational areas inside the ODD for the Platooning Autonomous Function on a main lane in the highway.
	Environmental conditions:	Any environmental condition inside the ODD for the platooning autonomous function
	Target vehicle(s):	Follower in a steady state platoon • Vehicle in front within sensor view • Vehicle in front within V2V range and reception of V2V from the closest vehicle in front Control messages over V2V are sent according to specification.
	Ego vehicle (s):	Leader in a steady state platoon • Vehicle in rear within V2V range and reception of V2V from the closest vehicle in the back Control messages over V2V are sent according to specification.
	Application status target vehicle(s):	Platooning If HMI available: platooning status
	Application status Ego vehicle	Advanced assist system (e.g. ACC and lane keeping) activated HMI: Platoon status

	Driver status target vehicle(s):	N/A
	Driver status Ego vehicle	Aware
	System status	All systems are ok.

Entire platoon starts from standstill

ID	PAF_3.3	
Name	Entire platoon starts from standstill	
Story	Each vehicle of the platoon is at a standstill. The leader (ego vehicle) starts accelerating and the following trucks follow the leader. The system of each following vehicle is responsible for checking the surrounding environment and assessing if it is safe to move. (Manoeuvre ID M3, Infrastructure characteristics I1, I2, I3, I4, I5, I6, I7, I8, Events E6)	
Initial condition	Operational area:	Any of the operational areas inside the ODD for the Platooning Autonomous Function
	Environmental conditions:	Any environmental condition inside the ODD for the platooning autonomous function
	Target vehicle(s):	Leader platooning standstill • Vehicle in rear within V2V range and reception of V2V from the closest vehicle in the back Control messages over V2V are sent according to specification.
	Ego vehicle (s):	Follower platooning standstill • Vehicle in front within sensor view • Vehicle in front within V2V range and reception of V2V from the closest vehicle in front Control messages over V2V are sent according to specification.
	Application status target vehicle(s):	Advanced assist system (e.g. ACC and lane keeping) activated or paused HMI: Platoon status
	Application status Ego vehicle	Platooning or standstill platooning HMI: If HMI available: show platooning status on HMI
	Driver status target vehicle(s):	N/A
	Driver status Ego vehicle	Aware
	System status	All systems are ok.
Trigger	Lead vehicle starts to accelerate	
Sequence	<u>Use case sequence:</u>  	



1. Initial state: standstill.
2. Ego vehicle checks the surrounding environment with its own sensors (or with the support of V2X information) and communicates to the leader if it is ready to move or not.
3. The driver of the lead vehicle decides to start moving taking into account the HMI information on the start status of the following/trailing vehicles, i.e. target vehicle starts to accelerate from standstill.
4. If the conditions allow to safely move the vehicle, the ego vehicle starts to move following the target vehicle.

NOTE: if a VRU or obstacle is detected by the ego vehicle when starting to move, it communicates that to the lead vehicle and the use case is then stopped.

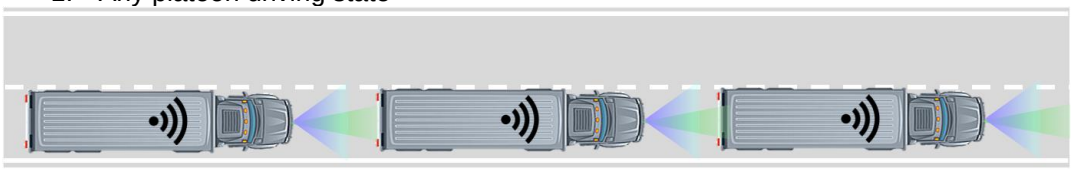
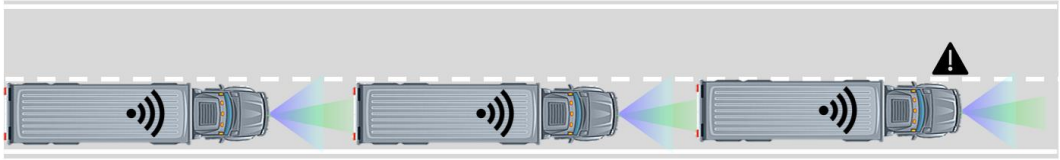
Final condition	Operational area:	Any of the operational areas inside the ODD for the Platooning Autonomous Function
	Environmental conditions:	Any environmental condition inside the ODD for the Platooning Autonomous Function
	Target vehicle(s):	Leader in a steady state platoon • Vehicle in rear within V2V range and reception of V2V from the closest vehicle in the back Control messages over V2V are sent according to specification.
	Ego vehicle (s):	Follower in a steady state platoon or standstill • Vehicle in front within sensor view • Vehicle in front within V2V range and reception of V2V from the closest vehicle in front Control messages over V2V are sent according to specification.

	Application status target vehicle(s):	Advanced assist system (e.g. ACC and lane keeping) activated HMI: Platoon status
	Application status Ego vehicle	Platooning HMI: If HMI available: show platooning status on HMI
	Driver status target vehicle(s):	Aware
	Driver status Ego vehicle	N/A
	System status	All systems are ok.

Emergency Manoeuvre

ID	PAF_3.4
Name	Emergency Manoeuvre
Story	The ego truck is part of a platoon, not the lead truck, and any truck ahead (in the platoon) sends relevant information, e.g. intended lateral acceleration, steering wheel rate and longitudinal deceleration. The ego truck receives these signals, at least from the preceding vehicle, and detects an Emergency Manoeuvre. The system will perform an emergency braking, requesting to brake according to the gap and speed difference to the truck ahead, up to full braking and/or will activate steering in order to avoid a collision or mitigate the consequences of a crash. (Manoeuvre ID M3, Infrastructure characteristics I1, I2, I3, I4, I5, I6, I7, I8, Events E2)
Initial condition	

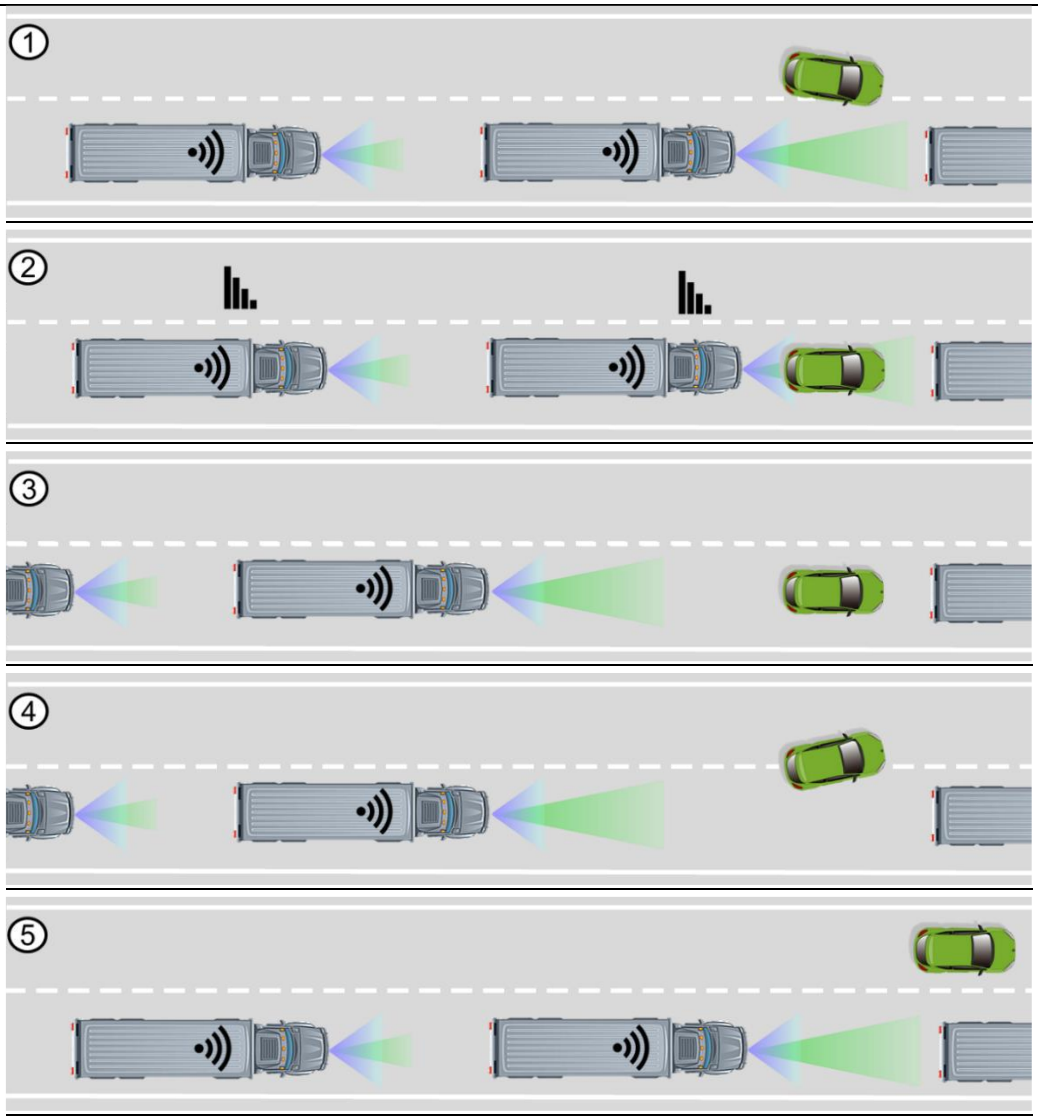
Operational area:	Any of the operational areas inside the ODD for the Platooning Autonomous Function
Environmental conditions:	Any environmental condition inside the ODD for the Platooning Autonomous Function
Target vehicle(s):	Follower in a steady state platoon • Vehicle in front within sensor view • Vehicle in front within V2V range and reception of V2V from the closest vehicle in front Control messages over V2V are sent according to specification.
Ego vehicle (s):	Leader in a steady state platoon • Vehicle in rear within V2V range and reception of V2V from the closest vehicle in the back Control messages over V2V are sent according to specification.
Application status target vehicle(s):	Platooning HMI: If HMI available: show platooning status on HMI
Application status Ego vehicle	Advanced assist system (e.g. ACC and lane keeping) activated HMI: Platoon status
Driver status target vehicle(s):	N/A

<table>
<tr><td></td><td>
<table>
<tr><td>Driver status Ego vehicle</td><td>Aware</td></tr>
<tr><td>System status</td><td>All systems are ok.</td></tr>
</table>
</td></tr>
<tr><td>Trigger</td><td>The truck in front of the ego vehicle initiates an Emergency Manoeuvre.
The status “emergency manoeuvre” is triggered by one or more of these events:
An immediate (predicted) acceleration of the front truck of <-4 m/s² [(UN R131, 2014)]
The driver is actuating emergency braking
If there is an AEB event in the front vehicle of the platoon
Intended lateral acceleration of <-X m/s² combined with steering wheel rate of X deg./s with longitudinal acceleration of X m/s² [exact signals and thresholds to be defined later]</td></tr>
<tr><td>Sequence</td><td>1. Any platoon driving state
 
2. Emergency manoeuvre
 
3. Ego vehicle recognises the emergency manouvre of the front vehicle via V2V information.
4. Ego vehicle starts to decelerate, till standstill, if needed, and activates [OPTIONAL] the lateral control system in order to avoid the collision or mitigate the consequences of a crash, according to what it detects with its own sensors (or in combination with V2X information) and accounting for its own vehicle dynamic performance limitations.</td></tr>
<tr><td>Final condition</td><td>
<table>
<tr><td>Operational area:</td><td>Any of the operational areas inside the ODD for the Platooning Autonomous Function</td></tr>
<tr><td>Environmental conditions:</td><td>Any environmental condition inside the ODD for the Platooning Autonomous Function</td></tr>
<tr><td>Target vehicle(s):</td><td>Leader in a steady state platoon or standstill
Vehicle in rear within V2V range and reception of V2V from the closest vehicle in the back
Control messages over V2V are sent according to specification.</td></tr>
<tr><td>Ego vehicle (s):</td><td>(Any) Follower in a steady state platoon or standstill
Vehicle in front within sensor view
Vehicle in front within V2V range and reception of V2V from the closest vehicle in front
Control messages over V2V are sent according to specification.</td></tr>
</table>
</td></tr>
</table>

	Application status target vehicle(s):	Platooning or standstill platooning HMI: if available, show platooning status
	Application status Ego vehicle	Advanced assist system (e.g. ACC and lane keeping) activated or paused HMI: Platooning status
	Driver status target vehicle(s):	N/A
	Driver status Ego vehicle	Aware
	System status	All systems are ok.

Cut-in

ID	PAF_3.5	
Name	Cut-in handling within the platoon. Cut in vehicle remains in the platoon for a limited period and then cuts out again.	
Story	Platoon members behind the intruder will adapt their speed and gap towards the cut-in vehicle and possibly between the platoon members to assure safety (as assessed by onboard sensors). The cut-in vehicle remains for a specific amount of time, then it performs a cut-out action. After a cut out, the platoon will automatically reduce the following distance (gap closing) to the rest of the platoon members and continue. Where needed the leader of the platoon will be supported to assist in the gap closing action by automatically lowering its speed during the gap closing action. (Manoeuvre ID M3, Infrastructure characteristics I1, I2, I3, I4, I5, I7, I8, Events E1)	
Initial condition	Operational area:	Any operational area inside the ODD for the platooning autonomous function
	Environmental conditions:	Any environmental condition inside the ODD for the platooning autonomous function
	Target vehicle(s):	Vehicle planning to cut in behind the leading or following truck of the platoon. Vehicle is driving on an adjacent lane.
	Ego vehicle (s):	Steady state following or trailing truck of a platoon in steady state (see steady state use case).
	Application status target vehicle(s):	N/A
	Application status Ego vehicle	Platooning HMI: it displays Platooning status information
	Driver status target vehicle(s):	Aware
	Driver status Ego vehicle	Not present
	System status	No failure of internal systems and communication (V2V) is online.
Trigger	Start of a cut-in is detected	
Sequence	Sketch:	



Use case sequence:

1. The ego application detects a vehicle that intends to cut-in or that is entering the ego vehicle lane.
2. Ego vehicle increases following distance (towards a safe following distance) towards the cut-in vehicle. Vehicle control will be performed using on-board sensors and cooperative information, if present.
3. If the speed of the cut-in vehicle is lower than the Platooning speed, a cohesion request is automatically sent and applied to the Leader (driver informed). (Cohesion UC)
4. If the intruder leaves the lane, the ego application automatically verifies if the preceding vehicle is the right Platoon member.
5. If this verification is successful, the ego application automatically starts to close the gap again to the platoon member ahead.
6. When the new target time gap is reached, the Platoon continues.
7. If the Platoon speed was lowered during the gap opening phase, it is automatically set back to the previous value.

Final condition	Operational area:	Any operational area inside the ODD for the platooning autonomous function
	Environmental conditions:	Any environmental condition inside the ODD for the platooning autonomous function
	Target vehicle(s):	Vehicle driving by itself in another lane than the platoon
	Ego vehicle (s):	Steady state following or trailing truck of a platoon in steady state (see steady state use case).
	Application status target vehicle(s):	N/A
	Application status Ego vehicle	Platooning HMI: it displays platooning status information
	Driver status target vehicle(s):	Aware
	Driver status Ego vehicle	Not present
	System status	Steady state platooning

Maintaining platoon cohesion

ID	PAF_3.6	
Name	Maintaining platoon cohesion	
Story	The driverless truck's platooning systems cyclically verify and try to maintain the set time gap. In the case that this is not possible, a cohesion request is sent to the Leader to keep the Platoon together. (Manoeuvre ID M3, Infrastructure characteristics I1, I2, I3, I4, I5, I7, I8)	
Initial condition	Operational area:	Any operational area inside the ODD for the platooning autonomous function
	Environmental conditions:	Any environmental condition inside the ODD for the platooning autonomous function
	Target vehicle(s):	Steady state leading truck of a platoon in steady state (see steady state use case).
	Ego vehicle (s):	Steady state following and trailing trucks of a platoon in steady state (see steady state use case).
	Application status target vehicle(s):	Platooning HMI: it displays platooning status information
	Application status Ego vehicle	Platooning HMI: If HMI available: show platooning status on HMI
	Driver status target vehicle(s):	Not present
	Driver status Ego vehicle	Aware
	System status	No failure of internal systems and communication (V2V) is online.
Trigger	• Ego vehicle sees that it is not able to keep the set target time gap	
Sequence	Use case sequence:	

	1. The ego vehicle application detects that the time gap (to the target vehicle) is opening towards an alert value (OEM Specific). This can happen because of: • The ego vehicle is approaching the maximum available torque (e.g. on uphill). • The ego vehicle speed is lower than the target one (e.g. delta of 10 km/h) due to a slow driving cut-in vehicle. • An intruder vehicle that has cut out. 2. The ego vehicle determines a new set speed that it is capable of, considering the reasons for the gap opening and thus would result in a stable gap in a reasonable time. 3. The ego application sends via V2V a cohesion request to the target vehicle, indicating the new desired maximum speed. 4. If the received desired maximum speed of the ego vehicle, received by the target vehicle (i.e. the leading truck), is lower than the current set speed of the target vehicle, the target vehicle application automatically applies the new set speed.
Final condition	

Operational area:	Any operational area inside the ODD for the platooning autonomous function
Environmental conditions:	Any environmental condition inside the ODD for the platooning autonomous function
Target vehicle(s):	Steady state leading truck of a platoon in steady state (see steady state use case).
Ego vehicle (s):	Steady state following and trailing trucks of a platoon in steady state (see steady state use case).
Application status target vehicle(s):	Platooning HMI: it displays platooning status information
Application status Ego vehicle	Platooning HMI: If HMI available: show platooning status on HMI
Driver status target vehicle(s):	Not present
Driver status Ego vehicle	Aware
System status	No failure of internal systems and communication (V2V) is online.

Lane change triggered by the leading truck

ID	PAF_3.7
Name	Lane change triggered by the leading truck
Story	The leading truck driver concludes, due to several reasons, that a lane change must be performed. (Manoeuvre ID M3, Infrastructure characteristics I1, I2, I3, I4, I5, I7, I8)
Initial condition	

Operational area:	Any operational area inside the ODD for the platooning autonomous function
Environmental conditions:	Any environmental condition inside the ODD for the platooning autonomous function
Target vehicle(s):	Steady state following and trailing truck of a platoon in steady state (see steady state use case).
Ego vehicle (s):	Steady state leading truck of a platoon in steady state (see steady state use case).

