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ENSEMBLE

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

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Revision history

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1. EXECUTIVE SUMMARY

1.1. 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 has been the ambition of ENSEMBLE to realise pre-standards for interoperability between trucks, platoons and logistics solution providers, to speed up actual market pick-up of (sub)system development and implementation and to enable harmonisation of legal frameworks in the member states.

1.2. Project scope

The main goal of the ENSEMBLE project is to pave the way for the adoption of multi-brand truck platooning in Europe to improve fuel economy, traffic safety and throughput. This 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 are:

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

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

1.3. Abstract of this Deliverable

This deliverable, entitled "Recommendations & Roadmap", gives a short overview of the results of the project and the major recommendations about multi-brand truck platooning and a roadmap towards its implementation.

2. INTRODUCTION

2.1. Background

Multi-brand truck platooning is the linking of two or more trucks in convoy, using connectivity. technology and automated driving support systems. While platooning is not a new concept, ENSEMBLE has made it possible to extend this technology to trucks of different brands. Before ENSEMBLE, mono-brand platooning has been demonstrated in Europe by the European Truck Platooning Challenge in 2016.

ENSEMBLE has gathered six truck OEMs, major suppliers, the European association of suppliers (CLEPA), the ITS community (ERTICO), and R&D entities (TNO, UGE, KTH, VUB) in the project. The participation of such a big number of industrial entities made possible the creation and the implementation of a platooning functionality with the agreement of many partners and stakeholders.

In WP4 of ENSEMBLE, studies have been performed on the impact of platooning, even from the business perspective. The outcomes of this research work have shown that the benefits are not so straightforward; for example, in real-life scenarios, the reduction in fuel consumption is not realistic for the Platooning Support Function, since it has following distances comparable to ACC. Other benefits, like increase of road capacity, need a careful implementation of truck platooning to be realisable. At the same time, the trend of the last years has shown a growing interest of many stakeholders in Europe on Connected Cooperative Autonomous Mobility (CCAM), that led also to the creation of a new European Partnership under the R&D programme Horizon Europe 1. This Partnership clearly shows that, in order to achieve automated vehicles on the road, an ecosystem approach is needed. This is because the advancements towards cooperative automation need also investments on infrastructure rather than the vehicle only. This is also aligned with the definition of the Platooning Autonomous Level, the second more automated platooning level defined in D2.5, that underlines the need of particular technologies provided by infrastructure (e.g. intelligent traffic lights).

Therefore, this deliverable will list recommendations based on the results of the project. Then, the roadmap itself will not be concentrated on multi-brand truck platooning only, but will also have a wider perspective on connected and automated mobility in general. This has been done because the outcomes of the ENSEMBLE project (e.g. the communication protocol) can also be used as an enabler for other (cooperative) automated functionalities; not only on trucks but any vehicle in general.

[1] https://www.ccam.eu/

2.2. Methodology

The issue of implementation and insertion of multi-brand truck platooning on open roads is linked to many other issues, as for example:

- automated and connected mobility,
- optimized freight transportation,
- collaboration with smart, resilient, adaptable infrastructure.

These points are already treated in specific, existing roadmaps. The current deliverable will be based mainly on these roadmaps, namely:

- ERTRAC: the ERTRAC CCAM roadmap (ERTRAC, 2022),
- ALICE: several roadmaps have been worked on, namely the urban freight roadmap (ALICE, 2016b), the Corridors, Hubs and Synchromodality roadmap (ALICE, 2016a), the Sustainable, Safe and Secure supply chain roadmap ((ALICE, 2019), and the Information systems for interconnected logistics roadmap (ALICE, 2014),
- FEHRL: the automated, adaptable and resilient roadmaps (FEHRL, 2013b, 2013a, 2019),
- CEDR: The position paper on road safety (CEDR, 2017),
- The CCAM Partnership (*CCAM Partnership Strategic Research and Innovation Agenda*).

2.3. Structure of this report

This deliverable is organized in three chapters: the first one will list and summarize the technical results from the technical Work Packages of project ENSEMBLE (WP2, 3 and 4). In the second chapter, recommendations will be given concerning the future of truck platooning, and/or the needs for safe implementation. Then, this report will give very succinctly, a roadmap for multi-brand truck platooning. Appendix A lists activities performed by the ENSEMBLE partners to discuss the roadmap, and disseminate it.

3. ENSEMBLE RESULTS

3.1. Impact on technology alignment and development

The main contribution of ENSEMBLE is the multi-brand definition of:

- Platooning Levels: Platooning Support Function (PSF) and the Platooning Autonomous Function (PAF),
- Use Cases for both platooning levels,
- Requirements and Specifications for both levels,
- Communication Protocol for PSF, and prepared for the PAF.

