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.	D5.4	
Deliverable Title	Operational tests of multi-brand platoons on Open Roads	
Dissemination level	Public	
Written By	Jordi Pont, Jose Javier Anaya, Sergio Silva, Marc Pérez, Raul Villalba, Armand Voskoboynikov IDIADA	05-10-2021
Checked by	Pablo Rodríguez, Eva Álvarez, IDIADA	01-02-2022

Approved by	Marika Hoedemaeker, TNO	25-02-2022
Status	APPROVED BY EC	06-08-2022

Please refer to this document as:

Pont, J; Anaya, JJ; Silva, S; Perez, M; Villalba, R; Voskoboynikov, A (2021). *Operational tests of multi-brand platoons on Open Roads.* D5.4 of H2020 project ENSEMBLE, (www.platooningensemble.eu)

Disclaimer:

https://ec.europa.eu/programmes/horizon2020/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.

TABLE OF CONTENTS

Revision history

Version	Date	Author	Summary of changes	Status
01.	09/11/2021	Jordi Pont IDIADA	Prepare structure	Prepared
02.	07/01/2022	Jordi Pont IDIADA	Added content for chapter 2, 3	Prepared
03.	12/01/2022	Marc Perez, Raul Villalba IDIADA	Added content for chapter 5	Prepared
04.	18/01/2022	Marc Perez, Raul Villalba IDIADA	Added screenshots for Chapter 5	Prepared
05.	21/01/2022	Jose Javier Anaya, Sergio Silva IDIADA	Added content for chapter 6	Prepared
06.	25/01/2022	Armand Voskoboynikov, IDIADA	Added content for chapter 4	Prepared
07.	31/01/2022	Pablo Rodríguez, Eva Álvarez IDIADA	Internal Review	Prepared
08.	01/02/2022	IDIADA	Feedback applied from Internal review	Prepared
09.	09/02/2022	WP5 members	Feedback from WP5 members	Prepared
10	18/02/2022	Coordinator	Final quality check	Approved

FIGURES

TABLES

EXECUTIVE SUMMARY

Context

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

Project scope

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

- Year 1: setting the specifications and developing a reference design;
- Year 2 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 road.

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

The present deliverable aims to show the results of the scenarios reproduced at Catalan Open Roads tests during September 2021. The scenarios were defined in D5.7 to cover all the aspects that need to be identified and validated in the project. Scenarios including manoeuvres like join, disengage or cut-in among other were executed in the public roads (AP-2, from IDIADA to Lleida and AP-7, from IDIADA to Barcelona). As a result of the execution of these scenarios, log data was generated to be analysed and to prove that were executed successfully. This deliverable provides the analysis done for the open road tests. The main objective of the operational tests in Open Road was to ensure the correct deployment of the platooning system in the real-world. The same scenarios (or most of them) that were tested in the Proving Grounds are now tested in an open-road with real conditions. The infrastructure of the highway, the elements during the road trip (tolls, bridges…) and the real traffic made an interesting challenge for the platooning system. The scenarios were executed successfully and, as it was seen during the Public Demonstration, the platoon functionality performed at the expected level during the Open Road tests.

1 INTRODUCTION

1.1 Background

This document refers to the tests performed during September 2021 at Open Roads (AP2 and AP7). For three days, the scenarios defined in deliverable D5.7 were executed at the Catalan roads, in order to validate the platooning support function as specified in D2.5 [1]. The information of other deliverables was also taken into account in order to correctly deploy all the scenarios. For the Use Cases, the information can be found in D2.3 [2], for the V2X communication protocol details, the information can be found in D2.8 [3] and for the security details the information can be found in D2.9 [4].

Before performing these final tests, mono-brand testing was performed as a first step to ensure the correct functionality of the communication protocol. After testing successfully mono-brand, the planning was to start validating the 3-brand tests. However, this was interrupted and impacted by the COVID pandemic. In the end, a number of 3-brand tests was performed on German test tracks with a delay in timing. Due to this, September 2021 was the first time that all 7 brands came together in Spain, to test the implementations of the Platooning Support Function. And thus, it was also the first time, that certain differences in implementation were discovered (see D2.5 [1]). This also meant that some time had to be spend on aligning and could thus not be spent on testing.

1.2 Aim

This deliverable aims to show the results of the scenarios executed on the open roads to prove the correct functionality of the multi-brand platooning. The scenarios were executed at Catalan highways and all the OEMs participated in the execution. The scenarios performed included different type of dynamic manoeuvres, in order to cover all the technical aspects of the validation.

Positioning within ENSEMBLE WP5 Context

The objective of WP5 is testing, validation and demonstration of the results achieved in the ENSEMBLE project. In this work package all testing is comprised, from integration testing until the final demonstration.

More precisely, the objective of the task that concludes with this deliverable, together with D5.2 [5] (which contains the validation results for Proving Grounds), is to show the validation results of all the scenarios previously defined to be executed on open road [6]. The information contained in this deliverable will prove that the multi-brand platooning was executed correctly during the test sessions.

1.3 Structure of this report

The core body of this report is divided in the following chapters:

- **Chapter 4: Test plan and scenarios**. In this chapter the executed scenarios are explained. It contains a brief summary of the scenarios specifically defined in D5.7 [6], and the scenarios that were executed. It also contains an explanation of the test plan.
- **Chapter 5: Open Road testing preparation**. This chapter contains information about the testing layout, designed for the Open Road tests.
- **Chapter 6: Open road driving results**. This is the main chapter of the deliverable, containing the results for the dynamic scenarios executed on open roads. For each test done, a detailed explanation including data analysis and results, is provided.
- **Chapter 7: Summary and conclusions**. This is the final chapter of the deliverable, where a summary of the results of each executed scenario can be found.

2 TEST PLAN AND SCENARIOS

2.1 Scenario's description

Below is a summary of the scenarios defined in previous deliverables, and planned to be executed during the test sessions.

Platoon join

Table 1 Platoon join scenarios

Scenario ID	Scenario Name	Scenario description
SC0101	Joining form behind by a single vehicle	An ego vehicle behind sends a join request to an existing platoon in front. The ego vehicle is accepted and joins the platoon.
SC0102	Joining from behind by an existing platoon	An existing platoon behind sends a join request to an existing platoon in front. The platoon behind is accepted and joins the platoon in front.
SC0103	Merge in between by single vehicle	A joinable external vehicle merges in an established, steady state driving platoon.
SC0104	Verification of the maximum number of trucks in a platoon	An ego vehicle from behind wants to join a platoon. When the ego vehicle would be joining the platoon, the platoon acquires the maximum number of trucks allowed.
SC0105	Refuse joining due to maximum number of trucks	An existing platoon behind tries to join a platoon in front. When the platoon would join, the new platoon would be too long. Hence the join request is rejected.

Steady State platooning

Table 2 Steady State platooning scenarios

Scenario ID	Scenario Name	Scenario description
SC0201	Steady state following a constant speed	An existing platoon in steady state maintains a constant speed.
SC0202	Steady state acceleration	An existing platoon in steady state maintains a constant acceleration.
SC0203	Steady state deceleration	An existing platoon in steady state maintains a constant deceleration.
SC0204	Steady state gap variation	An existing platoon in steady state changes gap size.
SC0205	Follow a braking target	An existing platoon in steady state reduces the speed until less than 30 km/h or even come to a full stop.
SC0206	Platoon in two adjacent lanes	An existing platoon in steady state overtakes another platoon in steady state.

Emergency braking

Table 3 Emergency braking scenarios

Scenario ID	Scenario Name	Scenario description
SC0301	Lead vehicle doing an emergency braking	The leading vehicle performs an emergency braking and communicates it to the platoon via V2V. The platoon reacts as well as required.