<table>
<tr><td></td><td><table>
<tr><td>Application status target vehicle(s):</td><td>Platooning
HMI: If HMI available: show platooning status on HMI</td></tr>
<tr><td>Application status Ego vehicle</td><td>Platooning
HMI: it displays Platooning status information</td></tr>
<tr><td>Driver status target vehicle(s):</td><td>Not present</td></tr>
<tr><td>Driver status Ego vehicle</td><td>Aware</td></tr>
<tr><td>System status</td><td>No failure of internal systems and communication (V2V) is online.</td></tr>
</table></td></tr>
<tr><td>Trigger</td><td>• Leading driver switches the turn signal on</td></tr>
<tr><td>Sequence</td><td><u>Use case sequence:</u>

1. The ego vehicle’s turn signal activation and direction are communicated to the target vehicles.
2. Target vehicles verify the possibility to perform the lane change by using their sensor set (e.g. side radars, V2V for upcoming cooperative vehicles, rear radars, etc.).
3. If the conditions to perform the lane change are confirmed (e.g. no upcoming vehicles, target lane free, enough available space), the target vehicles communicate this to the ego vehicle. If two target vehicles are part of the platoon, both have to verify the conditions to perform the lane change and to communicate it to the ego vehicle.
4. The HMI of the ego vehicle visualises the readiness of the target vehicles.
5. The ego driver performs the lane change.
6. The target vehicle(s), follow(s) the ego vehicle’s lane change manoeuvre using their own sensor set and V2V information.
7. The ego and target vehicles confirm the successful lane change to the lead truck driver via HMI.</td></tr>
<tr><td>Final condition</td><td><table>
<tr><td>Operational area:</td><td>Any operational area inside the ODD for the platooning autonomous function</td></tr>
<tr><td>Environmental conditions:</td><td>Any environmental condition inside the ODD for the platooning autonomous function</td></tr>
<tr><td>Target vehicle(s):</td><td>Steady state following and trailing truck of a platoon in steady state (see steady state use case).</td></tr>
<tr><td>Ego vehicle (s):</td><td>Steady state leading truck of a platoon in steady state (see steady state use case).</td></tr>
<tr><td>Application status target vehicle(s):</td><td>Platooning
HMI: If HMI available: show platooning status on HMI</td></tr>
<tr><td>Application status Ego vehicle</td><td>Platooning
HMI: it displays platooning status information</td></tr>
<tr><td>Driver status target vehicle(s):</td><td>Not present</td></tr>
<tr><td>Driver status Ego vehicle</td><td>Aware</td></tr>
<tr><td>System status</td><td>No failure of internal systems and communication (V2V) is online.</td></tr>
</table></td></tr>
</table>

Lane change triggered by following or trailing truck

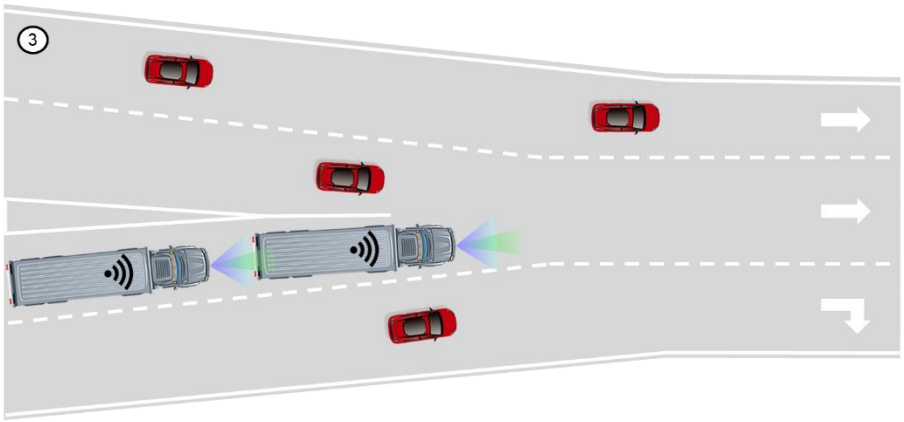
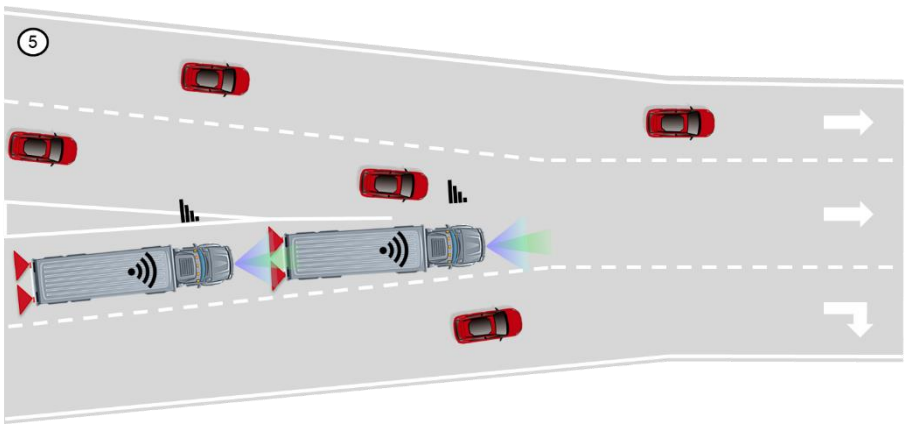
<table>
<tr><td>ID</td><td colspan="2">PAF_3.8</td></tr>
<tr><td>Name</td><td colspan="2">Lane change triggered by following or trailing truck</td></tr>
<tr><td>Story</td><td colspan="2">The Platooning as whole has the need to perform a lane change as evaluated by a following or trailing truck.
(Manoeuvre ID M3, Infrastructure characteristics I1, I2, I3, I4, I5, I7, I8)</td></tr>
<tr><td>Initial condition</td><td colspan="2"><table>
<tr><td>Operational area:</td><td>Any operational area inside the ODD for the platooning autonomous function</td></tr>
<tr><td>Environmental conditions:</td><td>Any environmental condition inside the ODD for the platooning autonomous function</td></tr>
<tr><td>Target vehicle(s):</td><td>Leading truck of a platoon in steady state (see steady state use case).</td></tr>
<tr><td>Ego vehicle (s):</td><td>Following and trailing truck of a platoon in steady state (see steady state use case).</td></tr>
<tr><td>Application status target vehicle(s):</td><td>Platooning
HMI: it displays Platooning status information</td></tr>
<tr><td>Application status Ego vehicle</td><td>Platooning
HMI: If HMI available: show platooning status on HMI</td></tr>
<tr><td>Driver status target vehicle(s):</td><td>Aware</td></tr>
<tr><td>Driver status Ego vehicle</td><td>Not present</td></tr>
<tr><td>System status</td><td>No failure of internal systems and communication (V2V) is online.</td></tr>
</table></td></tr>
<tr><td>Trigger</td><td colspan="2">• Ego vehicle(s) evaluates the need to perform a lane change.</td></tr>
<tr><td>Sequence</td><td colspan="2"><u>Use case sequence:</u>

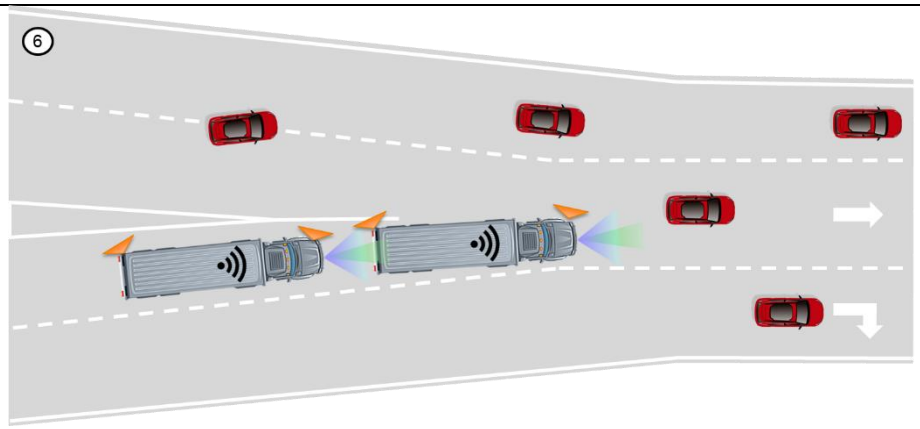
1. One of the ego vehicles sends a lane change request to the target vehicle.
2. Lane change request received, is visualised on the target vehicle’s HMI.
3. The target driver has the possibility to accept or reject the lane change request
4. If the request is accepted, the target driver switches the turn signal on.
5. The turn indicator activation and direction are communicated to the ego vehicle(s)
6. Ego vehicle(s) verify the possibility to perform the lane change by using their sensor set (e.g. side radars, V2V for upcoming cooperative vehicles, rear radar, etc.)
7. If the conditions to perform the lane change are confirmed (e.g. no upcoming vehicles, target lane free, enough available space), the ego vehicle(s) communicate it to the target vehicle.
8. If two ego vehicles are part of the platoon, both have to verify the conditions to perform the lane change and to communicate it to the target vehicle.
9. The target driver visualises the readiness of the ego vehicle(s) via HMI.
10. The target driver performs the lane change.
11. The ego vehicle(s) perform the lane change, according to the specific situation and using the target vehicle’s lane change trajectory and/or its (their) own sensor set.
12. The ego and target vehicles confirm the successful lane change to the lead truck driver via HMI.</td></tr>
<tr><td>Final condition</td><td colspan="2"><table>
<tr><td>Operational area:</td><td>Any operational area inside the ODD for the platooning autonomous function</td></tr>
<tr><td>Environmental conditions:</td><td>Any environmental condition inside the ODD for the platooning autonomous function</td></tr>
</table></td></tr>
</table>

	Target vehicle(s):	Steady state leading truck of a platoon in steady state (see steady state use case).
	Ego vehicle (s):	Steady state following and trailing truck of a platoon in steady state (see steady state use case).
	Application status target vehicle(s):	Platooning HMI: it displays platooning status information
	Application status Ego vehicle	Platooning HMI: If HMI available: show platooning status on HMI
	Driver status target vehicle(s):	Aware
	Driver status Ego vehicle	Not present
	System status	No failure of internal systems and communication (V2V) is online.

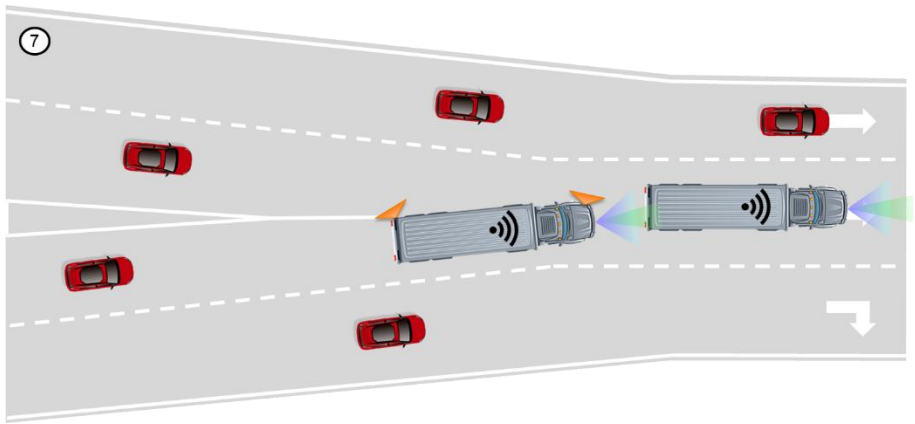
Lane merge

ID	PAF_3.9	
Name	Lane merge	
Story	Two lanes are merging into one. The platoon is in one lane and other vehicles might be in the other lane. This can happen both on the highway or on the road between the hub and the highway. (Manoeuvre ID M3, Infrastructure characteristics I1, I3, I4, I5, I7, I8)	
Initial condition	Operational area:	Any operational area inside the ODD for the platooning autonomous function
	Environmental conditions:	Any environmental condition inside the ODD for the platooning autonomous function
	Target vehicle(s):	Following and trailing truck of a platoon in steady state (see steady state use case).
	Ego vehicle (s):	Leading truck of a platoon in steady state (see steady state use case).
	Application status target vehicle(s):	Platooning HMI: If HMI available: show platooning status on HMI
	Application status Ego vehicle	Platooning HMI: it displays Platooning status information
	Driver status target vehicle(s):	Not present
	Driver status Ego vehicle	Aware
	System status	No failure of internal systems and communication (V2V) is online.
Trigger	The ego vehicle HMI visualises an upcoming lane merging (e.g. X km in advance) in front of the ego vehicle	
Sequence	<u>Use case sequence:</u> 1. The source of the upcoming lane merge information can be: • On-board HD map • I2V • Lead truck driver.	

	2. If it is required in order to follow the predefined route, the platoon performs a lane change (see Lane change UC) to be ready to negotiate the junction. 3. When the junction is reached, the Platoon follower and trailing vehicle follow the ego vehicle's lane.  4. Ego vehicle verifies the possibility to perform the lane merge by using its sensor set (e.g. side radars, V2V for upcoming cooperative vehicles, etc.) and cooperative environmental perception of the target vehicles. 5. If the conditions to perform the lane merge are not confirmed, the ego vehicle decelerates, to permit the upcoming vehicles to overtake the Platoon, until the conditions are met.  6. If the conditions to perform the lane merge are confirmed (e.g. no upcoming vehicles, target lane free, enough available space), the driver of the ego vehicle switches the turn signal on. The turn indicator activation and direction are communicated to the target vehicle(s). The ego vehicle enters the new lane.



7. The target vehicle(s) perform the lane change, according to the specific situation and using the ego vehicle's lane change trajectory and/or its (their) own sensor set.



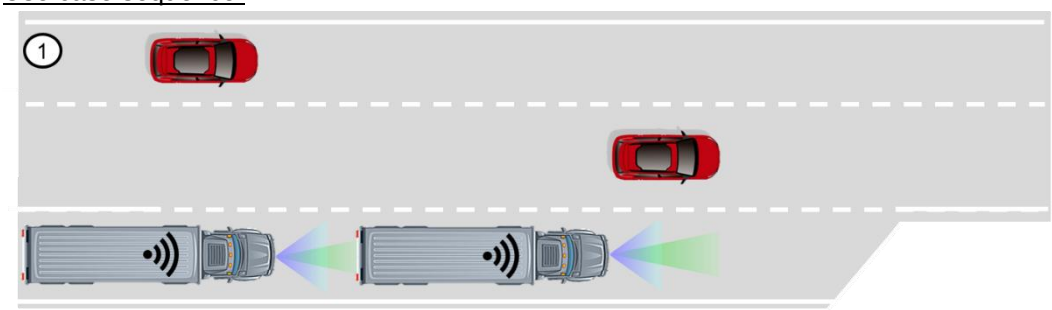
8. If an upcoming vehicle is detected (e.g. with side radars or V2V, rear radar), the target vehicle evaluates the possibility to accelerate to enter the new lane or to decelerate to let it pass.
9. If an external vehicle enters the ego lane in front of the ego vehicle, it will adapt the distance and speed (as Steady-state UC).
10. If an external vehicle enters the ego lane in front of the target vehicle(s), it will become an intruder within the Platoon (see Cut-in UCs).

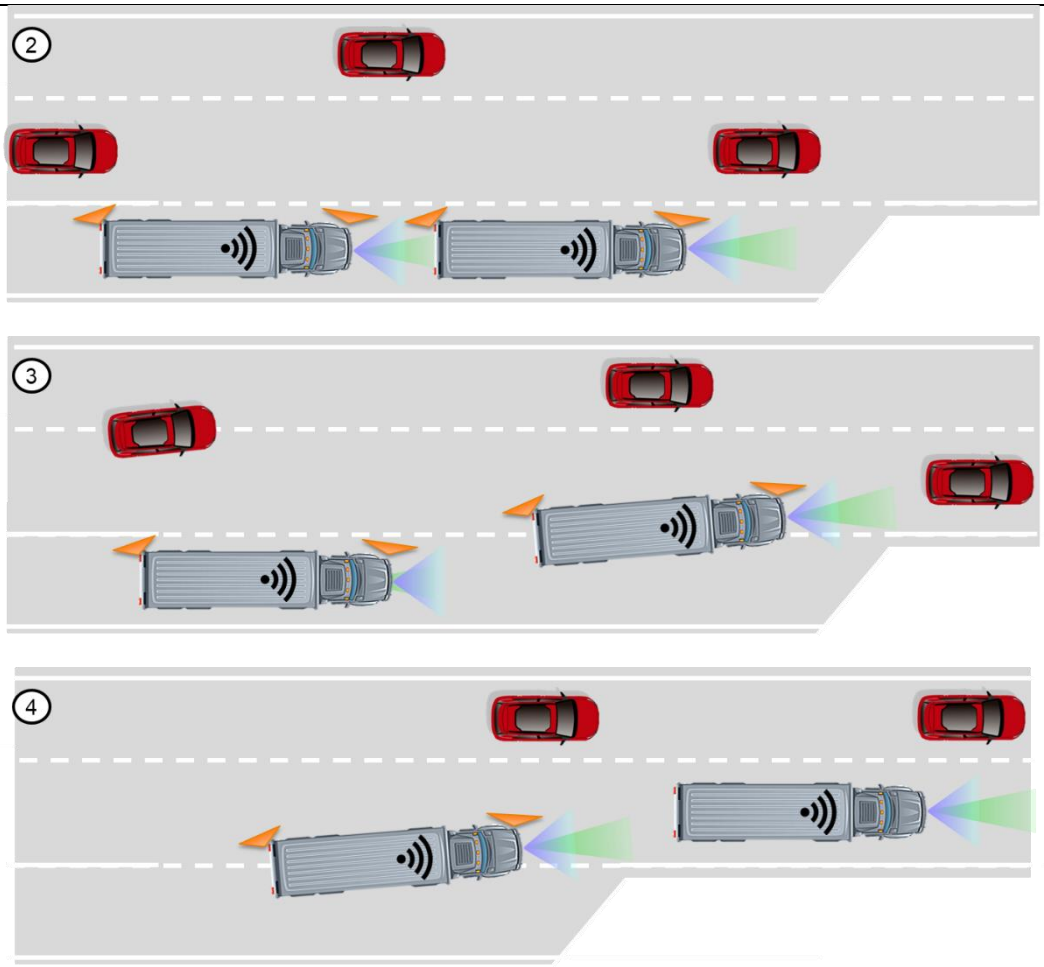
Final condition

Operational area:	Any of the operational areas inside the ODD for the platooning support function
Environmental conditions:	Any environmental condition inside the ODD for the platooning autonomous function
Target vehicle(s):	Steady state platooning in the merged lane.
Ego vehicle (s):	Steady state platooning in the merged lane.
Application status target vehicle(s):	Platooning HMI: If HMI available: show platooning status on HMI
Application status Ego vehicle	Platooning Shows platooning status on HMI
Driver status target vehicle(s):	Not present
Driver status Ego vehicle	Aware

	System status	Steady state platooning	

Entering highway via onramp

ID	PAF_3.10	
Name	Entering highway via onramp	
Story	The platoon wants to enter the highway and drives on the onramp. The platooning vehicles need to change lane to merge onto the highway. (Manoeuvre ID M3, Infrastructure characteristics I2)	
Initial condition	Operational area:	Onramps to highways inside the ODD for the platooning autonomous function
	Environmental conditions:	Any environmental condition inside the ODD for the platooning autonomous function
	Target vehicle(s):	Follower in a steady state platoon • Vehicle in front within sensor view • Vehicle in front within V2V range and reception of V2V from the closest vehicle in front Control messages over V2V are sent according to specification.
	Ego vehicle (s):	Leader in a steady state platoon • Vehicle in rear within V2V range and reception of V2V from the closest vehicle in the back Control messages over V2V are sent according to specification.
	Application status target vehicle(s):	Platooning HMI: If HMI available: show platooning status on HMI
	Application status Ego vehicle	Advanced assist system (e.g. ACC and lane centring) activated HMI: Platoon status
	Driver status target vehicle(s):	N/A
	Driver status Ego vehicle	Aware
	System status	All systems are ok.
Trigger	The lead truck driver switches the turn signal on.	
Sequence	Use case sequence: 	



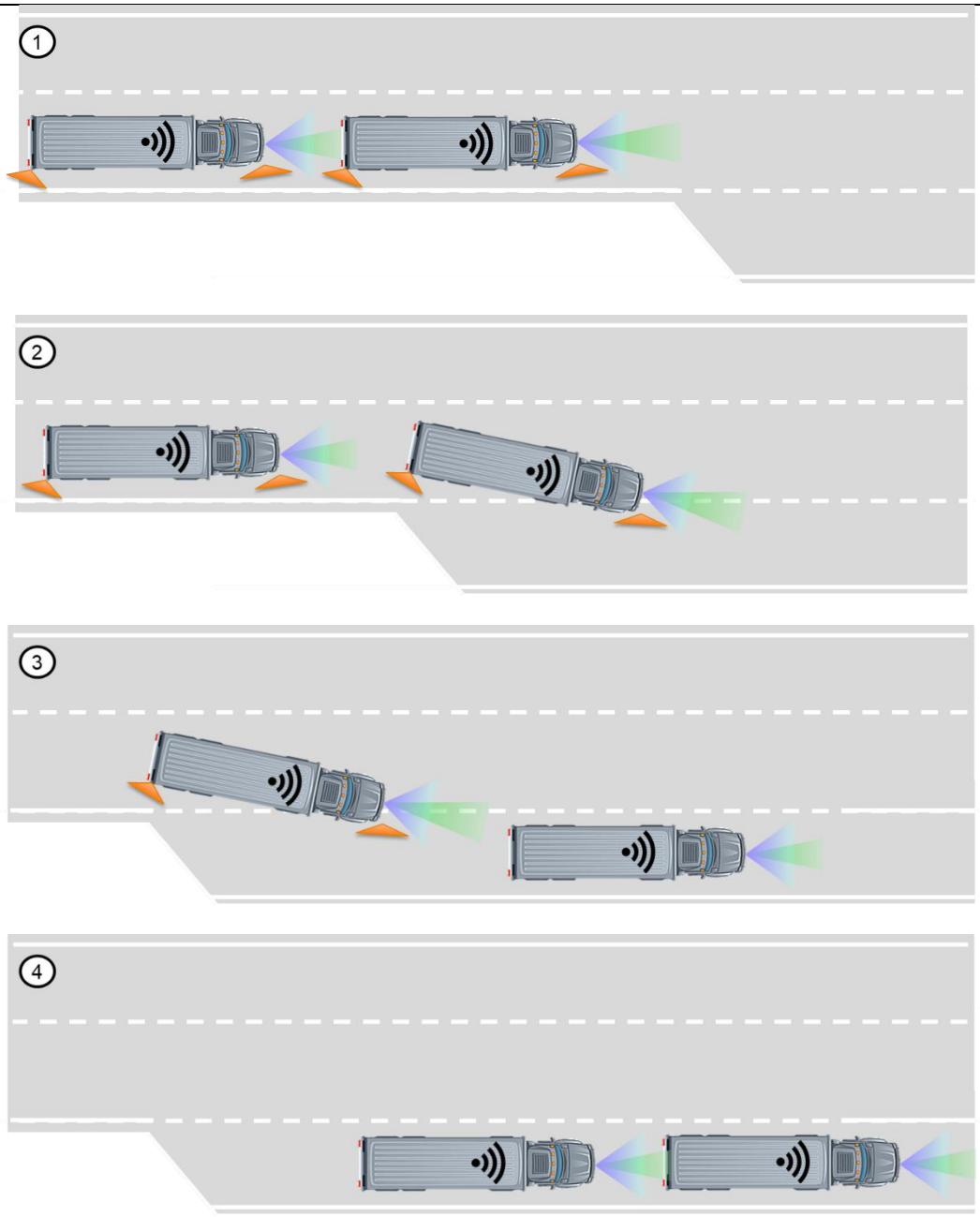
1. The lead truck driver observes the surrounding traffic, possibly supported by the HMI (and V2V communication: cooperative environmental perception)
2. When the lead truck driver is convinced that there is sufficient space for merging, he will switch the turn signal on. By doing this, the system of the follower truck is made aware about the lane change intention.
3.a The lead truck changes lane, either manually driven or using assist systems.
3.b The follower truck system is fully capable of autonomously performing the lane change (perception, path planning, control, maybe using information of the lead vehicle or the vehicle ahead), but will not start the lane change before the lead truck has changed lane (e.g. middle of the truck passes the lane boundaries).
4. Follower truck performs the lane change autonomously.

