ENSEMBLE

EUROPEAN COMMISSION

HORIZON 2020
H2020-ART-2016-2017/H2020-ART-2017-Two-Stages
GA No. 769115

ENSEMBLE

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

Deliverable No.	D2.7	
Deliverable Title	V2 Functional specification for intelligent Infrastructure (Strategic/Services layers)	
Dissemination level	Public	
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Approved by	Dehlia Willemsen, TNO	15-02-2022
Status	APPROVED BY EC	13-10-2022

Please refer to this document as:

Villette, C. (2021). D2.7 – V2 Functional specification for intelligent Infrastructure (Strategic/Services layers) – D2.7 of H2020 project ENSEMBLE, (www.platooningensemble.eu)

Disclaimer:

ENSEMBLE is co-funded by the European Commission, DG Research and Innovation, in the HORIZON 2020 Programme. The contents of this publication is the sole responsibility of the project partners involved in the present activity and do not necessarily represent the view of the European Commission and its services nor of any of the other consortium partners.

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Version	Date	Author	Summary of changes	Status
0.1	10/09/2021	Cecile Villette (ALTAROAD)	First Draft	Draft
0.2	16/11/2021	Cecile Villette (ALTAROAD)	Second Draft with feedbacks implemented	Draft
0.3	02/12/2021	Cecile Villette (ALTAROAD)	Third Draft with feedbacks implemented	Draft
1.0	22/12/2021	Cecile Villette (ALTAROAD)	Third Draft ready for WP Leader Review	For review by WP Leader
1.1	31/01/2022	Edoardo Mascalchi (CLEPA)	Final for approval by Coordinator	For review by Coordinator
1.2	18/02/2022	Edoardo Mascalchi (CLEPA)	Feedback by Coordinator implemented	Final
2.0	03/08/2022	Dehlia Willemsen	Adjusted after EC review comments	Final

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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 across national borders. During the years, the project goals were:

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

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

Abstract of this Deliverable

This deliverable provides a non-exhaustive overview of the infrastructure-based communication functions concerning platooning and which are based on vehicle-to-infrastructure (V2I) and infrastructure to vehicle (I2V) communication. These functions aim to answer the challenges that platoons still face today, from safety and acceptance to infrastructure needs

By highlighting relevant use cases, the objective is to provide more information on which infrastructure-based functions contribute to the safety and acceptance of (autonomous) platooning. Platooning may appear difficult in some situations, such as passing roundabouts, bridges, or tunnels, but as it will be shown, V2I/I2V communication systems can provide important support and act as an enabler for this technology and associated services.

Regarding the communication standards, the reader will find recommendations for a state-of-the-art protocol that enables what was considered the most efficient, secure, and safest V2I and I2V communication.

1. INTRODUCTION

1.1. Background

Societal challenges, including an ageing population, increased transport of freight, and higher use of personal mobility vehicles are pushing the ability of the road networks in Europe to meet demand. Without any action, this would lead to increased congestion, lower quality of services and higher economic costs, with consequently a decrease of European competitiveness.

In order to limit these impacts, initiatives conducted across Europe (including at national level) are defining new functionalities for the intelligent infrastructure:

- Forever Open Road initiative by FEHRL *and its national declinations, as*
  Route de 5ème Génération – R5G (5th Generation of Roads) in France,
  “*Die Straße des 21. Jahrhunderts”* (the Road of the 21st Century) in Germany,
  the *Ferry Free E39 programme* in Norway. (FEHRL, 2018) 2 4 5 (IDDRIM, n.d.) (development, 2014) (Hove, 2019)
- French project SCOOP on connected roads and vehicles, which proposes the cooperation between road managers and car manufacturers (transition, 2017)
- *Exploratory Advanced Research (EAR) Program* (USA) on transportation related innovations. (USA, 2015)
- OECD project CEDR on « Long Freight Distance Traffic » (EU), building on the report of *Policies to Extend the Life of Road Assets* (OECD, 2018)

These programs have already identified a consistent set of requirements for the infrastructure and for vehicles to operate more efficiently on existing roads. Obviously, market penetration and challenges to solve may differ between solutions and between countries/ regions since demands from road users and road authorities will develop at different rates. Still, there are some common aspects, and in order to smoothly integrate multi-brand platoons in the European ecosystem, there is the need of being able to interact with this new generation of intelligent infrastructures.

Indeed, multi-brand platooning is claiming to be an efficient way to transport goods and materials, being safer, lowering the fuel consumption and improving the overall traffic and delivery efficiency. Nevertheless, the impact of multi-brand platoons on the infrastructure (pavements, bridges, tunnels) requires further investigations, also performed in this project (performed in WP4), compared to traditional trucks. In coherence with the OECD report mentioned above, this ENSEMBLE deliverable shows that the impact of platoons on road infrastructure can be better controlled with the right interactions with the infrastructure, hence the critical importance of the implementation of the I2V functionalities to avoid applying overly restrictive measures whilst still guaranteeing minimal impact on the infrastructure.

Infrastructure is also able to send useful information to platoons about events that are out of line of sight with a potential improvement of safety for platoons and other road users. This information is optimal when the information that is available from/to the platoon is the most precise (type of vehicles, loading …).

1.2. Aim

The interest of infrastructure owners/managers' and authorities' is to facilitate the use of multi-brand platoons that are compatible with existing infrastructure and its usages, and fully leverage the potential of the next generation of vehicle-to-infrastructure communication to maximize safety and efficiency. Interoperability is, in turn, a major factor in achieving widespread use of platooning and increase economic benefit for fleets and service providers.