SC0302	Following vehicle doing an emergency braking	One of the following vehicles perform an emergency braking and communicates it to the platoon via V2V.
SC0303	Two instances of emergency braking in the platoon	The leader vehicle and an ego vehicle far from the leader vehicle perform two different emergency braking and communicate it to the platoon.
SC0304	Aborting emergency braking after TBD seconds	An ego vehicle of an existing platoon performs an emergency braking. Before being validated, the emergency braking is aborted.

I2V interaction

Table 4 I2V interaction scenarios

Scenario ID	Scenario Name	Scenario description
SC0401	New minimum distance policy	A platoon gap adaptation because of V2V interaction.
SC0402	New maximum speed policy	A platoon speed adaptation because of V2V interaction.

Cut-in

Table 5 Cut-in scenarios

Scenario ID	Scenario Name	Scenario description
SC0501	Cut-in	An external vehicle cuts in into a working platoon and remains within it.
SC0502	Cut-through	An external vehicle cuts through a working platoon.

SC0503	Cut-out	An external vehicle cuts out from a working platoon.
SC0504	Steady state multiple vehicles cut-in	An external vehicle cuts in into a working platoon and remains within it.

System status

Table 6 System status scenarios

Scenario ID	Scenario Name	Scenario description
SC0601	GPS failure	A platoon vehicle detects that the platooning system is not performing as expected (GPS failure).
SC0602	Communication failure	A platoon vehicle detects that the platooning system is not performing as expected (internal communication).
SC0603	Package loss	A platoon vehicle detects that the platooning system is not performing as expected (V2V communication).
SC0604	Steady state multiple vehicles cut-in	A platoon vehicle detects that the platooning system is not performing as expected (forward range sensor failure).

Disengage platoon

Table 7 Disengage platoon scenarios

Scenario ID	Scenario Name	Scenario description
SC0701	Leave by trailing truck	The ego vehicle sends a leave request to an existing platoon in front. The leave procedure is executed, and the ego vehicle leaves the platoon.

SC0702	Leave by following truck	One of the following vehicles (not the leader nor the trailing vehicle) sends a leave request to the platoon it is part of. The leave procedure is executed, and the following vehicle leaves the platoon.
SC0703	Leave by leading truck	The leading vehicle sends a leave request to an existing platoon behind. The leave procedure is executed, and the leading vehicle leaves the platoon.
SC0704	Split platoon	During a stable platoon, one of the follower vehicles (not the leader nor the trailer vehicle) starts the split procedure.
SC0705	Leave by steering out as following truck	During a stable platoon, one of the follower trucks decides to leave and steers out and takes an exit.
SC0706	Leave by steering out by leading truck	During a stable platoon, the leading truck decides to leave and steers out by changing lane.

Platoon cohesion

Table 8 Platoon cohesion scenarios

Scenario ID	Scenario Name	Scenario description
SC0801	Closing gap at maximum set speed	During a stable platoon, one of the vehicles sends the maximum attainable speed.
SC0802	Closing gap at maximum acceleration and speed performance	During a stable platoon, one of the vehicles sends the maximum attainable speed and acceleration.

2.2 Scenarios executed

The following scenarios were executed on Open Roads:

Table 9 Scenarios executed at Open Roads

Scenario ID	Scenario Name	Number of trucks involved
SC0101	Join from behind	2-7 trucks
SC0102	Joining from behind by an existing platoon	*2-7 trucks*
SC0201	Steady state following a constant speed	*2-7 trucks*
SC0202	Steady state acceleration	*2-7 trucks*
SC0501	Cut-in	*2-7 trucks*
SC0502	Cut-through	*2-7 trucks*
SC0503	Cut-out	*2-7 trucks*
SC0701	Leave by trailing truck	*2-7 trucks*
SC0702	Leave by following truck	*2-7 trucks*
SC0703	Leave by leading truck	*2-7 trucks*
SC0704	Split platoon	*2-7 trucks*

2.3 Test plan

A test plan has been developed for testing on public roads, taking into account the road situation, topography, infrastructure and administrative constraints. The road test consisted of three days of driving on different routes passing through C-32, AP-7 and AP-2 in both directions.

A driving plan was made of two driving shifts per day (morning and evening). Platoon was coordinated by the test manager during the tests considering input from road authorities.

updated 20/09/21

Route	Short description	Distance, km	Approx duration	Week 38 - open road tests: Monday - 20.09, Session 1: 7:30-10:00		Monday - 20.09, Session 2: 13:30-15:45	Tuesday - 21.09, Session 1: 7:45-10:00		Tuesday - 21.09, Session 2: 13:15-15:45	Wed - 22.09, Session 1: 7:30-10:00
AP2	IDIADA **LLEIDA** IDIADA	202	2:30:00	AP2 LLEIDA	03:30 hours rest			03:15 hours rest	AP2 LLEIDA	*AP2 LLEIDA*
C32 + AP7	IDIADA **C32 (tunnels)** BCN airport **AP7 (mountains)** IDIADA	150	2:15:00				C32 TUNNELS / AP7 MOUNTAINS			
AP7 + C32	IDIADA **AP7 (mountains)** BCN airport **C32 (tunnels)** IDIADA	150	2:15:00			AP7 MOUNTAINS / C32 TUNNELS				
Refuel	Trucks refuel	-	0:30:00							

driving in platoon
driving w.o. platoon

Figure 1 Open Road Test Plan

3 OPEN ROAD-TESTING PREPARATION

3.1 Open road layout

We equipped two reference vehicles for traffic monitoring, an Opel Corsa that was positioned in front of the platoon and IDIADA's prototype vehicle for ADAS/AV functions development, CAVRide, that was positioned behind the platoon. Both vehicles were behaving as normal as possible in the traffic around the platoon, with the intention not to interrupt the other vehicles/traffic behaviour.