Final condition	Operational area:	Highway inside the ODD for the platooning autonomous function
	Environmental conditions:	Any environmental condition inside the ODD for the platooning autonomous function
	Target vehicle(s):	Follower in a steady state platoon • Vehicle in front within sensor view • Vehicle in front within V2V range and reception of V2V from the closest vehicle in front Control messages over V2V are sent according to specification.
	Ego vehicle (s):	Leader in a steady state platoon

		• Vehicle in rear within V2V range and reception of V2V from the closest vehicle in the back Control messages over V2V are sent according to specification.
	Application status target vehicle(s):	Platooning HMI: If HMI available: show platooning status on HMI
	Application status Ego vehicle	Advanced assist system (e.g. ACC and lane centring) activated HMI: Platoon status
	Driver status target vehicle(s):	N/A
	Driver status Ego vehicle	Aware
	System status	All systems are ok.

Highway offramp

ID	PAF_3.11	
Name	Highway offramp	
Story	The platoon wants to leave the highway via the offramp. (Manoeuvre ID M3, Infrastructure characteristics I2)	
Initial condition	Operational area:	Highway inside the ODD for the platooning autonomous function
	Environmental conditions:	Any environmental condition inside the ODD for the platooning autonomous function
	Target vehicle(s):	Follower in a steady state platoon • Vehicle in front within sensor view • Vehicle in front within V2V range and reception of V2V from the closest vehicle in front Control messages over V2V are sent according to specification.
	Ego vehicle (s):	Leader in a steady state platoon • Vehicle in rear within V2V range and reception of V2V from the closest vehicle in the back Control messages over V2V are sent according to specification.
	Application status target vehicle(s):	Platooning HMI: If HMI available: show platooning status on HMI
	Application status Ego vehicle	Advanced assist system (e.g. ACC and lane centring) activated HMI: Platoon status
	Driver status target vehicle(s):	N/A
	Driver status Ego vehicle	Aware
	System status	All systems are ok.
Trigger	The lead truck driver switches the turn signal on.	
Sequence	Use case sequence:	

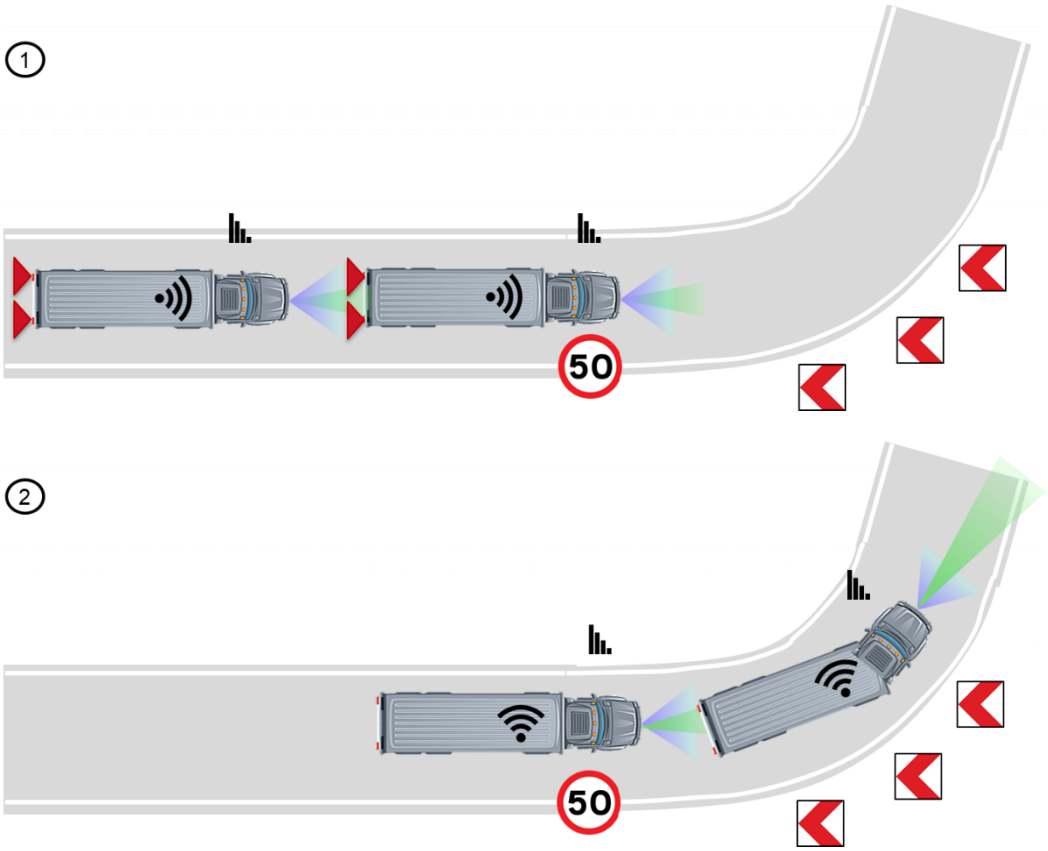


1. When approaching the offramp, the lead truck driver switches the turn signal on. By doing this, the system of the follower truck is made aware about the lane change intention.
2.a. The lead truck changes lane, either manually driven or using assist systems.
2.b The follower truck system is fully capable of autonomously performing the lane change (perception, path planning, control, maybe using information of the lead vehicle or the vehicle in front), but will not start the lane change before it has at least reached the offramp and evaluated that it is safe to perform the lane change. Additionally, requirements like the lead truck has to have reached a certain point in the lane change (e.g. middle of the truck passes the lane boundaries) before the following vehicle starts, maybe added to the manoeuvre.
3. Follower truck continues following the lane and performs the lane change autonomously when this is possible.

	4. Steady-state platooning.		
Final condition	Operational area:	Any roads inside the ODD for the platooning autonomous function	
	Environmental conditions:	Any environmental condition inside the ODD for the platooning autonomous function	
	Target vehicle(s):	Follower in a steady state platoon • Vehicle in front within sensor view • Vehicle in front within V2V range and reception of V2V from the closest vehicle in front Control messages over V2V are sent according to specification.	
	Ego vehicle (s):	Leader in a steady state platoon • Vehicle in rear within V2V range and reception of V2V from the closest vehicle in the back Control messages over V2V are sent according to specification.	
	Application status target vehicle(s):	Platooning HMI: If HMI available: show platooning status on HMI	
	Application status Ego vehicle	Advanced assist system (e.g. ACC and lane centring) activated HMI: Platoon status	
	Driver status target vehicle(s):	N/A	
	Driver status Ego vehicle	Aware	
	System status	All systems are ok.	

Platooning on a connection between two different highways

ID	PAF_3.12		
Name	Platooning on a connection between two different highways		
Story	Between highways, connector roads exist that can be approached via onramps, offramps and highway junctions. The lanes of these connector roads have different properties compared to the main roads, i.e. maximum speeds are lower, radii of curvature are smaller and road banking may be larger. (Manoeuvre ID M3, Infrastructure characteristics I4)		
Initial condition	Operational area:	Highway and connector roads inside the ODD for the platooning autonomous function	
	Environmental conditions:	Any environmental condition inside the ODD for the platooning autonomous function	
	Target vehicle(s):	Follower in a steady state platoon • Vehicle in front within sensor view • Vehicle in front within V2V range and reception of V2V from the closest vehicle in front Control messages over V2V are sent according to specification.	
	Ego vehicle (s):	Leader in a steady state platoon • Vehicle in rear within V2V range and reception of V2V from the closest vehicle in the back Control messages over V2V are sent according to specification.	

	Application status target vehicle(s):	Platooning HMI: If HMI available: show platooning status on HMI
	Application status Ego vehicle	Advanced assist system (e.g. ACC and lane centring) activated HMI: Platoon status
	Driver status target vehicle(s):	N/A
	Driver status Ego vehicle	Aware
	System status	All systems are ok.
Trigger	Approaching a highway connector road.	
Sequence	<u>Use case sequence:</u>  1. Lead truck driver brakes to adjust the speed of the lead truck to the speed limit/advised speed and the observed corner radius. The following truck follows the lead truck. 2. The following truck autonomously keeps itself in the lane, while longitudinally following the lead truck. The following truck reduces its speed when it detects that the speed is too high for safely negotiating the corner. Notes: • Camera systems for detecting lane markings may not work properly in sharp corners due to the truck and trailer in front of the ego vehicle obstructing its vision. • In sharp corners the trucks might need to plan another path than the lane centre path. • The trucks cannot simply follow the rear end of the preceding truck, because this may lead to corner cutting.	

Final condition	Operational area:	Highway inside the ODD for the platooning autonomous function
	Environmental conditions:	Any environmental condition inside the ODD for the platooning autonomous function
	Target vehicle(s):	Follower in a steady state platoon • Vehicle in front within sensor view • Vehicle in front within V2V range and reception of V2V from the closest vehicle in front Control messages over V2V are sent according to specification.
	Ego vehicle (s):	Leader in a steady state platoon • Vehicle in rear within V2V range and reception of V2V from the closest vehicle in the back Control messages over V2V are sent according to specification.
	Application status target vehicle(s):	Platooning HMI: If HMI available: show platooning status on HMI
	Application status Ego vehicle	Advanced assist system (e.g. ACC and lane centring) activated HMI: Platoon status
	Driver status target vehicle(s):	N/A
	Driver status Ego vehicle	Aware
	System status	All systems are ok.

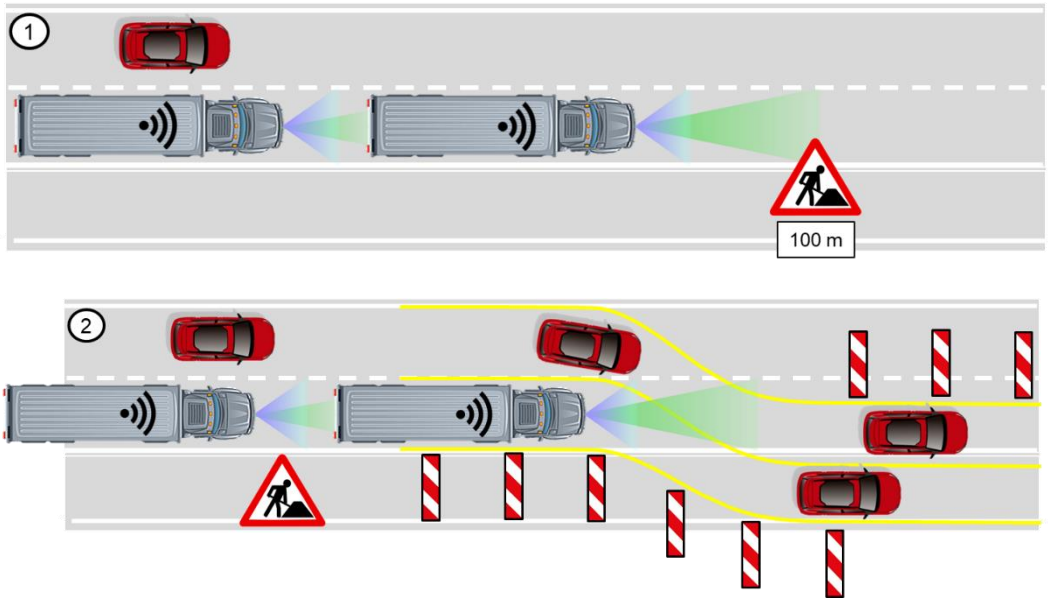
Traffic signs handling

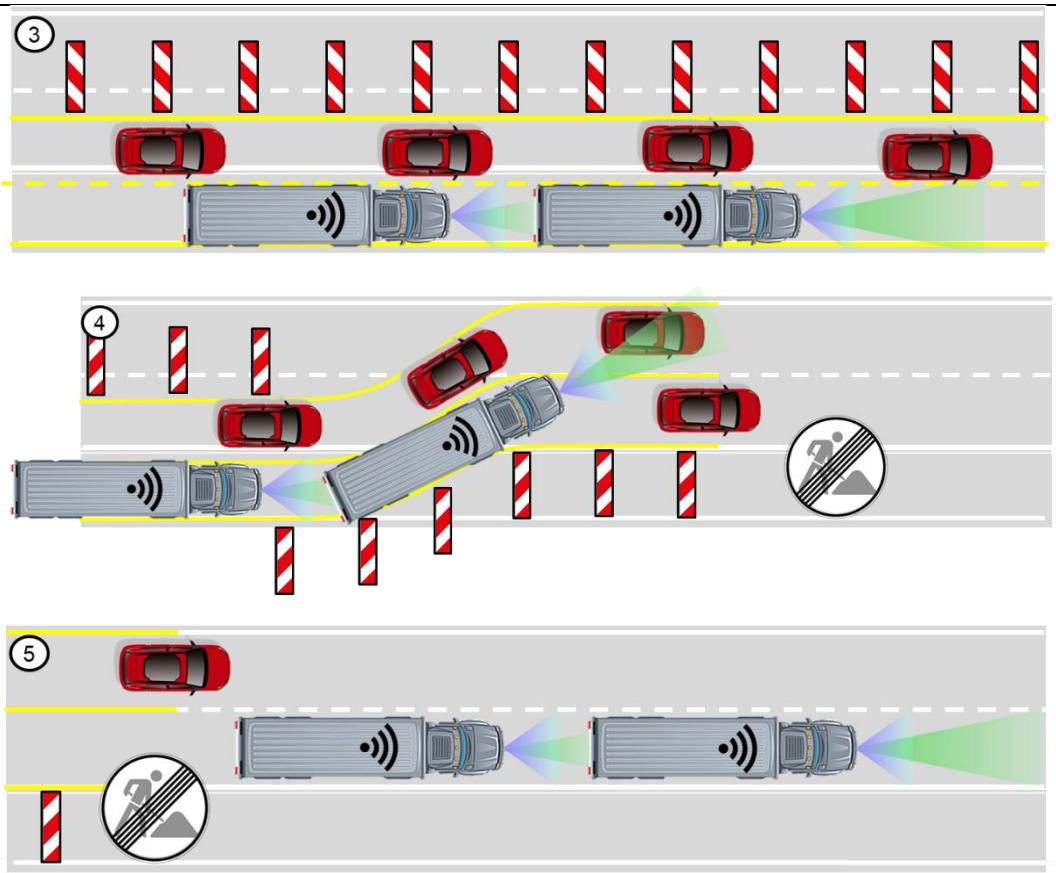
ID	PAF_3.13	
Name	Traffic signs handling	
Story	Using the available information coming from, e.g., the road operator, physical traffic signs and HD maps, the Platooning vehicles will adapt their dynamic behaviour to fulfil the requests/demands. (Manoeuvre ID M3, Infrastructure characteristics I1, I2, I3, I4, I5, I7, I8)	
Initial condition	Operational area:	Any operational area inside the ODD for the platooning autonomous function
	Environmental conditions:	Any environmental condition inside the ODD for the platooning autonomous function
	Target vehicle(s):	Steady state following and trailing truck of a platoon in steady state (see steady state use case).
	Ego vehicle (s):	Steady state leading truck of a platoon in steady state (see steady state use case).
	Application status target vehicle(s):	Platooning HMI: If HMI available: show platooning status on HMI
	Application status Ego vehicle	Platooning HMI: it displays Platooning status information
	Driver status target vehicle(s):	Not present
	Driver status Ego vehicle	Aware

	System status	No failure of internal systems and communication (V2V) is online.
Trigger	• The Platoon is approaching a road sign	
Sequence	Use case sequence: 1. The Platooning application can receive traffic sign information from different sources (e.g. HD map, I2V, on-board vehicle camera, etc.). 2. When received, the (upcoming) traffic sign can be: • notified to the ego driver through the HMI display • detected by the ego driver himself 3. The ego vehicle driver reacts adequately and the target vehicles will follow the ego vehicle's dynamic behaviour. 4. a. If, while doing that, the target vehicle evaluate that the time gap is increasing too much -> see Cohesion UC b. If the target vehicle cannot follow the ego vehicle (e.g. when a speed limit is over for the ego vehicle, but not yet for the target vehicle) -> see Cohesion UC 5. The Platoon continues to drive.	
Final condition	Operational area:	Any operational area inside the ODD for the platooning autonomous function
	Environmental conditions:	Any environmental condition inside the ODD for the platooning autonomous function
	Target vehicle(s):	Steady state following and trailing truck of a platoon in steady state (see steady state use case).
	Ego vehicle (s):	Steady state leading truck of a platoon in steady state (see steady state use case).
	Application status target vehicle(s):	Platooning HMI: If HMI available: show platooning status on HMI
	Application status Ego vehicle	Platooning HMI: it displays Platooning status information
	Driver status target vehicle(s):	Not present
	Driver status Ego vehicle	Aware
	System status	No failure of internal systems and communication (V2V) is online.

