EUROPEAN COMMISSION
SEVENTH FRAMEWORK PROGRAMME
GA No. 610990

Cooperative dynamic formation of platoons for safe and energy-optimized goods transportation

COMPANION

D7.1. Limited results of the on-board coordinated platooning system performance evaluation via physical testing

Deliverable No.	COMPANION D7.1	
Deliverable Title	Limited results of the on-board coordinated platooning system performance evaluation via physical testing	
Dissemination level	Public	
Written By	Marcos Pillado (Applus+ IDIADA) Lorena García-Sol (Applus+ IDIADA) Jonathan Batlle (Applus+ IDIADA) Samuel Sanchez (Applus+ IDIADA) Alex Freixas (Applus+ IDIADA) Shadan Shadeghian (OFFIS) Thomas Friedrichs (OFFIS)	
Checked by	Marcos Pillado (Applus+ IDIADA) WP leader	26/09/2015
Approved by	Magnus Adolfson (Scania) Technical Coordinator	27/09/2015
Issue date	29/09/2015	

History log

Name	*Status*	*Version*	*Date*	*Summary of actions made*
Applus+ IDIADA Marcos Pillado	Editor	0.1	17/03/2015	First draft. Scheme and descriptions
Applus+ IDIADA Marcos Pillado	Editor	0.2	18/03/2015	Extended information on Chapter 3
Applus+ IDIADA Lorena García-Sol	Contributor	0.3	20/03/2015	Added content to Annex A (platooning manoeuvres)
Applus+ IDIADA Lorena García-Sol	Contributor	0.4	24/08/2015	Written Annex B (assignment plans)
Applus+ IDIADA Lorena García-Sol Samuel Sánchez Jonathan Batlle	Contributor	0.5	26/08/2015	Added content to chapter 4
OFFIS Thomas Friedrichs Shadan Sadeghian	Contributor	0.6	21/08/2015	Added content to chapter 6
Applus+ IDIADA Alex Freixas	Contributor	0.7	04/09/2015	Added content to chapter 5
Applus+ IDIADA Marcos Pillado	Reviewer	0.8	07/09/2015	Unified format, merged contributions and corrected syntax
Applus+ IDIADA Marcos Pillado	Reviewer	1.0	20/09/2015	Included comments from OFFIS
Applus+ IDIADA Marcos Pillado	Reviewer	1.1	26/09/2015	Modified KPIs section

Executive summary

This document reports the work within the task 7.1 On-board systems integration and assessment of Actual merging of platoons belonging to work package WP7 – System Integration, Validation, Deployment and Demonstration in the COMPANION project.

The objective of WP7 [1] is the integration, validation and assessment of the full COMPANION system through the deployment and demonstration of the platoons in real field trials and simulation of the on-board and off-board systems. Task 7.1 evaluates the full performance of the platoon without considering the back office engine responsible for remote platoon's control. This task considers the different aspects of the platoon performance, including energy efficiency, safety issues and driver acceptance.

The platoon was tested under different scenarios, including platoon formation, docking and undocking manoeuvres of individual vehicles, regular driving in steady conditions with different gaps between vehicles, critical situations including lane change and emergency braking, interaction between driver and assistance system during all platooning stages together with interaction with non-platoon vehicles.

These tests took place at IDIADA's proving ground, more specifically on the high speed test track since it simulates a highway road. Additional equipment included differential GPS for accurate vehicle positioning and on-board fuel consumption measurement for energy efficiency evaluation. Platoon formation and management inaccuracies were evaluated on safety, driver acceptance and energy efficiency terms.

Contents

List of Figures

List of Tables

Terms

For the purpose of the present document, the following abbreviations appliy:

FC	Fuel Consumption
FV1	Following Vehicle 1
FV2	Following Vehicle 2
HMI	Human Machine Interface
HST	High Speed Track
KPI	Key Performance Indicator
LV	Leading Vehicle
TC	Test Case
WP	Working Package

1. Introduction

The objective of WP7 is the integration, validation and assessment of the full COMPANION system, through the deployment and demonstration of the platoons in real field trials and simulation of the on-board and off-board systems. A complete integration of the entire system will be performed in order to make a global assessment of the full system and for demonstration purposes. This will show the benefits on infrastructure usage, mobility and safety improvement, fuel consumption reduction and the relevance for different business models.

The work package includes three tasks designed for the implementation of different levels of the COMPANION architecture via physical testing and simulation and a final task analysing the performance of the different elements of the system and validating them as whole. The components and modules to be used in these tests shall be implemented and integrated at component level in previous WPs and ready to be used in the different test scenarios defined in WP2. Well defined interfaces between the sub-systems developed in WP5 and WP6, combined with rigorous and accurate testing and validation at sub-system level, which will be carried out in respective WP, will facilitate this process. However, WP7 will validate the previous integration activities and physically put together all the different systems developed in the previous work packages.

Physical tests in controlled environments will be used for the evaluation of the platoon performance (validation of WP6 results). Simulation techniques will provide a virtual test bed for the evaluation of the back-office engine (validation of WP5 results). Then, all the results will be integrated into a physical demonstration on real roads in several locations in Europe for the final validation of the full COMPANION system (including WP4 results).

This document reports the work within the task 7.1 On-board systems integration and assessment of Actual merging of platoons belonging to work package WP7 – System Integration, Validation, Deployment and Demonstration in the COMPANION project.

2. Overview of COMPANION on-board system

The on-board COMPANION system has a three layer for the planning and control hierarchy. The three layers of this hierarchy can be subdivided again. The topmost layer represents the strategic planning. Once the vehicle received a platooning plan, which incorporates a coarse speed profile, the tactical layer is responsible for refining this coarse speed profile. This happens according to the specific vehicles dynamical capabilities. The communication between the vehicles and the off-board platform is established via the cellular network (3G). The operational layer comprises the control of the platoon and the vehicle itself. The platoon controller is a distributed controller that is responsible for keeping the right distance between vehicles, performing merging manoeuvres and ensuring string stability of the platoon. The vehicles use an extended version of the ITS-G5 V2V communication at this layer. The vehicle controller, which is the inner control loop of the operational control, controls the vehicle’s speed according to the input of the platoon controller other ADAS systems and driver input. In the following three sections these three layers will be described in more detail.

2.1. Tactical Layer

The tactical layer consists of two main components; the Road Segment Optimizer and the Platoon Orchestrator. The Road Segment Optimizer defines the detailed speed profile and spacing policy for the vehicle according to the constraints given by the assignment plan. Hence, in its simplest form the speed profile equals the mean speed required to meet the given velocity and timing constraints. However, utilizing a detailed digital map including road attributes such as road incline, speed limits, etc, more fuel optimal speed profiles and spacing policies can be derived. The Platoon Orchestrator synchronizes vehicles and platoons that have to start to interact at a given point, e.g. a merging point. This is done before the point is reached and before direct contact via V2V-communication is established between the vehicles.

2.2. Operational Layer

The operational layer is where the control signals to the trucks engine management system and brake management system are defined. The main components of the operational layer are the Scenario Orchestrator, the Speed Control, the Environmental Model and the Vehicle Properties.
The Scenario Orchestrator defines the control state of vehicle based on the assignment plan and it also handles sequential events such as merging and splitting of platoons. The main control states used are driving in a platoon, driving as platoon leader, driving alone, merge into a platoon and split from a platoon. The Speed Control can be described as an adaptive cruise control that controls the vehicles speed based on the speed profile and spacing policy defined in the tactical layer and the current control state defined by the Scenario Orchestrator. Information about other vehicles that the Speed Control has to adapt to is obtained from the Environment Model and information about the ego vehicle is obtained from the Vehicle Properties component. The Environment Model is a component where data about the surrounding of the vehicle is fused based on sensor data from on-board sensors such as radar and data received from other vehicles and platoon members via V2V-communication.

2.3. HMI

Drivers in a platoon experience a new driving situation which differs to a large extend from the usual driving. Due to the small inter-vehicle distances, drivers miss visual information from the environment. This might result in a lack of Situation Awareness (SA), which can lead to human out-of-the-loop problems. In this semi-autonomous driving context, lateral movement is controlled by the driver while the longitudinal movement is controlled by the system. Moreover, the predefined assignments and manoeuvres narrow the ground for decision making for routes, manoeuvers, breaking times, and speed control. The goal of the HMI development is a) keep drivers in the loop by increasing SA, and b) assist drivers with platooning operations. To keep drivers in the loop and increase SA, information is shown to the driver. Novel interaction concepts are developed that will not violate the drivers' experience and expectations. However, it is important that drivers are not distracted from driving by directing too much attention to the HMI. Because of this, drivers should comprehend the information shown on the HMI quickly. For this, Ecological Interface Design (EID) can be a solution. It incorporates the skill, rules and knowledge (SRK) taxonomy of Rasmussen, which states that the perception of information should rely on visual low-level processes which are naturally fast, effortless and can proceed in parallel. Low-level perception features and a focus on supporting skill-based and rule-based behaviour will be used to reduce interpretation effort. Thus, the driver is not forced to direct his attention away from driving more than needed. For the HMI development, user-centred design approach is applied. Requirements are collected based on questionnaires, interviews, and observations from real drivers. These requirements are then applied in designing interaction concepts which are developed as low-fidelity prototypes. In an iterative process, different designs are evaluated with drivers, so that the HMI will gain large acceptance among drivers. Validation Test Plan

2.4. Test environment

This chapter describes the test environment, such as test objects, tools and test track, as well as external conditions and test plan.

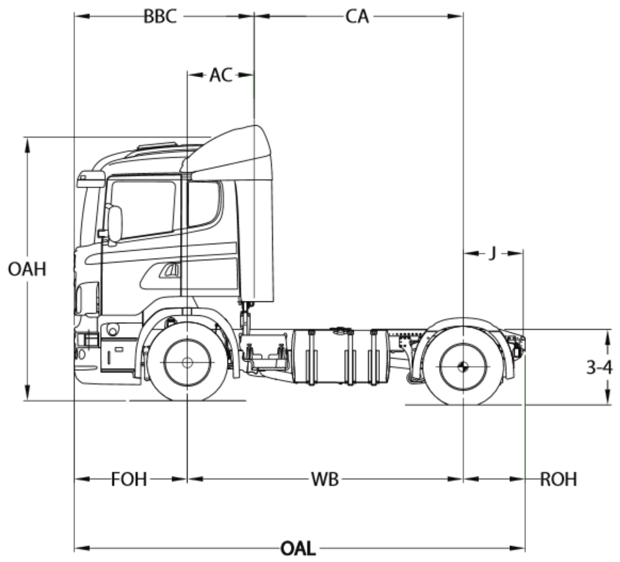
2.4.1. Test Objects

The platoon consists of three Scania trucks partially automated, i.e. longitudinal control is automated but the driver should always handle the steering to control the lateral position. The trucks are connected to trailers. The specific models are

Scania R480

Two R480 (see Figure 1, Figure 2) are used for the tests taking the role of Following Vehicles (FVs) since they only differ on the gearbox. Follows relevant specifications:

Figure 1. Scania R480



FOH	1458	AC	858
WB	3550	3-4	969-997
ROH	800	OAL	5808
BBC	2316	J	775
CA	2692	OAH	3385

Tare Weight: Front = 5490, Rear = 2245, Total = 7735
Tare weight includes, tanks full of fuel.
It does not include turntable, bull bar or driver.