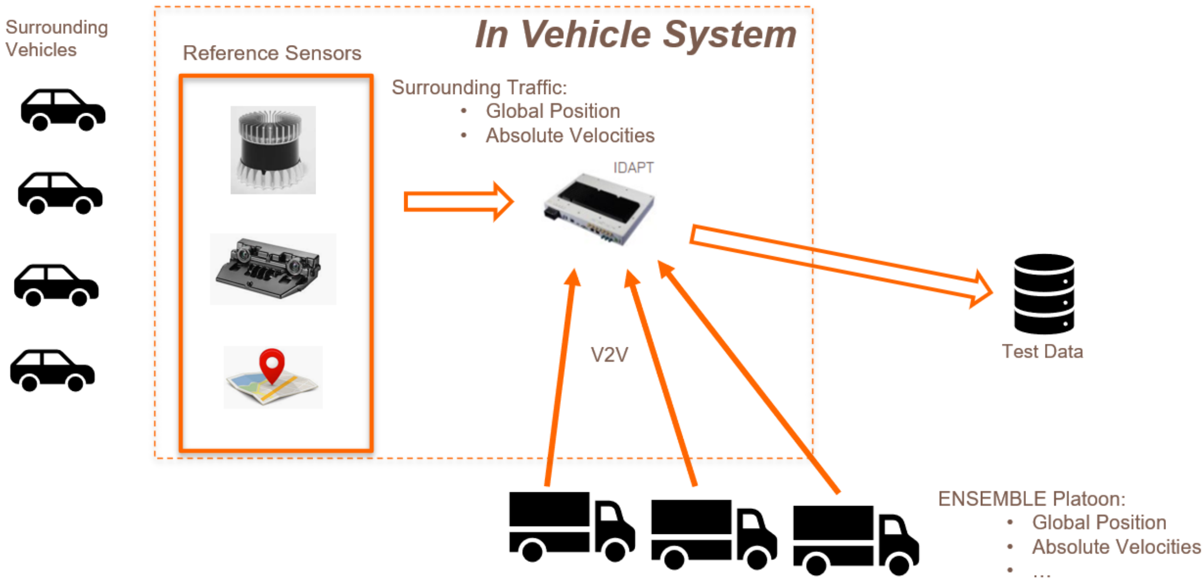

Figure 2 In-vehicle system diagram

Each vehicle was equipped with three cameras, facing front, left, and rear. Since the platoon must always drive on the right lane, we do not need to have a camera facing right. On top of both vehicles we mounted 360º lidars. These sensors provide high-resolution point clouds of the surroundings of the vehicle for accurate positioning of the detected objects. We also mounted a radar in each vehicle, on the front bumper, facing forward in the case of the CAVRide and on the rear bumper facing backwards in the case of the Opel Corsa, to capture more accurately the velocity data of vehicles overtaking the platoon. Additionally, the CAVRide had a Mobileye 630 camera mounted behind the rear-view mirror and facing forward, a camera with an integrated SoC that provides detections via CAN, and an ibeo LUX mounted on the front bumper, a front lidar that provides detections as well as the raw point cloud via Ethernet. To power all devices, we had a custom power supply using the battery of the vehicle. To record all this data, we used one IDAPT in each vehicle, the IDAPT is a computing device for fast prototyping of ADAS/AV and data acquisition developed by IDIADA. We used ROS as middleware for integration of all sensors and recording with the default bag format. Each system is time-synchronized with the GPS time on a Cohda device using chrony, the Cohda device is also used to store all V2X messages received in each vehicle from the platoon. For accurate positioning of the reference vehicles, we have a Settop M1 receiver in each vehicle providing GPS data.

3.2 Data post-processing

The goal of the data post-processing is to obtain the trajectories of all vehicles in traffic around the platoon, to analyse the effect of the platoon on traffic. The trajectories are provided as CSV files, one file for each monitoring vehicle and test session, and each file with the same columns containing information of the objects detected at different timestamp: Timestamp, Vehicle id, Test Vehicle (which reference vehicle detected the object), Longitude, Latitude, Speed, Heading, InterVehicleDistance (distance from the reference vehicle to the object), RelativeX (longitudinal position w.r.t. test vehicle), RelativeY, RelativeVx, RelativeVy, Type (integer representing either a car, truck, or motorcycle), Lane (lane w.r.t. the ego lane). From this CSV file we aggregate the overtakes to generate the traffic flow in another CSV file with the columns: Timestamp, TrafficFlowTenth (the traffic flow for the past tenth of a second), TrafficFlow15seconds, TrafficFlow1min. The traffic flow is defined as the number of vehicles that have completely overtaken the test vehicle in the selected time window, minus the number of vehicles that have been completely overtaken by the test vehicle in the selected time window.

To get the positions and velocities of all the objects object detection on images and point clouds, data fusion, and multiple object tracking was performed. Afterwards, the detections were converted to global coordinates using the ego vehicle global coordinates. These processing steps are explained in detail in the next subsections.

We use the Intempora Validation Suite (IVS) to manage the data and postprocessing, it is a web-based application that integrates well with ROS and allows users to visualize data from different recordings and launch jobs on these recordings, for instance to extract the trajectories.

4.2.1. Object detection on images

For 2D object detection, the input is an image, and we want to obtain a list of objects represented by [u, v, w, h, class, confidence], where [u, v] is the centre of the object in image coordinates, and [w, h] are the width and height of the bounding box in pixels. The class is an element from the list of classes [car, truck, motorcycle] corresponding to the type of the object. And the confidence is a score from 0 to 1, provided by the detection method, and it reflects the confidence of the method in the detection or the probability of existence of the object.

Given an input image, we rescale it and feed it to a convolutional neural network. We use YOLOv4 [7] to detect the objects using open-source implementations, with pretrained weights from the COCO [8] dataset that contains the classes we want to detect.

To improve the robustness of the detections, we keep a list of all the detections from the previous frame, to benefit from the temporal consistency of video sequences, using a temporal hysteresis thresholding scheme.

For 3D object detection, the input is an image, and we want to obtain a list of objects represented by [x, y, z, w, h, l, yaw, class, confidence, $\Sigma x,x$, $\Sigma x,y$, $\Sigma y,y$], where [x,y,z] is the center of the object in world coordinates, and [w, h, l] are the width, height, and length of the bounding box. Yaw is the rotation angle in the axis perpendicular to the road surface, pitch and roll are ignored since they are not relevant for the driving context. $\Sigma x,x$, $\Sigma x,y$, $\Sigma y,y$ are the covariances of the position.

We can use an off-the-shelf 2D detector, and project these detections to the 3D world by using the intrinsic and extrinsic camera matrices and a depth estimation algorithm. We have estimated the distance to the detected object by using a method based on similar triangles proposed by Mobileye [9]. The method uses the road geometry and the point of contact of the detected object with the road. This method has the advantage of being able to estimate the depth using only one camera as input; robust under normal conditions..

Figure 3 Detections projected to 3D world

4.2.2. Object detection on point clouds

The problem formulation for 3D object detection on point clouds, is the same as the one presented in the previous subsection, but with point clouds as input. We have implemented a method based on filtering and clustering of point clouds. We use functions from the Point Cloud Library (PCL) for an efficient implementation of the different algorithms involved in our point cloud detection pipeline. First, we filter points at ground level or too high above the ground, using a passthrough filter, to disconnect objects connected by the ground, to be able to cluster them separately and to remove bridges or road signs above the road (since we are not interested in detecting these as obstacles).

Then we use voxel grid filtering to remove redundant points that are closer than a threshold (e.g., 10 cm) to speed up the algorithm and to have a similar point density on objects that are far away. Without this step, objects that are closer would have a higher density. Then, we cluster the points using Euclidean clustering, on only the x and y coordinates, with KD-Tree searching for optimal performance. Ignoring the height component helps to make the detections more robust, especially for the case of lidars with a low number of beams that produce point clouds with very high separation in the z coordinate for objects that are far away. We also ignore clusters that have too many or too few points or based on the area/volume, these thresholds have been adjusted for each reference vehicle independently since they use different lidar sensors. To obtain the correct oriented bounding box, we first calculate the convex hull of the point cloud projected to the 2D plane (ignoring the z coordinate). Then for each edge on the convex hull, we calculate the minimum bounding box that has a side collinear with that edge. From all these bounding boxes we keep the ones with a smaller area and considering the distance from points to an edge, this is useful because the Lidar detects points on the edge of the object so if a lot of points are inside of the bounding box it is a good sign that this is not actually the correct bounding box even if it is smaller in area. The covariance matrix of the detection, in terms of frontal and lateral position, is set to fix values based on the performance of the sensor and algorithm (e.g. 10 cm).

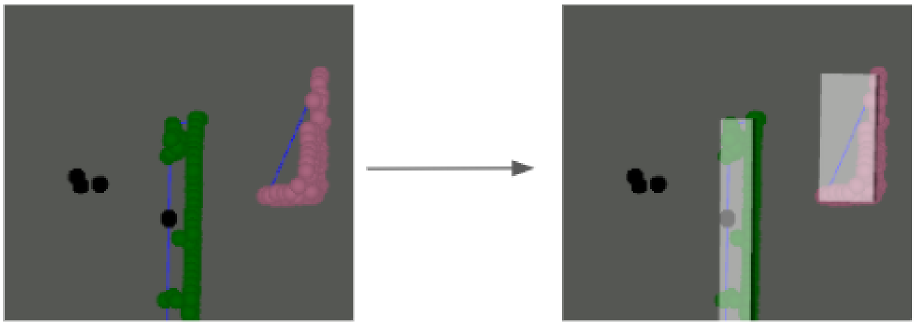

Figure 4 Object detection on point clouds. Top: On the left, each cluster is painted with a different color and the convex hull is displayed in blue, the corresponding bounding boxes are shown in the right image in white. Bottom: All the clusters and bounding boxes detected.