In addition to that, safety analyses have been performed for both levels.
The main documents that describe the two platooning levels defined in ENSEMBLE are:

- Levels definitions and Use Cases – D2.3 (Willemsen, Schmeitz, Mascalchi, et al., 2022),
- Requirements and Specifications - D2.5 (Willemsen, Schmeitz, Nordin, et al., 2022).

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

- V2X Protocol - D2.8 (Cécile Villette, 2018),
- Security - D2.9 (Atanassow et al., 2022),
- Intelligent infrastructure - Strategic and Services Layers – D2.6 (Cécile Villette, 2022) and D2.7 (Cécile Villette, 2021).

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

- Safety of the intended functionality (SOTIF) - D2.13 (Dhurjati et al., 2022),
- Functional Safety - D2.14 (Pezzano et al., 2022),
- Item Definition - D2.15 (Prashanth Dhurjati et al., 2022).

The Platooning Support Function has also been implemented and tested by all 7 truck brands that were part of ENSEMBLE. By doing this, the use cases, specifications and requirement were consolidated and the feasibility of the technology was demonstrated. The deliverables mentioned above have been updated with the findings of the implementation and testing.

Furthermore, a reference implementation of PSF on the basis of the use cases, specifications and requirements has also been developed and made available to the public o.a. to serve as a first verification of the use cases, specifications and requirements and as an example for standardisation:

- D3.1 Detailed design of the unbranded Tactical Layer (Schmeitz, 2019a),
- D3.2 Operational (non-automotive grade) ITS-G5 V2X communication, supporting the multi-brand truck (de Jongh, 2019),

- D3.3 Generic open-source RCP-level reference implementation of the Tactical Layer (Schmeitz, 2019b).

3.2. Impact on infrastructure

The wear induced by platoons might be less or more than the current situation, depending on the parameters of the platoon (number of trucks, loading, lateral position, etc.) and the definition of the "current situation" (heavy traffic, speed limit, etc.).

Platooning gives the possibility to "steer" the parameters to minimize and adapt the impact of platooning for a specific road.

Platoons could be a solution for higher traffic flow in tunnels (need for investment), or tunnels could be a bottleneck for trucks to pass because of the very long safety distance required in tunnels.

3.3. Platoon matching

Cross fleet matching services will add value by improving the likelihood of finding a platooning partner. Currently, Weigh-In-Motion data show that 14,51% of all trucks follow another truck with an inter-vehicle time gap of less than 2 seconds.

Platoon potentials have also been assessed with real logistical data from a subpopulation of the DAF fleet in the Netherlands region. The simulation has shown that, for a (sub)population of 5500 vehicles that have driven a daily aggregated average of 700.000 km, 14% of the total travel distance could have been driven as part of a platoon (assuming a match distance of 1000 m), if the technology was available and operational in the vehicles. This match rate has been determined without any changes to the schedules or routes of the vehicle, this implies that the match-rate might be higher when optimizations are considered.

3.4. Economic benefits

With more favourable core benefits to carriers, substantially higher fuel prices, or favourable spatial and traffic conditions, market uptake of platooning is possible (if the cost savings are on average about 3% or more, and if the cost of equipping a truck for platooning is 5k€ or less).

The spatial configuration is critical: the issue is both that of the road network configuration, and that of the commercial life cycle of trucks

The market shows inertia. It will take years for the market to mature, regardless of the long term market uptake

There is no reason to believe that Platoon Service Providers will be interoperable without regulation.

3.5. Fuel consumption and emissions

From the real-life tests with the implemented platooning support function we found:

- A negligible effect on fuel consumption and CO_2 emissions.
- A negligible impact was found on pollutant emissions from the exhaust for Euro VI and up, due to application of emissions abatement, that works very efficiently at cruising speeds.
- A negligible impact was found on NEE (non-exhaust emissions) because no large changes in driving dynamics and speeds are expected.

3.6. Impact on other road users

During driving simulator experiments, it was observed that the interactions between the platoon and the other road users give lead to different behaviours and feelings of the drivers of light vehicles. During an overtaking or exiting from the highway, the study shows that most of the drivers of light vehicles prefer to adopt a safety behaviour respecting the speed limit and/or waiting behind the platoon. When entering the highway, however, drivers showed not to wait until the platoon has passed, especially when the platoon is relatively long (7 trucks). In this case they cut in between the platoon to enter the highway and avoid dropping their speeds too much, although the insertion speed was found to be lower than the speed of the platoon. When encountering platoons of 3 trucks, the driving simulator studies show no cutting in behaviour.

