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Specifications for multi-brand truck platooning

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Abstract

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. It is the ambition of ENSEMBLE to realize pre-standards for interoperability between trucks, platoons and logistics solution providers, to speed up actual market uptake and to enable harmonization of legal frameworks in the member states.
This paper provides the definition of the specifications of the whole multi-brand truck platooning concept to be implemented in the testing and demonstration trucks of the six European OEMs in the project. It describes the functional architecture and captures the minimum set of operational layer requirements and tactical layer specifications for platooning. The building blocks of truck platooning consist of in-vehicle requirements (longitudinal control, sensors, HMI), infrastructure communication (V2I), communication between the trucks in the platoon (V2V), and platooning strategy (maneuver coordination).

Keywords: truck platooning, specifications, automated driving

1. Introduction

According to ACEA, truck platooning is the linking of two or more trucks in convoy, using connectivity technology and automated driving support systems (ACEA, 2016). 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. 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. Aiming for Europe-wide deployment of platooning, 'multi-brand' solutions are paramount. It is the ambition of ENSEMBLE to realize pre-standards for interoperability between trucks, platoons and logistics solution providers, to speed up actual market uptake and to enable harmonization of legal frameworks in the member states. This will be demonstrated by driving up to seven differently branded trucks in one (or more) platoon(s) under real world traffic conditions across national borders. Early platooning projects mostly concentrated on developing the in-vehicle platooning technology, whereas later projects more focused on either a specific technological challenge (e.g. antennae design and placement) or on the use of platooning technology (e.g. platoon coordination) (Willemsen, 2018). With respect to use cases and in-vehicle architectures, many commonalities are seen on a high level. However, details are often not published due to confidentiality reasons. Moreover, there was no separation between 'common' and 'truck specific' functionalities until now. This separation is needed for ENSEMBLE's multi-brand implementation. Hence, a clear task is reserved for ENSEMBLE to separate these functionalities in a way that the technology is still usable for all OEMs. To this end ENSEMBLE defined a tactical and operational layer (see Chapter 2). Besides that, the impact of non-homogeneous platoons is still unclear. Heterogeneity may stem from different sources: different operational implementations (spacing policies, control algorithms and information used for control, for instance), different vehicle capabilities in accelerating and decelerating (vehicle total mass, available engine power, brake capacity). Additionally, the road profile may affect platoon performance. Despite the substantial academic work on platooning, applied control design for (heterogeneous) platooning is still an open issue. Only very limited publications deal with implementation of relevant aspects and/or heterogeneity of platoons. This thus is still an open area also for ENSEMBLE.

In this paper we present the current status of the definition of the first level of platooning that will also be implemented in the trucks for evaluation and demonstration. During the first year of the project the views on this first level have changed. Initially a 'Level A' with a minimum inter-vehicle gap of 0.8s and full range longitudinal control, with the driver still responsible, was defined, Vissers (2018) However, taking real-life implementation of multi-brand platooning into account (e.g. any semi-trailer, of any technical state, could be hooked on to the tractor), the preliminary Hazard Analysis and Risk Assessment revealed safety critical cases with levels up to ASIL D, Mengani and Dhurjati (2019) and ISO 26262. Current state of the technology does not yet provide solutions for this (e.g. brake performance estimation, or communication partner identification). Hence, the project members decided to redefine the platooning levels as described in the next chapter.

2. Functional Architecture for the Platooning Support Function

The ENSEMBLE project foresees two types of platooning functions:

- Platooning Support Function (longitudinal control with the driver responsible);
- Platooning Autonomous Function (longitudinal and lateral control where the platooning system is responsible).

The concept of the ENSEMBLE platooning system consists of a hierarchical system, with interacting layers with different functionalities, as depicted in Fig. 1, Coda et al. (2018). The different layers have the following responsibilities:

- The service layer represents the platform on which logistical operations and new initiatives can operate.
- The strategic layer is responsible for high-level decision-making regarding scheduling of platoons based on vehicle compatibility, optimization 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 centralized fashion in so-called traffic control centers.
- The tactical layer coordinates platoon forming and platoon dissolution. In addition, this layer ensures platoon cohesion on hilly roads. This is implemented through the execution of an interaction protocol using short-range wireless inter-vehicle communication (i.e. V2X). In fact, the interaction protocol is implemented by message sequences, initiating the maneuvers that are necessary to form a platoon, to merge into it, or to leave it, also considering scheduling requirements due to vehicle compatibility.