The aim of this deliverable is to identify the functional requirements for platoons to enable communication with infrastructure (V2I/I2V).

More specifically, the objective of the deliverable D2.7 is to provide a list of use cases and their functional requirements, as well as to provide recommendations for the standardization. It also provides inputs regarding the potential evolution of these technologies.

1.3. Positioning within ENSEMBLE WP2 context

This deliverable D2.7 uses as a basis the deliverable D2.6 (C. Villette, 2018), written at the beginning of the ENSEMBLE project, and enriches it with the lesson learned during the project.

Given the current market penetration of 5G, this deliverable will only cover services that can be also enabled by short range V2I and I2V based services like ITS-G5. In the future these services can be also enabled by cellular connection. All cellular-only communication-based services are described in deliverable D4.2 (J. Luetzner, 2022).

1.4. Structure of this report

This deliverable is structured as follows:

- A background introduction on the concept of intelligent infrastructure and potential services linked to multi-brand platooning.
- A non-exhaustive list of challenges multi-brand truck platooning faces.
- A non-exhaustive list of services and functional requirements for multi-brand truck platooning, divided into three categories:
  - services to support the platoon
  - services to secure user acceptance

- A recommendation for the standardization of a communication protocol with the infrastructure (V2I).

2. DESCRIPTION OF NEW CHALLENGES

2.1. What is intelligent infrastructure?

The next generation of roads will require high levels of adaptation, automation, and resilience. The Forum of European Highway Research Laboratories (FEHRL) (FEHRL, 2018) lists the three following elements as the ones that will define the next generation of roads:

- **The Adaptable Road**: focusing on ways to allow road operators to respond in a flexible manner to changes in road users' demands and constraints;
- **The Automated Road**: focusing on the full integration of intelligent communication technology applications between the user, the vehicle, traffic management services, and the road operations;
- **The Resilient Road**: focusing on ensuring that service levels are maintained under extreme conditions (weather and traffic conditions).

The key point regarding multi-brand platooning is the so-called Automated Road aspect, on which this chapter will focus, and which includes generally:

- Comprehensive, interoperable communications systems connecting driver, vehicle, and the road operator;
- Advanced vehicle and user guidance, speed control, management and direction guidance, including on-road guidance to manage traffic; platoons in particular introduce specific challenges to merge onto highways;
- Integrated traffic control, monitoring of traffic and road conditions to improve reliability and efficiency; platoons in particular introduce specific challenges regarding dynamic loads on roads;
- Incident monitoring and automated response systems to reduce delays;
- Effective road charging and tolling;
- Efficient electric vehicle power provision.

Future traffic management measures and information provision will become more personalised, with services able to provide direct information to (traffic) groups and users, while taking into account road conditions and other road users. Specifically, for platoons, there is a challenge in making sure that they integrate themselves in traffic in an efficient way, in situations such as highway entry/exit, or overtaking.

Independent of the V2I/I2V communication, the individual road users can/will provide data that can be used for traffic management purposes, including information about departure, destination, objective of the journey, and intended route. In addition to receiving such information, that are in some cases anonymised, location data is being collected from mobile phone companies and from connected vehicles. By using this information, operators will offer tailored services to the specific road user.

The availability of data and connectivity will improve the effectiveness of measures and services thereby leading to a higher user acceptance of the service due to the more positive experience. The road user must, however, give consent and be able to share specific (personal) information with service providers and the road operators. The new role of the future road user will probably consist of being a participant in the management of our road systems in addition to being a customer.

2.2. Challenges identified at the beginning of the project

Even though the technology is moving forward, several challenges remain to achieve a full implementation and adoption of multi-brand truck platooning. At the beginning of the ENSEMBLE project, some of these challenges were identified. A workshop was conducted with five high-profile individuals representing the industry (ACEA, Alice, CEDR, IRU, Peloton Technology, USA), who expressed their view on the challenges that still hold back the complete adoption of multi-brand truck platoons and autonomous vehicles in general.

The challenges are as follows:

- **Safety & security**: ensuring the safety of platoons and autonomous vehicles. This is a top priority in platoon and autonomous vehicles development. Safety and security are interdependent (security attacks can cause safety failures), therefore there is the need of an alignment in the early system development phases to ensure the required level of protection. Consequently, an autonomous vehicle or platoon cannot be considered safe without a cybersecure design. Moreover, data privacy has become essential.
- **Acceptance by society**: society does not yet demand a transition to smart and automated mobility since the implications and benefits of platoons and automated vehicles are not yet well understood. Consequently, there is a lack of awareness and acceptance by citizens and policy makers. Changing public opinion requires evidence that autonomous vehicles and multi-brand truck platooning systems are safe, and that they offer social, economic, and environmental benefits.
- **Need for new traffic rules and new regulation**: autonomous vehicle and platoon technologies use technical standards (ISO standards) as a basis. Nevertheless, new national and international regulation still needs to be established to keep up to speed with the technological developments. Proper standardization and regulation are key for reaching deployment readiness quickly.
- **Infrastructure needs**: the EU physical and digital infrastructure needs to be made fit to support new sustainable and automated mobility services. The aspects of automation, connectivity, and interoperability need further research and testing. In addition to that, the massive amount of data generated and collected requires new computing architectures and infrastructures.