3.7. Impact on traffic flow

Truck platoons, as part of mixed traffic, are potentially able to increase road capacity and to postpone and mitigate traffic congestions. However, at merging areas it was found that adverse impacts on road capacity can occur when merging traffic enters the mainline traffic with a lower speed. The impact largely depends on the penetration rate of trucks in as part of the traffic flow and the platoon control settings (lane management and platoon coordination).

Assuming 20% of the trucks are equipped with the platooning function, impacts of platooning on traffic flow with a large truck ratio are more significant and positive, compared to the impacts with a small truck ratio. It suggests that the expected improvements and benefits from truck platoon operation are largely affected by the mixed traffic conditions. For truck platooning it is therefore more beneficial for traffic flow to be operated in the traffic where trucks take a large composition of the traffic, e.g. industrial areas or port areas.

The impacts of truck platoons on road capacity were found to be different between support and autonomous platooning, due to the difference in distance between the trucks. Truck platoons with a smaller following gap show fewer improvements to road capacity than platoons with a larger following gap at a merging bottleneck.

3.8. Overall results

The main results of project ENSEMBLE are:

- A multi-brand platooning technology agreed between all European OEMs, consisting of two levels: Platooning Support Function (driver is in charge in each truck) and Platooning Autonomous function (only a driver in charge of the first truck),
- A definition of multi-brand Platooning Support Function ready for standardization,
- Different use case definitions based on situations encountered in normal traffic, for both platooning functions
- Specifications and requirements for both platooning functions,
- A general impact assessment, for which open points have been highlighted.

4. RECOMMENDATIONS

4.1. Technology alignment and development

From the implementation and testing, the following recommendations can be made with respect to technology research and development needs:

- Alignment and quality of the data sent through the platooning messages (mainly PCM): The signals in the V2X messages contain measurement values from different data sources having different refresh cycle times. For instance, most data from the vehicle CAN have a much shorter refresh cycle than measurements of a GNSS receiver. An additional requirement might be needed to define multiple timestamps separated for groups of signals having similar refresh cycles. Moreover, specific processing, like e.g. filtering, of certain signals has not been considered/discussed, but may be required when these data are going to be used for more closed loop control.

- To identify the platooning partner (i.e. is the vehicle driving directly ahead indeed the vehicle sending the messages) a routine has been defined for the PSF. This routine may be too conservative and other technologies (e.g. improved positioning, data matching algorithms, etc.) are expected to provide faster and better results.

- Signing and verification: this appeared to be computationally demanding during testing. The platooning message PCM is sent with a frequency of 20Hz. These PCMs are currently signed, verified and encrypted. Encryption is relatively computationally cheap. It is probably sufficient from a security perspective to only encrypt PCMs and skip the signing and verification or do the signing and verification with a lower rate. However, further developments in the field of implementation of signing and verification may also solve this bottleneck.

- More specifically for the PAF, apart from what is already needed for automated driving: a reliable brake performance estimation. This function is the enabler for achieving smaller time gaps than 1.2 s and therefore offers typical platooning benefits like energy savings and improved road capacity. Furthermore, the smaller time gaps are an important strategy to discourage cut-in actions to happen that might split the platoon.

4.2. Infrastructure

The benefit of platooning is that road authorities are given the possibility to influence the parameters according to which the trucks are driving on their pavements. Depending on the state of the road infrastructure and the specific situation, road authorities can request a certain headway, maximum speed, number of trucks in one platoon, inter-truck time gaps and even a specific lateral position.

As an indirect benefit also the digitalization (enabled) by platooning allows road authorities for monitoring and regulating freight transport, especially when trucks share precise data about their trip. This could lead to win-win situations, where trucks sharing (anonymized and secure) data about their journey are given easier access to the road (for example, allocated priority access to toll gates or reserved lanes).

In tunnels, the benefit of platooning is that it gives the possibility to decrease the current huge distances between trucks, if some conditions are met. This will lead to a higher flow of trucks through the tunnel and therefore to more efficient logistics around tunnels. In combination with an information sharing functionality on loads as part of the service layer the tunnel authority might be able to respond more adequate to potential incidents.

These positive impacts are only possible if road infrastructure, be it the road itself or specific locations like bridges or tunnels, are equipped with sensing possibilities and connectivity/communication means. Therefore, there is a need of investment. A recommendation linked to the infrastructure part of the multi-brand platooning (or CCAM) assessment would be to assess the global benefits for well-chosen case studies: on one side, the investment needs have to be listed, on the other side the potential benefits should be assessed. For that, both private and public roads (or road authorities) have to be considered, as their business cases are different.