Figure 2. Scania R480 dimensions

Engine

- Scania DC 13 480 13Litre In-line 6 cylinder
- Euro5 (ADR 80/03)
- Power – 480 hp (353 kW) @1900 rpm
- Torque – 2300 Nm @1000 – 1300 rpm

Gearbox

- Scania GRSO905R, Overdrive 14 speed

Scania G450

The platoon is led by a Scania G450 model (see Figure 3, Figure 4), therefore it takes the role of the Leading Vehicle (LV).

Figure 3. Scania G450

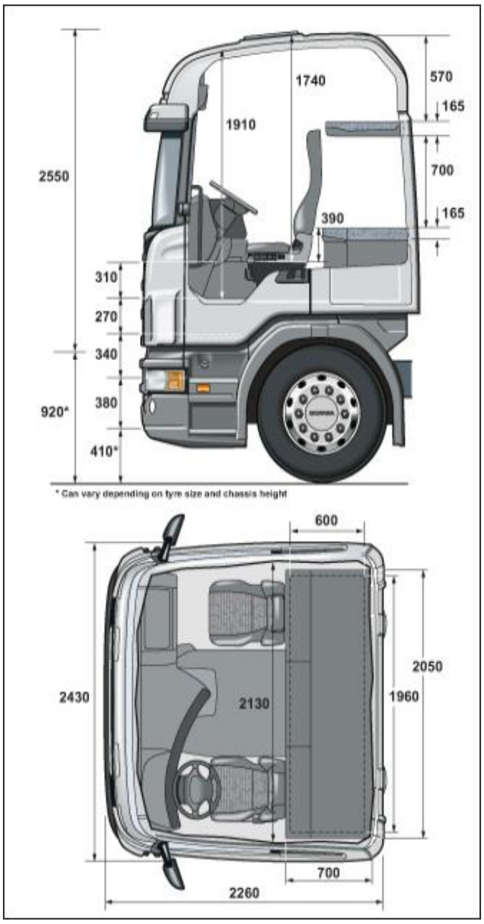


Figure 4. Scania G450 dimensions

Engine

- Scania DC 13 450 13Litre In-line 6 cylinder
- Euro6 (ADR 80/03)
- Power – 450 hp (331 kW) @1900 rpm
- Torque – 2350 Nm @1000 – 1300 rpm

Gearbox

- Scania GRS895R, Overdrive 14 speed

Trailers

- The specifications of trailers are summarizing on Table 1.

DESCRIPCIÓN	R3187BCR	R3687BCR	R3692BCR
MASA EN ORDEN DE MARCHA	8653	8887	8887
MASA MÁXIMA EN CARGA TECNICAMENTE ADMISIBLE	42000	39000	39000
MASA MÁXIMA EN CARGA TECNICAMENTE ADMISIBLE EN CADA EJE	9000/9000/9000	9000/9000/9000	9000/9000/9000
MASA MÁXIMA EN CARGA TÉCNICAMENTE ADMISIBLE EN 5ª RUEDA O PIVOTE DE ACOPLAMIENTO	15000	12000	12000
MASA MÁXIMA EN CARGA ADMISIBLE DEL VEHICULO EN CIRCULACION	35000	36000	36000
MASA MÁXIMA AUTORIZADA EN CADA EJE	8000/8000/8000	8000/8000/8000	8000/8000/8000
ALTURA TOTAL	4000	4000	4000
ANCHURA TOTAL	2600	2600	2600
LONGITUD TOTAL	14000	14040	14040
Nº EJES Y RUEDAS	3 EJES / 6 RUEDAS	3 EJES / 6 RUEDAS	3 EJES / 6 RUEDAS

Table 1. Trailer specifications

2.4.2. Test Track

The on-board coordinated platooning system is validated in the proving ground that Applus+ IDIADA has 70 Km south-west of Barcelona. The track selected was the High Speed Track (see Figure 5), it is an oval track of 7,5 Km, with four lanes of 4 meters width, north and south straights of 2 Km long and a maximum banking bend of 80% (38,66°) on the west and east curves. The travel direction is always clockwise and the speed limit is 250 Km/h in share use.

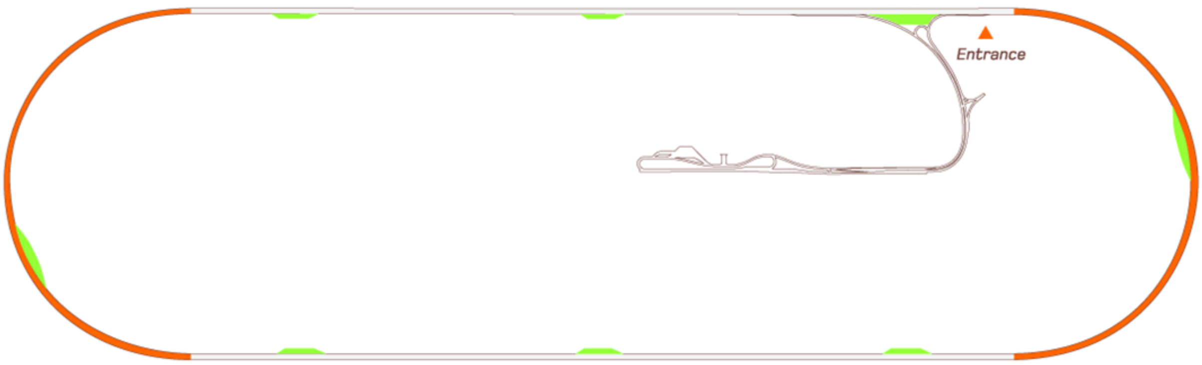


Figure 5. Layout of the High Speed Track

2.4.3. Test Tools and Conventions

The vehicles were equipped with different support systems for the analysis of vehicle data as well as key performance indicators for the manoeuvres.

The devices installed on the different trucks are listed below:

Leading Vehicle - Lotus

- OXTS RT2002 (GPS antenna, differential antenna + SATEL radio modem)
- OXTS RTXLAN WLAN Unit (client)
- Racelogic Video VBox (GPS antenna, 2 cameras + 1 microphone)

Following Vehicle - Pluto

- OXTS RT2002 (GPS antenna, differential antenna + SATEL radio modem)
- OXTS RTXLAN WLAN Unit (base)
- OXTS RT-Range Hunter
- Racelogic Video VBox (GPS antenna, 2 cameras + 1 microphone)

Following Vehicle - Platon

- OXTS RT2002 (GPS antenna, differential antenna + Pacific Crest radio modem)
- OXTS RTXLAN WLAN Unit (client)

GNSS Devices

GNSS equipment from Oxford Technical Solutions was installed on the different test vehicles since they provide accurate motion, position and orientation. The configuration schema for each one is the following depicted on Figure 6 and Figure 7.

Lotus & Platon

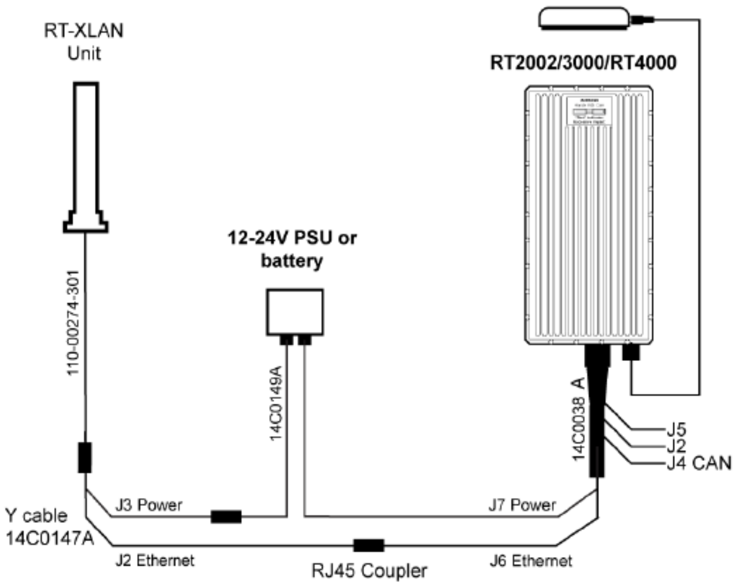


Figure 6. Lotus & Platon GNSS architecture.

Pluto

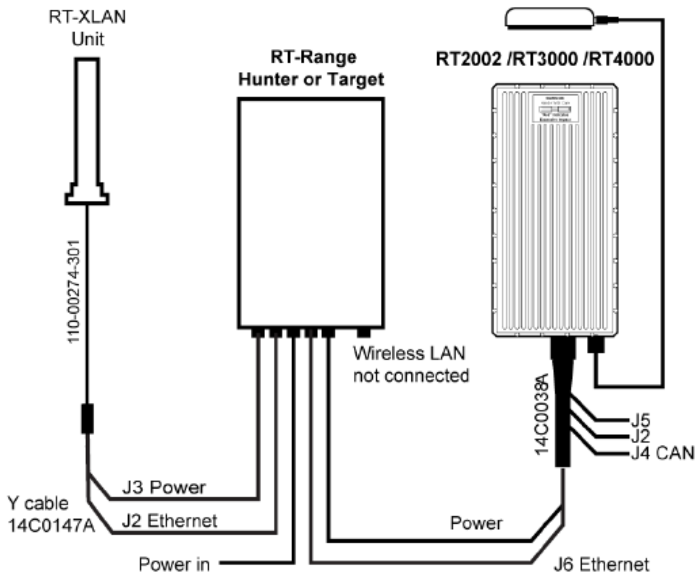


Figure 7. Pluto GNSS architecture.