- The operational layer involves the vehicle actuator control (i.e. accelerating/braking, steering), the execution of the maneuvers, 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 and/or speed and, depending on the level of implementation, the lateral position relative to the lane or to the preceding vehicle. Key performance requirements for this layer are vehicle-following behavior and 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. The short-range wireless inter-vehicle communication is the key enabling technology.

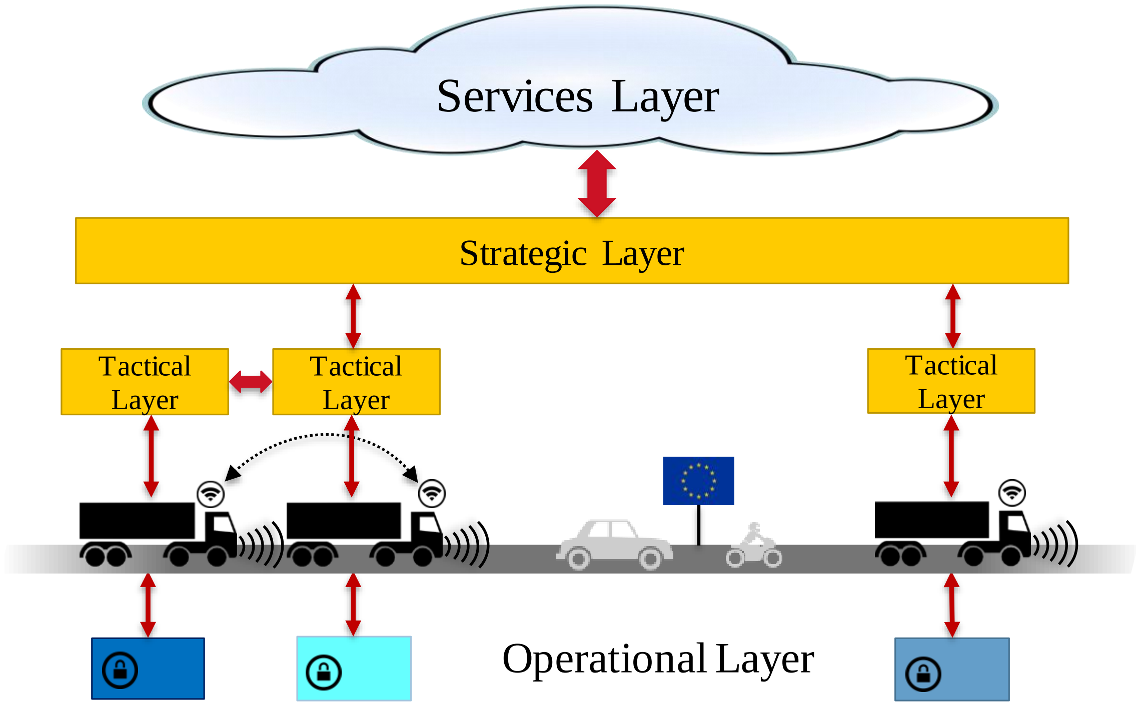

Fig. 1 ENSEMBLE Platooning Layers

The concept of a white label truck was introduced in the project to be able specify brand-less functionality and requirements on the different layers. Specifications are made only for the tactical and the strategic layer, because these are common to all OEMs. Requirements are formulated for the operational layer as it will be OEM specific. At the current stage of the project the specifications and requirements have been determined for the Platooning Support Functions. In a later stage of the project the same will be done for the full automated platooning function (Platooning Autonomous Function).

The detailed description of the modules of the different layers is shown in Fig. 2. The light blue boxes indicate the common functionality for which specifications have been made (tactical layer and the common parts of the operational layer).

- V2X communication: this is the whole set of messages contents, sequencing and security to establish the communication required for platooning.
- Platooning information sharing: this is a module that collects and contains the relevant information (properties, status) of the platoon and the platooning vehicles that must be commonly shared in the platoon.
- Platoon maneuver coordinator: this is a module that coordinates specific maneuvers that need a cooperative approach rather than an individual one.
- Platoon cohesion mechanism: this is a module that contains the common tactical strategies to preserve the cohesion of a platoon, e.g. on a hilly road, or after a cut-in. Platoon cohesion as a function is addressed both in the tactical layer and the operational layer. The tactical layer provides the required information, the operational layer uses this information to perform the platoon cohesion in the longitudinal control function.