4.3. Platoon matching

Looking at the current traffic situation (without any platooning), matching simulations show that at least 15% of all trucks could benefit from platooning with at least 2 trucks. This is because they are already following at distances corresponding to those of the ENSEMBLE support function. The actual implementation of the ENSEMBLE support function could give the expected benefits without having to change their behaviour.

A platoon matching service can enable and support the forming of multi-brand platoons. Given that matching is mainly a (technical) planning and optimization problem it only provides a part of the puzzle. Next to matching, it is also important to consider a method in which the earnings generated by the cooperation of competing entities are divided. Finally, it must be determined which data and under which circumstances any cross-fleet data can be shared.

4.4. Economic benefits

Economic analysis has shown that market uptake (carriers buying the platooning functionality) can take place when the net cost savings are 3% or more for trucks in platoon. European and member state regulations can influence these net costs by supporting and/or mandating the implementation of platooning functionalities in new trucks. However, this is not a quick solution since trucks have an average life cycle of about 7 years. Also, the interoperability of different platoon service providers should be regulated.

Also of influence on the market uptake are policy measures, like mandating data sharing and an accompanying communication box to enter cities or regions that might employ future ‘Urban Vehicle Access Regulation’ schemes, such as intelligent access dynamic emission zones.

It is difficult to make a reliable business case given the uncertainties regarding the required technological developments for the platooning autonomous function. It is relatively easy to assume and calculate the benefits, but the (development-) costs are very uncertain. Also, we cannot predict when a platooning autonomous function will be available for the market.

4.5. Fuel consumption and emissions

As expected from earlier research, ENSEMBLE found that the platooning support function does not show an effect in fuel consumption and emissions during the real life tests on the test track and on the public roads. This is due to the fact that the platooning support function is following at 1.5 s, which is not significantly closer compared to the current driving situations on the roads.

As part of autonomous function, with headways lower than 1 s, potential effects on fuel consumption and emissions are feasible, but this requires further testing under circumstances that represent real-life logistical operations.

4.6. Impact on other road users

The ENSEMBLE driving simulator study has shown that other drivers on the highway will wait behind the platoon to take an exit.

When entering the highway, however, drivers do not wait until the platoon has passed. Specifically in the case when the platoon is relatively long (7 trucks). In this case they cut in between the platoon to enter the highway and avoiding dropping their speeds too much, although the insertion speed was found to be lower than the speed of the platoon.

Based on the driving simulator studies it is advised to avoid long platoons of 6 trucks or more.

4.7. Impact on traffic flow

ENSEMBLE micro simulation studies have shown that truck platooning can increase road capacity. The effect depends on the ratio of truck platoons as part of the total traffic and the location in the network. For example at merging areas it was found that adverse impacts on road capacity can occur when merging traffic enters the mainline traffic with a lower speed.

The ENSEMBLE studies also show that the positive effect of truck platooning on road capacity increases when the percentage of trucks in the total traffic flow is high (around 30%).

The impacts of truck platoons on road capacity were found to be different between support and autonomous platooning due to the difference in gap distance between the trucks. Truck platoons with a smaller following gap show fewer improvements to road capacity than platoons with a larger following gap at a merging bottleneck.

The suggestion that follows from these results is that it is beneficial for road capacity and traffic flow to avoid truck platooning on road segments with a lot of highway entries. Hub to hub platooning and platooning at night can be a very good solution. This is also in line with the finding that it is more beneficial for traffic flow that truck platoons are operated in traffic where trucks take a large part of the traffic, e.g. industrial areas or port areas.

Also road operators can potentially mitigate adverse effects by temporally increase the platooning headways to allow merging traffic to fluently enter the mainline traffic. And they can take advantage of platooning trucks to increase their road capacity by applying temporal large following gaps near merging bottlenecks. The V2I and I2V communication possibility of platoons can be used to announce the presence of a platoon to the ramp metering installations, such that these installations can adjust the traffic that is merging into the highway.

4.8. Overall recommendations

The overall conclusion from the implementation and testing of the Platooning Support Function was that it is technically feasible, as described in the deliverables. Currently the specifications and requirements are taken into consideration for standardization at ETSI and ISO. The studies on the impact of platooning give a variated view on the matter and the impact also depends on the specific parameter settings used by the platoon (e.g. the following distance, length of the platoon).

Considering the Platooning Support Function, some changes are needed to legislation and enforcement: although the safety analysis in ENSEMBLE showed that time gaps of around 1.5 s are safe for the PSF, driving at around 1.5 s results in following distances that are shorter than currently legally allowed. It should be noted that this situation in principle exists already for decades for vehicles equipped with ACC systems, and that drivers may already follow other trucks at shorter intervehicle distances than legally allowed compromising safety. Obviously, the benefit that the PSF offers compared to the current situation is that safety is not compromised. Considering this, it seems to be logical to legally allow smaller time gaps for vehicles driving in platoons with the PSF engaged. The latter might offer a challenge in enforcement: how to distinguish trucks driving safely at close distance with the PSF engaged and other non-PSF trucks driving at similar close following distances?