4.2.3. Data fusion and multiple object tracking

Once we have the 3D detections from each sensor, we convert them from the sensor reference frame to the same frame of reference, and combine them using this module, to obtain more robust detections. The goal is to use the multiple detections to reduce the number of false positives and negatives that each sensor produces, and use the strengths of each sensor to compensate for the weaknesses of others. So, the input is a sequence of detections from different sensors; each detection includes a timestamp, and [x, y, z, w, h, l, yaw, class, confidence, $\Sigma x,x$, $\Sigma x,y$, $\Sigma y,y$] as explained previously. For some sensors, e.g. radars, additionally the velocity with its covariance [vx, vy, $\Sigma vx,vx$, $\Sigma vx,vy$, $\Sigma vy,vy$] is available.

The output is a list of tracks at each time step, such that the same objects keep the same id over time. Each track includes [id, x, y, vx, vy, w, h, l, yaw, class, confidence] along with the covariance matrices for the position, velocity, and acceleration Σr , Σv , Σa . Most variables are already explained previously, id is a unique identifier for the track, which is constant over time. At each step the module keeps a track list with the state of all the objects that are being tracked, and when the module receives a detection, all the tracks are updated to that time using the Extended Kalman Filter (EKF) equations. Then the detections are associated to tracks at each time step, by minimizing the global distance of the associations, using the Mahalanobis distance. The detection is used to update the track it has been associated with following the EKF equations. If the detection is not associated, it can be used to create a new track. Then a track remover periodically checks the track list and removes tracks for which the probability of existence has dropped below a certain threshold. Each track contains an EKF, considering a constant velocity model. For simplicity, some terms in the information vector are not included in the EKF and are separately computed.

For the constant velocity model, we define the state of this filter at step k to be given by s = [x, y, vx, vy], where [x, y] is the position and [vx, vy] the velocity in the ground plane. We omit the position and velocity in the Z axis (perpendicular to the ground plane) for simplicity because this information is not required in our driving context.

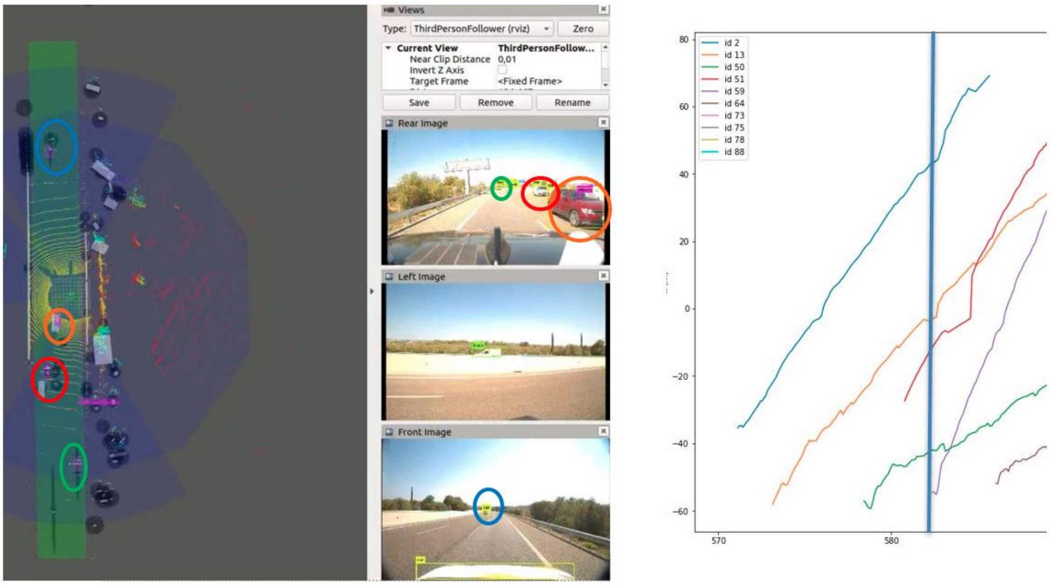

Figure 5 Data Fusion and multiple object tracking

4.2.4. Local position to global coordinates

Given the following information: ego global coordinates, ego global heading angle, x and y relative distance between ego and detected object, we get the object's global coordinates. In order to do so, we do the following computations: From x and y position (w.r.t ego vehicle) we get the angle between ego vehicle and obstacle. With this angle and the ego vehicle heading, we get the bearing angle (ego vehicle to obstacle) clockwise with 0 at north. Once we have the bearing, we can compute the obstacle latitude and longitude using conventional coordinate transformation equations.

4 OPEN ROAD DRIVING RESULTS

4.1 Platoon Join

SC_0101 & SC_0102: Joining from behind

An ego vehicle behind sends a join request to an existing platoon in front. The ego vehicle is accepted and joins the platoon.

Data analysis on SC_0101 & SC_0102

First is necessary check the conditions of the initial state:

- The ego vehicle is driving behind an existing platoon at the same lane.
- The existing platoon in front is formed and in steady stable condition with a specific number of trucks.
- The platoon is joinable (Only the trailing vehicle).

V2X acceptance criteria

Check that the ego vehicle has joined to the platoon and if the V2X parameters are according with the specifications as described in D2.5 and D2.8 ([1] [3]) (principal parameters):

- A join request was sent.
- A join response was received.
- The ego vehicle is Joinable if it is the last truck in the platoon.
- The platoon ID is the same.

Acceptance criteria Acceleration higher than –4.5 m/s^2

- The acceleration shall not have values lower than –4.5 m/s^2 during the scenario. This was successfully achieved. The plot below gives an example from the logged data.

Acceptance criteria GAP bigger than 1.4 s

- The limit distance gap between trucks is respected during overall the procedure. The time gap shall not have values lower than 1.4 s during the scenario This was successfully achieved. The plot below gives an example from the logged data.