GNSS data from the different test vehicles was collected in Pluto for posterior analysis.

NAV Graph

NAV Graph is a tool supplied with the OXTS software that process the data recorded with the RT's devices. It provides a comfortable interface (see Figure 8) for post-processing of the data recorded during the tests by the RTXLAN network:

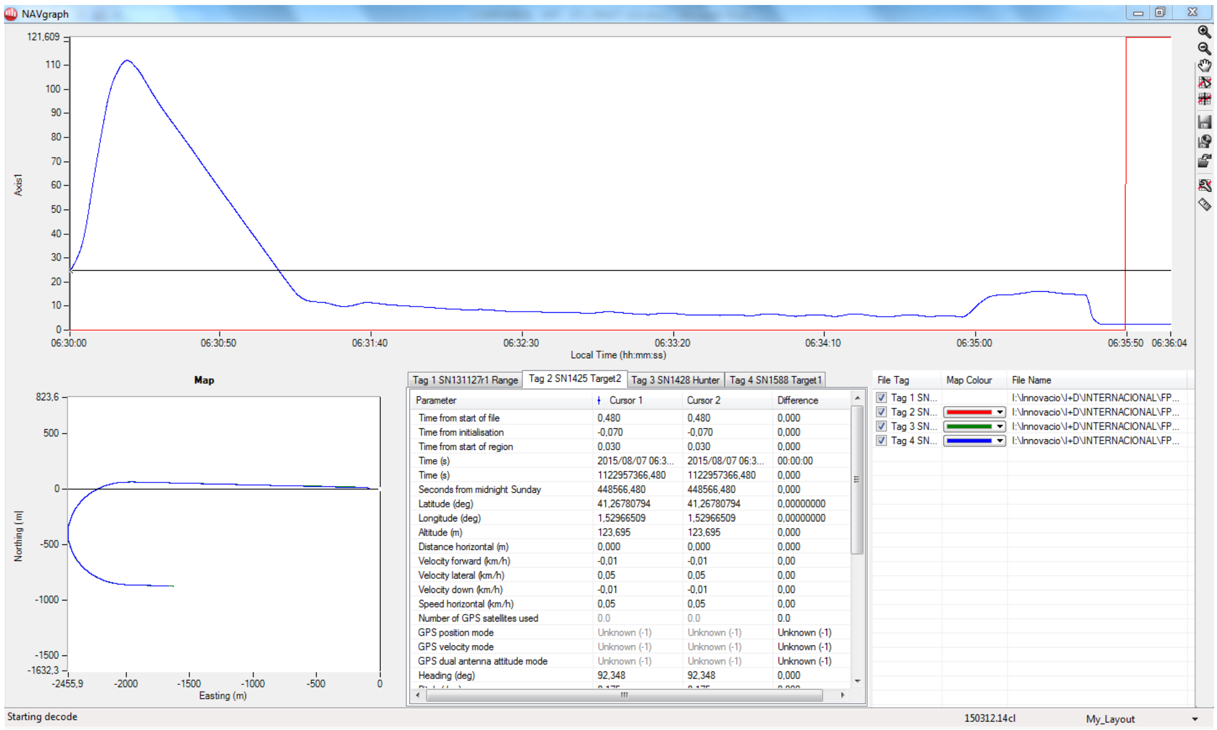


Figure 8. NAV Graph interface

Racelogic Video VBox

For user acceptance analysis, the cockpit of Louts and Pluto was recorded during platooning manoeuvres. For that purpose, Video VBox was used (Figure 9).

Figure 9. Racelogic Video VBox

More specifically, one of the cameras tracked the HMI whilst another was focused on recording the driver reactions and comments.

2.5. Test Plan

The assessment of the on-board system was performed as black box tests, i.e. the focus was on analysing the performance of the COMPANION system from an outer perspective. The Test Cases were built around the main scenario described on D2.1 [2] and derived from the user requirements defined in D2.3 [3] and the technical requirements defined in D2.4 [4].

The tests consider three different aspects that can be group into platoon performance, fuel consumption and driver acceptance. For the objective evaluation of the results, Key Performance Indicators (KPIs) were defined.

On Annex A: Test Plan summarizes the platooning manoeuvres and fuel consumption tests.

3. Platooning Manoeuvre Tests

3.1. Test Cases / Methodology

According with the previous explanation, a series of test cases for platooning manoeuvres and fuel consumption procedures have been defined. For each test performed, a corresponding assignment planned was defined. An assignment plan specifies the manoeuvre, time and position constrains.

The High Speed Track was divided in four segments (see Figure 10). On each segment a specific manoeuvre is performed according to the assignment plan. The respective assignment plans are loaded on the on-board units before the tests starts.

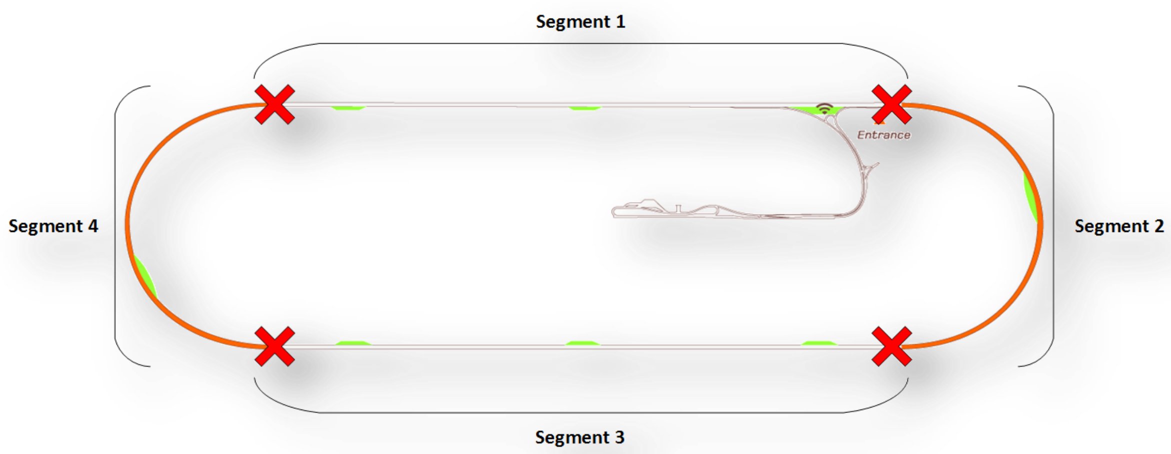


Figure 10. Segments of the High Speed Truck

The test cases were selected based on COMPANION DoD v2.0 functionalities included in there as well as taking into account the most representative scenarios.

A narrative description of each of the test cases listed on Table 11 is provided in the following sub-sections.

3.1.1. **Merge to Platoon**

The goal of these tests is to validate the merging functionality.

Only to remark that the validation of the merging functionality is of highly importance since it is an enabler for other tests (TC_PLT_ MERGE-TO-PLATOON_02 or TC_PLT_MERGE-TO-PLATOON_03).

1. TC_PLT_MERGE-TO-PLATOON_02

For this test, only 2 vehicles platoon. The LV starts driving manually alone in the HST and stabilises its speed to a constant value. After few seconds, the FV1 starts driving alone manually behind the LV on the same lane. After that, the execution of the assignment plan starts on the specific segment. The system takes control of the FV1 and adapts the speed to close the gap with the LV up to fix the gap.

The result is 2 vehicles platooning at a specific speed and gap where the only part controlled by the driver of the FV1 is the steering wheel.

2. TC_PLT_MERGE-TO-PLATOON_03

This test involves 2 vehicles platooning (LV+FV1) on the HST and a third vehicle (FV2) willing to extend the platoon. The test starts once the LV+FV1 have already performed the TC_PLT_MERGE-TO-PLATOON_02. Whilst these 2 vehicles are platooning in the HST, a third vehicle (FV2) enters the HST a drives manually behind the platoon. Right after, once the three vehicles reach the appropriate segment for the manoeuvres, the third vehicle (FV2) adapts its speed in order to merge to it.

The result is 3 vehicles platooning at a specific speed and gap where the only part controlled by the driver of the FV1 and FV2 is the steering wheel.

3.1.2. Split from Platoon

The goal of these tests is to validate the splitting functionality of the vehicles involved.

1. TC_PLT_SPLIT-FROM-PLATOON_02

The vehicles driving in a platoon split according to the assignment plan. As a result, the LV and FV1 are driven manually in the HST.

2. TC_PLT_SPLIT-FROM-PLATOON_03

The test involves three vehicles, LV, FV1 and FV2. The three vehicles are platooning in the HST. The third vehicle splits according to the assignment plan. As a result, LV+FV1 keep platooning and FV2 continues driving manually in the HST.

3.1.3. Double Lane Change

The goal of these tests is to validate the robustness of the platooning, i.e. the platoon must keep platooning after changing lanes according to the assignment plan. A typical real scenario could be either the platoon overtaking another vehicle or the platoon avoiding an obstacle.

1. TC_PLT_DOUBLE-LANE-CHANGE_02

The driver of the LV steers the vehicle to the left lane at a specific point, the driver of the FV1 steers the vehicle to the left lane accordingly. Once the vehicles have changed to the left lane, the driver of the LV steers the vehicle to the right lane, so the driver of the FV1. The result of the test should be the two vehicles platooning on the right lane.

Notice that the drivers always control the steering of the vehicles but the gap and the speed is automatically control by the system.

2. TC_PLT_DOUBLE-LANE-CHANGE_03

The procedure of this test is exactly the same as the one before but on this case, three vehicles are part of the platoon.

3.1.4. Reduce Speed

On these tests, the objective is to validate the speed control system. More precisely, the speed of the platoon should be reduce according to the assignment plan or because the speed is reduce manually by the driver of the LV.

1. TC_PLT_REDUCE-SPEED_02

This is a controlled braking manoeuvre. The test is performed by two vehicles LV and FV1. Once the vehicles are driving in platoon, either the driver of the LV decides to reduce the speed or the assignment plan orders the platoon to reduce the speed on the specific segment. Consequently without the intervention of the driver of the FV1, the speed of the vehicle is adapted accordingly.

2. TC_PLT_REDUCE-SPEED_03

On this case, the procedure is the same as the previously described but with three vehicles platooning. On this case, it is again the LV the one that triggers the test.

3.1.5. Emergency Braking

The purpose of this test is to validate that the vehicles members of the platoon can completely stop in a safe manner

1. TC_PLT_EMERGENCY-BRAKING_02

Two vehicles are platooning on the HST. The driver of the LV pushes the brake hard to try to stop the vehicle in the shortest distance. The FV1 automatically brakes the vehicle in order to try to avoid the collision.