Road Works/Construction zone

ID	PAF_3.14
Name	Road Works/Construction zone
Story	The platoon needs to go through road works or a construction zone. This can happen both on the highway or between the hub and the highway. The construction zone has temporary lane markings to guide the traffic around the construction zone. In principle, all vehicles are able to automatically recognise the upcoming road works, e.g. by traffic sign recognition, a real-time map or V2I. Nevertheless, a probability exists that the road works are not recognised or they may have changed. In that case the lead truck driver can recognise the situation and inform the following trucks by V2V. The lanes of the construction zone may be narrower than regular lanes, requiring precise lane keeping. (Manoeuvre ID M3, Infrastructure characteristics I7)

<table>
<tr><td>Initial condition</td><td><table>
<tr><td>Operational area:</td><td>Any of the operational areas inside the ODD for the platooning autonomous function</td></tr>
<tr><td>Environmental conditions:</td><td>Any environmental condition inside the ODD for the platooning autonomous function</td></tr>
<tr><td>Target vehicle(s):</td><td>Follower in a steady state platoon
Vehicle in front within sensor view
Vehicle in front within V2V range and reception of V2V from the closest vehicle in front
Control messages over V2V are sent according to specification.</td></tr>
<tr><td>Ego vehicle (s):</td><td>Leader in a steady state platoon
Vehicle in rear within V2V range and reception of V2V from the closest vehicle in the back
Control messages over V2V are sent according to specification.</td></tr>
<tr><td>Application status target vehicle(s):</td><td>Platooning
HMI: If HMI available: show platooning status on HMI</td></tr>
<tr><td>Application status Ego vehicle</td><td>Advanced assist system (e.g. ACC and lane keeping) activated
HMI: Platoon status</td></tr>
<tr><td>Driver status target vehicle(s):</td><td>N/A</td></tr>
<tr><td>Driver status Ego vehicle</td><td>Aware</td></tr>
<tr><td>System status</td><td>All systems are ok.</td></tr>
</table></td></tr>
<tr><td>Trigger</td><td>Automatic recognition of road works by all vehicles via (HD) map, V2I or traffic sign recognition.
[ALTERNATIVE] Driver notices the upcoming road works and provides the road works trigger.</td></tr>
<tr><td>Sequence</td><td><u>Use case sequence:</u>
 
</td></tr>
</table>



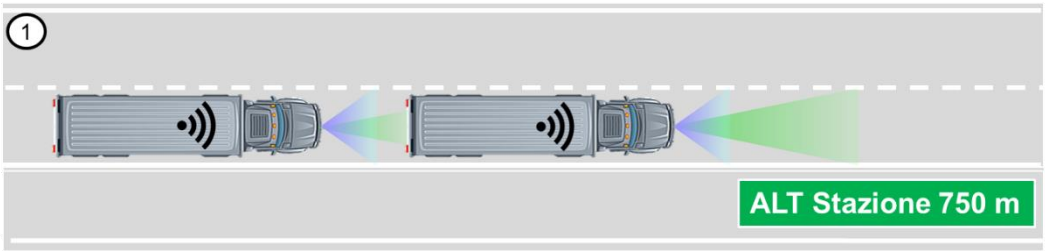
1 All vehicles automatically recognise the upcoming road works. The lead truck driver checks if the following trucks have noticed the upcoming road works, and if not the lead truck driver will manually provide the road works trigger. When receiving the road works trigger, the target vehicles activate their “lateral following” mode. In this mode, the follower truck will follow the same path as the lead truck, taking into account the restrictions from other traffic, delimiters, etc.
2 The driver of the lead truck disables the driver assist functions and manually steers the truck along the lane diversion towards the temporary lane. The follower truck automatically follows the lead truck.
3. As long as the trucks drive through the road works the “lateral following” mode is enabled. The lead truck driver may, whilst in the temporary lane, engage the driver support functions, e.g. ACC and lane keeping again.
4. At the end of the road works the lead truck driver disables the driver support functions and controls the truck to follow the lane diversion back to the normal lane. The follower truck keeps following the lead truck.
5. After that the road works or construction zone is passed, the target vehicles automatically recognise this and deactivate the “lateral following” mode. In case the lead truck driver notices that the automatic recognition fails, the driver presses a button on the HMI to deactivate the “lateral following” mode, after the driver has ascertained that the follower truck is out of the construction zone.

Final condition	Operational area:	Any of the operational areas inside the ODD for the platooning autonomous function
	Environmental conditions:	Any environmental condition inside the ODD for the platooning autonomous function

	Target vehicle(s):	Follower in a steady state platoon • Vehicle in front within sensor view • Vehicle in front within V2V range and reception of V2V from the closest vehicle in front Control messages over V2V are sent according to specification.
	Ego vehicle (s):	Leader in a steady state platoon • Vehicle in rear within V2V range and reception of V2V from the closest vehicle in the back Control messages over V2V are sent according to specification.
	Application status target vehicle(s):	Platooning HMI: If HMI available: show platooning status on HMI
	Application status Ego vehicle	Advanced assist system (e.g. ACC and lane centring) activated HMI: Platoon status
	Driver status target vehicle(s):	N/A
	Driver status Ego vehicle	Aware
	System status	All systems are ok.

Toll gates

ID	PAF_3.15
Name	Toll gates
Story	In several EU countries a large part of the highway network consists of toll roads. To enter such a toll road, the platoon needs to pass toll gates. In general, these toll gates contain very narrow lanes next to the toll booths. Furthermore, typically a toll plaza diverging area exists to allow more toll booth lanes than the original highway lanes. These toll plaza diverging areas are generally considered risky to vehicles, as diverging and crossing behaviour of vehicles increases the risk of a collision. Additionally, the perception of automated vehicles might not be able to handle the diverse and non-uniform road markings. After the payment, the platoon enters the toll plaza converging area and needs to determine the correct path to the right highway lane again. Also, the toll plaza converging area is risky due to vehicle movements and strange or lacking road markings. Different systems exist in the EU and dedicated solutions for payment exist with different requirements. For this use case story, the European TELEPASS system is used as an example to illustrate the possible complexity for the platoon. An additional complexity for toll gates is that regulations exist to lower the V2X TX power close to toll gates, which might have a negative impact on the communication range. Due to this it might be more difficult to keep the platoon together. Notes: It is assumed that the platooning vehicles will use the TELEPASS system, meaning that a device for automatically paying the toll is available in the trucks. Using TELEPASS also means that the platoon does not have to stop, but can drive trough. Nevertheless, there

<table>
<tr><td></td><td>are some requirements: the speed limit of 30 km/h and the 4 m safety distance from the vehicle in front must be respected. Drivers need to verify that the TELEPASS beeps when entering.
(Manoeuvre ID M3, Infrastructure characteristics I8)</td></tr>
<tr><td>Initial condition</td><td>
<table>
<tr><td>Operational area:</td><td>Highway inside the ODD for the platooning autonomous function</td></tr>
<tr><td>Environmental conditions:</td><td>Any environmental condition inside the ODD for the platooning autonomous function</td></tr>
<tr><td>Target vehicle(s):</td><td>Follower in a steady state platoon
Vehicle in front within sensor view
Vehicle in front within V2V range and reception of V2V from the closest vehicle in front
Control messages over V2V are sent according to specification.</td></tr>
<tr><td>Ego vehicle (s):</td><td>Leader in a steady state platoon
Vehicle in rear within V2V range and reception of V2V from the closest vehicle in the back
Control messages over V2V are sent according to specification.</td></tr>
<tr><td>Application status target vehicle(s):</td><td>Platooning
HMI: If HMI available: show platooning status on HMI</td></tr>
<tr><td>Application status Ego vehicle</td><td>Advanced assist system (e.g. ACC and lane centring) activated
HMI: Platoon status</td></tr>
<tr><td>Driver status target vehicle(s):</td><td>N/A</td></tr>
<tr><td>Driver status Ego vehicle</td><td>Aware</td></tr>
<tr><td>System status</td><td>All systems are ok.</td></tr>
</table>
</td></tr>
<tr><td>Trigger</td><td>Automatic recognition of the toll gates by all vehicles via (HD) map, V2I or traffic sign recognition.
[ALTERNATIVE] Driver notices the upcoming toll gates and manually engages the “lateral following” mode functionality.</td></tr>
<tr><td>Sequence</td><td><u>Use case sequence:</u>
 
</td></tr>
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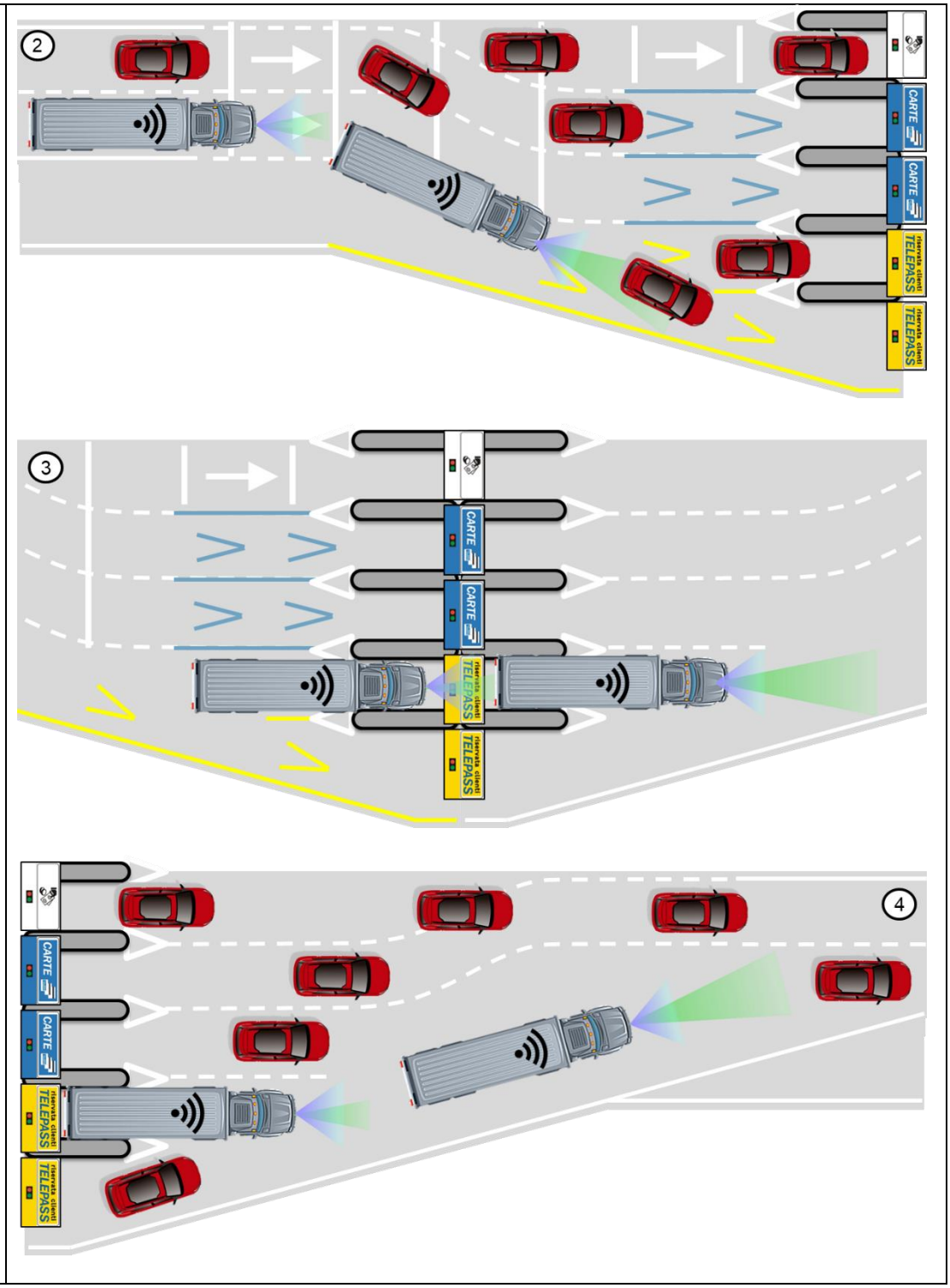
2
CARTE
CARTE
riserva client
TELEPASS
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3
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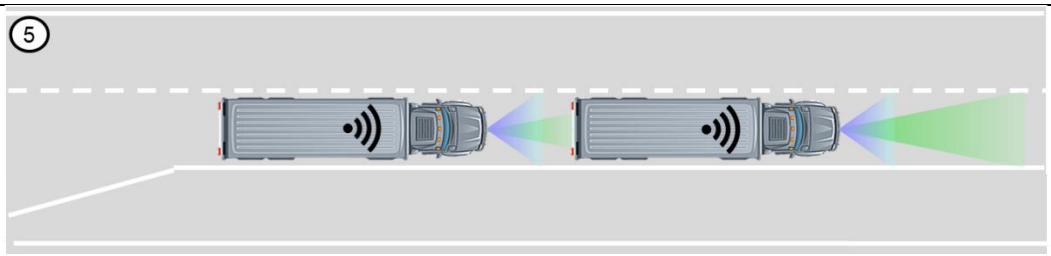
TELEPASS



1.a The system and/or the lead truck driver notices the upcoming toll gates.
1.b The “lateral following” mode is automatically enabled by the system or the driver presses a button on the HMI to activate it. In this mode, the follower truck will follow the same path as the lead truck. Any lane keeping or HD map localisation techniques are disabled. The follower truck will remain fully responsible for its own safety.
2 The driver of the lead truck disables the driver assist functions and manually steers the truck at the toll plaza diverging area to the correct toll booth lane. The follower truck automatically follows the lead truck.
3.a The lead truck driver drives the lead truck with a speed of 30 km/h through the toll gate. The follower truck follows the lead truck with a gap of 4 m, respecting the toll gate rules. Note: other rules may apply to other toll systems.
3.b When passing the toll booth, the lead truck driver verifies that the TELEPASS beeps. The HMI of the lead truck has a functionality for informing the lead truck driver about the TELEPASS confirmation for the following truck. If the beeps are not heard the lead truck driver contacts the service provider about this as soon as possible. Note: other rules may apply to other toll systems.
4. When leaving the toll gate, the driver of the lead truck steers the truck at a moderate speed towards the right lane of the highway at the toll plaza converging area. The follower truck keeps following the lead truck.
5. After the trucks leave the toll plaza converging area, the system automatically deactivates the “lateral following” mode, or the lead truck driver presses a button on the HMI to do this. The system of the follower truck can now again make use of lane information from a camera or HD map.

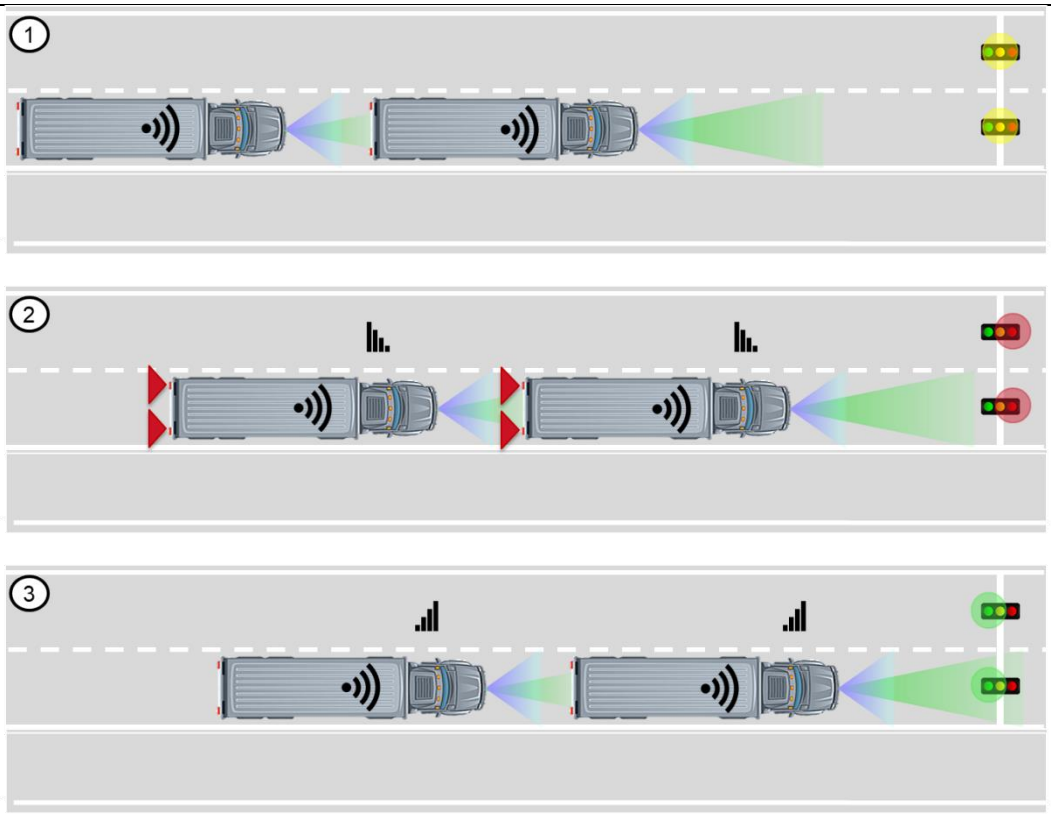
Final condition

Operational area:	Highway inside the ODD for the platooning autonomous function
Environmental conditions:	Any environmental condition inside the ODD for the platooning autonomous function
Target vehicle(s):	Follower in a steady state platoon • Vehicle in front within sensor view • Vehicle in front within V2V range and reception of V2V from the closest vehicle in front Control messages over V2V are sent according to specification.
Ego vehicle (s):	Leader in a steady state platoon • Vehicle in rear within V2V range and reception of V2V from the closest vehicle in the back Control messages over V2V are sent according to specification.
Application status target vehicle(s):	Platooning HMI: If HMI available: show platooning status on HMI
Application status Ego vehicle	Advanced assist system (e.g. ACC and lane centring) activated HMI: Platoon status

	Driver status target vehicle(s):	N/A
	Driver status Ego vehicle	Aware
	System status	All systems are ok.

Traffic light on highway

ID	PAF_3.16	
Name	Traffic light on highway	
Story	The platooning trucks approach a traffic light that is placed before e.g. a tunnel or bridge. The traffic light turns red and the platoon has to stop. The traffic light is intelligent and able to recognise the platoon. Traffic light timing is adapted to avoid traffic lights to turn yellow/red while the platoon is passing. (Manoeuvre ID M3, Infrastructure characteristics I1)	
Initial condition	Operational area:	Highway inside the ODD for the platooning autonomous function
	Environmental conditions:	Any environmental condition inside the ODD for the platooning autonomous function
	Target vehicle(s):	Follower in a steady state platoon • Vehicle in front within sensor view • Vehicle in front within V2V range and reception of V2V from the closest vehicle in front Control messages over V2V are sent according to specification.
	Ego vehicle (s):	Leader in a steady state platoon • Vehicle in rear within V2V range and reception of V2V from the closest vehicle in the back Control messages over V2V are sent according to specification.
	Application status target vehicle(s):	Platooning HMI: If HMI available: show platooning status on HMI
	Application status Ego vehicle	Advanced assist system (e.g. ACC and lane centring) activated HMI: Platoon status
	Driver status target vehicle(s):	N/A
	Driver status Ego vehicle	Aware
	System status	All systems are ok.
Trigger	• The driver of the lead truck notices that the traffic light is turning to red. • The intelligent traffic light recognises the platoon is approaching, either by itself and/or via V2I communication.	
Sequence	Use case sequence:	



1.a The platoon approaches the traffic light and the intelligent traffic light recognises this.
1.b The traffic light controller adapts the timing of the traffic light such that it will turn yellow earlier if it detects that the platoon cannot pass through completely during the current green phase.
2.a The lead truck driver notices the traffic light turning to red.
2.b The lead truck driver brakes and stops the truck before the traffic light. The follower truck follows the lead truck and stops as well.
3. When the light turns green, the lead truck driver will start accelerating the ego truck. The follower truck will automatically follow. The traffic light will adapt the green time such that the complete platoon can pass.