3. LINK WITH PLATOONING LEVELS

Two Platooning Levels are proposed in the ENSEMBLE project. These are described in D2.3 (Use Cases and level definition) (Willemsen, 2022), D2.5 (Requirements and specifications) (Mascalchi E., 2022), D2.8 (V2X Protocol) (B. Atanassow, D2.8, 2022a) and D2.9 (Security) (B. Atanassow, 2022b). The first level, the Platooning Support Function (PSF), has been implemented and demonstrated, while the second and more automated one, the Platooning Autonomous Function (PAF), is only defined through use cases, specifications and requirements. In other words, in contrast to the PSF, implementation of the PAF is not part of the ENSEMBLE project and the specification of the PAF 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 defining.

A summary of the descriptions of each level can be found below:

- **Platooning Support Function (PSF)**: With this function active, the driver is still 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 1.5s have to be respected. The Platooning Support Function is a longitudinal control function, but lateral driver assistance systems, such as lane centring, may be available and used as well.

- **Platooning Autonomous Function (PAF)**: The lead truck has a driver, who is 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 in the following vehicles, is one of the enabler to reduce time gaps to a minimum of 0.3s if each vehicle is able to assess its own braking capabilities.

This deliverable will address services that can be enabled using short range communications technologies such as ITS-G5 or cellular connectivity (4G, 5G). Services that can only be based on cellular connectivity will be described in D4.2 (J. Luetzner, 2022). The current deliverable will assess potential new services provided by infrastructure for both levels of platooning. For each suggested functionality provided by infrastructure, it will be then indicated to which platooning level it refers. If the PSF is mentioned, this means that the functionality applies to both levels. In the implementation of ENSEMBLE functionality for the PSF, the only tested functionality was the transmission of the recommended speed and gap information.

As described in D2.3 (Willemsen, 2022), the PAF, relies on the infrastructure to avoid splitting of the platoon as much as possible. This is necessary since following trucks are with the driver out of the loop (or even unmanned) and can be operated safely only when part of the platoon. Disconnecting from the platoon (in the case of a split) will force the following trucks to go to a safe state (e.g. stopping in the lane or parking). In order to avoid such situations, requirements for infrastructure such as intelligent traffic lights have been defined for the PAF and will also be further described as functionalities from infrastructure in this deliverable.

4. PLATOONING COMMUNICATION FUNCTIONALITIES

4.1. Services to support the platoon

Securing the objective: how to avoid breaking the platoon

For the PAF, maintaining platoon cohesion for major part of the trip is a key element of the business case, it is critical to be able to handle obstacles/situations without splitting the platoon. The following items and potential management have been identified.

a) Intersection & roundabout management

When manoeuvring through junctions the main challenge lies in not splitting the platoon, which is why the project/deliverable gives a non-exhaustive list of requirements that will avoid this. Often an additional problem arises from the lack of visibility that may happen when the intersection is behind a corner or during night-time. For this reason, V2I/I2V communication is essential when the platoon approaches a junction. The following use cases present some functions that may be considered to avoid breaking the platoon.

Table 1 - Use cases and suggested functionalities for junction management (when 'PSF' is mentioned, this means that the functionality applies to both platooning levels)

Use cases	Suggested functionalities	PAF /PSF
Intersections with intelligent traffic lights	• UC in D2.3 (Willemsen, 2022) - Stop the entire platoon at the traffic light or authorize the entire platoon (negotiation) to pass • Send out of line-of-sight information in order to avoid braking and potential crashes with vehicles that are out of line-of-sight at the moment of entering the intersection. • The intelligent traffic lights should be turned on when a platoon approaches, including at night.	PAF
Roundabouts with intelligent traffic lights	• Intelligent traffic lights at roundabouts to orchestrate prioritization of platoons. • Rotating priorities roundabouts with traffic lights before the platoon enters the roundabout. • Turn on the traffic light for the platoon and stop the other traffic to allow the platoon to enter the roundabout safely.	PAF

b) Other challenging situations on roads

In addition to junctions, other situations on roads, such as bridges and tunnels, may cause dangerous situations to platoons and to other road users. The questions which need to be answered are:

- How to avoid splitting the platoon?
- How to solve other issues that may lead to potentially dangerous situations?
- How do platoons manage parking?

Table 2 - Use cases and suggested functionalities for other challenging situations on roads (when 'PSF' is mentioned, this means that the functionality applies to both platooning levels)

Use cases	Suggested functionalities	PAF /PSF
Highway entry ramps	• Traffic lights at the highway entry, showing "green to enter" for the platoon to avoid potential collisions with other vehicles. • Temporarily close a lane on the highway to allow the platoon to enter. The feasibility of this solution needs ad hoc validation with road operators.	PSF
Toll gates	• Using "digital vignettes" that allow the platoon to automatically go through the toll gates without stopping / braking. The platoon can also be recognized as one single entity. • V2I communication between the toll infrastructure and the platoon using a short-range Wi-fi connection. • Examples: o In France, Renault & Sanef have already used this kind of V2I communication (SCOOP Project) (transition, 2017). o Electronic toll collection already exists in China (JHCTECH ETC IPC), allowing automatic detection and identification of vehicles. Toll fees are paid without stopping. (JHCTECH, 2019)	PSF
Tunnels	• Depending on the traffic, to signal the need for increasing the time gap between trucks to secure a safe distance between vehicles (e.g. 2 seconds), manage the flows (slow down lighter vehicles), or stop the entire platoon. • Control the light intensity in the tunnel to enable optimum environment perception. • Turning on external displays in advance (external and internal lights). • Send out information on rain/snow outside of the tunnel before the trucks exit the tunnel to anticipate braking or to enlarge the gap.	PSF

Bridges	• Depending on the traffic, to signal the need for increasing the time gap between trucks to secure a safe distance between vehicles (e.g. 2 seconds), manage the flows (slow down lighter vehicles), or stop the entire platoon. • Turning on external displays in advance (external and internal lights).	PSF
Parking	• Provide information on platoon parking availability in advance of a truck stop/truck parking • Intelligent parking lots that guide platoons to specific parking spaces where they can park in formation, in an automated way.	PSF

Maximising efficiency

Improving fuel savings and traffic efficiency are part of the main goals of the ENSEMBLE project. Beyond avoiding the platoon to split, it is possible to further optimize fuel consumption by avoiding unnecessary decelerations, as well as planning more efficient routes for the platoon to take.