2. TC_PLT_EMERGENCY-BRAKING_03

On this case, the procedure is the same but there are three vehicles involved in the manoeuvre, therefore, FV1 and FV2 brake automatically.

3.1.6. Increase Speed

On the case, the speed control system is validated. More precisely, it validates that the vehicles can speed up according to the assignment plan.

1. TC_PLT_INCREASE-SPEED_02

Two vehicles are platooning on the HST with a specific cap a stabilised speed. According to the assignment plan, the platoon increases the speed.

The result should be the two vehicles platooning but a higher speed.

2. TC_PLT_INCREASE-SPEED_03

Same procedure as the one described on the previous point but with three vehicles involved in the manoeuvres.

3.1.7. Increase Gap

These tests have the purpose to validate that the system is capable of detecting vehicles not belonging to the platoon and increase the gap accordingly to maintain a safe distance between them.

1. TC_PLT_INCREASE-GAP-VI_02

Two vehicles are platooning on the HST and a vehicle not belonging to the platoon moves in between. The FV1 detects the intruder and increases the gap accordingly. If the intruder leaves the platoon, the LV and FV1 will close the gap.

Notice that in any case the platoon is dissolved.

2. TC_PLT_INCREASE-GAP-VI_03

Three vehicles are platooning on the HST and a vehicle not belonging to the platoon interferes between FV1 and FV2. Accordingly, the FV2 increases the speed to maintain a safe distance with the vehicle external to the platoon. If the intruder leaves the platoon, the FV2 will close the gap.

3.1.8. Platooning

For these tests, the objective is to test the stability of the system in order to guarantee stability for the fuel consumption tests.

1. TC_FC_DRIVE-IN-PLATOON_02

Two vehicles platoon on the HST and drive for 5 laps platooning with a specific gap and speed.

The results should be the two vehicles platooning all 5 laps with the specific gap and speed.

2. TC_FC_DRIVE-IN-PLATOON_03

The procedure of these tests is the same as the one described before but on this case, three vehicles are involved.

3.2. KPIs

This section provides an overview of the Key Performance Indicators (KPIs) identified to assess the performance of the on-board System. A detailed description of the KPIs defined from end-user perspective is given. These KPIs are classified in platooning, safety, driver acceptance, fuel consumption and mobility.

Next sections provide a description of the defined KPIs.

3.2.1. Duration of Platooning Manoeuvre

This KPI is in charge to measure the duration of the platooning manoeuvre. This KPI is measured in seconds, and it can analyse the performance of merging to platoon or splitting from platoon.

$$KPI = (Time\ platoon\ was\ formed) - (Time\ last\ member\ of\ the\ platoon\ arrives\ to\ merging\ point)\ [s]$$

3.2.2. Level of Smoothness

This KPI evaluates the harmony between the speeds of the vehicles part of the platoon.

$$KPI = \frac{|FV1_{speed} - FV2_{speed}| + \cdots + |FV(n-1)_{speed} - FVn_{speed}|}{(n-1)}\ [Km/h]$$

3.2.3. V2X Failures

This KPI evaluates the performance of the communications. It provides the ratio between the number of packets expected to be received compared to the number of messages finally received.

$$KPI = \frac{Packet\ received}{Theoretic\ Packets\ received}$$

3.2.4. Longitudinal Position Accuracy

This KPI measures the difference between the theoretical distance defined for the platoon and the real distance in meters.

$$KPI = |Distance\ to\ vehicle\ in\ front\ -\ Real\ distance\ to\ vehicle\ in\ front|\ [m]$$

3.3. Results of Platooning Manoeuvres

Follows an analysis of the most representative platooning manoeuvres performed during first week of tests. The legend for all graphics on this section is shown on Figure 11.

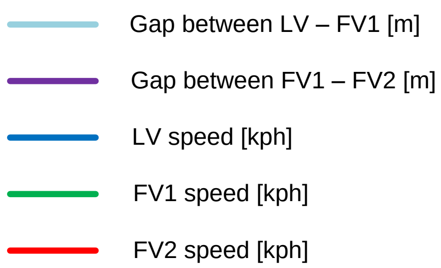


Figure 11. Legend for platooning manoeuvres

3.3.1. Platooning – 3 vehicles – 80 Km/h

This test corresponds to a splitting manoeuvre between 3 vehicles. The test starts on the north straight at 07:43 and finishes on the same point at 07:46.

On the Figure 12 is shown the speed of the 3 different vehicles during the test and on Figure 13 the actual gap. According to them, at 07:45:12 a split is performed, therefore, the speed of FV1 (77 Km/h) and FV2 (76.03 Km/h) is reduced (see Figure 13). On Figure 12 can be seen how the gap is increased as of 07:45:12 reaching the 33 m. In this splitting manoeuvre the measured duration (defined on KPI – Duration of Platooning Manoeuvre) lasts 17 seconds. The smoothness level in this platooning manoeuvre (defined on KPI – Level of Smoothness) results 0.9 Km/h. Regarding the robustness of the link, 99.61% of the packages are received on the LV and 99.88% of packages are received of the FV1.

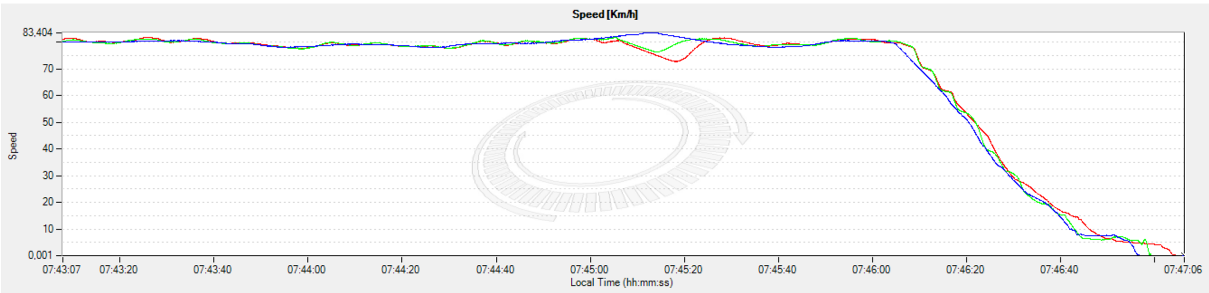


Figure 12. Split, 3 vehicles, 80 Km/h

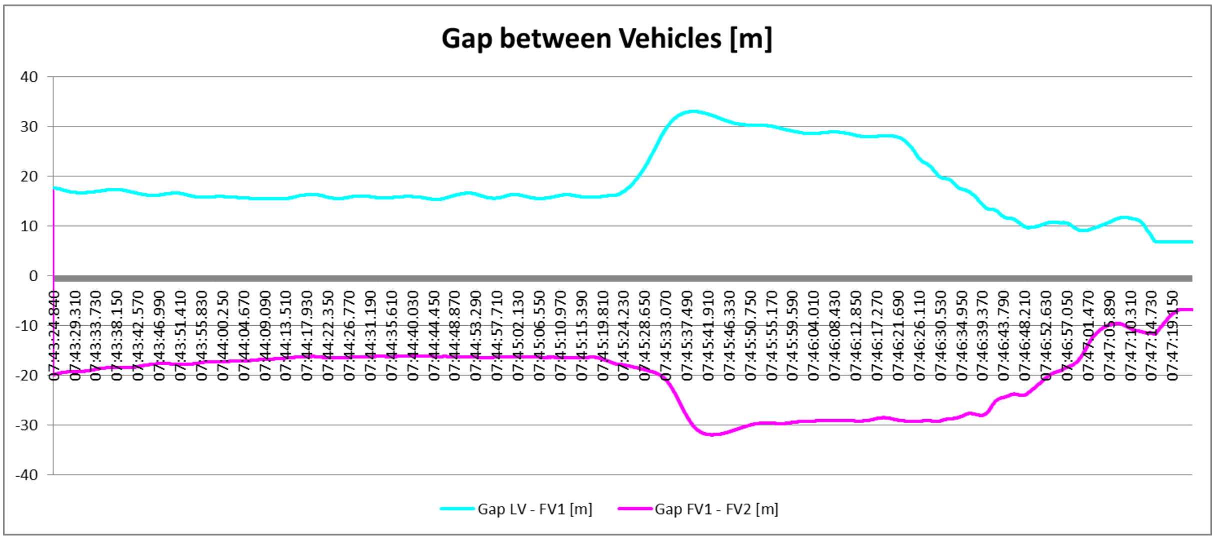


Figure 13. Gap between Vehicles, 80 Km/h

According to Figure 12, the vehicles reduce their speed till full stop at 07:46. Considering the KPI – Longitudinal Position Accuracy, the difference between the distances is 1.2 m.

3.3.2. Increasing Gap and Speed – 3 Vehicles – 70 to 80 Km/h

On this test can be seeing that the gap between the vehicles is modified due to the fact that a fourth vehicle external to the platoon gets in between. The test starts on the north straight and finishes on the same point after 2 laps. On Figure 14 is displayed the actual speed during the test, from 09:32 till 09:42. The speed of the LV is roughly constant at 70 Km/h, but more difficult to maintain at 80 Km/h. At 70 Km/h the fourth vehicle first interferes between the LV and FV1 and then between FV1 and FV2. Close to 09:33:20, the speed of the FV1 and FV2 is reduced due to the interfering vehicle, in order to increase the gap between LV and FV1. FV2 has to reduce the speed accordingly to avoid the collision. On Figure 15 can be seen the increment of the gap at that specific time. As of 09:34:33, the gap is reduced and the vehicles speed up to close the gap since the intruder left the platoon. Second time the fourth vehicle interferes is about 09:35:50. There, is only the FV2 the one that reduces the speed in order to increase the gap. It is interesting to mention the oscillations of the speed on FV2 when it tries to close the gap once the intruder leaves the platoon. As of 09:36:40, the vehicles increase the speed to 80 Km/h. The speed is not as constant as it was for 70 Km/h. The fourth vehicle interferes twice. Once at 09:38:11 and 09:40:18, it can be easily correlated the speed with the actual gap.