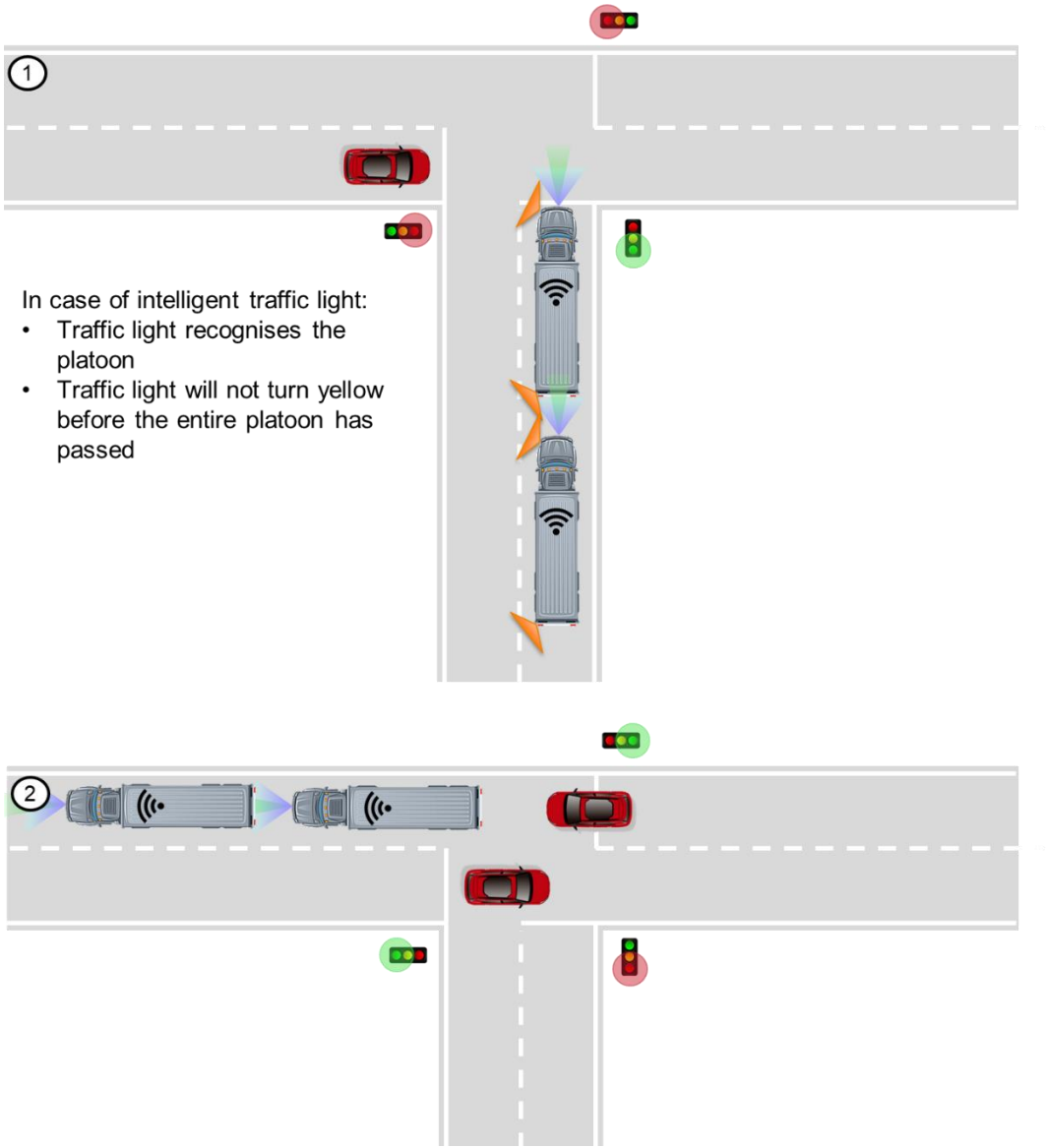
(alternatively the traffic light can also adapt the current green phase to let the whole platoon pass before turning red)

Final condition	Operational area:	Highway inside the ODD for the platooning autonomous function
	Environmental conditions:	Any environmental condition inside the ODD for the platooning autonomous function
	Target vehicle(s):	Follower in a steady state platoon • Vehicle in front within sensor view • Vehicle in front within V2V range and reception of V2V from the closest vehicle in front Control messages over V2V are sent according to specification.
	Ego vehicle (s):	Leader in a steady state platoon • Vehicle in rear within V2V range and reception of V2V from the closest vehicle in the back

		Control messages over V2V are sent according to specification.
	Application status target vehicle(s):	Platooning HMI: If HMI available: show platooning status on HMI
	Application status Ego vehicle	Advanced assist system (e.g. ACC and lane centring) activated HMI: Platoon status
	Driver status target vehicle(s):	N/A
	Driver status Ego vehicle	Aware
	System status	All systems are ok.

Traffic light on intersection

ID	PAF_3.17	
Name	Traffic light on intersection	
Story	The platooning trucks approach a traffic light that is at an intersection. The lead truck driver decides on stopping for the traffic light in case of a yellow or red light. The follower truck(s) follow(s) the lead truck. V2I interaction with traffic lights is available. The traffic lights will adapt their timing on knowing that the platoon is approaching. This avoids traffic lights to turn yellow/red while the platoon is passing. (Manoeuvre ID M3, Infrastructure characteristics I5)	
Initial condition	Operational area:	Between the hub and the highway inside the ODD for the platooning autonomous function
	Environmental conditions:	Any environmental condition inside the ODD for the platooning autonomous function
	Target vehicle(s):	Follower in a steady state platoon • Vehicle in front within sensor view • Vehicle in front within V2V range and reception of V2V from the closest vehicle in front Control messages over V2V are sent according to specification.
	Ego vehicle (s):	Leader in a steady state platoon • Vehicle in rear within V2V range and reception of V2V from the closest vehicle in the back Control messages over V2V are sent according to specification.
	Application status target vehicle(s):	Platooning HMI: If HMI available: show platooning status on HMI
	Application status Ego vehicle	Advanced assist system (e.g. ACC and lane centring) activated HMI: Platoon status
	Driver status target vehicle(s):	N/A
	Driver status Ego vehicle	Aware
	System status	All systems are ok.

Trigger	• Platoon approaches signalised intersection. • Intelligent traffic light recognises the approaching platoon.
Sequence	Use case sequence: Note: The example of a T-junction is used to describe the sequence, but the use case applies to any other type of signalised intersection.  1. The platoon approaches a green traffic light. The platoon completely passes the traffic light before it turns yellow or red. This is facilitated by the intelligent traffic light that adapts its timing on knowing that the platoon is approaching and passing. This avoids the traffic light to turn yellow/red while the platoon is passing. The platoon is recognised by V2I interaction. 2. The platoon has passed the traffic light. Note: in an alternative flow the intelligent traffic light controller could also decide to turn yellow when it recognises the approaching platoon. In that way, an undesirable long green

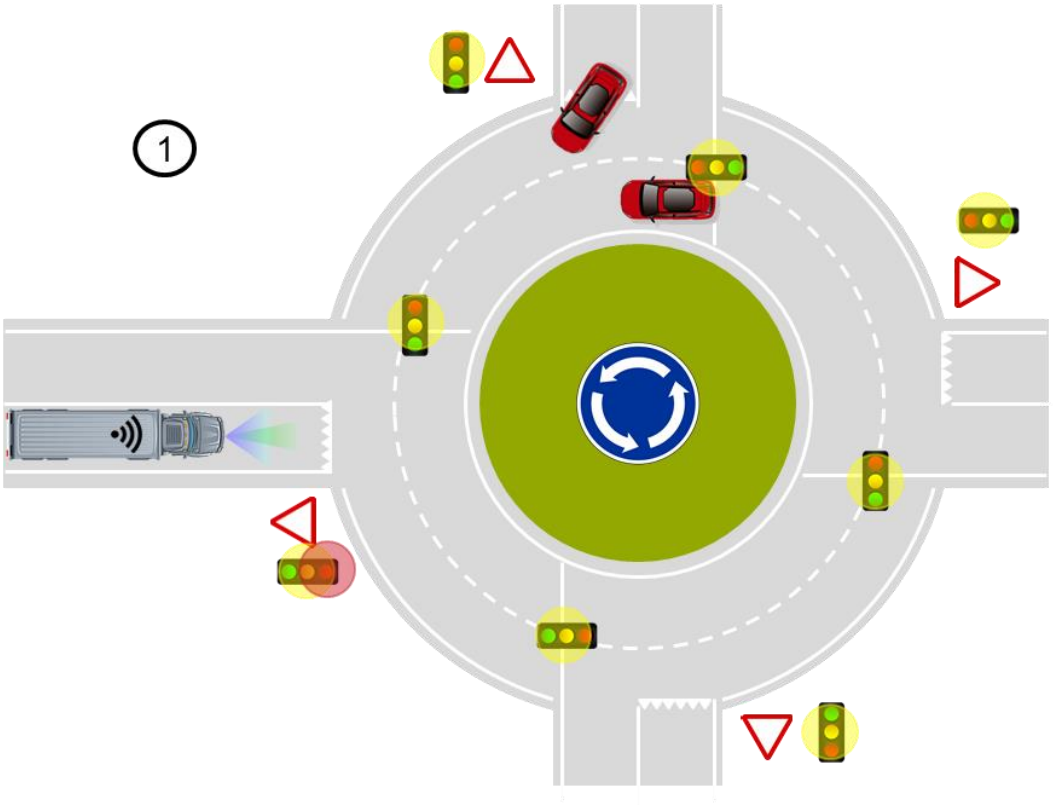
	cycle could be prevented. Nevertheless, it will be more energy efficient to avoid the platoon having to brake. In that respect, it is also desirable to turn the traffic light to green to let the platoon pass.
Final condition	

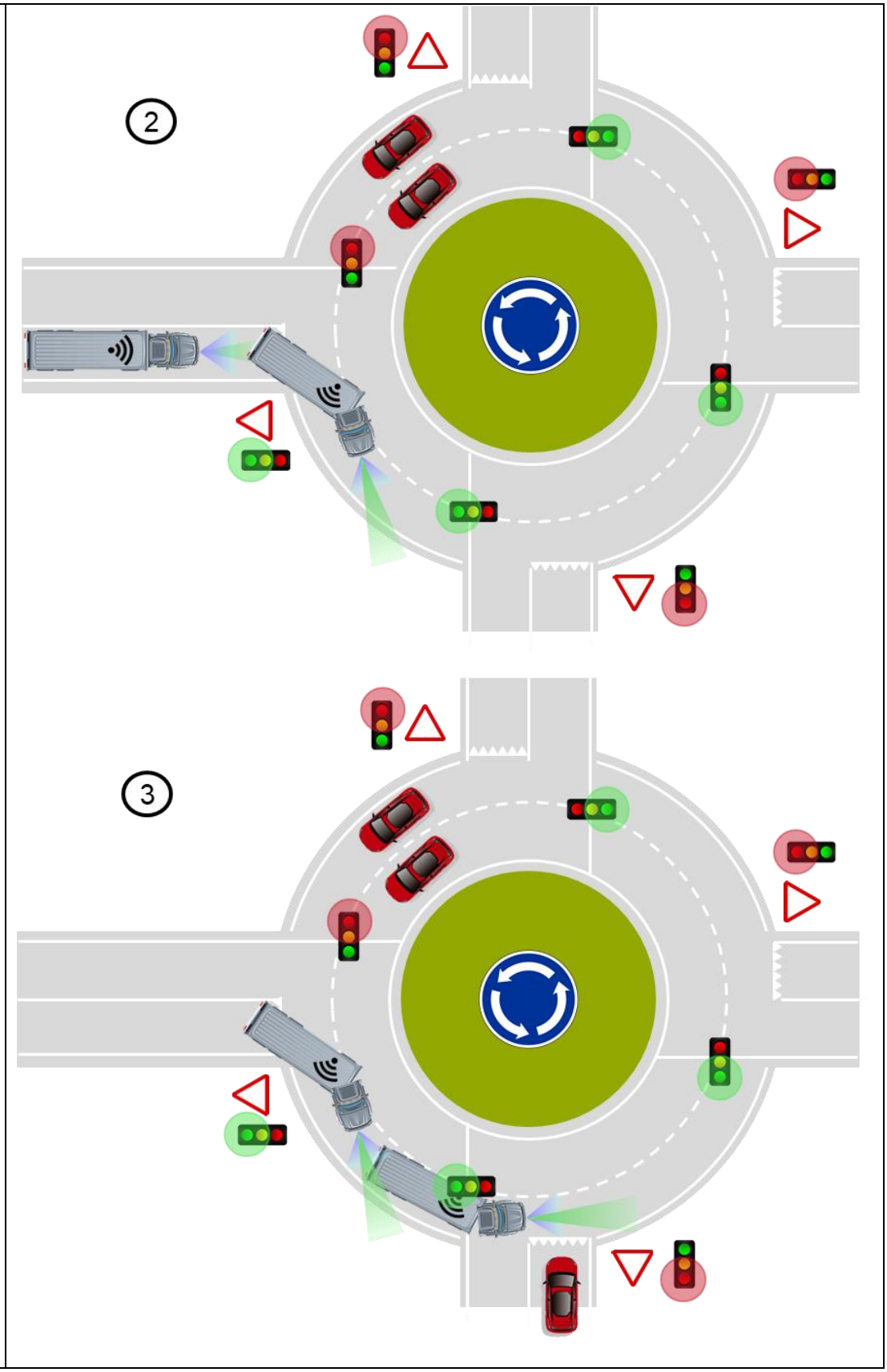
Operational area:	Between the hub and the highway inside the ODD for the platooning autonomous function
Environmental conditions:	Any environmental condition inside the ODD for the platooning autonomous function
Target vehicle(s):	Follower in a steady state platoon • Vehicle in front within sensor view • Vehicle in front within V2V range and reception of V2V from the closest vehicle in front Control messages over V2V are sent according to specification.
Ego vehicle (s):	Leader in a steady state platoon • Vehicle in rear within V2V range and reception of V2V from the closest vehicle in the back Control messages over V2V are sent according to specification.
Application status target vehicle(s):	Platooning HMI: If HMI available: show platooning status on HMI
Application status Ego vehicle	Advanced assist system (e.g. ACC and lane centring) activated HMI: Platoon status
Driver status target vehicle(s):	N/A
Driver status Ego vehicle	Aware
System status	All systems are ok.

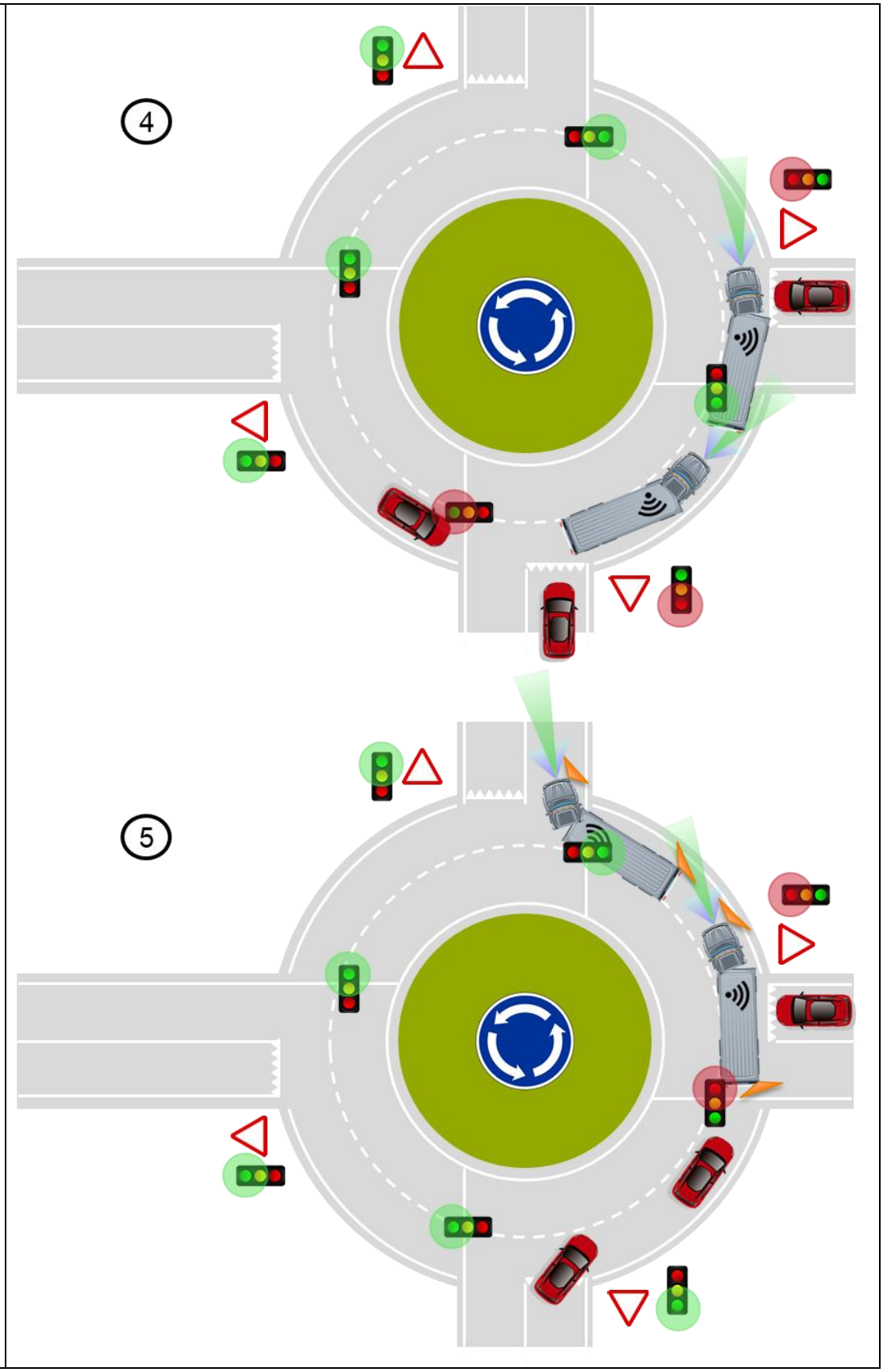
Roundabouts

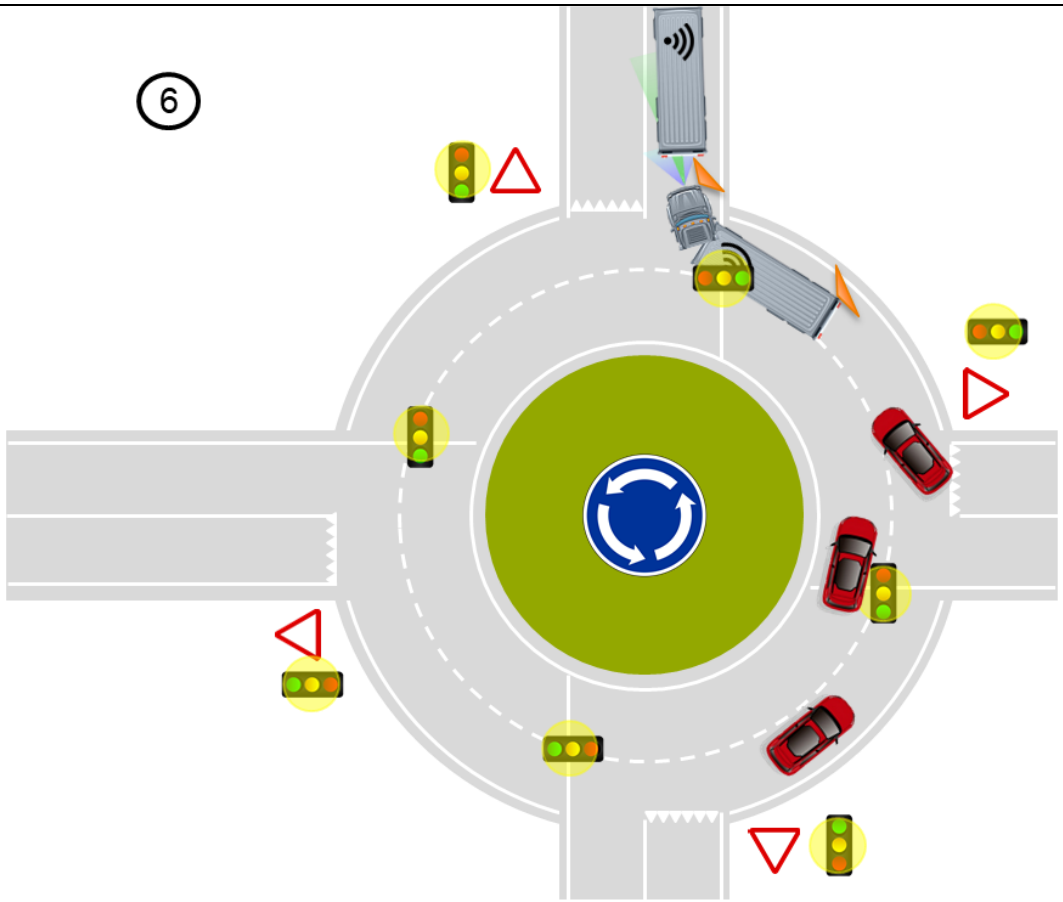
ID	PAF_3.18
Name	Roundabouts
Story	While platooning between the hub and highway, and vice versa, the platoon may have to negotiate roundabouts. In order to allow the platoon to negotiate these roundabouts without the platoon breaking up, intelligent traffic lights with V2I interaction are available. (Manoeuvre ID M3, Infrastructure characteristics I5)
Initial condition	

Operational area:	Any of the operational areas between highway and hub inside the ODD for the platooning autonomous function
Environmental conditions:	Any environmental condition inside the ODD for the platooning autonomous function
Target vehicle(s):	Follower in a steady state platoon • Vehicle in front within sensor view • Vehicle in front within V2V range and reception of V2V from the closest vehicle in front

		Control messages over V2V are sent according to specification.
	Ego vehicle (s):	Leader in a steady state platoon • Vehicle in rear within V2V range and reception of V2V from the closest vehicle in the back Control messages over V2V are sent according to specification.
	Application status target vehicle(s):	Platooning HMI: If HMI available: show platooning status on HMI
	Application status Ego vehicle	Advanced assist system (e.g. ACC and lane centring) activated HMI: Platoon status
	Driver status target vehicle(s):	N/A
	Driver status Ego vehicle	Aware
	System status	All systems are ok.
Trigger	The platoon approaching a roundabout	
Sequence	<u>Use case sequence:</u>  	


2
3


4
5



1. The platoon approaches a roundabout that is equipped with intelligent traffic lights. These traffic lights are by default blinking yellow, but will be activated if the approaching platoon is detected by V2I interaction. The lights will let the lead truck stop if required by turning yellow or red.
2. The lead truck driver has anticipated on the traffic situation and starts to negotiate the roundabout after getting green light. The lead truck driver chooses to take the right lane. The intelligent traffic lights give the platoon a green corridor. Other traffic is prevented from entering the roundabout.
3. The follower truck follows the lead truck at small inter-vehicle distance.
4. The lead truck driver keeps driving on the right lane and the follower truck follows the lead truck.
5. The lead truck takes the exit and the follower truck follows.
6. After the platoon has passed a certain point on the roundabout, such that other traffic cannot interfere anymore, the traffic lights will be turned off, or set to blinking yellow.