Table 3 - Use cases and suggested functionalities for maximizing efficiency (when 'PSF' is mentioned, this means that the functionality applies to both platooning levels)

Use cases	Suggested functionalities	PAF /PSF
Avoid braking / deceleration	• Send out messages that define "green zones" for platooning where platooning is authorized and where speed can be optimized. • Send out messages to allow traffic anticipation to avoid hard braking. • Provide traffic jam notifications to allow rerouting.	PSF

Interaction between the truck and the road	• Providing messages on dynamic speed limits to ensure a more efficient traffic flow depending on the vehicle density. (Data on traffic density can be acquired by on/off ramp sensors)
	    o Munich experimentation (REACT project) (REACT, 2006).
	    o Has been used to regulate traffic at peak hour.
	• Providing messages about potential issues on the road, and that could be dangerous for certain types of traffic like potholes for platoons.
		PSF

Dealing with road friction to maximise efficiency	• Send road sensor information on road friction estimation to the platoon. This might be used by the brake performance estimation to then calculate the safe time gap.	PAF

Localisation

Localisation is one of the fundamental capabilities that enables autonomous driving. It can be performed by the vehicle itself, whereby connectivity can help to improve the functionality. In a simple case, (cellular) connectivity can provide correction signals to optimize the GNSS (Global Navigation Satellite System) performance. Cellular connectivity can supply updates to the onboard HD map. Smart infrastructure could also support localization by providing information from an offboard environmental model. All this can support the correct identification of platooning partners, for instance.

Table 4 - Use cases and suggested functionalities for relative localisation (when 'PSF' is mentioned, this means that the functionality applies to both platooning levels)

Use cases	Suggested functionalities	PAF /PSF
Improving localisation	• Provide map update, provide correction signals for RTK (Real Time Kinematic) GNSS, send information in advance (e.g. topology of a tunnel) to anticipate problematic situations that may lead to a loss of signal, e.g., tunnels. In those cases, the platoon might choose to reduce speed or increase time gaps.	PSF

4.2. Services to facilitate acceptance

Safety & acceptance: informing other road users

Society and policy makers are not yet keen on adopting autonomous vehicles due to currently perceived state of technology to evaluate the safety of the people around the autonomous vehicle. Even though the large majority of road accidents are caused by human error, there is the need to further demonstrate that autonomous vehicles and multi-brand truck platooning do not compromise the safety of other road users. Sharing information, between the platoon and other road users, is required and this may consist, for example, of sending warnings between the vehicles with the support/relay of the infrastructure. In addition, autonomous functionalities like the PAF may anticipate dangerous situations and avoiding potential crashes.

Table 5 - Use cases and functional requirements for safety & acceptance: informing other road users (when 'PSF' is mentioned, this means that the functionality applies to both platooning levels)

Use cases	Suggested functionalities	PAF/PSF
Out of line-of-sight information	• V2V / V2I: receive information (shared by a other road users) if there is a crash, traffic jams, or other roadside accidents and send it to the platoon to allow rerouting or more efficient braking. This can be done also by sharing information about intentions to perform specific manoeuvres with the platoon. (infrastructure can spread the information along the highway also thanks to cellular connection)	PSF

	• Send messages to the platoon in zones where there is higher probability to have a crash. using algorithms, possibly based on AI and big data to analyse crash databases Send a warning when a critical situation is identified based on pattern recognition through recurrent neural networks, . • Example: o Already existing e-call. • Receive information about a blind intersection.	
Alerts / warnings from other road users to platoon	• Inform the platoon about vulnerable road users, about special purpose vehicles (e.g. ambulances), detected by infrastructure.	PSF
Alerts / warnings from platoon to other road users	• Inform other road users about messages sent by the platoon such as "Do not pass" warnings, exiting the roundabout or highway warnings, approaching a junction warnings or alerting other road users on the length of the platoon.	PSF
AI intervention in case of danger	• Anticipate dangerous situations or minimize the consequences of a crash by sharing information about speed limits, speed adaptation, synchronization between all the trucks, stability control, cruise control using AI • Accident and emergency management systems, airbags, pedestrian protection systems.	PSF
Control of the length of the platoon	• Send information about limitations on the total number of trucks in the platoon (e.g. reduce the occupation of the road by the platoon). This should be ideally known beforehand to ensure efficiency and therefore can be also shared by services based on cellular connectivity only.	PSF

Acceptance: limit the impact of platoons on the life of the infrastructure

The acceptance of multi-brand truck platooning by society also requires evidence on the fact that the platoon does not compromise the quality of infrastructure more than what other vehicles do. The question is how to effectively control and mitigate the platoon's effect on infrastructure.