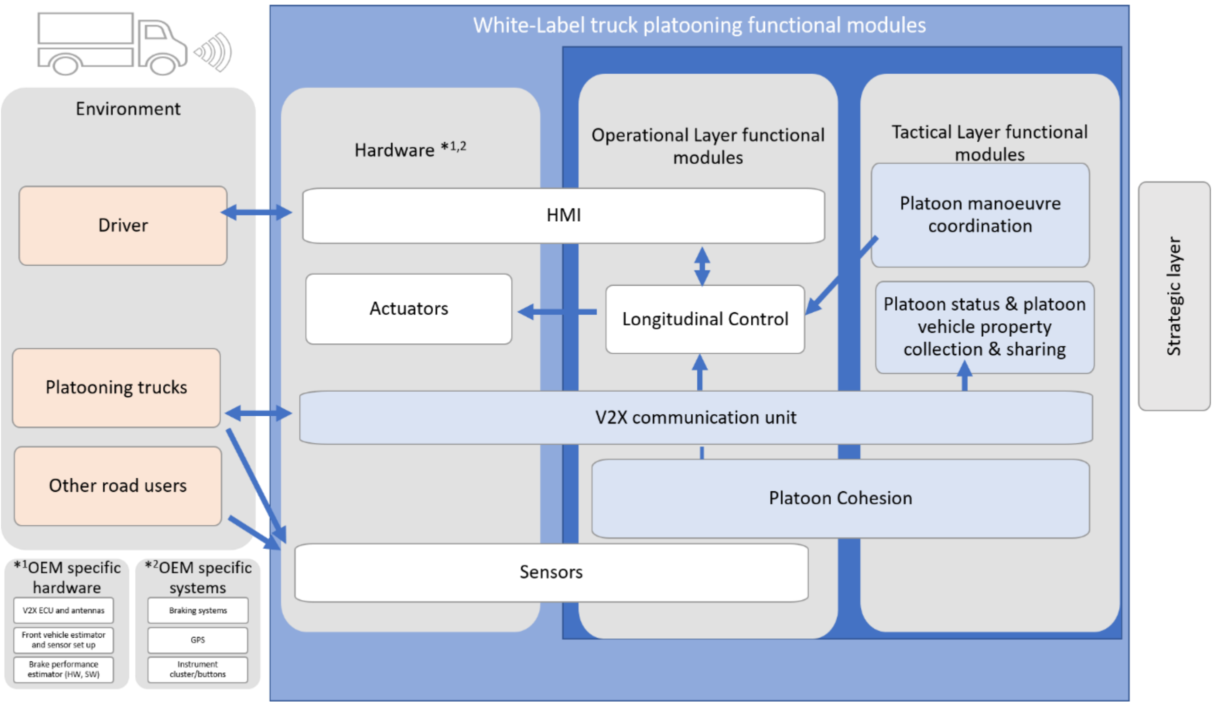

Fig. 2 Functional modules of the white label truck

The white blocks in Fig. 2 represent the requirements that have been formulated for the operational layer which are OEM specific:

- HMI: this module provides the interfacing to the driver;
- Sensors: this software module provides the host vehicle environmental perception and localization based on vehicle-mounted sensors;
- Longitudinal control: this module contains the control algorithms for automatically executing vehicle acceleration and deceleration, e.g. to drive at a certain speed, to maintain a desired inter-vehicle gap or to perform emergency braking;
- Communication between platooning trucks (V2V) and with infrastructure (V2I) is needed in order to provide the necessary information and interact with the platoon.

The items that are OEM specific are: the hardware required for the V2I communication including antennas and the front vehicle estimator.

3. Specifications & Requirements for Multi-Brand Truck Platooning

After the definition of the Platooning levels, the next step in the project has been to define the specific maneuvers and use cases. The following list represents the high level use cases for each maneuver that have been defined in the project, Vissers (2018).

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 or should become part of a new or existing platoon. Platoon formation can be done orchestrated real time or non-real time. The basic use cases for this maneuver are:

- Based on generic match making
- On just extended awareness

Engaging to platoon. During Platoon Engaging, using wireless communication (V2V), the platoon candidate (a single vehicle or an existing platoon) sends a join request to the platoon target (a single vehicle or an existing platoon) in front. When conditions are met, the system starts the platooning functionality, which amongst others means that the platoon specific communication is started. The basic use cases defined for this maneuver are:

- Join from behind by single vehicle
- Merge from behind by platoon

- Merge in between by single vehicle in existing platoon

Platooning. During platooning, a group of two or more cooperative vehicles are in line. This maneuver contains the majority of the defined use cases.