Note:

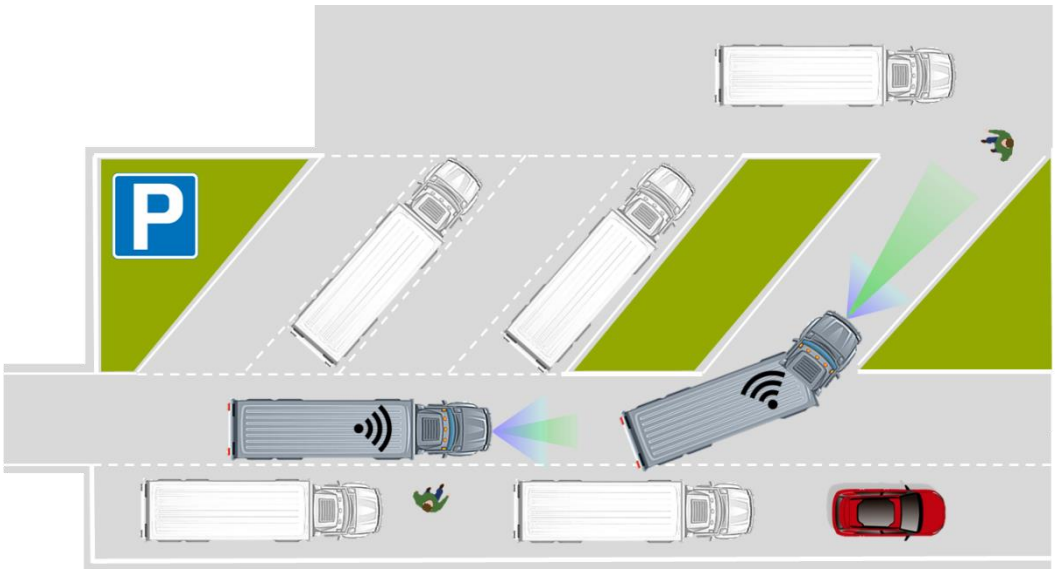
- For this use case it is necessary that the following truck can follow the same path as the lead truck.

Final condition	Operational area:	Any of the operational areas between highway and hub inside the ODD for the platooning autonomous function
	Environmental conditions:	Any environmental condition inside the ODD for the platooning autonomous function
	Target vehicle(s):	Follower in a steady state platoon

		• Vehicle in front within sensor view • Vehicle in front within V2V range and reception of V2V from the closest vehicle in front Control messages over V2V are sent according to specification.
	Ego vehicle (s):	Leader in a steady state platoon • Vehicle in rear within V2V range and reception of V2V from the closest vehicle in the back Control messages over V2V are sent according to specification.
	Application status target vehicle(s):	Platooning HMI: If HMI available: show platooning status on HMI
	Application status Ego vehicle	Advanced assist system (e.g. ACC and lane centring) activated HMI: Platoon status
	Driver status target vehicle(s):	N/A
	Driver status Ego vehicle	Aware
	System status	All systems are ok.

Resting Areas/Parking lots

ID	PAF_3.19	
Name	Resting Areas/Parking lots	
Story	The platoon will drive in parking lots (of e.g. the hub) or resting areas. (Manoeuvre ID M3, Infrastructure characteristics I6)	
Initial condition	Operational area:	Resting areas/parking lots (inside the ODD for the platooning autonomous function).
	Environmental conditions:	Any environmental condition inside the ODD for the platooning autonomous function
	Target vehicle(s):	Follower in a steady state platoon • Vehicle in front within sensor view • Vehicle in front within V2V range and reception of V2V from the closest vehicle in front Control messages over V2V are sent according to specification.
	Ego vehicle (s):	Leader in a steady state platoon • Vehicle in rear within V2V range and reception of V2V from the closest vehicle in the back Control messages over V2V are sent according to specification.
	Application status target vehicle(s):	Platooning HMI: If HMI available: show platooning status on HMI
	Application status Ego vehicle	Advanced assist system (e.g. ACC and lane centring) activated HMI: Platoon status
	Driver status target vehicle(s):	N/A
	Driver status Ego vehicle	Aware

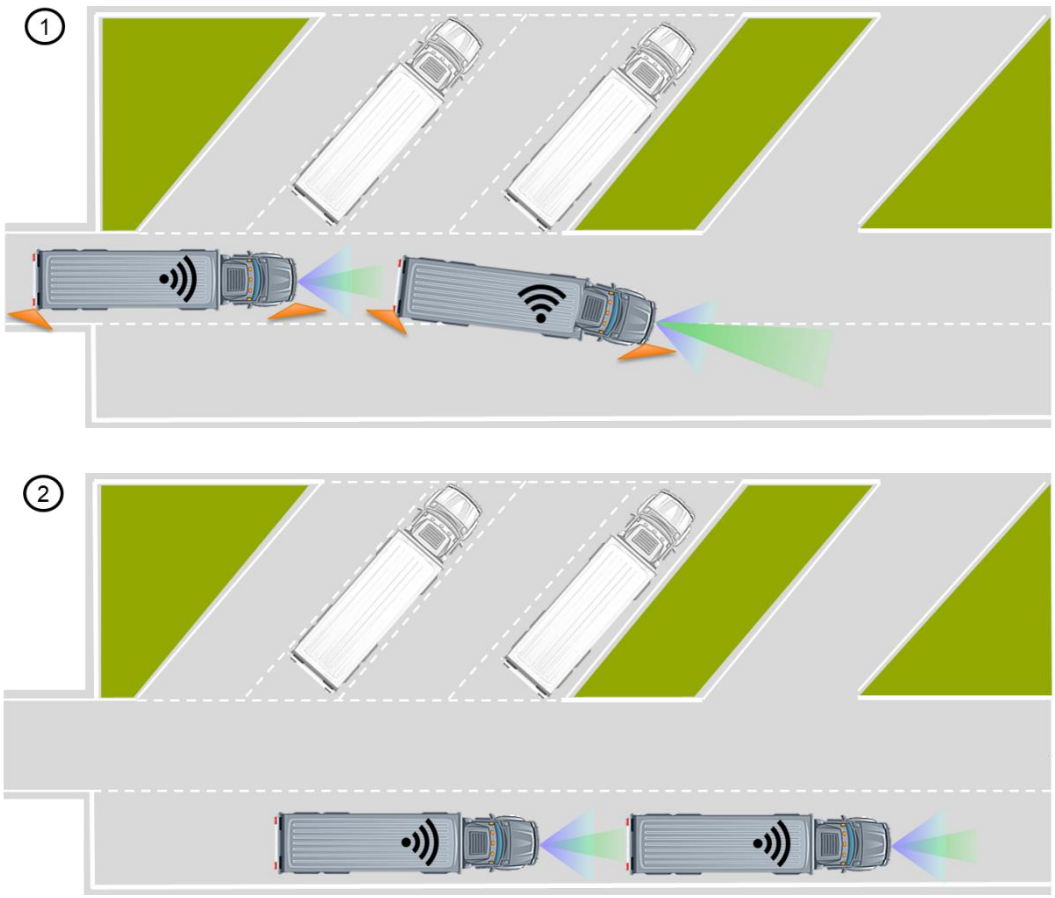
<table>
<tr><td></td><td><table><tr><td>System status</td><td>All systems are ok.</td></tr></table></td></tr>
<tr><td>Trigger</td><td>N/A</td></tr>
<tr><td>Sequence</td><td>Use case sequence:
 
The platooning vehicles manoeuvre on the parking lot, where they encounter:
• Tight corners
• Pedestrians and other vehicles
The follower truck follows the lead truck at short inter-vehicle distance.
The follower truck will stop if a pedestrian gets in front or too close to the truck. If this happens the lead truck driver will be warned, such that he can also bring the lead truck to a standstill, such that a split of the platoon can be avoided.

Note: driving speeds are assumed to be low in these areas. This may however not be the default situation, as lower speeds only apply if the road operator places speed limit signs. Therefore, this should be considered in the requirements for the infrastructure.</td></tr>
<tr><td>Final condition</td><td><table>
<tr><td>Operational area:</td><td>Resting areas/parking lots inside the ODD for the platooning autonomous function</td></tr>
<tr><td>Environmental conditions:</td><td>Any environmental condition inside the ODD for the platooning autonomous function</td></tr>
<tr><td>Target vehicle(s):</td><td>Follower in a steady state platoon
• Vehicle in front within sensor view
• Vehicle in front within V2V range and reception of V2V from the closest vehicle in front
Control messages over V2V are sent according to specification.</td></tr>
<tr><td>Ego vehicle (s):</td><td>Leader in a steady state platoon
• Vehicle in rear within V2V range and reception of V2V from the closest vehicle in the back
Control messages over V2V are sent according to specification.</td></tr>
<tr><td>Application status target vehicle(s):</td><td>Platooning
HMI: If HMI available: show platooning status on HMI</td></tr>
<tr><td>Application status Ego vehicle</td><td>Advanced assist system (e.g. ACC and lane centring) activated</td></tr>
</table></td></tr>
</table>

		HMI: Platoon status
	Driver status target vehicle(s):	N/A
	Driver status Ego vehicle	Aware
	System status	All systems are ok.

Parking

ID	PAF_3.20	
Name	Parking	
Story	The lead truck driver parks the platoon to take a rest or for some other reason. The intention is to continue with the same platoon after the break. (Manoeuvre ID M3, Infrastructure characteristics I6)	
Initial condition	Operational area:	Hub or parking lot inside the ODD for the platooning autonomous function
	Environmental conditions:	Any environmental condition inside the ODD for the platooning autonomous function
	Target vehicle(s):	Follower in a steady state platoon • Vehicle in front within sensor view • Vehicle in front within V2V range and reception of V2V from the closest vehicle in front Control messages over V2V are sent according to specification.
	Ego vehicle (s):	Leader in a steady state platoon • Vehicle in rear within V2V range and reception of V2V from the closest vehicle in the back Control messages over V2V are sent according to specification.
	Application status target vehicle(s):	Platooning HMI: If HMI available: show platooning status on HMI
	Application status Ego vehicle	Advanced assist system (e.g. ACC and lane centring) activated HMI: Platoon status
	Driver status target vehicle(s):	N/A
	Driver status Ego vehicle	Aware
	System status	All systems are ok.
Trigger	The lead truck driver presses the “Standby” button on the HMI after having parked the platoon.	
Sequence	Use case sequence:	



1. The lead truck driver parks the platoon at a safe position, e.g. in a parking space. The driver selects a parking space and manoeuvres such that the follower truck can park safely behind the lead truck.
2.a. When parked, the lead truck driver presses the “Standby” button on the HMI.
2.b. If conditions are met, the lead truck and following truck will enter standby mode and will stop sending V2V messages
2.c. The trucks will shut down their engines.
2 d. The lead truck driver leaves the truck and locks the doors.
3 a. After the break, the lead truck driver returns to the cabin to resume the journey.
3 b. The lead truck driver turns off the standby functionality on the HMI.
3 c. The platoon is now ready for the start from standstill use case.

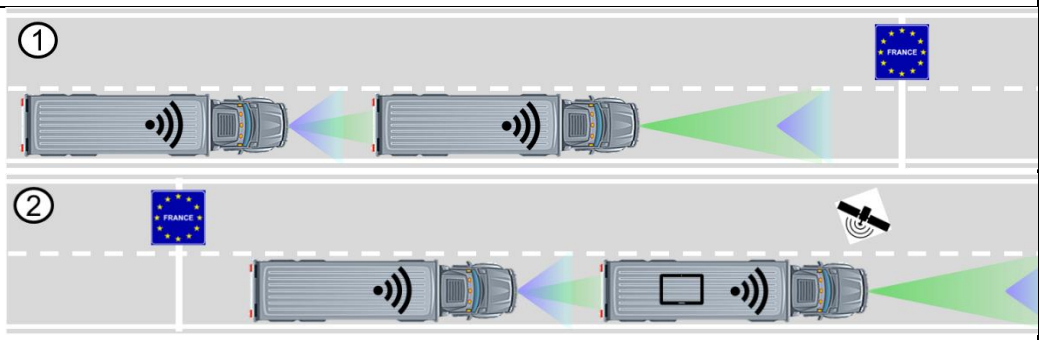
Final condition	Operational area:	Hub or parking lot inside the ODD for the platooning autonomous function
	Environmental conditions:	Any environmental condition inside the ODD for the platooning autonomous function
	Target vehicle(s):	Follower in a standstill platoon • Vehicle in front within sensor view • Vehicle in front within V2V range and reception of V2V from the closest vehicle in front Control messages over V2V are sent according to specification.
	Ego vehicle (s):	Leader in a standstill platoon

		• Vehicle in rear within V2V range and reception of V2V from the closest vehicle in the back Control messages over V2V are sent according to specification.
	Application status target vehicle(s):	Platooning HMI: If HMI available: show platooning status on HMI
	Application status Ego vehicle	Advanced assist system (e.g. ACC and lane centring) activated HMI: Platoon status
	Driver status target vehicle(s):	N/A
	Driver status Ego vehicle	Aware
	System status	All systems are ok.

Border Crossing

ID	PAF_3.21	
Name	Border Crossing (Manoeuvre ID M3, Infrastructure characteristics I1, I5)	
Story	The platoon crosses a border and enters another European country. The platoon needs to adapt its speed and time gap to the traffic regulation and potential road tolls of the country being entered, using information provided by the navigation system and/or other internal sensors (in combination with I2V information). OPTIONAL: a remote service (cellular communication) can provide the necessary information to continue platooning in the other country.	
Initial condition	Operational area:	Any of the operational areas inside the ODD for the Platooning Autonomous Function
	Environmental conditions:	Any environmental condition inside the ODD for the Platooning Autonomous Function
	Target vehicle(s):	Follower in a steady state platoon • Vehicle in front within sensor view • Vehicle in front within V2V range and reception of V2V from the closest vehicle in front Control messages over V2V are sent according to specification.
	Ego vehicle (s):	Leader in a steady state platoon • Vehicle in rear within V2V range and reception of V2V from the closest vehicle in the back Control messages over V2V are sent according to specification.
	Application status target vehicle(s):	Platooning HMI: If HMI available: show platooning status on HMI
	Application status Ego vehicle	Advanced assist system (e.g. ACC and lane keeping) activated HMI: Platoon status

	Driver status target vehicle(s): N/A Driver status Ego vehicle: Aware System status: All systems are ok.
Trigger	Border between two countries crossed. Detected by localisation features with the potential support of internal sensors.

Sequence	
	
	1. Any platoon driving state
	2. The platoon crosses a border, entering in another country
	  1. The driver in the leading vehicle is responsible for adapting his driving behaviour (speed, time gap, …) with respect to the traffic regulation of the new country. New information about road tolls in the specific country will be provided as well, via the (connected) navigation system or specific short range I2V communication.
	  2. The systems of the automated following trucks are responsible for adapting their behaviour (speed, time gap…) with respect to the traffic regulation of the country that is entered, using information provided by navigation system features and/or internal sensors (with support of I2V).
	  3. OPTIONAL: a remote service (with cellular communication) can provide the necessary information to continue platooning in the new country.

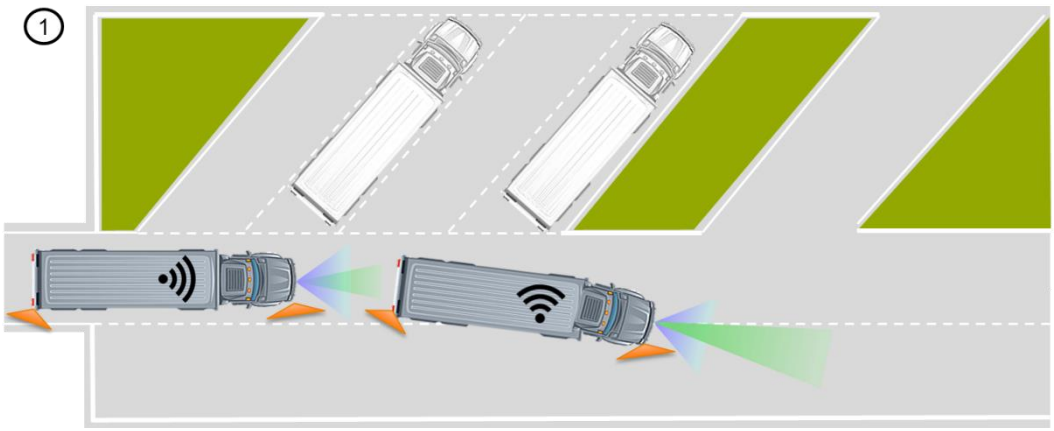
Final condition	Operational area: Any of the operational areas inside the ODD for the Platooning Autonomous Function Environmental conditions: Any environmental condition inside the ODD for the Platooning Autonomous Function

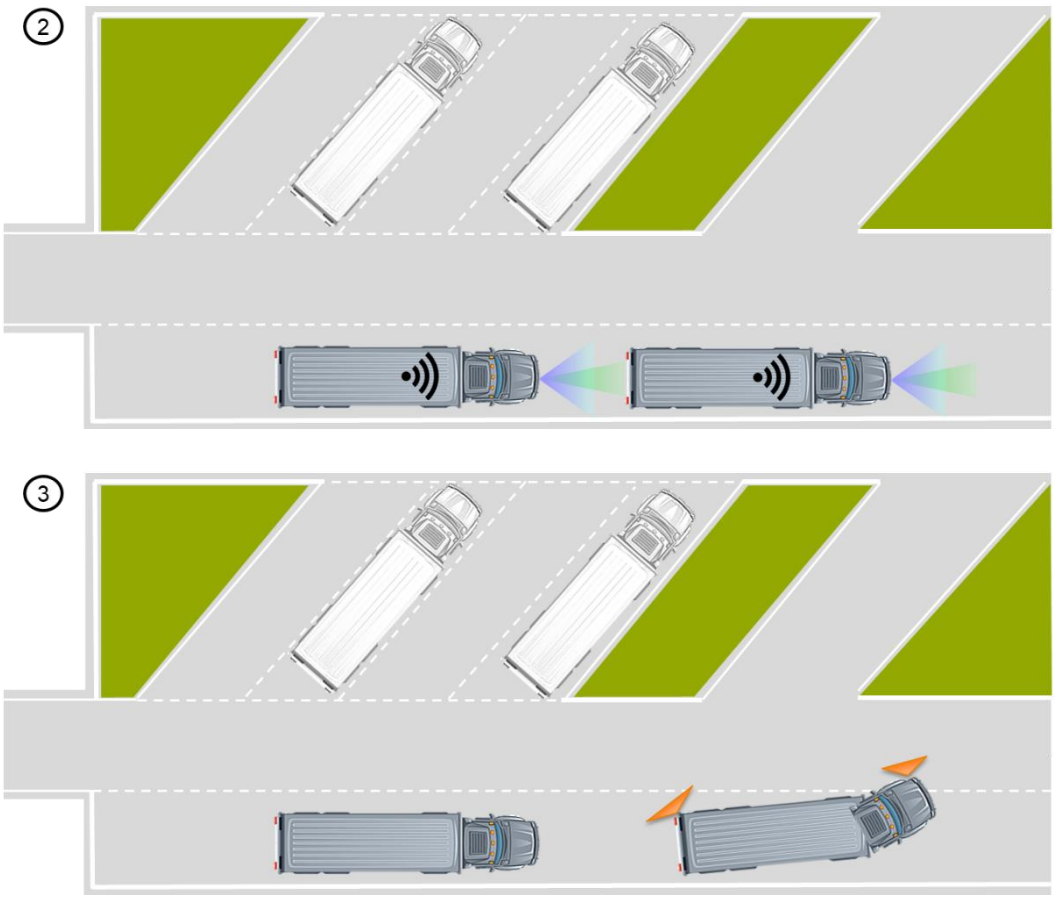
	Target vehicle(s):	Follower in a steady state platoon • Vehicle in front within sensor view • Vehicle in front within V2V range and reception of V2V from the closest vehicle in front Control messages over V2V are sent according to specification.
	Ego vehicle (s):	Leader in a steady state platoon • Vehicle in rear within V2V range and reception of V2V from the closest vehicle in the back Control messages over V2V are sent according to specification.
	Application status target vehicle(s):	Platooning HMI: If HMI available: show platooning status on HMI
	Application status Ego vehicle	Advanced assist system (e.g. ACC and lane keeping) activated HMI: Platoon status
	Driver status target vehicle(s):	N/A
	Driver status Ego vehicle	Aware
	System status	All systems are ok.