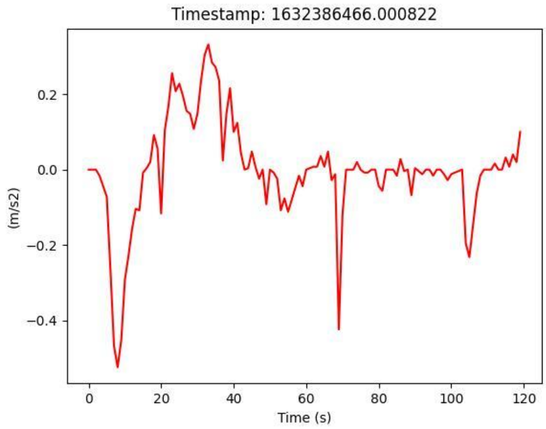

Figure 6 Acceleration Join Sample 1

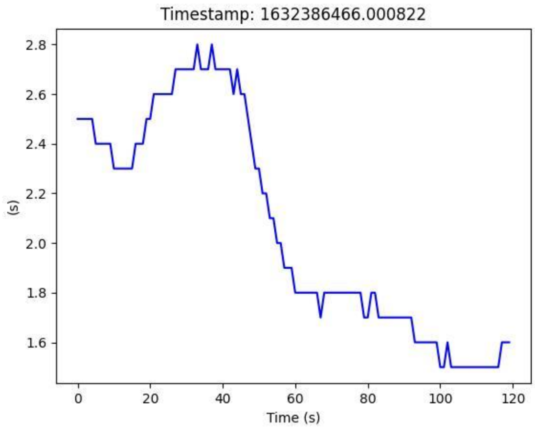

Figure 7 GAP Join Sample 1

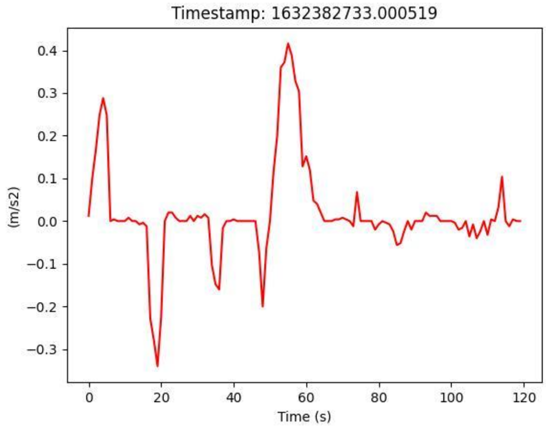

Figure 8 Acceleration Join Sample 2

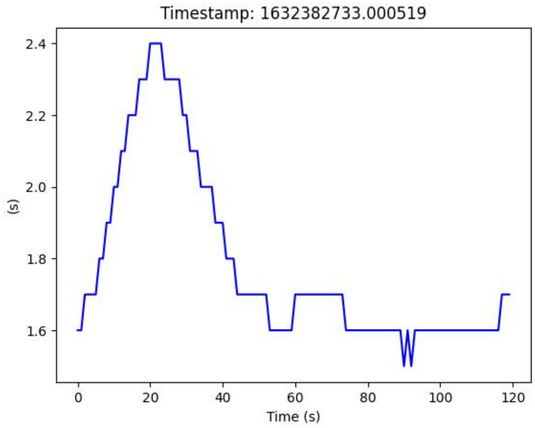

Figure 9 GAP Join Sample 2

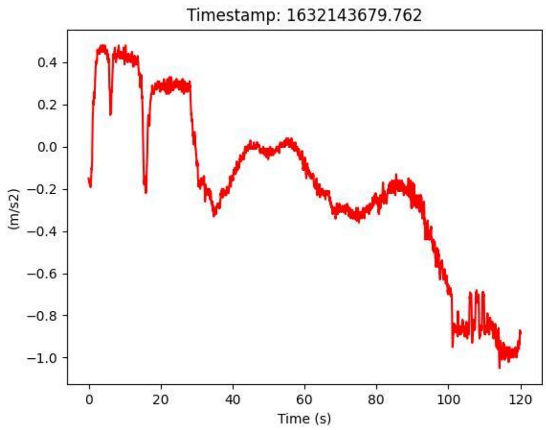

Figure 10 Acceleration Join Sample 3

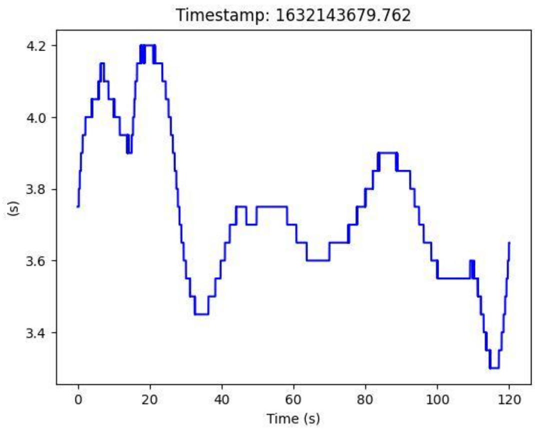

Figure 11 GAP Join Sample 3

Result for SC_0101 & SC_0102

Table 10 Scenario result (SC_0101 & SC_0102)

Test ID	Test Name	Result	Comment
SC_0101	Join from behind by a single vehicle.	Partial PASS	According to the results obtained partially past as there are several unsuccessful attempts. In addition, the complexity of the processing and analysis of the data collected during the tests must be taken into account.
SC_0102	Join from behind by a platoon.	Partial PASS	

Table 11 Iterations scenario SC_0101 & SC_0102

Date	Success	Fail	Success ratio
20th September 2021	209	210	49
21th September 2021	219	315	41

4.2 Steady State

SC_0201, SC_0202 & SC_0203: Steady state acceleration and deceleration

This test wants to validate that the platoon can be kept for long periods and the message sharing is working for maintaining the distance between trucks in all conditions.

Data Analysis on test SC_0201, SC_0202 & SC_0203

Details for the platoon data selection:

- Trucks are in platoon
- Number of trucks in the platoon is bigger than 3
- No trucks leave the platoon
- No trucks join the platoon
- Platoon duration should be greater than 70s to be able to check that key update is working as expected

Acceptance criteria:

- PCM sending rate per truck is 20Hz
- Gap distance is equal or bigger than 1.4 seconds
- Truck's speed must be the same after transitions (joining, platoon accelerating, etc.)
- Truck's acceleration must be lower than 4.5 m/s^2

- Key update is done every 60 seconds

Following these requirements and after manually analysing multiple platoons that met the requirements, a detailed analysis has been done to a platoon in which all OEMs were involved with a duration of 120 seconds. Ideal case would be a platoon with a greater duration, but due to traffic on open roads, most of the platoons were split or dissolved due to intruder vehicles.
For better understanding of the results, we have selected only the most representative data to be shown in order to focus only on the interesting part of the analysis.

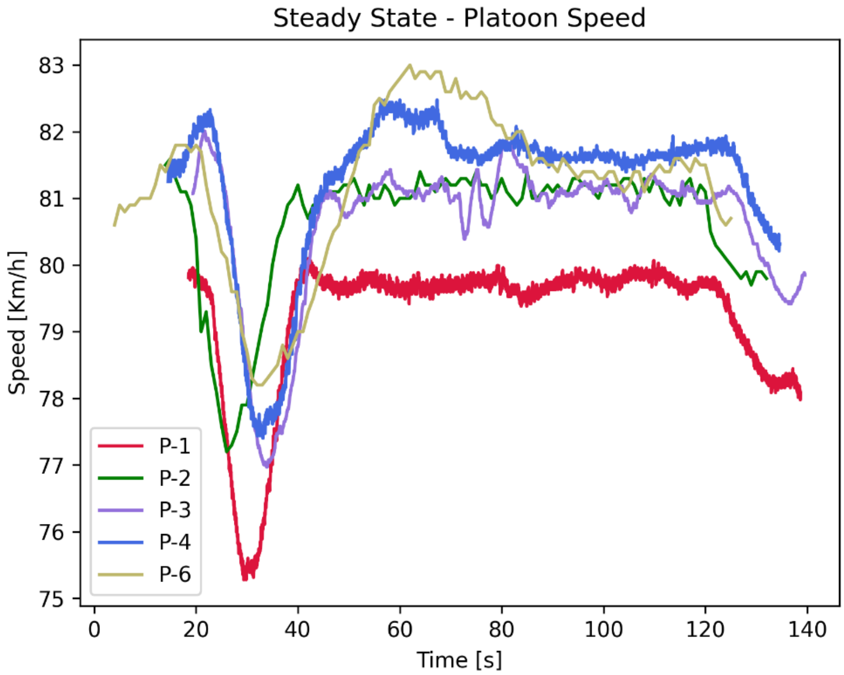

Figure 12 Speed Steady State sample

Figure 14 graph shows platoon reactions to a leader speed variation. This case is a daily use case when for example vehicles perform a temporary speed adjustment to advance to some potential danger in the roads, like for example when a vehicle aproaches a road entrance or a low visibility corner.

This quick decelarion and acceleration causes all the trucks to react to keep the target time gap, taking up to 20 seconds to come back to the steady state.