Table 6 - Use cases and suggested functionalities for acceptance and extending the life of the infrastructure (when 'PSF' is mentioned, this means that the functionality applies to both platooning levels)

Use cases	Suggested functionalities	PAF/PSF
I2V control	• Send messages about limited size (number of vehicles), speed, and time gap of platoons on specific infrastructure sections based on safety and weather conditions.	PSF

Information on the impact to infrastructure	• Send information on road ageing and status of tunnels and bridges to the dynamic maps (this should be done beforehand to ensure efficiency and therefore can be also performed with a cellular only based service). • Here, the output from WP4 suggests that sending out the full configuration of the platoon (number of axles, axle configuration, total weight) could allow a better assessment of the aggressiveness to the road/bridges/etc. of specific platoons. This would allow for more flexible platooning authorizations than when the rule has to be set based on the most aggressive configurations of trucks (e.g. single axles are more aggressive to the road/bridges than coupled axles)	PSF
Specific routes or lanes for platoons	• Send information about suggestions on route/lane changes based on current truck/platoon density to the dynamic map. • Example: ○ Millennium bridge in London: "Move to the left".[1]	PSF
Integrating the platoon in the transport system	• Send information from all road transport operators and actors including private and commercial vehicles to enable automated vehicles in mixed traffic. • Send information to enable sensor fusion, supporting on-board decision making, and enable new HMI and active safety solutions (Association, 2022) • Send information to ensure smooth and safe coexistence of connected cooperative automated vehicles and all other road users and ensure a seamless exchange of data.	PSF

[1] See section on bride resonance https://en.wikipedia.org/wiki/Millennium_Bridge,_London

5. RECOMMENDATION FOR PROTOCOLS

Based on the outcome of the ENSEMBLE project, some requirements that improve platooning safety and performance, or ensure safety of infrastructure and other vehicles are not yet covered by existing standards. For example, it is likely that high level of autonomous driving will be ensured via the platoon manufacturer's backend, through the use of virtual maps updated in real time and transmitted to the platoon.

This section is listing recommendations to enhance the existing I2V/V2I communication standards to best cover the functional requirements listed in the previous chapter. The approach in ENSEMBLE for I2V/V2I has been to identify standard protocols, that were as close as possible to the desired behaviour, to leverage as much as possible existing standards. As mentioned before, this Deliverable addresses solutions based on connectivity that can be done using several options (ITS-G5, cellular communications, or backend interaction with the road management supervision). Services based on cellular connectivity only have been defined in D4.2 (J. Luetzner, 2022).

The following sources have been investigated to evaluate the best approach for a recommendation for a protocol:

- ISO 21217 (ISO21217, 2020)
- ISO TC204 (ISO/TC204, 1992)
- ETSI TS 103 301 (ETSITS103301, 2018)
- CEN TC 278 WG17 (2017). 17143:2017 (CEN/TR17143:2017, 2017)
- Final joint CEN/ETSI-Progress Report on Mandate M/453 (CEN, 2013)
- EU EIP SA42. European ITS Platorm. Autonomic functions implemented in existing ITS (EUEIP, 2016)

After the evaluation of all the resources mentioned before, it has been highlighted that ETSI norm TS 103 301 appears to be the best match available to cover the functional requirements listed in the previous chapter at the moment. The ETSI norm TS 103 301 (ETSITS103301, 2018) on "Intelligent Transport Systems (ITS); Vehicular Communications; Basic Set of Applications; Facilities layer protocols and communication requirements for infrastructure services" covers several of the required use cases. The V1.2.1 (2018-08) was used as the basis for this document. Within the ETSI specification, DEN messages have their own specific technical specification.

5.1. Traffic light management (TLM)

TLM is already automating some functionalities. It is recommended to build on top of these functionalities, an extension to include platoon management and negotiation, in order to facilitate passing through without split, or when there is not enough time, to stop the platoon. In any case, the objective is that the platoon passes as a single entity.

Some reminders about the existing functionalities for Traffic Light Management (TLM):

The TLM service uses Signal, Phase and Timing Extended Message (SPATEM) to disseminate the status of the traffic light controller, traffic lights and intersection traffic information. It transmits continuously in real-time the information relevant for all manoeuvres in the area of an intersection. The goal is to address all traffic participants using the intersection for travel or cross walking. Due to different equipment of end users, the SPATEM may be disseminated using different access technologies for short range or for long range communication.

The TLM service informs in real-time about the operational states of the traffic light controller, the current signal state, the remaining time of the state before changing to the next state, the allowed manoeuvres and provides assistance for crossing. Additionally, the TLM service foresees the inclusion of detailed green way advisory information and the status for public transport prioritization.

Traffic Light Control (TLC):

The Traffic Light Control service is one instantiation of the infrastructure services to manage the generation, transmission of Signal Request Message (SREM) and Signal request Status Extended Message (SSEM). The TLC service supports **prioritization of public transport and public safety vehicles** (ambulance, fire brigade, etc.) to traverse a signalized road infrastructure (e.g. intersection) as fast as possible or using a higher priority than ordinary traffic participants.

The corresponding **SREM** is sent by an ITS-S (e.g. vehicle) to the traffic infrastructure environment (e.g. R-ITS-S, TCC). In a signalized environment (e.g. intersection) the SREM is sent for requesting traffic light signal priority (public transport) signal preemption (public safety). *The service may not only be requested for the approaching signalized environment but also for a sequence of e.g. intersections along a defined traffic route.*

In response to the request the infrastructure (e.g. R-ITS-S/TLC or TCC) will acknowledge with a **SSEM** notifying whether the request has been granted, cancelled or changed in priority due to a more relevant signal request (e.g. ambulance). ETSI 27 ETSI TS 103 301 V1.2.1 (2018-08) (ETSITS103301, 2018)

Here is how these messages could be adapted to support platoon crossing:

Table 7 - Messages to support a platoon crossing a traffic light

Traffic Light	Message	Platoon
Broadcast	SPATEM >>	Listens to message including time to next status change.
		Calculates if it can go through in one go. *This calculation step is done within the platoon, based on its configuration.*
	<< SREM	When passing in one go is not possible: Request prioritization (increase green to secure full passage). *Add Platoon vehicle type to prioritization list with low priority.* *Add specific duration for full passage to transmit to traffic light.*
Accepts or declines prioritization	>> SSEM	Receives response
		Adapts speed based on response
		Monitor evolving conditions and restart process if needed, till manoeuvre is ended.