6.2.4. Disengage platoon

Drop-off area at the destination hub

ID	PAF_4.1	
Name	Drop-off area at the destination hub	
Story	When the destination is reached the platooning trucks (possibly) need to decouple, before or after these have been unloaded and/or loaded. (Manoeuvre ID M4, Infrastructure characteristics I6)	
Initial condition	Operational area:	Drop-off area at the destination hub inside the ODD for the platooning autonomous function.

<table>
<tr><td></td><td>
<table>
<tr><td>Environmental conditions:</td><td>Any environmental condition inside the ODD for the platooning autonomous function</td></tr>
<tr><td>Target vehicle(s):</td><td>Follower in a steady state platoon
Vehicle in front within sensor view
Vehicle in front within V2V range and reception of V2V from the closest vehicle in front
Control messages over V2V are sent according to specification.</td></tr>
<tr><td>Ego vehicle (s):</td><td>Leader in a steady state platoon
Vehicle in rear within V2V range and reception of V2V from the closest vehicle in the back
Control messages over V2V are sent according to specification.</td></tr>
<tr><td>Application status target vehicle(s):</td><td>Platooning
HMI: If HMI available: show platooning status on HMI</td></tr>
<tr><td>Application status Ego vehicle</td><td>Advanced assist system (e.g. ACC and lane centring) activated
HMI: Platoon status</td></tr>
<tr><td>Driver status target vehicle(s):</td><td>N/A</td></tr>
<tr><td>Driver status Ego vehicle</td><td>Aware</td></tr>
<tr><td>System status</td><td>All systems are ok.</td></tr>
</table>
</td></tr>
<tr><td>Trigger</td><td>The lead truck driving pressing the “Leave” button on the HMI while the platoon is at standstill.</td></tr>
<tr><td>Sequence</td><td><u>Use case sequence:</u>
 
</td></tr>
</table>



1. The lead truck driver parks the platoon at a safe position, e.g. in a dedicated drop-off area at the hub. The driver selects a parking space and manoeuvres such that the follower truck can park safely behind the lead truck.
2.a. When parked, the lead truck driver presses the “Leave” button on the HMI.
2.b. If conditions are met, the lead truck and following truck will become standalone vehicles and will stop sending V2V messages. The platooning function on the trucks will be deactivated.
2.c. The follower truck will enter “standby mode”, i.e. it shuts down its engine but will be in contact with a remote service that can unlock the truck or start it again for platooning.
3. The lead truck driver drives out of the drop-off parking area and the follower truck stays there at standstill.
4. The following truck can be picked up later by a human driver, or moved autonomously or remotely on the confined area of the hub.

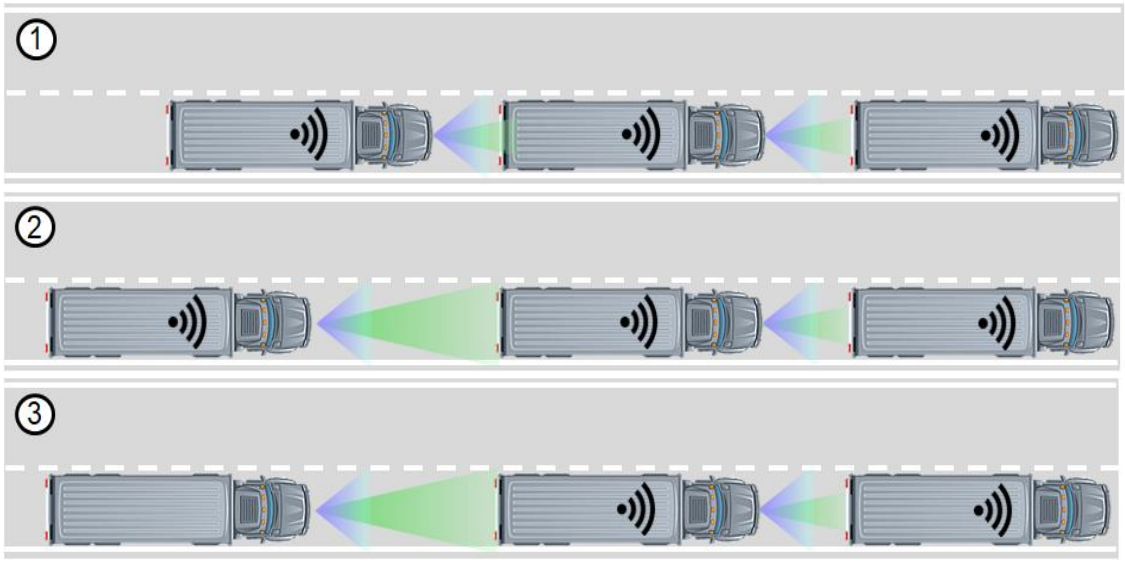
Final condition

Operational area:	Drop-off area at the destination hub inside the ODD for the platooning autonomous function.
Environmental conditions:	Any environmental condition inside the ODD for the platooning autonomous function
Target vehicle(s):	Follower is standing still in standby mode
Ego vehicle (s):	Platooning function is off Vehicle is driven standalone
Application status target vehicle(s):	Follower is standalone at standstill. Platooning function is off; vehicle is in “standby” mode.

	Application status Ego vehicle	Manually driven, optionally using advanced assist system support (e.g. ACC and lane centring). HMI: Platoon status => standalone
	Driver status target vehicle(s):	N/A
	Driver status Ego vehicle	Aware
	System status	All systems are ok.

Leave (while platooning, with a manned trailing truck)

ID	PAF_4.2	
Name	Leave (while platooning, with a manned trailing truck)	
Story	While the Platoon is active, the ego vehicle (a manned following vehicle) starts the leaving procedure. The driver, by giving an HMI input, starts the leaving procedure and, by doing that, acknowledges that he/she will take back control. The system increases the inter-vehicle time gap with respect to the preceding truck (if necessary). (Manoeuvre ID M4, Infrastructure characteristics I1, I2, I3, I4, I5, I7, I8)	
Initial condition	Operational area:	Any of the operational areas inside the ODD for the Platooning Autonomous Function
	Environmental conditions:	Any environmental condition inside the ODD for the Platooning Autonomous Function
	Target vehicle(s):	Leader in a steady state platoon • Vehicle in rear within V2V range and reception of V2V from the closest vehicle in the back Control messages over V2V are sent according to specification. Or: Follower in a steady state platoon • Vehicle in front within sensor view • Vehicle in front within V2V range and reception of V2V from the closest vehicle in front Control messages over V2V are sent according to specification.
	Ego vehicle (s):	Trailing vehicle in a steady state platoon • Vehicle in front within sensor view • Vehicle in front within V2V range and reception of V2V from the closest vehicle in front Control messages over V2V are sent according to specification.
	Application status target vehicle(s):	Platooning HMI: If HMI available: show platooning status on HMI
	Application status Ego vehicle	Advanced assist system (e.g. ACC and lane keeping) activated HMI: Platoon status

	Driver status target vehicle(s):	N/A	
	Driver status Ego vehicle	Aware	
	System status	All systems are ok.	
Trigger	The ego vehicle driver pushes the leave button		
Sequence	Sketch:  Sequence in time as bullet points: 1.1 The driver of the ego vehicle pushes the leave button and the platooning application enters the “Leave” mode. 1.2 The start of the leaving procedure from the ego vehicle is broadcasted to the preceding Platoon member through V2V communication. 2.1 The ego vehicle starts to increase the inter-vehicle distance with respect to the target vehicle. 2.2 When the required inter-vehicle distance is reached, the ego vehicle notifies the preceding platooning vehicle of this via V2V. 2.3 The driver of the ego vehicle is informed about the successful gap opening and needs to acknowledge the stopping of the Platooning communication. 3.1 The ego vehicle’s Platooning communication is disconnected after driver’s acknowledgement. When the driver does not acknowledge, the vehicle will reduce the time gap again and continue platooning. 3.2 The ego vehicle HMI informs the driver that the platooning function is being turned off; and that the driver is now responsible for performing the dynamic driving task. 3.3 The platooning function is turned off and thus the platooning communication is stopped. 3.4 The other Platoon members continue to platoon.		

Final condition		Operational area:	Any of the operational areas inside the ODD for the Platooning Autonomous Function	
		Environmental conditions:	Any environmental condition inside the ODD for the Platooning Autonomous Function	
		Target vehicle(s):	Steady state following truck of platoon.	
		Ego vehicle (s):	Stand-alone state truck driving @ ACC following distance.	
		Application status target vehicle(s):	Platooning HMI: Shows platooning status: platooning active, platoon specific information and functions.	
		Application status Ego vehicle	Stand-alone (Stand-alone HMI, could be OEM specific)	
		Driver status target vehicle(s):	Aware	
		Driver status Ego vehicle	Aware and responsible for the DDT	
		System status	Vehicle platform: no failure V2V: same as ”stand-alone” with Platooning functionality active	

6.3. Potential threats and suggested solutions to the platooning use cases of the Platooning Autonomous Function

In some of the above specified use cases (especially the ones under 'Platooning') there is a possibility that the platoon is split up. An example is a car that cuts in at a roundabout and remains in the platoon, maybe even cause a large distance between the platooning members. Since the following trucks may not have full SAE level 4 capability to drive completely autonomous and a driver may not be present to take over, this may lead to undesirable situations.

For the other use cases (like e.g. platoon formation or engaging) platoon split is not applicable as either there is not yet a platoon, or the speed of other traffic is very low, the trucks are still on a yard or parking area, etc.

Firstly, a platoon split should be attempted to be avoided. As described in section 6.3.1, this may be achieved in several ways.

Secondly, when a split occurs, depending on the resulting safety threat, a procedure to enter a safe state may be executed. This needs to be defined by the safety analysis, which is not part of this document (the interested reader is referred to D2.14 (Pezzano,2022)). Section 6.3.2 lists common solutions after a cut-in in the platoon has happened and section 6.3.3 highlights specific situations. The safe states are described in section 6.3.4.

6.3.1. Avoiding platoon split by external factors

This section describes general suggested approaches to avoid unwanted splitting of a platoon either by a vehicle entering the platoon ('cut-in long') or external factors like a traffic light turning red before the whole platoon has passed.

Adapt traffic regulation

A platoon may be designated by legislation as a special traffic participant like a "military platoon" or "convoi exceptionnel" and thus be seen as one vehicle. Then it should for example be allowed to pass through a red light when the first truck passed at a green light, or to pass a non-signalised intersection without breaking up the platoon. To limit the disruption of the traffic, the platoon may be limited to include a maximum number of trucks. Also, the platoon should then be recognisable to other road users. This should be clearly visible and understandable, yet not too invasive (trailers and trucks have personalised designs) and it should be easily hidden when the vehicle is not in a platoon. More research is required to investigate how this works out on the road and how traffic flow is impacted when there are many of these platoons. Furthermore, this approach may only offer a solution - without other measures - up to certain maximum speed in order to allow other traffic participants to stop well in time to give right of way to the platoon at e.g. non-signalised intersections.

Finally, even without a specific platoon legislation, making a platoon visually well recognisable to other road users may help in avoiding possible cut-ins.

Communication and cooperation

Communication with infrastructure may offer a very good solution for e.g. traffic lights. When traffic lights send out their timing, a platoon leader may predict whether passing through green light is feasible. However, the platoon may also already stop at the last seconds of the green phase, which may be unexpected behaviour for other road users. An intelligent cooperative traffic light may offer the solution here by either granting the platoon a long enough green phase to pass, or, to go to red earlier to avoid the before mentioned stop at a green traffic light. Uphill situations may be challenging in estimating the time of arrival of the platoon at the traffic light.

Likewise, fitting relevant roundabouts a hub2hub route with cooperative traffic lights could ensure platoon cohesion when e.g. entering/negotiating a roundabout preventing other vehicles from entering the roundabout with a platoon driving on(to) it.

In the (far) future, cooperation with other road users using V2V communication will contribute in negotiating non-signalised intersections and roundabouts. However, this requires all other road users to have a certain level of communication capability and cooperative behaviour.

On a more general basis, other cooperative vehicles can be informed about the presence of the platoon and be discouraged to cut-in in the platoon.

Use very small following distances between the trucks

This should discourage or even prevent other vehicles to cut-in. However, this is very much related to the specific situation and actual speeds for the obvious safety goals. A platoon could evaluate the situation and activate this feature when appropriate.

A technology that is considered a prerequisite for achieving small following distances safely is brake performance estimation. To be able to calculate the (minimum) safe following distance, each platoon member needs to know its own and its predecessor's immediate brake performance. Taking the driver(s) out-of-the-loop is considered to offer the possibility to reduce time gaps to a minimum of 0.3 s in ideal conditions, such as dry weather, sufficient homogeneity of the vehicles' brake performance, optimal ordering of vehicles, etc. However, non-optimal conditions still require larger time gaps.

6.3.2. Solutions after intruders cut-in in a platoon

This section gives general solutions to the situation when a platoon is split by an external vehicle (intruder vehicle).

An intruder vehicle may be warned when it enters the platoon, e.g. by extra lighting or a LED message board on the trailer. This implies the need of extra devices or use of devices. These are currently not regulated. Nevertheless, in combination with regulation that does not allow for cutting into a platoon, this may be a solution.

Additionally, when the intruder vehicle is equipped with communication capabilities (V2V), it can be warned about entering a platoon and be asked to leave or switch position with some platoon members. Latter requires appropriate positioning accuracy.

The platoon itself can also apply a driving strategy to stimulate or facilitate overtaking by slowing down, but it depends on the situation if this can be done safely. Furthermore, it may interfere with the average speed of the platoon and certain expected time of arrival.

Finally, when the intruder vehicle also has platooning capability, it may be an option for this vehicle to join the platoon, although this is not foreseen for the first application.

6.3.3. Specific situations

This section goes through the specific use cases and states the possible threats and ways to avoid these or possible solutions, more specific for these use case.

Traffic lights

The following situations may occur, alternatively to the normal, wanted flow:

1. The lead truck can pass through a green light, but the light turns to red before the last trucks have started passing the light. Either these trucks pass through red, or, the platoon is split.
2. Stopping at a green light as the platoon knows it cannot pass during the current green phase.
3. Heavy braking of a lead truck driver for stopping at a traffic light, to keep the platoon together, which may also increase fuel consumption.
4. When turning left at e.g. a T-junction, there may be oncoming traffic that has also green and should get right of way.
5. The traffic light is not working (i.e. switched off).

Additionally to the already stated general solutions in sections 6.3.1 and 6.3.2, the following solutions may help in these situations, but may be not feasible or desirable in many occasions:

1. Always stop at a green traffic light to use the next full green phase.
2. In case of non-intelligent traffic lights, offline evaluate the traffic flow and estimate the traffic lights phases of other cars passing the intersection. When looking at a bigger picture one could think of services that offer the prediction of these timings to the platoon navigation system. This solution might, however, work less effectively for traffic lights with non-fixed timings.
3. Offer a physical space (e.g. like a parking space) after the traffic light to facilitate regrouping.
4. Have a mode in the platooning function to enable a "partial/limited" platooning functionality even if some vehicles have to stop due to traffic lights. Have a mode for the

left-behind vehicle to complete the intersection manoeuvre by itself. This is especially possible when there is V2V with sufficiently accurate positioning and trajectory information to be shared among platoon members.

Roundabouts

The following situations may occur, alternative to the normal, wanted flow:

1. The platoon might not get enough space to enter a roundabout without having to give way to other vehicles, resulting in cut-ins, especially in times of heavy traffic.
2. In multilane roundabouts, insufficient space may prevent a lane change which is necessary to exit the roundabout.
3. On very tight roundabouts a target may get out of sensor field of view.

Suggested ways to deal with above situations are:

1. Putting traffic lights at a roundabout including V2X cooperation, regulating entrance. These traffic lights may only be active when a platoon arrives at the roundabout.
2. Estimate the potential decrease of gap size due to the low speed at the roundabout and allow vehicles to platoon up to this small gap size.
3. Regroup while in the roundabout, possibly using more laps than required for the journey.
4. Have a physical space after the roundabout, like for the traffic light, to regroup.

Cut-in long time

This is especially an issue on single lane roads, as these offer no possibilities for overtaking.

Some specific ways to avoid or deal with the cut-in vehicle are:

1. Have a cut-in prediction algorithm and use e.g. the lights or horn to warn the driver of the cut-in vehicle not to cut-in into the platoon. This would require regulations.
2. Use special bypass ways, like on steep uphill roads.
3. Have dedicated lanes for trucks (and even only platoons).

Entering highway via onramp

Specific situations that can occur at onramps are:

1. Vehicle(s) on the highway block the follower(s) to merge onto the highway.
2. Not enough space available for the whole platoon to merge onto the highway.

Possible specific ways to prevent a platoon break-up or possible solutions when this happens are:

1. Through traffic rules: make changing lane towards the first lane prohibited. This should ease merging into this first lane from the entry ramp.
2. Have cars/trucks on highway to shift lane before the entry ramp to free the first lane. This may be done in several ways, e.g. via matrix static signs, variable signs, in-vehicle signage, traffic lights, I2V, also in combination with smart sensing that detects a platoon entering onto the ramp.
3. Wait until there is the space to enter the highway.

Passing entry ramps

While passing an entry ramp, traffic on the highway may be obligated to give way to entering vehicles (this may be different in different countries).

When staying in the lane next to the entry ramp, a situation can occur in which multiple vehicles merge into a platoon (i.e. multiple cut-ins in a platoon at different positions).