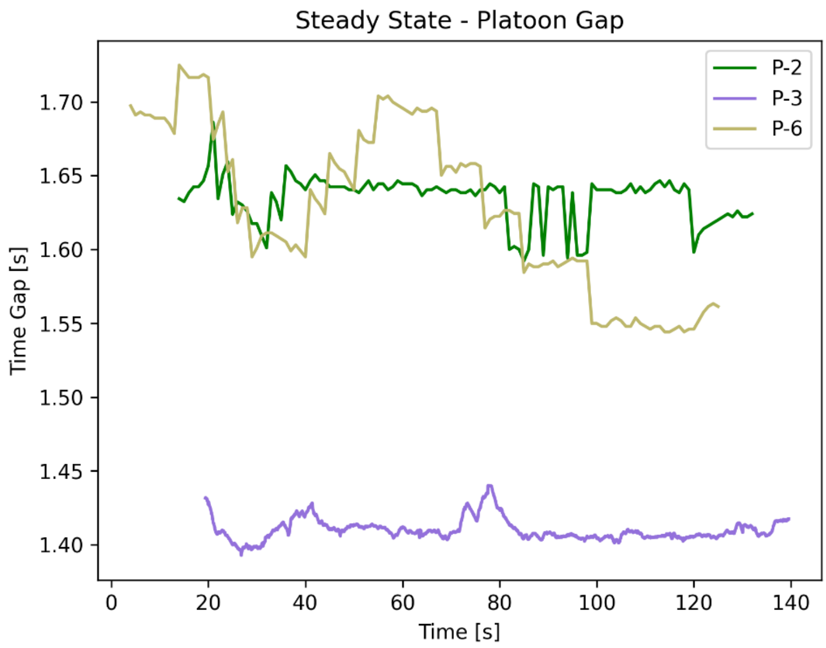

Figure 13 GAP Steady State sample

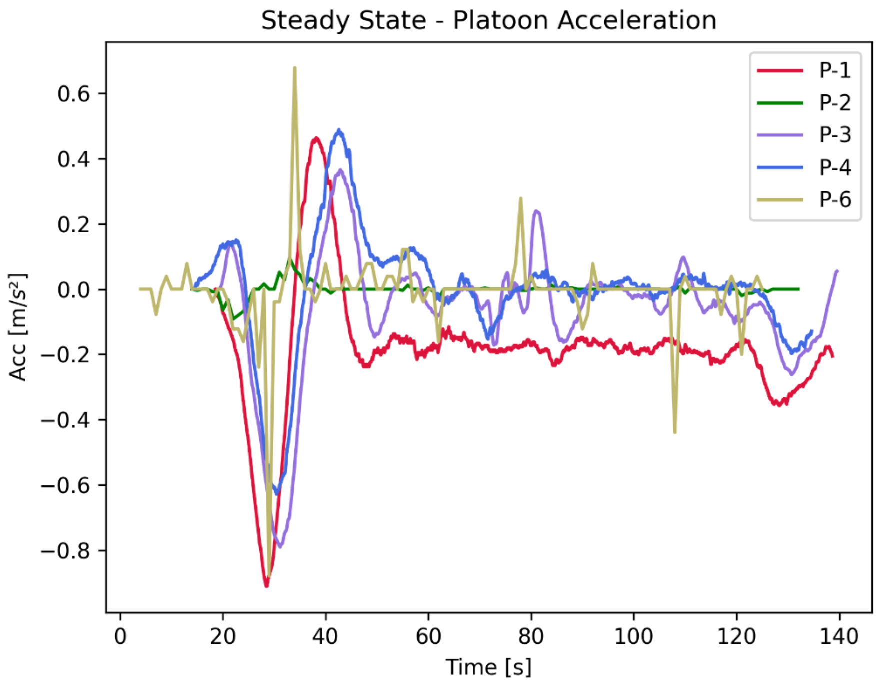

Figure 14 Acceleration Steady State sample

Result for Test SC_0201, SC_0202 & SC_0203

Table 12 Scenario result (SC_0201, SC_0202 & SC_0203)

Test ID	Test Name	Result	Comment
SC_0201	Steady State	PASS	
SC_0202	Steady State Acceleration	PASS	
SC_0203	Steady State Deceleration	PASS	

4.3 Cut-in

SC_0501: Cut-in

An external vehicle cuts in into a steady state platoon and remains within it.

Data analysis on SC_0501

First is necessary check the conditions of the initial state:

- An existing platoon formed in a specified distance gap and speed in steady state platooning.

V2X acceptance criteria

Check that the ego vehicle informs of the presence of the intruder and if the V2X parameters are according with the specifications as described in D2.5 and D2.8 ([1] [3]) (principal parameters):

- The intruder is detected, and the rest of the platoon is informed of its presence by PCM message.
- The platoon continues with desired speed and distance in steady state platooning.

Acceptance criteria Acceleration higher than –4.5 m/s^2

- The acceleration shall not have values lower than –4.5 m/s^2 during the scenario. This was successfully achieved. The plot below gives an example from the logged data.

Acceptance criteria GAP bigger than 1.4 s

- The limit distance gap between trucks is respected during overall the procedure. The time gap shall not have values lower than 1.4 s during the scenario This was successfully achieved. The plot below gives an example from the logged data.

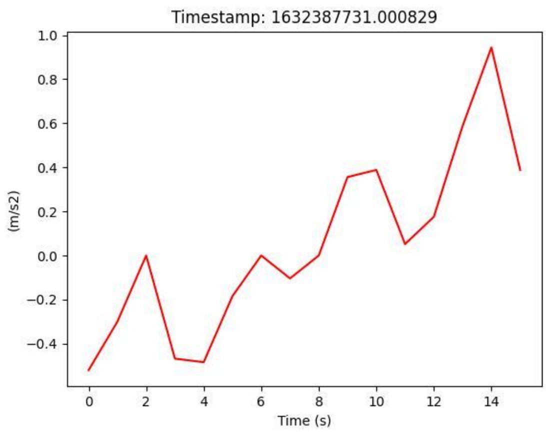

Figure 15 Acceleration cut-in sample

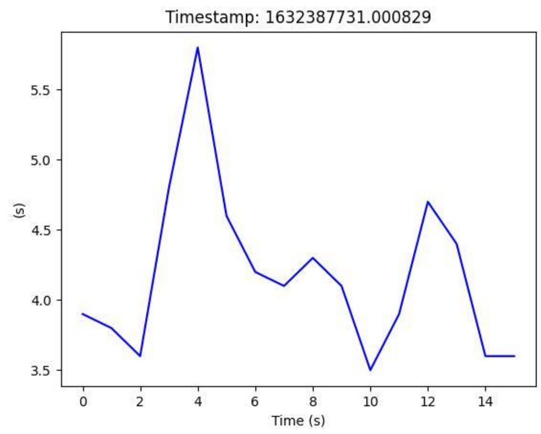

Figure 16 GAP cut-in sample

.

Result for SC_0501

Table 13 Scenario result (SC_0501)

Test ID	Test Name	Result	Comment
SC_0501	Cut-In	PASS	

Table 14 Iterations scenario SC_0501

Date	Success	Fail	Success ratio
20th September 2021	13	1	93
21th September 2021	17	15	53

SC_0502: Cut-through

An external vehicle cut-through in a steady state platoon.

Data analysis on SC_0502

First is necessary check the conditions of the initial state:

- An existing platoon formed in a specified distance gap and speed in steady state platooning.

V2X acceptance criteria

Check that the ego vehicle informs the platoon of the presence of the intruder and if the V2X parameters are according with the specifications as described in D2.5 and D2.8 ([1] [3]) (principal parameters):

- The intruder is detected and the rest of the platoon is informed of its presence by PCM message.
- The platoon continues with desired speed and distance in steady state platooning.

Acceptance criteria Acceleration higher than –4.5 m/s^2

- The acceleration shall not have values lower than –4.5 m/s^2 during the scenario. This was successfully achieved. The plot below gives an example from the logged data.

Acceptance criteria GAP bigger than 1.4 s

- The limit distance gap between trucks is respected during overall the procedure. The time gap shall not have values lower than 1.4 s during the scenario This was successfully achieved. The plot below gives an example from the logged data.