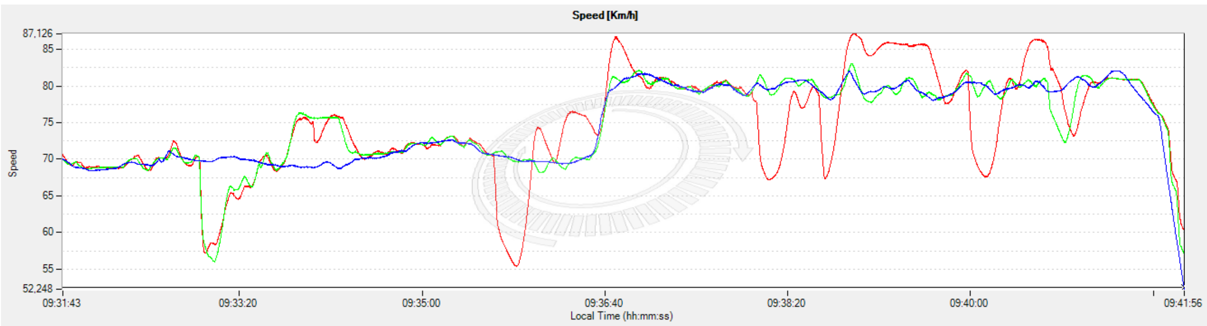


Figure 14. Increase of speed

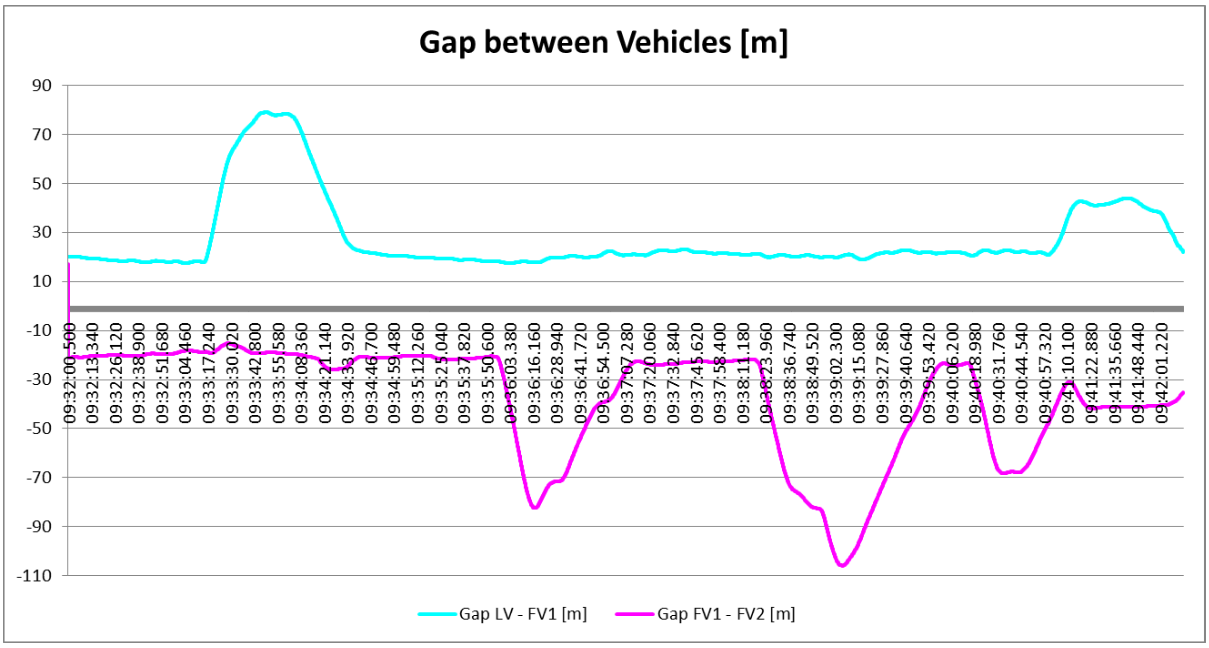


Figure 15. Gap between Vehicles, 70 to 80 Km/h

3.3.1. Increasing Gap – 3 vehicles – 60 Km/h

Same test as before but with constant speed. As it can be seen on Figure 16, as of 11:29 and 11:30, the speed of FV1 and FV2 is decreased, consequently, the gap between LV and FV1 is increased in order provide enough space to the interfering vehicle. As of 11:30, the gap between LV and FV1 is reduced to reach 10 meters, the theoretical one. Considering again the KPI – Longitudinal Position Accuracy, the difference between the distances is 1.6 m.

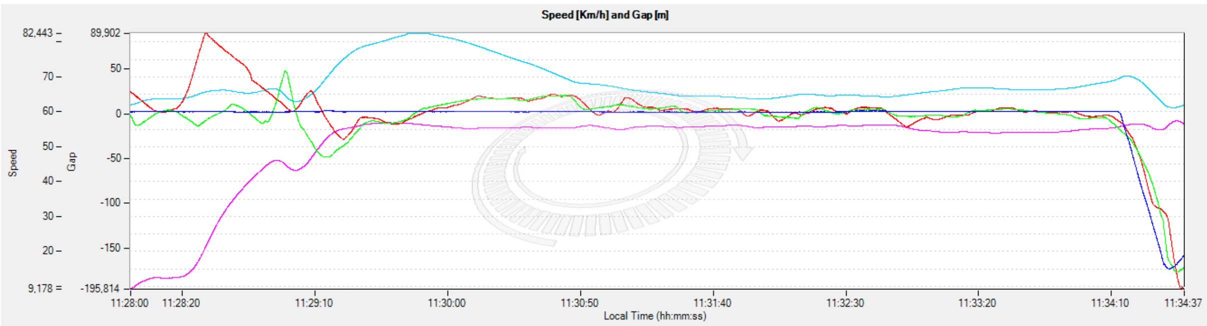


Figure 16. Increasing of the gap, 60 Km/h, 10 meters

3.3.1. Drive in Platoon – 3 Vehicles - 70 Km/h

On this test three vehicles are driving in a platoon, the speed and gap of the vehicles is displayed on Figure 17. Once the speed is stabilised, the gap is quite constant. In this manoeuvre, the measured duration merging to platoon (defined on KPI – Duration of Platooning Manoeuvre) lasts 20 seconds. The smoothness level in this platooning manoeuvre (defined on KPI – Level of Smoothness) results 1.1 Km/h.

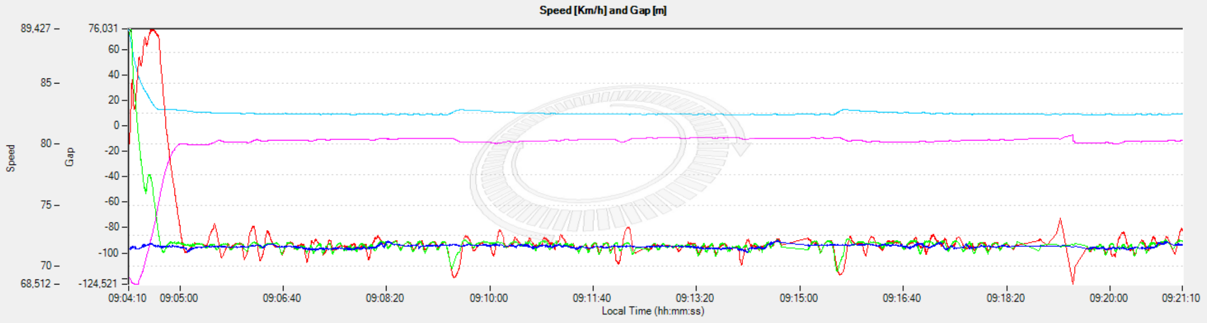


Figure 17. Driving in Platoon, 3 Vehicles, 70 Km/h

3.3.2. Driving in Platoon – 3 Vehicles – 80 Km/h

This test consists in three vehicles platooning during 5 laps at 80 Km/h. A sample of the test is displayed on Figure 18 with the actual gap and speed. The LV has the most stable speed (80 Km/h) and the others (FV1 and FV2) try to follow it in order to drive in platoon. The third vehicle is the one with more problems trying to maintain a constant speed. Important to remark that the gap between LV – FV1 is around 26 meters and FV1 – FV2 is around 15 meters. Both gaps are different and quite constant but different between them, and different to the theoretical one.

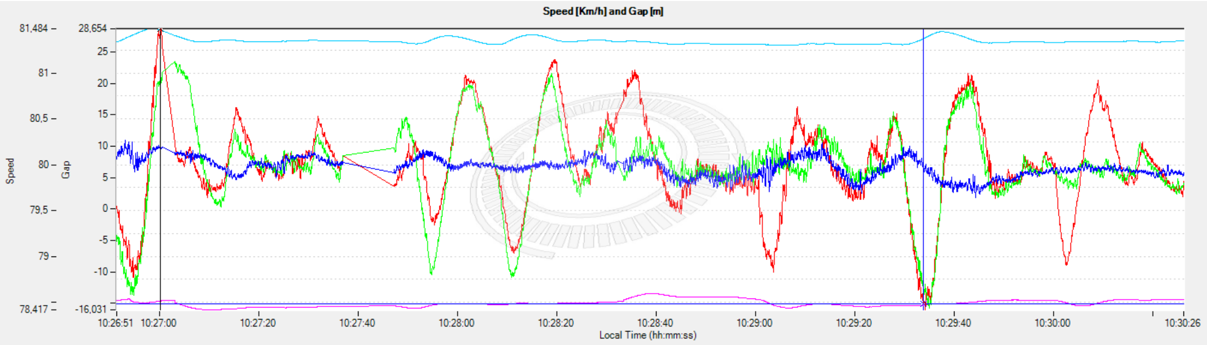


Figure 18. Driving in Platoon test, 5 laps

3.3.3. Driving in Platoon – 3 Vehicles – 80 Km/h

This test is exactly the same as the one described before. Three vehicles drive at 80 Km/h. On Figure 19 can be seeing that the LV is the one with the most stable speed. FV1 and FV2 speed varies between 78.5 and 80.5 Km/h. The gaps between LV – FV1 is 22 and FV1 – FV2 12 m. Same as before, gaps are quite constant but different. In this manoeuvre the measured duration of merging to platoon and split from platoon(defined on KPI – Duration of Platooning Manoeuvre) lasts 12 seconds.