Finally, for the PSF, market penetration is of the essence: sufficient other vehicles should be equipped with a PSF function in order for it to work. At least two vehicles are needed, but for benefits that make a significant impact on societal level (e.g. to improve traffic safety, throughput) many platooning enabled vehicles are required. The developed (technical) multi-brand solution in ENSEMBLE is an important step for the adoption of multi-brand truck platooning, but more is needed to achieve sufficient market penetration of platooning. The economic benefits study has shown that, especially for the PSF, market uptake by the users of the trucks is not a ‘paved road’. Since the benefits are mainly expected in terms of safety, incentives from regulatory bodies are more likely to support market penetration.

To provide a future vision of platooning to accelerate and initiate research and development into next levels of platooning and (digital) infrastructure, and to reflect on potential future needs for adaptation of regulations, the Platooning Autonomous Function (PAF) was defined in the ENSEMBLE project. The specification of the PAF 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. Most of the technical challenges for the PAF are also general challenges in the development of autonomous vehicles, such as precise localisation, perception, etc. However, one important challenge in the development of Autonomous Platooning that stands out is the development of a reliable brake performance estimation function. This function is the enabler for achieving smaller time gaps than 1.2 s and therefore offers typical platooning benefits like energy savings and improved road capacity.

5. ROADMAPS

5.1. New European CCAM partnership

The CCAM Partnership (Connected Cooperative Autonomous Mobility) (Https://www.ccam.eu/) gathers 180 innovation stakeholders, in order to:

- Assess the impacts and understand user and societal effects to harmonise European R&I efforts to accelerate awareness and implementation of innovative CCAM technologies and services,

- Exploit the full systemic benefits of new mobility solutions enabled by CCAM: increased safety, reduced environmental impacts, and inclusiveness.

Platooning is linked to CCAM as "platooning and higher-levels of automation can increase the resilience of supply chains by enabling goods to move with less, or even without, human intervention, broadening access to citizens and destinations in critical areas or under exceptional circumstances such as pandemics" (*CCAM Partnership Strategic Research and Innovation Agenda*).

Connected, Cooperative and Automated Mobility (CCAM) will create new opportunities, but also face new challenges. Nevertheless, the roadmaps need to make the technology available and cost efficient to ensure its generalized usage.

Since multi-brand truck platooning can be seen as one segment of CCAM, the next paragraphs will be in general about CCAM.

5.2. Market and business roadmap

Business models need to be established, tested and validated with the numerous co-actors of the CCAM ecosystem (ERTRAC, 2022). In particular, there might be the need to involve national or public bodies, in order to include also advantages or positive impacts whose value cannot be estimated easily: for example, road safety increase, fuel consumption or emissions reduction, reduction or optimization of road wear/damage compared to the traffic flow (FEHRL, 2013b), increase road capacity and therefore travel time reduction, etc. These impacts will have to be analysed jointly, and not independently of each other. Research and development of new public and private business and cooperation patterns (and the associated payments) need to be investigated. These new types of business models innovation and governance ('orgware') have to be encouraged with best collaborative practices and approaches for fast deployment of innovations (ALICE, 2016a).

In order to tend towards road safety and CEDR's Vision Zero (CEDR, 2017), the need for **geofencing and procurement** has been highlighted. To improve road safety, a first solution has been given, namely speed management. Nevertheless, the measures in terms of **traffic**

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management have to be adapted, based on specific needs and on the various approaches across Europe and individual jurisdictions.

The **regulation** needs to be adapted for CCAM: in specific corridors where the conditions and information are optimal, the regulation must ensure safe operation at higher levels of automation, also in mixed traffic and multi-brand conditions. Regulations are also required to ensure that testing in projects can be undertaken. This should be done by gathering all actors of the system around the same issues and by applying harmonised and agreed-on testing for CCAM all over Europe.

5.3. Technology (availability) roadmap

The technology roadmap is linked to both the automation technology and standardization. Automation will only be possible thanks to artificial intelligence and connectivity technologies, whereas standardization may concern databases, data formats, but also domains linked to the road infrastructure.