Suggested solutions for the mentioned cases are:

1. Using signals to warn the driver of a cut-in vehicle that the cut-in vehicle is not allowed to stay in the platoon.
2. Using V2V communication to show on the HMI that the cut in vehicle is not allowed to stay in a platoon.
3. Not allowing to merge into a platoon in the traffic regulations.
4. Visual information signs showing timing information of platoon passing to entering traffic.
5. HMI in vehicle using V2I showing timing information of platoon passing to entering traffic.

Leaving highway via offramp

Specific situations that can occur at offramps are:

1. The exit is half full, causing part of a platoon to be standing still on the highway.
2. The exit full, this may cause late cut-in situations.
3. Short exit, the platoon has to reduce speed early which may cause a large speed difference to the other traffic on the highway that is nor already expecting this.

Suggested solutions for the mentioned cases are:

1. Risk of platoon split is assessed to be small at exit ramps.
2. Short distance keeping at slow moving, not allowing cut-ins.

Lane change / merge

As mentioned for the offramp case, in some Member States in the European Union, regulation foresees that, in the case of having two lanes merged into one, only one car for each lane is allowed to pass. Some situations where three lanes merge into one lane may also occur. This may lead to situations with several cut-ins.

Suggested solutions for the mentioned cases are:

1. Using V2X communication or Digital Maps that trigger an external information panel or HMI on a vehicle to indicate the presence of a platoon.
2. Having a short intervehicle distance in the platoon.

Toll gates

Traffic movements at the diverging and conversion areas can lead to other vehicles cutting into the platoon.

Closing the gap will be fundamental to discourage such cut ins.

Manoeuvre at a (non-signalised) T-junction (90 degrees turn)

Following vehicles need to stop to give right of way to other vehicles at a left turn.

Suggested solutions are:

1. Consider making traffic lights to be mandatory on the routes the platoons will take.
2. Give platoon right of way by regulation in areas where the speed limit is low to allow other traffic participants to react adequately.

6.3.4. Safe states

A “Safe State” is a specific condition that a system has to reach after a hazardous event (that it is not manageable within the ODD) and that is considered safe for itself and, possibly, for the other traffic participants.

For the Platooning Autonomous function, 4 different “Safe States” are considered:

- Stop in Parking area;
- Stop on hard shoulder;
- Stop in lane;
- Tele-operation – remote operation.

The triggers that start the transition to the safe states will be analysed in the Functional Safety analysis and will be reported in a separate document (Pezzano, 2022).

Once the triggering event(s) happen(s), the system starts to evaluate the options it has, to behave safely.

The factors considered for the decision will most probably include:

- Motion capability: the system must be able to evaluate if it is still able to safely control its longitudinal and lateral dynamics.
- Local Connectivity: the system, making use of its connectivity devices, is capable of receiving information from the infrastructure, from other cooperative vehicles and from the Platoon members. Verifying the availability of this capability will lead to different safe state evaluations.
- Backend Connectivity: the system is normally always connected to a backend that is tracking its behaviour and following its mission remotely; the availability of this “connection”, in combination with other factors (e.g. motion capability), will steer the safe state capability evaluation.
- Environmental perception: the system makes use of on-board sensors to perceive the surroundings and to properly plan the path that it is following; this includes vehicle positioning, making also use of improved or more interactive maps.

The safe state evaluation, then, makes use of all these factors to decide the best trade-off between safety for the vehicle and the other traffic participants and costs, with the intention to lower down as much as possible the harmful situations.

6.3.4.1. Stop in a parking area

This Safe State considers the possibility for the vehicle to safely reach a parking lot using its own sensors set and “intelligence”.

Once the Safe State is selected, the vehicle will inform the other Platoon member(s) about the next destination it must reach and, if needed, it will request a lane change to the right most lane.

When the parking area is reached and the vehicles are standing still, the leading truck driver can remove the “faulty” vehicle from the platoon from his/her HMI; doing so, the system of the remaining 2 vehicles will re-negotiate the communication.

The driver, at this point, can park the removed vehicle and activate an assistance request to the offboard system for it.

Finally, the new 2 vehicles Platoon can start to drive again (see Parking UC).

6.3.4.2. Stop on hard shoulder

This Safe State considers the possibility for the vehicle to safely park on the nearest hard shoulder or emergency lane using its own sensors set and “intelligence”.

Once the Safe State is selected, the vehicle informs the other Platoon member and requests to the leading truck a lane change to the right most lane, if needed.

After the hard shoulder condition evaluation (e.g. enough space available, no vehicles parking and approaching), the vehicle performs the lane change occupying the space available on the hard shoulder.

Once stopped, an assistance request is sent to the off-board system/service.

The following vehicle, if any and if needed, sends a cohesion request to the Leading truck to be able to continue in platoon.

6.3.4.3. Stop in lane

This Safe State considers the possibility for the vehicle to safely stop in lane as last possibility to handle a harmful situation, using its own sensor set and “intelligence”.

Once the Safe State is selected, the vehicle informs the other platoon member(s).

The trailing vehicle(s), if any, request a lane change to the leading truck to be able to continue after the “faulty” truck left.

When this manoeuvre is completed and communicated to the “faulty” truck, it initiates an open loop braking manoeuvre in order to stop as soon as possible, taking into account the situation (other traffic participants, infrastructure, etc.) when performing the deceleration.

Once stopped, an assistance request is sent to the off-board system/service; the remaining 2 trucks will continue to drive in a platoon.

6.3.4.4. Tele-operation – remote operation

In a nutshell, tele-operation means that a vehicle is controlled by an operator which is not physically in the vehicle. The operator has a very reliable connection with low latency to the vehicle to receive sensor input, usually in the form of video images very close to real time. The operator has a multitude of possibilities to control the vehicle. These range from sending the vehicle a trajectory which the vehicle uses as input for own manoeuvre planning all the way to manoeuvring the vehicle itself via an operator HMI. The inputs/commands to the vehicle are also routed via the reliable, low latency connection.

From a realistic perspective tele-operation can only start when the vehicle is at standstill. Anything else would mean that operators must permanently monitor all vehicles. In this way, the operator has time to comprehend the situation and thereby can safely take over control. The initial standstill position of the vehicle can be a non-optimal safe state which should be improved, e.g. moving from standstill within a lane to standstill at the next parking lot.

Tele-operation should be a last resort, since it requires considerable off-board infrastructure and well trained personnel. Efforts should focus on achieving a system that is always capable of reaching an acceptable safe state with its own means. The functional safety analysis will provide the necessary foundation to decide whether this is necessary or not.

7. SUMMARY AND CONCLUSION

This report defines the platoon levels in the ENSEMBLE project and the use cases which form the basis for the technical detailing in the rest of WP2 and WP3. This is the final version of this definition, following the deliverable D2.2 (Vissers, 2018).

7.1. Platooning levels

The platoon levels as envisioned by the ENSEMBLE consortium and presented in D2.2 (Vissers, 2018) were revised after first results of the safety analyses. The Platooning Support Function and the Platooning Autonomous Function are fully detailed in this final deliverable. The Platoon Support Function is defined in line with the held demonstration on public road in September 2021.

Two levels of platooning have finally been defined:

- **Platooning Support Function**: the driver is responsible for the driving task. Hence (s)he is also responsible to choose a safe following distance and monitor the system e.g. whether the right platooning partner is being followed (though supported by the system as much as possible). To give the driver sufficient time to react, minimum time gaps around 1.5 s have to be respected. The Platooning support function is a longitudinal control function, but lateral driver assistance systems, such as e.g. lane keeping, might be optionally available as well,
- **Platooning Autonomous Function**: The lead truck has a driver responsible for the driving task, but the following trucks are fully automated, i.e. the system performs the complete driving task within the specified (limited) operational design domain. Taking the driver(s) out-of-the-loop offers the possibility to reduce time gaps to a minimum of 0.3 s.

In contrast to the Platooning Support Function, implementation of the Platooning Autonomous Function is not part of the ENSEMBLE project and the specification of the Platooning Autonomous Function and its use cases is solely done on theoretical considerations to sketch a future vision of platooning. The latter is also due to the low technology readiness level of certain required autonomous driving subfunctions at the time of writing.

Basis for the Platooning Support Function is Adaptive Cruise Control (ACC) as defined in (15622, 2018). Main characteristics of this level are:

- Based on ACC, the driver is responsible for the complete driving task.
- Longitudinal coordinated automated control for the whole velocity range from 0 (brake to standstill, acceleration from standstill optional) to maximum cruise speed (depending on country regulations).
- Time gap: is conform current ACC time gaps. Depending on the brand, the minimum gap ranges between 1.4 s and 1.6 s.

- Limited accelerations (>-3.5 m/s2).
- Under adverse conditions like bad weather, slopes, etc.… the drivers have the responsibility to increase the time gap or disengage the platoon completely.
- Interaction with platooning services and infrastructure is technically available.

On the other hand, the main idea of the Platooning Autonomous Function is having autonomous following vehicles, but also a driver in the lead truck. When engaged, the Platooning Autonomous Function performs the entire dynamic driving task for the following vehicles. The driver in the lead truck has a responsibility to guide the platoon through traffic, but is not responsible for the (operational and functional) safety of the entire platoon. This also implies that the lead truck driver has the responsibility to obey the rules of the road (i.e. laws and informal rules). In other words, the lead truck driver is 'driving' a 'long truck' consisting of electronically coupled automated following vehicles. It is believed that this type of autonomous platooning, could be an earlier deployable (and a less costly) step on the roadmap of automated long-haul freight transport, because of potentially less complex technical challenges, since following trucks are not responsible to respect the traffic rules and accomplishing the mission (e.g. driving to destination), as these are relying on the lead truck driver.

The main properties of the Platooning Autonomous Function are:

- A lead truck with a driver, who is responsible for performing part or all of the dynamic driving task.
- Following trucks that are driverless (but can be manned). When these start platooning at a hub, the system will be able to handle all situations autonomously within the limited ODD (including faults, by being fault tolerant and SOTIF situations like cut-ins, weather, etc.).
- Envisioned ODD of the platooning function is hub-to-hub highway driving on selected driving routes important for long-haul freight transport.
- The ODD of the following vehicles is additionally limited by 'being part of the platoon', which means that these vehicles are designed to follow the lead or other following vehicles autonomously as part of the platoon (also called "follow-me" or "auto-follower" functionality).

7.2. Use cases

The high level use cases for the Platooning Support Function are detailed. First of all the methodology how to derive the use cases is defined and after that the high level manoeuvres for the Platooning Support Function and additional assumptions are added which can together be used for the detailed use cases and may be part of the background for the technical deliverables (e.g. D2.5 (Mascalchi, 2022), D2.8 (Atanassow, 2022a).

The main high level use cases of the Platooning Support Function are:

- Engaging to platoon
  - Join from behind
  - Merge in between by single vehicle in existing platoon

- Platooning
  - Steady state platooning
  - Follow to stop
  - Emergency braking
  - Platoon gap adaptation
    - I2V interaction
    - Cut-in
    - System status (e.g. packet loss)
  - Cohesion request
- Disengaging platoon
  - Leave
  - Split
  - Leave by steering out

Similarly, the use cases of the Platooning Autonomous Function have been identified:

- Platoon formation
  - Formation of driverless platoon in dedicated area (Orchestrated non real-time)
- Engaging to platoon
  - Join a stationary platoon/vehicle from behind at the hub
  - Join from Behind by a manned, single vehicle on the highway
- Platooning
  - Platooning between the hub and the highway
  - Platooning in lane on the highway
  - Entire platoon starting from a standstill
  - Emergency manoeuvre
  - Cut-in
  - Maintaining Platoon cohesion
  - Lane change triggered by Leading truck
  - Lane change triggered by Following or Trailing truck
  - Lane merge
  - Entering highway via an onramp
  - Highway offramp
  - Platooning on a connection between two different highways
  - Road Works/Construction zone
  - Traffic signs handling
  - Toll gates
  - Traffic lights on highways
  - Traffic lights on intersections
  - Roundabouts
  - Resting Areas/Parking lots

  - Parking
  - Border Crossing
- Disengage platoon
  - Drop-off area at the destination hub
  - Leave (while platooning, with a manned trailing truck)
- Safe state
  - Safe state evaluation and reaching (nearest parking area)
  - Safe state evaluation and reaching (hard shoulder/emergency lane)
  - Safe state evaluation and reaching (stop in lane)

Since the following trucks may not have full SAE level 4 capability, without being part of the platoon, a platoon split may lead to enter a safe state, which can affect the traffic flow. Potential threats that can lead to a split have been identified and solutions are suggested, e.g. in the contexts of adapting (digital) infrastructure and traffic rules. Therefore, it is concluded that the Platooning Autonomous Function requires adaptation of the (digital) infrastructure and traffic rules, but this needs the consensus of lawmakers and the public in order to be implementable.

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9. APPENDIX A.

9.1. Glossary

9.1.1. Definitions

Term	Definition	
Back split	The ego vehicle breaks the platoon with its direct following truck (typically by sending a back split request, see D2.8 and D2.5)	
Convoy	A truck platoon may be defined as trucks that travel together in convoy formation at a fixed gap distance typically less than 1 second apart up to 0.3 seconds. The vehicles closely follow each other using wireless vehicle-to-vehicle (V2V) communication and advanced driver assistance systems	
Cut-in	A lane change manoeuvre performed by vehicles from the adjacent lane to the ego vehicle's lane, at a distance close enough (i.e., shorter than desired inter vehicle distance) relative to the ego vehicle.	
Cut-out	A lane change manoeuvre performed by vehicles from the ego lane to the adjacent lane.	
Cut-through	A lane change manoeuvre performed by vehicles from the adjacent lane (e.g. left lane) to ego vehicle's lane, followed by a lane change manoeuvre to the other adjacent lane (e.g. right lane).	
Ego Vehicle	The vehicle from which the perspective is considered.	
Emergency brake	Brake action with an acceleration of <-4 m/s2	
Event	An event marks the time instant at which a transition of a state occurs, such that before and after an event, the system is in a different mode.	
Fail-safe	A fail-safe in engineering is a design feature or practice that in the event of a specific type of failure, inherently responds in a way that will cause no or minimal harm to other equipment, the environment or to people.	
Following truck	Each truck that is following behind a member of the platoon, being every truck except the leading and the trailing truck, when the system is in platoon mode.	

Front split	The ego vehicle breaks the platoon with its direct preceding vehicle. The front vehicle is notified through a dedicated message (see D2.8 and D2.5).
Leading truck	The first truck of a truck platoon
Legal Safe Gap	Minimum allowed elapsed time/distance to be maintained by a standalone truck while driving according to Member States regulation (it could be 2 seconds, 50 meters or not present)
Manoeuvre ("activity")	A particular (dynamic) behaviour which a system can perform (from a driver or other road user perspective) and that is different from standing still, is being considered a manoeuvre.
ODD (operational design domain)	The ODD should describe the specific conditions under which a given automation function is intended to function. The ODD is the definition of where (such as what roadway types and speeds) and when (under what conditions, such as day/night, weather limits, etc.) an automation function is designed to operate.
Operational layer	The operational layer involves the vehicle actuator control (e.g. accelerating/braking, steering), the execution of the aforementioned manoeuvres, and the control of the individual vehicles in the platoon to automatically perform the platooning task. Here, the main control task is to regulate the inter-vehicle distance or velocity and, depending on the Platooning Level, the lateral position relative to the lane or to the preceding vehicle. Key performance requirements for this layer are vehicle following behaviour and (longitudinal and lateral) string stability of the platoon, where the latter is a necessary requirement to achieve a stable traffic flow and to achieve scalability with respect to platoon length, and the short-range wireless inter-vehicle communication is the key enabling technology.
Platoon	A group of two or more automated cooperative vehicles in line, maintaining a close distance, typically such a distance to reduce fuel consumption by air drag, to increase traffic safety by use of additional ADAS-technology, and to improve traffic throughput because vehicles are driving closer together and take up less space on the road.
Platoon Automation Levels	In analogy with the SAE automation levels subsequent platoon automation levels will incorporate an increasing set of automation functionalities, up to and including full vehicle automation in a multi-brand platoon in real traffic for the highest Platooning Automation Level. The definition of "platooning levels of automation" will comprise elements like e.g. the minimum time gap between the vehicles, whether there is lateral automation available, driving speed range, operational areas like motorways, etc. Three different levels are anticipated; called A, B and C.

Platoon candidate	A truck who intends to engage the platoon either from the front or the back of the platoon.
Platoon cohesion	Platoon cohesion refers to how well the members of the platoon remain within steady state conditions in various scenario conditions (e.g. slopes, speed changes).
Platoon 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. 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. This can be achieved either through a front split or a back split.
Requirements	Description of system properties. Details of how the requirements shall be implemented at system level
Scenario	A scenario is a quantitative description of the ego vehicle, its activities and/or goals, its static environment, and its dynamic environment. From the perspective of the ego vehicle, a scenario contains all relevant events. Scenario is a combination of a manoeuvre (“activity”), ODD and events
Service layer	The service layer represents the platform on which logistical operations and new initiatives can operate.

Specifications	A group of two or more vehicles driving together in the same direction, not necessarily at short inter-vehicle distances and not necessarily using advanced driver assistance systems
Steady state	In systems theory, a system or a process is in a steady state if the variables (called state variables) which define the behaviour of the system or the process are unchanging in time. In the context of platooning this means that the relative velocity and gap between trucks is unchanging within tolerances from the system parameters.
Strategic layer	The strategic layer is responsible for the high-level decision-making regarding the scheduling of platoons based on vehicle compatibility and Platooning Level, optimisation with respect to fuel consumption, travel times, destination, and impact on highway traffic flow and infrastructure, employing cooperative ITS cloud-based solutions. In addition, the routing of vehicles to allow for platoon forming is included in this layer. The strategic layer is implemented in a centralised fashion in so-called traffic control centres. Long-range wireless communication by existing cellular technology is used between a traffic control centre and vehicles/platoons and their drivers.
Tactical layer	The tactical layer coordinates the actual platoon forming (both from the tail of the platoon and through merging in the platoon) and platoon dissolution. In addition, this layer ensures platoon cohesion on hilly roads, and sets the desired platoon velocity, inter-vehicle distances (e.g. to prevent damaging bridges) and lateral offsets to mitigate road wear. This is implemented through the execution of an interaction protocol using the short-range wireless inter-vehicle communication (i.e. V2X). In fact, the interaction protocol is implemented by message sequences, initiating the manoeuvres that are necessary to form a platoon, to merge into it, or to dissolve it, also taking into account scheduling requirements due to vehicle compatibility.
Target Time Gap	Elapsed time to cover the inter vehicle distance by a truck indicated in seconds, agreed by all the Platoon members; it represents the minimum distance in seconds allowed inside the Platoon.
Time gap	Elapsed time to cover the inter vehicle distance by a truck indicated in seconds.
Trailing truck	The last truck of a truck platoon
Truck Platoon	Description of system properties. Details of how the requirements shall be implemented at system level
Use case	Use-cases describe how a system shall respond under various conditions to interactions from the user of the system or surroundings, e.g. other traffic participants or road conditions. The user is called actor on the system, and is often but not always a human being. In addition, the use-case describes the response of the system towards other traffic participants or environmental conditions. The use-cases are described as a sequence of actions, and the

	system shall behave according to the specified use-cases. The use-case often represents a desired behaviour or outcome. In the ensemble context a use case is an extension of scenario which add more information regarding specific internal system interactions, specific interactions with the actors (e.g. driver, I2V) and will add different flows (normal & alternative e.g. successful and failed in relation to activation of the system / system elements).

9.1.2. Acronyms and abbreviations

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

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

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

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

TF	Task Force
TOR	Take-Over Request
TOT	Take-Over Time
TTG	Target Time Gap
UNECE	United Nations Economical Commission of Europe
V2I	Vehicle to Infrastructure
V2V	Vehicle to Vehicle
V2X	Vehicle to any (where x equals either vehicle or infrastructure)
VDA	Verband der Automobilindustrie (German Association of the Automotive Industry)
VECTO	Vehicle Energy Consumption Calculation Tool
VMAD	Validation Method for Automated Driving
WIFI	Wireless Fidelity
WP	Work Package
WP.1	Working Party 1 - Global Forum for Road Traffic Safety
WP.29	Working Party 29 - World Forum for Harmonization of Vehicle Regulations