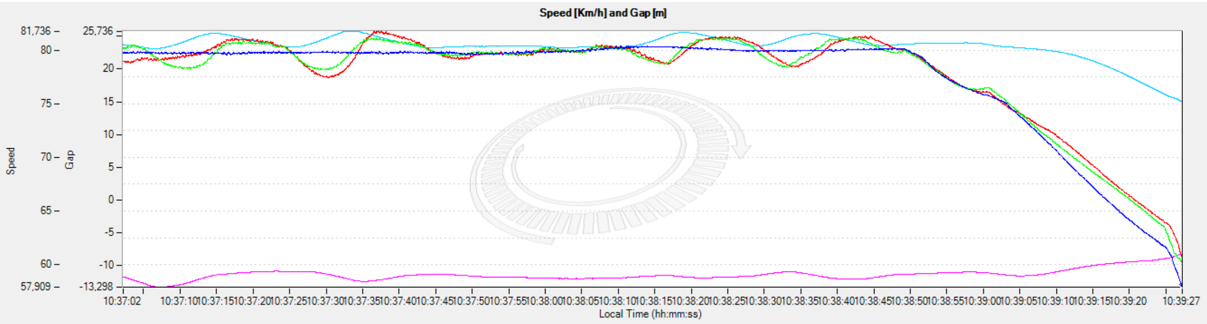


Figure 19. Driving in Platoon, 5 laps

3.3.4. Driving in Platoon – 3 Vehicles – 80 Km/h

On this test, it was study how the speed affects the gap between the vehicles since the minimum gap is of 0.5 s. First part of the test, the platoon drives at 80 Km/h and second part 8 Km/h. On Figure 20 can be seen that the platoon maintains a quite stable gap of 12 m. except when the platoon speeds up, the gap between LV and FV1 is increased and closed few seconds after. The smoothness level in this platooning manoeuvre results quite lower than lasts 0.7 Km/h. Considering the KPI – Longitudinal Position Accuracy, the difference between the distances is also quite lower than the last tests 0.9 m.

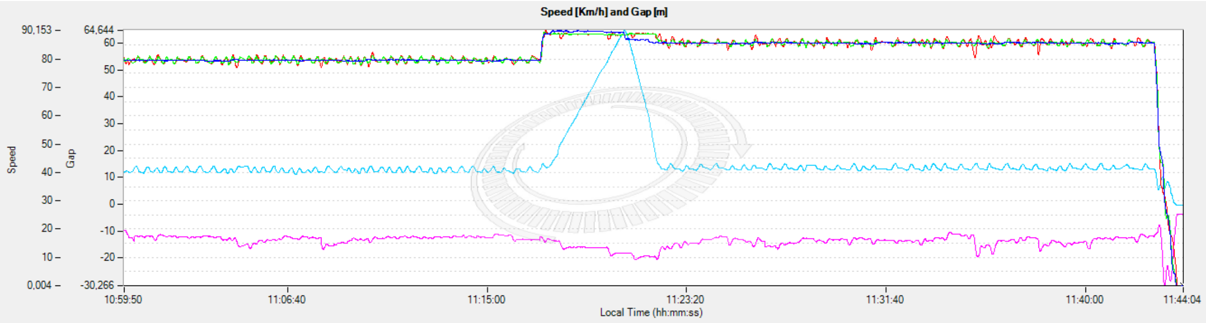


Figure 20. Driving in Platoon, 5 laps

3.3.5. 1st Emergency Braking – 2 Vehicles – 40 Km/h

Due to safety reasons, the system was trick and the emergency braking was performed in parallel. On this case, two vehicles are involved on the manoeuvre. On Figure 21 and Figure 23 is shown that the vehicles are driving at 40 Km/h. LV maintains a quite constant speed compared to FV1. The driver of the LV performs an emergency braking at 06:27:00 and the FV1 automatically brakes FV1.

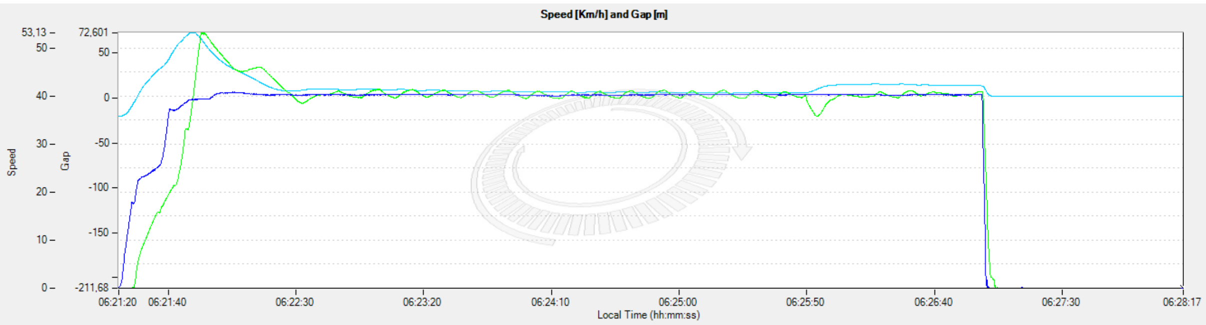


Figure 21. 1st Emergency Braking, 2 Vehicles, 40 Km/h

Figure 22 is part of Figure 22 zoomed in. Before 06:26:00 LV and FV1 are platooning and the gap is of 8 meters. As of 06:26, FV1 moves to the left lane and the gap between vehicles is increased up to 15 meters.sssss

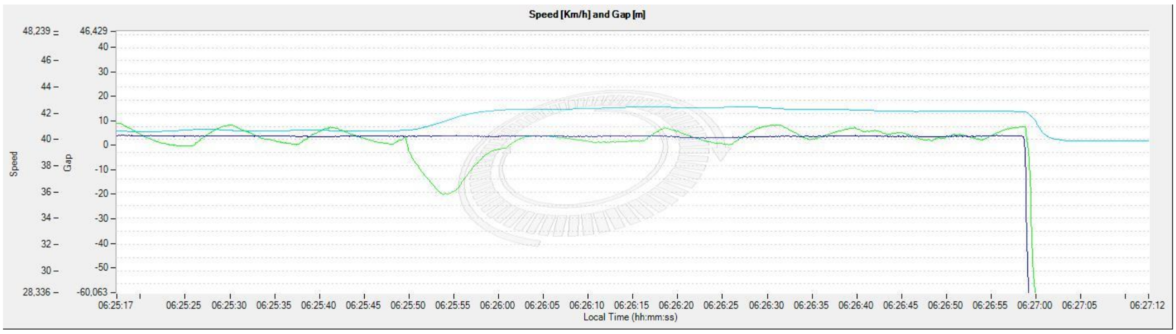


Figure 22. 1st Emergency Braking, 2 Vehicles, 40 Km/h, Zoomed In

On Figure 23 is depicted that the final gap between both vehicles is 1.8 m.

Figure 23. Gap after the emergency braking of two Trucks after 40 Km/h

3.3.6. 1st Emergency Braking – 3 Vehicles – 50 Km/h

On this test, three vehicles are driving at 50 Km/h and perform an emergency brake on the south straight line.

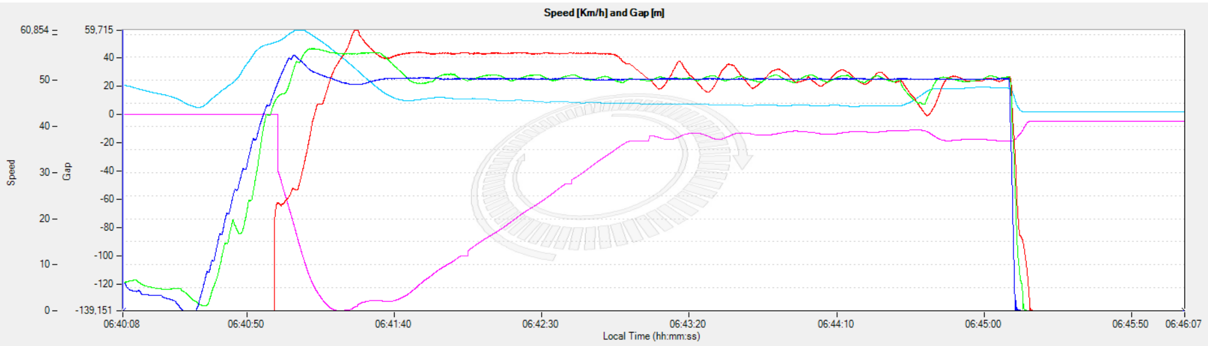


Figure 24. 1st Emergency Braking, 3 Vehicles, 50 Km/h

The vehicles platoon as of 06:40 and at 06:45 they arrive to the south straight. The driver of the LV performs an emergency braking and automatically the FV1 and FV2 perform an automatic emergency braking.

Figure 25. Gap after emergency braking of 3 vehicles at 50 Km/h

On Figure 25 is displayed the result of the test. Gap between Lv and FV1 is 1,8 meters and between FV1 and FV2 is 4,6 meters.

3.3.7. 2nd Emergency Braking – 3 Vehicles – 50 Km/h

Same test as before but on this case, the test is performed on the north straight line. The gap between vehicles maintains constant, about 7 meters between LV and FV1 and 10 meters between FV1 and FV2. The speed of the three vehicles variates around 50 Km/h, see Figure 26.

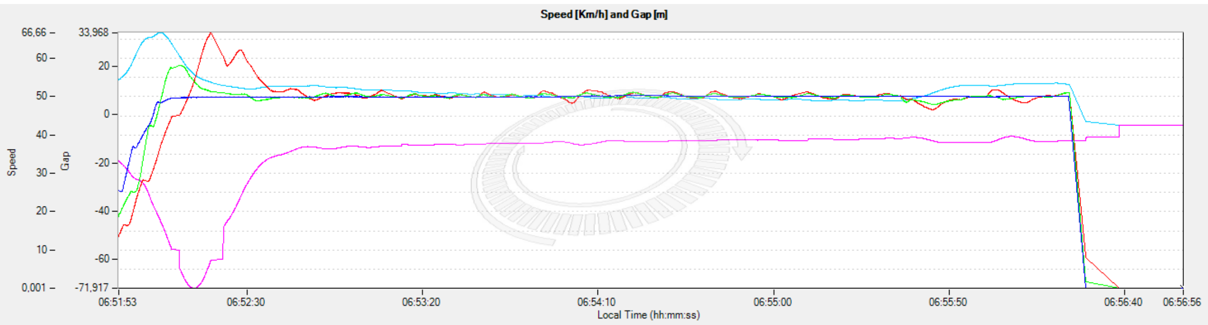


Figure 26. 2nd Emergency Braking, 3 vehicles, 50 Km/h

On Figure 27 is shown the final scenario, i.e. once the vehicles are completely stopped. There is no gap between LV and FV1, the FV1 overpasses the LV 4,25 meters. FV1 and FV2 maintain a gap of 4,3 meters.