This workflow could be adapted to manage access ramps when critical ramps on platooning routes are identified and when these are equipped with traffic lights.

5.2. Sensitive infrastructure crossing management

For the first level of platooning, there are two key elements to be transmitted by the infrastructure: maximum speed and a minimum distance between vehicles. The limitation of the maximum speed is available in all European countries, but the use of the minimum distance is not. However, the road sign exists in most European countries[2] and it is in use to ensure safety in specific infrastructure, such as the Mont Blanc tunnel[3], and could be generalized to all sensitive infrastructure to ensure the safety of all users and to prevent damages to the infrastructure.

To transmit these two elements, the recommendation is to use the ETSI standard TS 103 301 V1.2.1 (ETSITS103301, 2018) on “Intelligent Transport Systems (ITS); Vehicular Communications; Basic

[2] https://en.wikipedia.org/wiki/Comparison_of_European_road_signs
[3] https://www.tunnelmb.net/en-US/traffic-regulations-and-rules-of-behaviour

Set of Applications; Facilities layer protocols and communication requirements for infrastructure services" to transmit the digital traffic signs for maximum speed and minimum distance between vehicles.

The message to be used are the Infrastructure to Vehicle Information Messages (IVIM) described in TS 103 301 (ETSITS103301, 2018). An IVIM supports mandatory and advisory road signage such as contextual speeds and road works warnings. An IVIM can be transmitted based on specific timings (e.g. only valid between 8:00 and 20:00) and due to the context (e.g. applicable in case of fog).

The two digital traffic signs to be used are standardized in the graphic data dictionary (GDD) of the ISO document TS 14823 (ISO14823, 2017), developed to create a common basis for transmitting encoded information for existing road traffic signs and pictograms. It supports Intelligent Transport System (ITS) application such as in-vehicle signage or in-vehicle information. The two digital signs to be used in the case of platooning are:

- International Sign-maximumSpeed
- International Sign-distanceBetweenVehicles

The sign for distance between vehicle is an optional attribute of the graphic data dictionary structure. It corresponds to the signs shown below, in the case of a minimum distance of 150 meters for all vehicles or 70 meters for vehicles over 3,5T respectively:

Figure 1 - Traffic signs for inter-vehicle distance

The International Sign-distanceBetweenVehicles is a GDD optional attribute.

5.3. Signalling presence to all other users

Table 8 - Messages to signal the presence to all other users

Roadsite unit	Message	All users, including road side units
Notifies platoon presence when reaching the area of the sensitive infrastructrure *New type of alert for signalling platoon presence* *Vehicle type is platoon*	>> DENM / CAM	*Detect Platoon arrival in vicinity and trigger IVI update (if necessary).*

5.4. Introduce specific speed limits for specific populations such as platoons.

Table 9 - Messages to set specific speed limits for dedicates users (e.g. platoons)

Road side unit	Message	Platoon
Broadcast of specific truck speed and inter-distance. *Systematically use time gap/ inter-distance to broadcasted messages* *Introduce specific broadcast of recommended speed for platoons (or just for trucks)*	IVIM >>	Listens to broadcasted information, including potential speed and/or time gap / inter-distance recommendation
		Adapts speed and/or inter-distance based on safety requirements

6. SUMMARY AND CONCLUSIONS

Summary

Regarding the interaction with intelligent infrastructure, this deliverable introduced the concept of intelligent infrastructure and potential services linked to multi-brand platooning and links to the challenges that multi-brand truck platooning might face. The deliverable links to other documents prepared as part of the ENSEMBLE project, notably to WP4, where assessment of the impact of platoons have been conducted and where further services, to be brought only via cellular networks, have been investigated (T4.2).

In a second part, this deliverable provides a non-exhaustive list of services and functional requirements for multi-brand truck platooning, divided into two categories: 1) services to support the platoon and make it more efficient; and 2) services to facilitate user acceptance, with a specific focus on acceptance from the road operators, as the pressure on infrastructure increases with truck traffic increase and climate change.

In a last section, suggestions have been made on how to adapt existing standard protocols to include the required functionalities to support platooning. The objective is the standardization of a communication protocol with the infrastructure (V2I), to secure at least the minimum requirements for platoons to be used safely and to be accepted by other users and infrastructure managers.

Conclusions and suggested next steps

Based on the work done within the ENSEMBLE project and our research of existing protocols, some of the obstacles to multi-brand platoon circulation could be managed on the main axis:

- the introduction of smart traffic light management: to avoid breaking of the platoon in case of automated platooning (PAF) at intersections and roundabouts,
- ramp management: for easy and safe merging onto the highway of both the platoon and other traffic (while a platoon is close by),
- the systematic use of the maximum speed and minimal time gap: to secure acceptance by infrastructure managers and other road users.