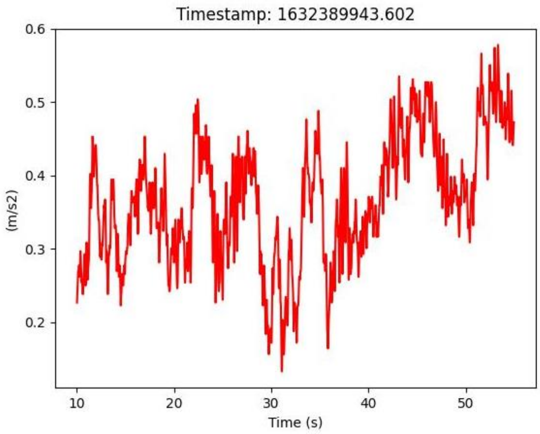

Figure 17 Acceleration cut-through sample

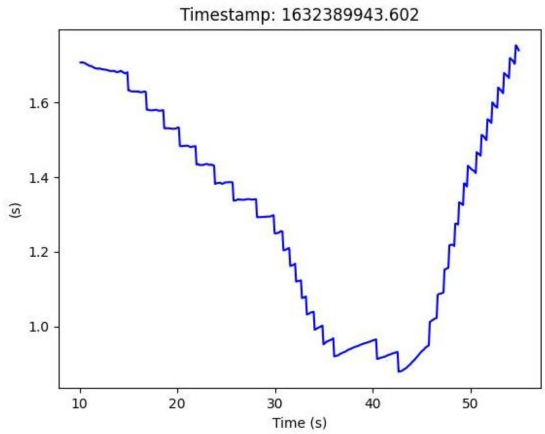

Figure 18 GAP cut-through sample

Result for SC_0502

Table 15 Scenario result (SC_0502)

Test ID	Test Name	Result	Comment
SC_0502	Cut-Through	PASS	

Table 16 Iterations scenario SC_0502

Date	Success	Fail	Success ratio
20th September 2021	96	1	99
21th September 2021	96	4	96

SC_0503: Cut-out

An external vehicle that previously had cut-in a steady state platoon and remained within it, the vehicle cut-out from the formation.

Data analysis on SC_0503

First the initial condition should be checked:

- An existing platoon formed in a specified distance gap and speed in steady state platooning.
- An external vehicle is between trucks.

V2X acceptance criteria

Check that the ego vehicle informs of the presence of the intruder to the platoon and if the V2X parameters are according with the specifications as described in D2.5 and D2.8 ([1] [3]) (principal parameters):

- The platoon is informed of the presence of the intruder and when they leave the formation by PCM messages.
- The platoon continues with desired speed and distance in steady state platooning.

Acceptance criteria Acceleration higher than –4.5 m/s^2

- The acceleration shall not have values lower than –4.5 m/s^2 during the scenario. This was successfully achieved. The plot below gives an example from the logged data.

Acceptance criteria GAP bigger than 1.4 s

- The limit distance gap between trucks is respected during overall the procedure. The time gap shall not have values lower than 1.4 s during the scenario This was successfully achieved. The plot below gives an example from the logged data..

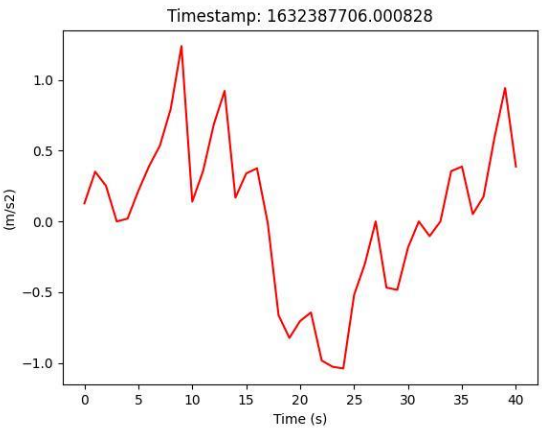

Figure 19 Acceleration Cut-out sample

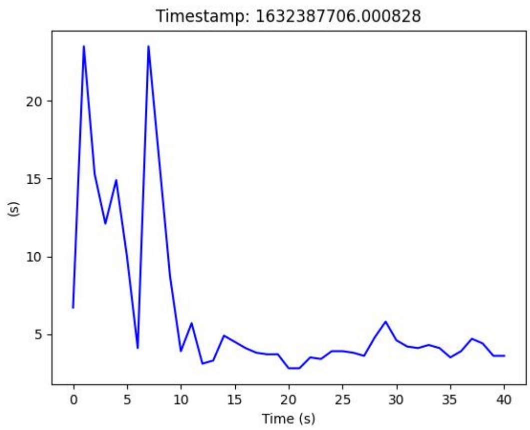

Figure 20 GAP Cut-out sample

Result for SC_0503

Table 17 Scenario result (SC_0503)

Test ID	Test Name	Result	Comment
SC_0503	Cut-out	PASS	

Table 18 Iterations scenario SC_0503

Date	Success	Fail	Success ratio
20th September 2021	13	0	100
21th September 2021	17	0	100

4.4 Disengage platoon

SC_0701, SC_0702, SC_0703: Front split

A vehicle or several vehicles leave the platoon using split in front by the ego vehicle (SC_0701: Leave by trailing truck, SC_0702: Leave by following truck and SC_0704: Split platoon).

Data analysis on SC_0701, SC_0702 & SC_0704

First the initial condition should be checked:

- An existing platoon formed in a specified distance gap and speed in steady state platooning.

V2X acceptance criteria

Check that the ego vehicle leaves the platoon and if the V2X parameters are according with the specifications as described in D2.5 and D2.8 ([1] [3]) (principal parameters):

- The ego vehicle sends a PCM message with "front split" to the vehicle in front, first with preparing front split, and later with front split prepared.
- The platoon continues with desired speed and distance in steady state platooning.
- The ego vehicle must be outside of the original platoon.

Acceptance criteria Acceleration higher than –4.5 m/s^2

- The acceleration shall not have values lower than –4.5 m/s^2 during the scenario. This was successfully achieved. The plot below gives an example from the logged data.

Acceptance criteria GAP bigger than 1.4 s

- The limit distance gap between trucks is respected during overall the procedure. The time gap shall not have values lower than 1.4 s during the scenario This was successfully achieved. The plot below gives an example from the logged data.

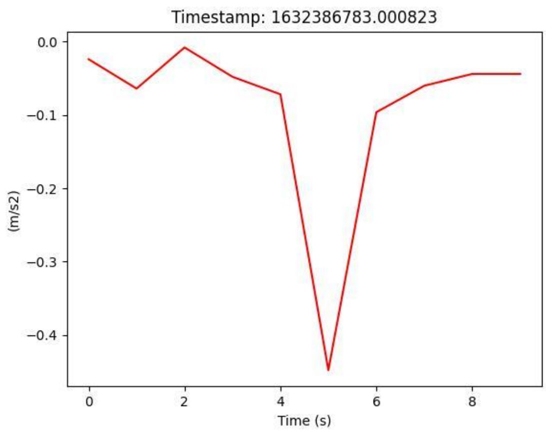

Figure 21 Acceleration front split sample

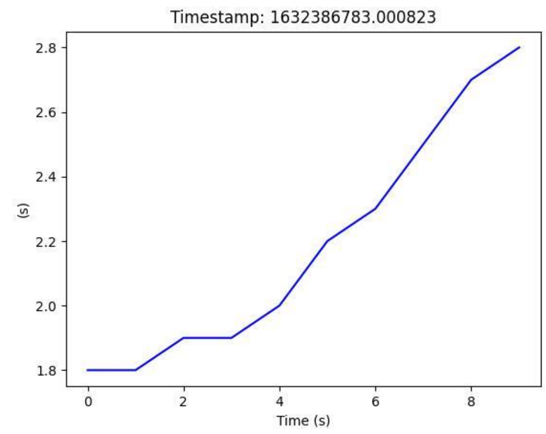

Figure 22 GAP front split sample

Result for SC_0701, SC_0702 & SC_0704

Table 19 Scenario result (SC_0701, SC_0702 & SC_0704)

Test ID	Test Name	Result	Comment
SC_0701	Leave by trailing truck	PASS	
SC_0702	Leave by following truck	PASS	
SC_0704	Split platoon	PASS	

Table 20 Iterations scenario SC_0701, SC_0702 & SC_0704

Date	Success	Fail	Success ratio
20th September 2021	128	487	21
21th September 2021	191	511	27

SC_0702, SC_0703, SC_0704: Back split

A request for back split is performed by the ego vehicle to the truck in back, this request can affect one vehicle or several vehicles (SC_0702: Leave by following truck SC_0703: Leave by leader truck and SC_0704: Split platoon).