Automated driving will be based on methods coming from the domain of **artificial intelligence** (ERTRAC, 2022), in particular images and pattern recognition. Two consequences of this can be seen quite immediately: Firstly, there will be the need to create big databases, on which the developments can be based. These databases need to gather the data coming from the various actors of the system, in particular the vehicle actors and the road actors. Moreover, transport is now seamlessly integrated with manufacturing and distribution (ALICE, 2016a). This (these) database (databases) needs to be open, scalable and with an agreed-upon structure. Also, these databases have to be able to gather historical data, but also data measured by new types of (new) devices, like for example intelligent edge based systems (IoT, ITS, smart objects, …, see (ALICE, 2014)).This leads to other issues like data exchange formats, calculation time (quantum calculation) and energy use. Secondly, as presumably the future of automated transport may be based at least partially on neural networks (in particular deep learning), a methodology of validation of such kind of “black box” algorithms need to be proposed and agreed upon. This validation must be seen from a technical (mathematical/physical) point of view, but also a general public point of view, for an acceptance of the technology and a facilitated uptake of this transport means.

To improve safety across all types of network, further investment in speed and traffic management can deliver optimized controls for traffic flow, speed, distances between vehicles, etc. Technologies to be listed by NRAs (CEDR, 2017) are digitalisation and cameras, but the need of road infrastructure to interact with increasingly digitalised vehicles is mentioned. This interaction has to go both ways (from the infrastructure to the vehicle and also in the other direction). In fact, the communications are between all actors of the system, namely the driver, the road, the vehicle and the operator (FEHRL, 2019).The transition period, with mixed traffic, has to be treated carefully in action plans. This is also mentioned by the ERTRAC roadmap (ERTRAC, 2022), which supports the **Infrastructure Support for Automated Driving** (ISAD) levels that should extend the Operational Design Domains (ODD) of the automation functions.

This interaction, or even collaboration, will need precise **positioning** and **C-ITS adequate connectivity**. These technologies have to be sufficiently developed to make CCAM possible: for that, the coverage must be sufficient, quality of service must be good enough for the functions that are foreseen and the data that is sent or received must be trustworthy. The connectivity interfaces should be standardized for several (all?) type of V2X technologies, namely ITS-G5, LTE and 5G.

Nevertheless, the need for **standardization** is not restricted to the data or connectivity formats (ERTRAC, 2022): indeed, there needs to be a standardization of perception performance for both vehicle and infrastructure. Similarly, the concept of functional safety needs to be the same and applied similarly for vehicle and infrastructure. For example, the concept of "forgiving roads" would make it possible to implement zones which mitigate the impact of poor driving or poor driving choices (FEHRL, 2013a). (ALICE, 2019) highlights the need for simplification, which also brings about the necessity of agreement and common view on the issues by the various actors of the system. Business process harmonization will allow stakeholders to integrate cost effectively the operations, manage the complexities from one network to another, and improve the efficiency of the operations by experience (ALICE, 2019).

5.4. Product/services roadmap

Enforcement technologies are important (CEDR, 2017), but some challenges may arise (like e.g. data protection) since, databases will have to be exchanged, with both static and dynamic information. The road information may be provided, partially or fully, with **digital twins**. This huge amount of data may lead to cooperation between all actors of the system, while the safety and the impacts of each measure have to be assessed globally (on the level of the whole system). This brings about the need to derive and propose formats of databases, methodologies for validating, processing, saving and sharing (parts of) these databases.

An **action plan** for the various traffic management activities has to be prepared, based in particular on geofencing. Some examples of use cases can be found in (ERTRAC, 2022). Some safe zones (for example the hard shoulders) are necessary.

While complete solutions may be offered to the actors, it should be also be possible to activate parts of it, which makes **modularized solutions** compulsory. Nevertheless, the services should be designed in the frame of a holistic end-to-end co-modal approach (ALICE, 2016b).

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APPENDIX A: OTHER INFORMATIVE ACTIVITIES PERFORMED BY ENSEMBLE

Several publications and meetings have made it possible to build and disseminate the roadmap within ENSEMBLE among stakeholders.

6.2. Informative meetings done by CLEPA

CLEPA is the European Association of Automotive Suppliers. It gathers more than 100 suppliers companies. The Research and Innovation group is formed by more than 20 companies and it is divided in a Working Group, that deals with the more strategic decisions, and three thematic experts group. CLEPA is member of the ENSEMBLE Project and leader of the Work Package 2.

In order to facilitate the dissemination of the results of the project, CLEPA has held two meetings with its members in order to inform about the ENSEMBLE outcomes and vision of truck platooning. The discussions happened in two meetings are shortly summarised below.

CLEPA R&I SAC EG SAC (Safety, Automation and Connectivity) Meeting on 06/12/2021

The CLEPA Research and Innovation Experts Group on Safety, Automation and Connectivity organised a meeting to share the technical results of the project ENSEMBLE on 06/12/2021.