In terms of next steps regarding infrastructure, planned or real time interactions with the infrastructure has the potential to dramatically reduce the ageing of infrastructure, whilst maintaining acceptable restriction levels. *Not all jurisdictions have taken advantage of the opportunities to improve pavement wear performance of existing vehicle combinations. The additional capacity that flexible regulation can achieve through authorising high productivity vehicles for use in the right circumstances needs to be exploited* (OECD, 2018). This is especially relevant for platoons and the required information transmission could be standardized. The required messaging for traffic management (traffic lights, bridges) exists, but may be improved with the introduction of an additional vehicle type: platoon. This way specific messaging to a platoon becomes possible. Also an extension of certain message contents may improve safety, efficiency and acceptance like e.g. maximum length of a platoon, platooning allowed/prohibited on certain road section/lane, presence of a platoon on a road section, specific platooning speed, do not pass platoon, etc.

Finally, for further developments, specific backend platforms and virtual maps communicating via cellular networks only, will most likely be required to secure a safe and efficient experience to all, as can be found in T4.2.

7. BIBLIOGRAPHY

Bibliography

Association, C. P. (2022). *CCAM Partnership SRIA*. Retrieved from CCAM Partnership Association: https://www.ccam.eu/wp-content/uploads/2022/01/CCAM-Partnership-SRIA-FINAL-2021.pdf

B. Atanassow, K. S. (2022a). *D2.8 - Platooning protocol definition and Communication strategy.* H2020 Project ENSEMBLE.

B. Atanassow, K. S. (2022b). *D2.9 - Security Framework of Platooning.* H2020 Project ENSEMBLE.

C. Villette, F. S. (2018). *D2.6 Functional specification for intelligent infastructure and platooning coordination services - Stretegic and Services Layers.* IFSTTAR.

CEN. (2013). *Final joint CEN/ETSI-Progress Report to the European Commission.* ETSI.

CEN/TR17143:2017. (2017). *Intelligent transport systems - Standards and actions necessary to enable urban infrastructure coordination to support Urban-ITS.* CEN.

development, G. M. (2014). *Roads in the 21st century, Innovativ road contruction in Germany*. Retrieved from https://www.bast.de/EN/Publications/Media/S-roads-21st-century.pdf?__blob=publicationFile&v=1

ETSITS103301. (2018). *ITS - Vehicular Communications - Basic Set of Applications - Facilities Layer protocols and communication requirements for infrastructure services.* ETSI.

EUEIP. (2016). *EU EIP SA42.* EUEIP.

FEHRL. (2018). *Forever Open Road Initiative - a roadmap for research*. Retrieved from Forever Open Road Initiative: https://www.foreveropenroad.eu/forx4/document

Hove, H. A. (2019). *The ferry Free E39 Program*. Retrieved from Norwegian Public Roads Administration: https://www.ntnu.edu/kt/research/concrete/projects/e39-ferry-free

IDDRIM, I. H. (n.d.). *Route 5e Generation*. Retrieved from IDDRIM: https://www.idrrim.com/ressources/documents/3/1675,route-de-cinquieme-generation.pdf

ISO/TC204. (1992). *Intelligent transport systems.* ISO.

ISO14823. (2017). *Intelligent transport systems - Graphic data dictionary.*

ISO21217. (2020). *Intelligent transport systems — Station and communication architecture.* ISO.

J. Luetzner, e. a. (2022). *D4.2 - Results of Service & strategic layer design.* H2020 Project ENSEMBLE.

JHCTECH. (2019). *Intel and JHCTECH Jointly Create ETC Solutions Based on Intel® Architecture*. Retrieved from https://trends.directindustry.com/jhctech/project-210517-1115699.html

Mascalchi E., e. a. (2022). *D2.5 - Final Version Functional specification for white label truck.* H2020 Project ENSEMBLE.

OECD. (2018). *Policies to extend the life of road assets*. Retrieved from OECD: https://www.itf-oecd.org/sites/default/files/docs/policies-extend-life-road-assets.pdf

REACT, P. (2006). Dynamics of variable speed limit system surrounding bottleneck german autobahn. *Transportation research record journal of the transportation reserach board*.

transition, F. M. (2017). *C-ITS French Use Cases Catalogue*. Retrieved from Directorate General for infrastructure transport and the sea: http://www.scoop.developpement-durable.gouv.fr/IMG/pdf/20200421_c-its_french_use_cases_catalog_v5.pdf

USA, D. o. (2015). *Positioning Challenges and Vision for Transportation*. Retrieved from Exploratory Advanced Research (EAR) Program: https://highways.dot.gov/sites/fhwa.dot.gov/files/docs/research/publications/multimedia/6591/position.pdf

Willemsen, D. S. (2022). *D2.3 - Platooning use cases, scenario definition and Platooning Levels.* H2020 Project ENSEMBLE.

8. APPENDIX A. - GLOSSARY

Term	Definition
Convoy	A truck platoon may be defined as trucks that travel together in convoy formation at a fixed gap distance typically less than 1 second apart up to 0.3 seconds. The vehicles closely follow each other using wireless vehicle-to-vehicle (V2V) communication and advanced driver assistance systems
Cut-in	A lane change manoeuvre performed by vehicles from the adjacent lane to the ego vehicle's lane, at a distance close enough (i.e., shorter than desired inter vehicle distance) relative to the ego vehicle.
Cut-out	A lane change manoeuvre performed by vehicles from the ego lane to the adjacent lane.
Cut-through	A lane change manoeuvre performed by vehicles from the adjacent lane (e.g. left lane) to ego vehicle's lane, followed by a lane change manoeuvre to the other adjacent lane (e.g. right lane).
Ego Vehicle	The vehicle from which the perspective is considered.
Emergency brake	Brake action with an acceleration of <-4 m/s2
Event	An event marks the time instant at which a transition of a state occurs, such that before and after an event, the system is in a different mode.
Following truck	Each truck that is following behind a member of the platoon, being every truck except the leading and the trailing truck, when the system is in platoon mode.
Leading truck	The first truck of a truck platoon
Legal Safe Gap	Minimum allowed elapsed time/distance to be maintained by a standalone truck while driving according to Member States regulation (it could be 2 seconds, 50 meters or not present)
Manoeuvre ("activity")	A particular (dynamic) behaviour which a system can perform (from a driver or other road user perspective) and that is different from standing still, is being considered a manoeuvre.
ODD (operational design domain)	The ODD should describe the specific conditions under which a given automation function is intended to function. The ODD is the definition of where (such as what roadway types and speeds) and when (under what conditions,