Data analysis on SC_0702, SC_0703 & SC_0704

First the initial condition should be checked:

- An existing platoon formed in a specified distance gap and speed in steady state platooning.

V2X acceptance criteria

Check that the vehicle in back of the ego vehicle leaves the platoon and if the V2X parameters are according with the specifications as described in D2.5 and D2.8 ([1] [3]) (principal parameters):

- The ego vehicle sends a pcm message with "back split" to the vehicle in back
- The truck in back shall respond with a "front split" first with preparing front split, and later with front split performed.
- The platoon continues with desired speed and distance in steady state platooning.
- The ego vehicle must be outside of the original platoon.

Acceptance criteria Acceleration higher than –4.5 m/s^2

- The acceleration shall not have values lower than –4.5 m/s^2 during the scenario. This was successfully achieved. The plot below gives an example from the logged data.

Acceptance criteria GAP bigger than 1.4 s

- The limit distance gap between trucks is respected during overall the procedure. The time gap shall not have values lower than 1.4 s during the scenario This was successfully achieved. The plot below gives an example from the logged data.

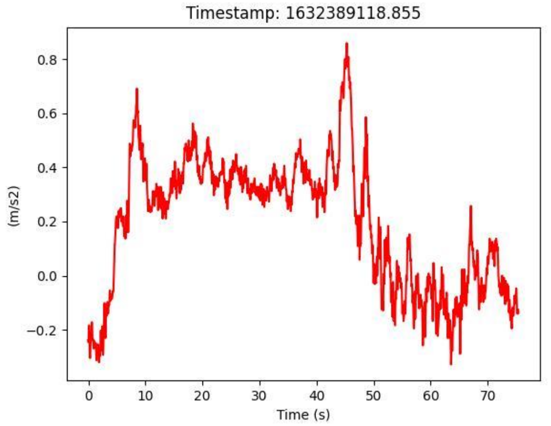

Figure 23 Acceleration Back Split sample

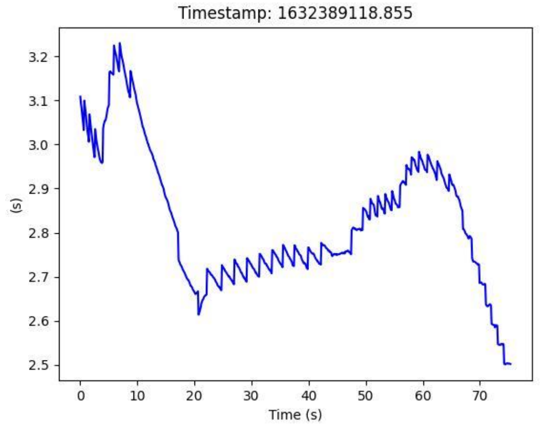

Figure 24 GAP Back Split sample

Result for SC_0702, SC_0703 & SC_0704

Table 21 Scenario result (SC_0702, SC_0703 & SC_0704)

Test ID	Test Name	Result	Comment
SC_0702	Leave by following truck	PASS	
SC_0703	Leave by leading truck	PASS	
SC_0704	Split platoon	PASS	

Table 22 Iterations scenario SC_0702, SC_0703 & SC_0704

Date	Success	Fail	Success ratio
20th September 2021	86	91	49
21th September 2021	163	275	37

5 SUMMARY OF THE TEST RESULTS AND CONCLUSIONS

In general, most of the tests that have been executed on Open Roads were successfully. However, it would be helpful if the platooning system increased its robustness level. This would be useful in the future in order to increase the success ratio of each scenario and safety perception of the rest of the road users.

It is worth to mention that the logging system of the truck could also be improved. When executing some of the scenarios, the logging process was affecting the functionality of the system. This meant that the functionality could be affected if the logging was performed according the project requirements. This concluded with a challenge situation: the scenario was executed successfully but there were not enough data evidence to perform a validation of it. Improving the logging system, will solve these issues for future executions of the platoon system.

Nevertheless, a large number of scenarios was executed successfully on Open Road and the logging data was sufficient to validate the results. A representative sample of the dataset is added to the previous chapter of the deliverable in order to demonstrate the correct achievement of each scenario.

The main objective of the operational tests in Open Road was to ensure the correct deployment of the platooning system in the real-world. The same scenarios (or most of them) that were tested in Proving Grounds are now tested in an open-road with real conditions. The infrastructure of the highway, the elements during the road trip (tolls, bridges…) and the real traffic made an interesting challenge for the platooning system. The scenarios were executed successfully and, as it was seen during the Public Demonstration, the platoon functionality performed at the expected level during the Open Road tests.

Finally, as it is usual in the Innovation Projects, we have learnt some lessons to improve the next time we face the same challenge:

The lessons learned from this testing period are:

- System requirements must be defined in order to be able to perform quality tests. The use cases alone are not enough.
- The system shall be defined in parallel with the signals for analysis.
- The signals shall be well defined, both in range and in units.
- The measurement and logging systems must be well synchronized.

Table 23 Summary of the Open Road test results

Scenario ID	Scenario Name	Result
SC0101	Join from behind	*PASS*
SC0102	Joining from behind by an existing platoon	*PASS*
SC0201	Steady state following a constant speed	PARTIALLY PASS
SC0202	Steady state acceleration	*PASS*
SC0501	Cut-in	*PASS*
SC0502	Cut-through	*PASS*
SC0503	Cut-out	*PASS*
SC0701	Leave by trailing truck	*PASS*
SC0702	Leave by following truck	*PASS*
SC0703	Leave by leading truck	*PASS*
SC0704	Split platoon	*PASS*

6 BIBLIOGRAPHY

[1] M. E., “D2.5 Final Version Functional specification for white-label truck (Version A) H2020 project ENSEMBLE, (www.platooningENSEMBLE.eu),” 2019.

[2] D. Willemsen, “D2.3 Platooning use cases, scenario definition and Platooning Levels of H2020 project ENSEMBLE, (www.platooningensemble.eu,” 2020.

[3] B. S. K. Atanassow, “D2.8 Platooning protocol definition and Communication strategy of H2020 project ENSEMBLE (platooningensemble.eu),” 2018.

[4] B. Atanassow, “D2.9 Security framework for platooning of H2020 project ENSEMBLE,(www.platooningensemble.eu),” 2019.

[5] J. Pont, M. Perez, J. Anaya, A. Voskoboynikov and S. Silva, “D5.2 Validation results of Multi-brand platoons on Test Track of H2020 project ENSEMBBLE (www.platooningensemble.eu),” 2022.

[6] J. J. Anaya, “D5.7 Final version demonstration and test plan. D5.7 of H2020 project http://www.platooningensemble.eu/,” 2020.

[7] C. W. a. H. L. A. Bochkovskiy, “Yolov4: Optimal speed and accuracy of object detection,” April 2020.

[8] “Microsoft coco: Common objects in context,” European conference on computer vision, September 2014, pp. pp. 740-755.

[9] M. B. a. A. S. I. Gat, “A monocular vision advance warning system for the automotive aftermarket,” in *SAE World Congress and Exhibition*, 2005.

[10] “European Commission, Horizon 2020, ENSEMBLE,” 2018. [Online]. Available: https://ec.europa.eu/inea/en/horizon-2020/projects/h2020-transport/automated-road-transport/ensemble. [Accessed 26 10 2021].

[11] “ENSEMBLE,” [Online]. Available: https://www.platooningensemble.eu/. [Accessed 22 10 2021].

7 APPENDIX. DEFINITIONS & ACRONYMS

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).

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