Figure 27. Gap between vehicles after emergency braking, 3 vehicles, 50 Km/h

3.3.8. Emergency Braking – 3 Vehicles – 70 Km/h

Three vehicles are platooning at 70 Km/h. On Figure 28 can be seen that the driver of the LV brakes at 07:04 on the south straight. Figure 29 shows show the result of the test. FV1 overpasses LV in 5.7 meters and FV2 overpasses FV1 in 12 meters.

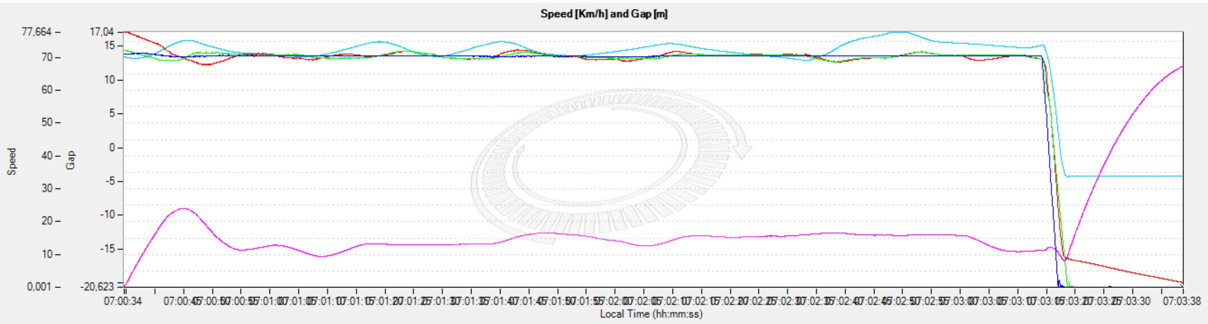


Figure 28. Emergency braking, 3 Vehicles, 70 Km/h

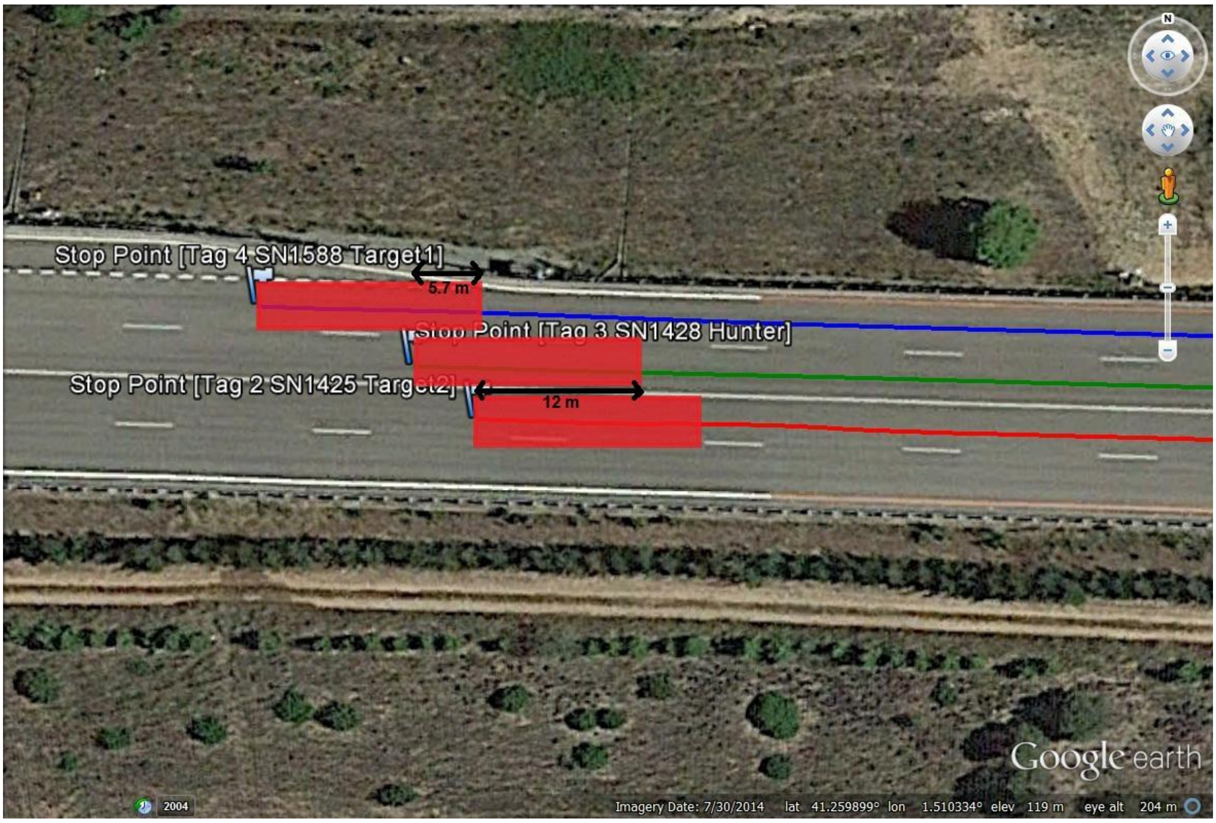


Figure 29. Gap between vehicles after emergency braking at 70 Km/h, 3 Vehicles

3.3.9. Increasing and Reduction of Speed

This test is a kind of stability test for the system. The objective is to maintain the platoon even increasing and reducing the speed. On Figure 30 are displayed the speed and gaps of the vehicles member of the platoon. First he platoon drives at 60 Km/h. At 11:42 it increases the speed to 70 Km/h and at 11:45 the platoon is interfered. At 11:49 the interfering vehicle leaves the platoon. Immediately the platoon reduces the speed till 60 Km/h. At 11:50, the speed of the platoon is increased again till 70 Km/h. At 11:52 it increases again the speed to 80 Km/h. At 11:55 reduces the speed to 70 Km/h and finally, at 11:55 the speed of the platoon is increased until 80 Km/h.

Notice that between 11:46 and 11:49 the gap between LV and FV1 is increased. The reason behind is that the two vehicles lose the signal.

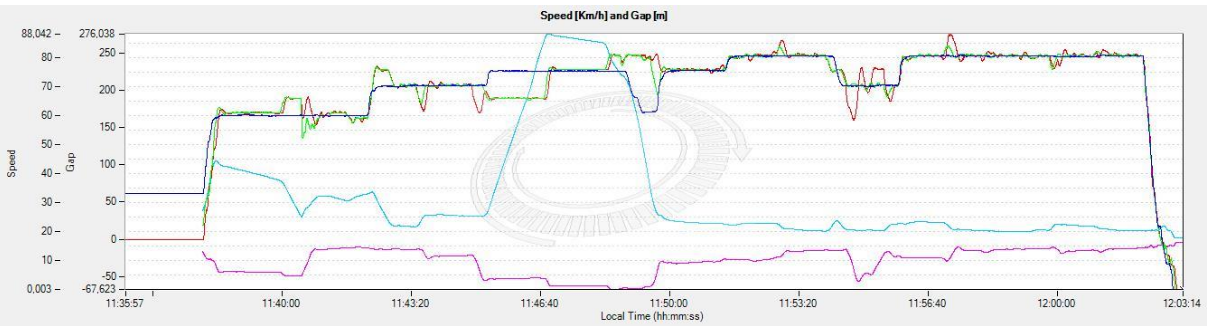


Figure 30. Modification of the speed platoon formed

4. Fuel Consumption Tests

4.1. Test Cases / Methodology

According with the previous explanation, a serial of test cases of fuel consumption procedures has been defined. The goal is to study how the fuel consumed can be affected when the vehicles are platooning.

The tests will be performed with platoons of two vehicles and three vehicles (see Table 2).

Group	Action	ID	Description
Fuel Consumption	Platooning	TC_FC_DRIVE-IN-PLATOON_02	Fuel consumption test driving in platoon with 2 vehicles involved at 70km/h and 80km/h in gaps of 20, 15, 12 and 10 meters
		TC_FC_DRIVE-IN-PLATOON_03	Fuel consumption test driving in platoon with 3 vehicles involved at 70km/h and 80km/h in gaps of 20, 15, 12 and 10 meters

Table 2. Test cases list of fuel consumption manoeuvers

A narrative description of each one of these test cases listed in the previous table is provided in the following sub-sections. A more detailed background of each test case is presented in the A.2. Fuel Consumption Test Plan.

4.2. Vehicle characteristics and fuel consumption procedure

4.2.1. Platoon vehicles characteristics

The convoy consisted of two or three vehicles (three trucks), in the following order:

1. Scania G450 truck, called Lotus or Lead Vehicle (LV)
2. Scania R480 truck, called Pluto or Following Truck (FV1)
3. Scania R480 truck, called Platoon or Following Truck (FV2)

The following figure shows the three vehicles on platooning on IDIADA's High Speed Track:

Figure 31. Full Platoon on testing track

Table 3 summarizes the testing conditions of the vehicles involved in the tests.

Vehicle	Scania G450 - LV	Scania R480 – FV1	Scania R480 – FV2
Engine	Euro VI - 13l	Euro V - 13l	Euro V - 13l
Gear box	GRS895R	GRSO905R OD box	GRS905R no OD box
Tires	315/70 R22,5	315/70 R22,5	315/70 R22,5
Nominal pressure (bar)	9,0 / 8,0	8,5 / 8,0	8,5 / 8,0
Empty weight	7500,0	7.580,0	7.530,0
Test weight (truck + trailer)	16.500,0	16.675,0	16.600,0

Table 3. Vehicle characteristics

4.2.2. Fuel consumption test conditions

External conditions

- The track was in good condition and dry.
- The test was performed on a straight part of the oval circuit with a distance of 2 km (segment 1 and segment 3).
- Maximum gradient of each straight of +/- 0,3% (uphill and downhill). The results in both directions will be presented as an average.
- The atmospheric pressure was greater than or equal to 82.5 kPa.
- The wind speed was below 3 m/s.
- The external temperature was between 20 and 30°C.
- The humidity level was below 95%.

Vehicle conditions during the tests

- Heating and ventilation switched off.
- Interior lighting is switched off. Dipped headlights are on

4.2.3. Fuel consumption test procedure

Warm up

The vehicles were warmed up for at least 20 minutes, it was necessary to perform as minimum of four laps of the high-speed track at constant speed of 85 km/h. The warming cycle was the same for all the vehicles. The vehicles were warmed up at the same time, immediately before the tests, to ensure consistent measurements.