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Term	Definition
	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

Term	Definition
Platoon dissolve	All trucks are disengaging the platoon at the same time. A.k.a. decoupling, a.k.a. disassemble.
Platoon engaging	Using wireless communication (V2V), the Platoon Candidate sends an engaging request. When conditions are met the system starts to decrease the time gap between the trucks to the platooning time gap. A.k.a. join platoon
Platoon formation	Platoon formation is the process before platoon engaging in which it is determined if and in what format (e.g. composition) trucks can/should become part of a new / existing platoon. Platoon formation can be done on the fly, scheduled or a mixture of both. Platoon candidates may receive instructions during platoon formation (e.g. to adapt their velocity, to park at a certain location) to allow the start of the engaging procedure of the platoon.
Platoon split	The platoon is split in 2 new platoons who themselves continue as standalone entities.
Requirements	Description of system properties. Details of how the requirements shall be implemented at system level
Scenario	A scenario is a quantitative description of the ego vehicle, its activities and/or goals, its static environment, and its dynamic environment. From the perspective of the ego vehicle, a scenario contains all relevant events. Scenario is a combination of a manoeuvre (“activity”), ODD and events
Service layer	The service layer represents the platform on which logistical operations and new initiatives can operate.
Specifications	A group of two or more vehicles driving together in the same direction, not necessarily at short inter-vehicle distances and not necessarily using advanced driver assistance systems
Steady state	In systems theory, a system or a process is in a steady state if the variables (called state variables) which define the behaviour of the system or the process are unchanging in time. In the context of platooning this means that the relative velocity and gap between trucks is unchanging within tolerances from the system parameters.
Strategic layer	The strategic layer is responsible for the high-level decision-making regarding the scheduling of platoons based on vehicle compatibility and Platooning Level, optimisation with respect to fuel consumption, travel times, destination, and impact on highway traffic flow and infrastructure, employing cooperative ITS cloud-based solutions. In addition, the routing of vehicles to allow for platoon forming is included in this layer. The strategic layer is implemented in a

Term	Definition
	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).

8.1.1. Acronyms and abbreviations

Acronym / Abbreviation	Meaning
ACC	Adaptive Cruise Control
ADAS	Advanced driver assistance system
AEB	Autonomous Emergency Braking (System, AEBS)
ASIL	Automotive Safety Integrity Level
ASN.1	Abstract Syntax Notation One
BTP	Basic Transport Protocol
C-ACC	Cooperative Adaptive Cruise Control
C-ITS	Cooperative ITS
CA	Cooperative Awareness
CAD	Connected Automated Driving
CAM	Cooperative Awareness Message
CCH	Control Channel
DEN	Decentralized Environmental Notification
DENM	Decentralized Environmental Notification Message
DITL	Driver-In-the-Loop
DOOTL	Driver-Out-Of-the Loop
DSRC	Dedicated Short-Range Communications
ETSI	European Telecommunications Standards Institute
EU	European Union
FCW	Forward Collision Warning
FLC	Forward Looking Camera
FSC	Functional Safety Concept
GN	GeoNetworking
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GUI	Graphical User Interface

Acronym / Abbreviation	Meaning
HARA	Hazard Analysis and Risk Assessment
HIL	Hardware-in-the-Loop
HMI	Human Machine Interface
HW	Hardware
I/O	Input/Output
IEEE	Institute of Electrical and Electronics Engineers
ISO	International Organization for Standardization
ITL	In-The_Loop
ITS	Intelligent Transport System
IVI	Infrastructure to Vehicle Information message
LDWS	Lane Departure Warning System
LKA	Lane Keeping Assist
LCA	Lane Centring Assist
LRR	Long Range Radar
LSG	Legal Safe Gap
MAP	MapData message
MIO	Most Important Object
MRR	Mid Range Radar
OS	Operating system
ODD	Operational Design Domain
OEM	Original Equipment Manufacturer
OOTL	Out-Of The-Loop
PAEB	Platooning Autonomous Emergency Braking
PMC	Platooning Mode Control
QM	Quality Management
RSU	Road Side Unit
SA	Situation Awareness

Acronym / Abbreviation	Meaning
SAE	SAE International, formerly the Society of Automotive Engineers
SCH	Service Channel
SDO	Standard Developing Organisations
SIL	Software-in-the-Loop
SPAT	Signal Phase and Timing message
SRR	Short Range Radar
SW	Software
TC	Technical Committee
TOR	Take-Over Request
TOT	Take-Over Time
TTG	Target Time Gap
V2I	Vehicle to Infrastructure
V2V	Vehicle to Vehicle
V2X	Vehicle to any (where x equals either vehicle or infrastructure)
VDA	Verband der Automobilindustrie (German Association of the Automotive Industry)
WIFI	Wireless Fidelity
WLAN	Wireless Local Area Network
WP	Work Package