The meeting has been moderated by David Storer and Edoardo Mascalchi (CLEPA).

Two different presentations have been organised.

Presentation 1 – What ENSEMBLE Demonstrated

The ENSEMBLE EU Project is focused on truck platooning, which is the linking of two or more trucks in convoy, using connectivity technology and automated driving support systems. The ENSEMBLE consortium is made by 7 truck manufacturers, major suppliers, universities and research providers. ENSEMBLE, took the results of the European Truck Platooning Challenge (ETPC), which demonstrated mono-brand platooning, to develop a multi-brand solution. Multi-Brand Platooning is key to ensure the deployment of such technology on the road. ENSEMBLE defined two levels of Platooning: Platooning Support Function and Platooning Autonomous Function. The first one has been also demonstrated on 23/09/2021 with a 7-trucks convoy in Barcelona. ENSEMBLE, to ensure a multi-brand solution, developed the so called “Platooning Layers”. These are the fundamental aspect to ensure the multi-brand approach, since a clear division between what is OEM restricted and common to all brands is defined. Furthermore, additional layers ensure the proper organisation of a platoon on the road and enable potential new services linked to that. The Platooning Support Function has as a basis the current definition of Adaptive Cruise Control (ACC) as defined by the ISO. It adds then the benefit of V2X Communication that enables earlier notification of emergency braking, proper platoon coordination, more comfort and less stress for the driver and the possibility to communicate with infrastructure. Three main categories of Use Cases have been defined, to ensure the formation of the platoon, tackle all the potential situations during the platooning phase and finally the disengagement. For each use case, specification for the common part and requirement for the OEM restricted one have been also defined. The ENSEMBLE Communication Protocol has been then presented. The Communication Protocol is the enabler for a multi-brand solution, allowing trucks of different brands to communicate with each other. The communication protocol has also an important role in making all the use cases and platooning phases to happen correctly. The protocol has also security solutions. In particular, message encryption and certificate signing and verification are implemented. For the encryption, both asymmetric and symmetric encryption are used, the first one during the join phase (where the communication is established) and the second one during the platooning one. The security aspects contribute to establish a correct level of trust between vehicles in the platoon together with the “Platooning Partner Identification Procedure”, that ensures that the V2V messages received are coming from the truck immediately in front of the ego-vehicle (and therefore it is possible to use them to adapt the longitudinal behaviour). Finally, the differences between the ENSEMBLE Communication Protocol and the Cooperative Adaptive Cruise Control (C-ACC) have been also explained. While the C-ACC, that does not use encryption, shares V2V Cooperative Awareness Messages (CAMs) to all traffic participants, the ENSEMBLE Communication Protocol ensures a more intimate communication (thanks to encryption), making the platoon a separate entity in the traffic. Furthermore, a higher frequency in the messages is also ensured. In conclusion, the ENSEMBLE project demonstrated multi-brand platooning, with specifications and requirements agreed by 7 truck manufacturers and major suppliers. The main feature of this function is the tailor-made communication protocol.

<u>Presentation 2 – What is the ENSEMBLE vision for the future of platooning?</u>

The vision for the future of the ENSEMBLE Consortium has been also presented. This is the second level defined by the project: the Platooning Autonomous Function. The scope of defining a second platooning level without demonstrating is mainly to assess the needs from policymakers, road operators and other stakeholders for a more automated platooning function. In particular, in this second platooning level, the following trucks, thanks to V2V Connectivity, are able to be automated (similar to L4) with the driver out of the loop. It has been explained that the Operational Design Domain (ODD) foresees an Hub-to-Hub possibility and that, thanks to the fact that the driver is out of the loop, a shorter time-gap is also possible (till 0.3s). These two additional features introduce challenges on the infrastructure and the vehicles in terms of technology.

An explanation of the two safety analysis made in the ENSEMBLE project has been given. This has been done for both platooning levels: The Functional Safety (FuSa) and the Safety of the intended functionality (SOTIF). These two safety assessments ensure that the level of safety of an automated vehicle is above the target defined.

- Functional Safety – FuSa - (ISO 26262): Ensures absence of unreasonable risk due to hazards caused by malfunctioning behaviour of E/E systems. ISO 26262 does not address nominal performance of the system.
- Safety of the Intended Functionality – SOTIF - (ISO/PAS 21448): Ensures absence of unreasonable risk due to performance limitations or insufficiencies of the specification or misuse. Does not deal with malfunctions due to failure of E/E components.

For the Platooning Autonomous Function, it has been concluded that the safety requirements (derived by the FuSa) are similar to a SAE L4 vehicle, while the SOTIF has shown that the function might be easier to implement with respect to a fully automated vehicle, since there is still a driver in the first truck that can take additional responsibilities and deal with corner-cases.