- Steady state platooning: this is the main use case and describes a platoon running at an "ACC" distance/time in an efficient formation
- Follow braking target: at least each platooning system should be able to follow the front platooning partner to a full stop
- Emergency Braking
- Platoon gap adaptation: both a speed or gap adaptation is performed here due to several causes:
    - I2V Interaction: from the road side instructions (speed/gap change) are received, which are in turn presented to the driver, so that (s)he can react to it
    - Cut In
    - System Status: the platooning function informs the driver about anomalies, such that the driver can decide to either increase the gap to the vehicle in front or to leave the platoon/stop platooning

Disengaging platoon. To leave the platoon, a disengage needs to be performed, e.g. to stop the platoon specific communication. This can be initiated in three ways:

- Leave: the driver initiated the leave by requesting that via the HMI
- Split: when the communication to other platooning partners has been lost for a longer time
- Leave by steering out: when the driver steers out of the platoon without 'leaving'.

After the definition of each use case, specifications and requirement have been defined.

The tactical layer requirements ensure the platoon cohesion and organization. This is achieved by sharing information within the entire platoon like the number of trucks in the platoon, the speed of the platoon, the reason for a gap adjustment etc. This information is updated cyclically with a frequency depending on the importance of the data. Information regarding maximum acceleration or speed requested to the platoon is shared in order to ensure the cohesion functionality. With this functionality, a truck in the platoon can request to adjust speed in order to close the gap with the other.

The Operational Layer requirements are divided into the following sub-sections: Longitudinal Control, HMI, and Sensors. The Longitudinal Control is currently managed by the function and the system has been designed to give the driver the choice of different time gaps similar to Adaptive Cruise Control (ACC). The driver remains responsible for the correct execution of the driving task. Longitudinal control requirements manage how to increase the inter-vehicle time gap in a safe way and how to close gaps and keep the platoon together. The platoon cohesion functionality is summarized in two requirements, where the first requirement is aiming for solving an existing cohesion issue e.g. after a cut-in, whereas the second requirement is about avoiding cohesion issues to occur, e.g. due to limited capabilities in uphill driving situations. The common HMI-logic is shaped as the "lowest common denominator" for each OEM's design for platooning. The purpose of the common HMI-logic is to provide not only a structure for coherent interactions between the driver and the platoon system but also still allow for OEM specific solutions. Regarding the sensing specifications, sensors are required for a white-label solution to assess the distance to the vehicle in front and the associated relative speed, as well as, the global position of the ego vehicle. Detecting cut-ins from other vehicles is also essential for improved safety. For the platooning demonstration it is planned to use the sensors and actuators which are currently present in state-of-the-art vehicles. These are already used in ACC (Adaptive Cruise Control) and AEBS (Advanced Emergency Braking Systems) functions for instance. This could change over time once the results of the safety analysis become available. In ENSEMBLE the safety analysis is divided in Functional Safety and SOTIF (Safety of the intended functionality), ISO/PAS 21448.

The ENSEMBLE project will also perform additional work on specifying the Operational Design Domain (ODD) requirements. ODD is the description of the specific operating conditions in which the automated driving system is designed to properly operate, including but not limited to roadway types, speed range, environmental conditions (weather, daytime/night-time, etc.), prevailing traffic law and regulations, and other domain constraints, Society of Automotive Engineers (2018).

4. Conclusions and Next steps

The current definition of the specifications of the multi-brand truck platooning concept has taken driver responsibility as a basis. For the implementation and testing of the ENSEMBLE concept, the project will focus on the multi-brand characteristics of this Platooning Support Function. All requirements and specifications should be regarded as a draft and subject to changes as platoon systems are tested and evaluated from technical, safety, as well as from user (driver) point of view. Further work in the project will focus on updating these specifications and requirements, also for the Platooning Autonomous Function. The Platooning Autonomous Function will include both longitudinal and lateral control and further considerations will need to be investigated such as the choice of the time gap setting, necessary redundancy, braking performance estimation and system fallback.

Regarding the sensing module, the paper highlights the sensing requirements which enable a white label solution to assess the environment specific for the Platooning Support Function. It describes the environmental sensing tasks/requirements which need to be performed. The HMI-logic is based on the current knowledge from platooning and from general human factors guidelines in the field of driver-automated vehicle interaction. The HMI-logic has not been evaluated and validated, for example in field tests or in simulator studies and, therefore, the HMI-logic is on a high level and does not stipulate specific messages, icons, symbols, colors or if and how multi-modal output (sounds and haptic) should be used to enhance the driver-platoon system interaction. These issues are important to investigate further once the overall HMI-logic is in place and be subject for standardization.

Regarding the V2V communication, additional effort in the ENSEMBLE project will focus on the specification of a V2X security framework. It describes which measure should be applied to ensure how trucks can communicate with each other in a secure and private way. Moreover, for the V2I communication, an important issue is that regulation and requirements by the road authorities and member states might also generate additional requirements and might impact testing and verification of trucks platooning systems on the roads.

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