CLEPA R&I WG Meeting on 02/03/2022

On 02/03/2022, during a meeting of the CLEPA R&I WG, the outcomes of the WP4 activities on the assessment of the impact of truck platooning has been given.

The meeting has been moderated by David Storer and Edoardo Mascalchi (CLEPA).

An overview of the ENSEMBLE project has been presented, including a summary of the technical and impact assessment results, agreed statements and Memorandum of Understanding. Role of CLEPA as Leader of WP2 (definition of the platooning functions) was highlighted. An overview of the outcomes of WP4 of the project has been also given, which focused on the impact assessment of platooning, reminding the participants that these results will be presented in the ENSEMBLE Final Event on 17/03/2022. An overview of the most relevant deliverables under WP4 and the overall main achievements of the project were presented. The conclusions from the impact assessment were summarised.

6.3. European Truck Platooning Challenge

The ETPC has made in possible to exchange views about the future of platooning and derive the roadmap. Some presentations made during ETPC meetings can be listed here:

- Several updates to the Members have been provided by the project Coordinator in different meetings,
- Informative meeting about the WP4.2 work within ENSEMBLE: the subject has been the foreseen services linked to platooning,
- Road authorities has had the possibility to share their views and needs.

6.4. Road authorities

Several road authorities have been contacted during ENSEMBLE project, and their input has been essential for the roadmap:

- PIARC: The tunnel community of PIARC has helped designed the questionnaire for the tunnel issue, and several members have answered it,
- ATMB: The Tunnel du Mont Blanc company has given their (positive) view about platooning, and how connected traffic could make it possible for them to decrease the distances between trucks,
- CETU: The French national Tunnel authority has told their mistrust in platooning and other connected traffic, as they would not have the means to ensure the compliance with local, tunnel-specific traffic regulations,
- CEDR: The Conference of European Directors of Roads has expressed their interest in the work within ENSEMBLE, and their interest in collaborative road-traffic systems.

6.5. Conferences by the coordinator

- Fusco, M, Semsar, E., Zegers, J. & Ploeg, J. (2018). Decision making for Connected and Automated Vehicles: A Max-Plus Approach. In IEEE 88th Vehicular Technology Conference: VTC2018-Fall-27-30 August 2018, Chicago, USA. Available online: [(PDF) Decision Making for Connected and Automated Vehicles: A Max-Plus Approach (researchgate.net)]
- Hoedemaeker, M. ENSEMBLE. Presented in the workshop "Transforming Freight Movement through ITS". ITS WC2018, Copenhagen Sept 17-21)
- Hoedemaeker, M. ENSEMBLE. Presented in the workshop "Creating synergies between CEF and H2020, the example of road freight transport". ITS WC2018, Copenhagen Sept 17-21)
- Willemsen, D. ENSEMBLE. Presented at Car2Car Forum Lelystad, November 20, 2018.
- Hoedemaeker, M. ENSEMBLE. Presented at 3rd International VDI Conference Autonomous Trucks, the future of transportation. March 27-28, 2019 Munich Germany
- Hoedemaeker, M. ENSEMBLE. Presented at H2020 RTR19 conference, 4-5 dec 2019, Brussels
- Hoedemaeker, M. ENSEMBLE. Presented at H2020 RTR21 conference, 29-30 March 2022, Brussels

- Hoedemaeker, M. ENSEMBLE. Presented at SUMMITS'22 – 3rd International Intelligent Transportation Systems Summit, Ankara, Turkey, 09-10 March 2022 http://www.auszirvesi.org/en
- Hoedemaeker, M. ENSEMBLE. Presented at ITS WC 11-15 Oct 2021 Hamburg. SIS38: Connected & Automated Driving research cooperation between Europe and Japan.
- Hoedemaeker, M. ENSEMBLE. Presented at Sweden4Platooning Closing Conference. 11 March, 2020 Stockholm Sweden. S4PCC (google.com)
- Hoedemaeker, M. Efficient Freight transport by deployment of ICT technologies. TRB session 1421; Game-Changing Technologies for Multimodal Freight Corridor Management: North American, European, and Asian Initiatives. Transportation Research Board 98th Annual Meeting, 13-17 January 2019, Washington D.C.
- Hoedemaeker, M. ENSEMBLE. TRB session 1468; Truck Platooning: The Likely First Adopter of Cooperative Automation on Highways. Transportation Research Board 98th Annual Meeting, 13-17 January 2019, Washington D.C.

APPENDIX B. GLOSSARY

6.6. Definitions

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

Term	Definition
design domain)	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).

6.7. 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