Speed stabilization

Before the measurement, the testing speed was stabilized at least 200 meters before the measuring starting point (point zero). This is to ensure that all the vehicles are in a steady-state, with no accelerations or decelerations that could affect fuel consumption.

Fuel consumption measurement

Every measuring platoon distance at steady-state in both directions was repeated at least five laps in both directions. Due to weather conditions or other factors the repetition of the tests was necessary.

If there was a difference of less than 3% in at least three repetitions in each straight the fuel consumption results were acceptable. If not it was necessary to repeat the tests until three fuel consumption values under 3% were obtained.

The final fuel consumption was the average of the final values of each direction.

Final fuel consumption = [average (A1,B1)+average (A2,B2)+average(A1,B2)]/3

Test conditions

It was necessary to measure the fuel consumption individually for every vehicle in order to compare it with the fuel consumption in platooning. The fuel consumption for the reference test has been measured at a minimum distance of 200m between vehicles at 70km/h and 80km/h.

A minimum of one reference test per day for each vehicle was performed.

The fuel consumption was measured while the vehicles were in platooning at different distances of 20, 15, 12 and 10m at steady state speeds of 70 and 80 km/h.

Fuel consumption equipment installed

The vehicle instrumentation used during the test was as follows:

- Speed sensor
  Brand: Racelogic
  Model: VBox VB2SX10

- Flowmeter for LV
  Brand: TRIMEC INDUSTRIES
  Model: RT Flow Rate Totaliser
- Flowmeter for FV1 and FV2
  Brand: EMERSON
  Model: Micromotion 2400 S

4.3. Fuel consumption results

4.3.1. Summary of the performed tests

The order and characteristics of the tests performed every day are described in the following points:

First day 11/08/2015 – Platooning in two vehicles at 70km/h

- Performance of the fuel consumption reference test on LV and FV1 at 70km/h.
- Performance of the fuel consumption reference test at 70km/h and gap of 15m.
- Performance of the fuel consumption reference test at 70km/h and gap of 12m.
- Performance of the fuel consumption reference test at 70km/h and gap of 10m.

- Performance of the fuel consumption reference test at 70km/h and gap of 20m.

Second day 12/08/2015 – Platooning in two vehicles at 80km/h

- Performance of the fuel consumption reference test on LV and FV1 at 80km/h.
- Performance of the fuel consumption reference test at 80km/h and gap of 20m.
- Performance of the fuel consumption reference test at 80km/h and gap of 12m.
- Performance of the fuel consumption reference test at 80km/h and gap of 15m.

Third day 13/08/2015 – Platooning in three vehicles at 70km/h

- Performance of the fuel consumption reference test on LV, FV1 and FV2 at 70km/h.
- Performance of the fuel consumption reference test at 70km/h and gap of 20m.
- Performance of the fuel consumption reference test at 70km/h and gap of 15m.
- Performance of the fuel consumption reference test at 70km/h and gap of 12m.
- Performance of the fuel consumption reference test at 70km/h and gap of 10m.

Third day 14/08/2015 – Platooning in three vehicles at 80km/h

- Performance of the fuel consumption reference test on LV, FV1 and FV2 at 80km/h.
- Performance of the fuel consumption reference test at 80km/h and gap of 20m.
- Performance of the fuel consumption reference test at 80km/h and gap of 15m.
- Performance of the fuel consumption reference test at 80km/h and gap of 12m.

4.3.2. **Fuel consumption tests results at 70km/h FV1 vehicle.**

First day 11/08/2015 – FV1 at 70km/h – Platooning of **two vehicles**

The following table shows the fuel consumption results obtained on the FV1 at 70km/h at different distance gaps:

Hour	Theoretical Gap (m)	Real Mean Gap (m)	Mean Lateral offset (m)	Down straight (l/100km)	Speed (km/h)	Up straight (l/100km)	Speed (km/h)	Average (l/100km)	Speed km/h	KPI Fuel efficiency
1:35	Alone	Alone	Alone	15,5	69,88	23,2	69,77	**19,3**	69,83	--
5:31	20	20,78	0,09	14,4	70,13	22,2	70,01	**18,3**	70,07	5,4%
2:35	15	15,05	0,18	14,0	70,49	22,1	70,45	**18,0**	70,47	6,7%
3:40	12	11,73	0,08	14,2	70,18	21,2	69,98	**17,7**	70,08	**8,5%**
4:55	10	9,79	0,02	14,4	70,13	21,3	70,01	**17,9**	70,07	7,4%

Table 4. FV1 fuel consumption results at 70km/h

Third 13/08/2015 – FV1 at 70km/h – Platooning of **three vehicles**

The following table shows the fuel consumption results obtained on the FV1 at 70km/h at different distance gaps:

Hour	Theoretical Gap (m)	Real Mean Gap (m)	Mean Lateral offset (m)	Down straight (l/100km)	Speed (km/h)	Up straight (l/100km)	Speed (km/h)	Average (l/100km)	Speed km/h	KPI Fuel efficiency
0:15	Alone	Alone	Alone	15,4	70,20	22,9	70,10	**19,3**	70,15	--

1:37	20	18,11	0,38	14,2	70,39	21,1	70,32	**17,7**	70,35	8,3%
2:14	15	15,53	0,34	13,8	70,39	20,8	70,32	**17,3**	70,36	10,1%
3:31	12	11,99	0,45	13,6	69,94	20,1	69,90	**16,8**	69,92	**12,6%**
4:10	10	10,22	0,47	13,3	70,00	20,6	69,86	**17,0**	69,93	11,9%

Table 5. FV1 fuel consumption results at 70km/h

The following graph shows the speed and fuel consumption behaviour of the FV1 at 70km/h in Platooning of **two vehicles** for the different tested gaps and on Figure 33 the lateral offset:

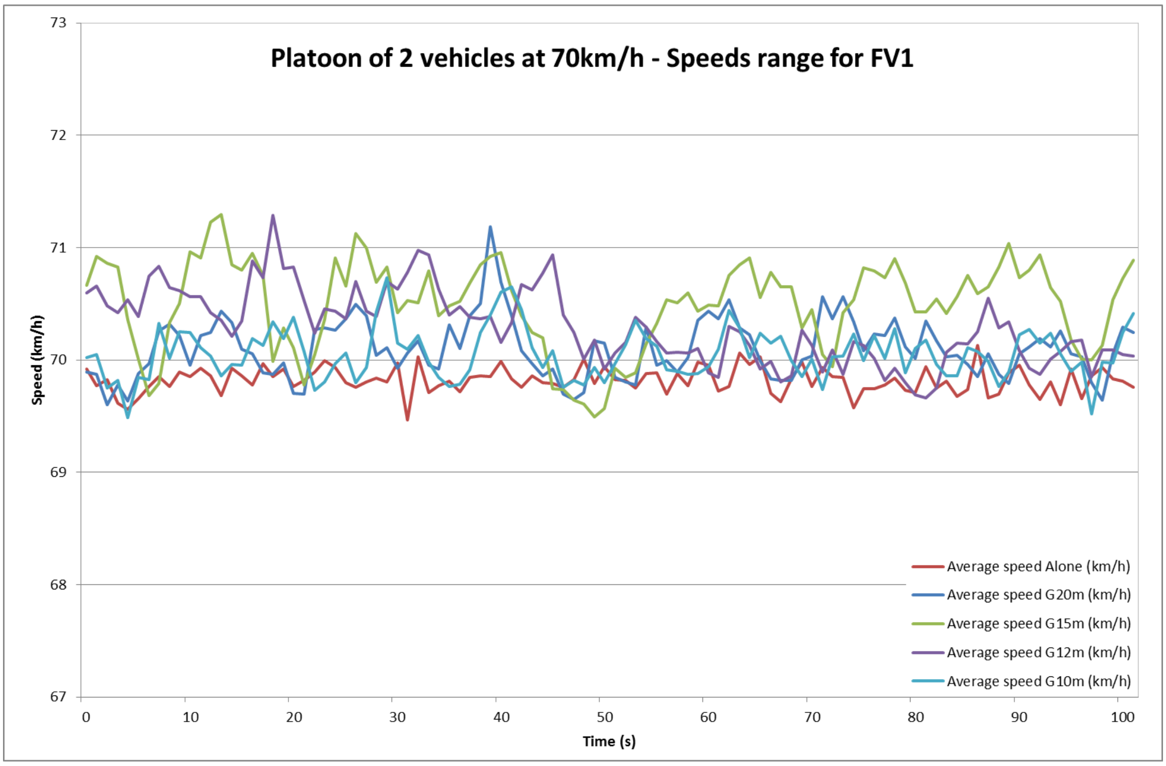


Figure 32. FV1 speed range

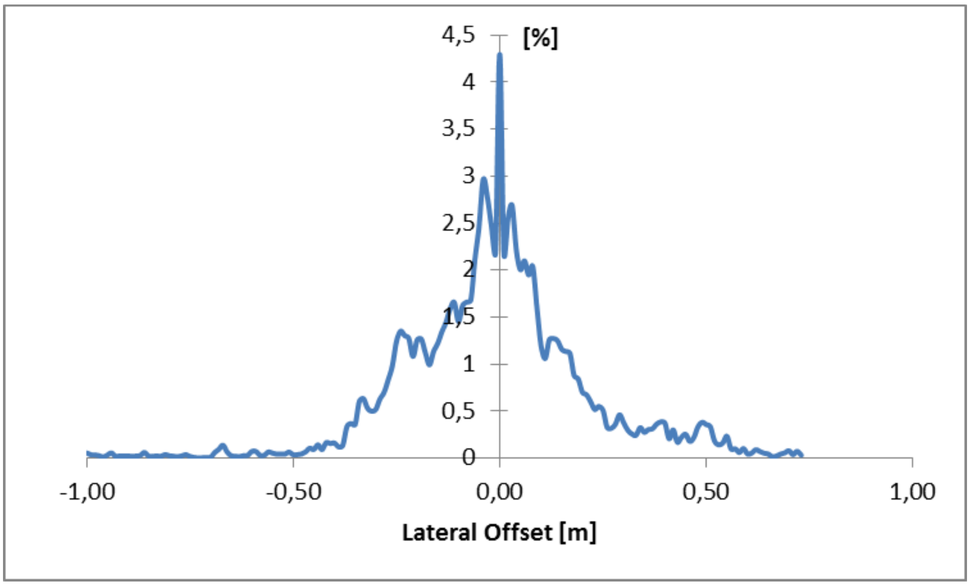


Figure 33. FV1 lateral offset

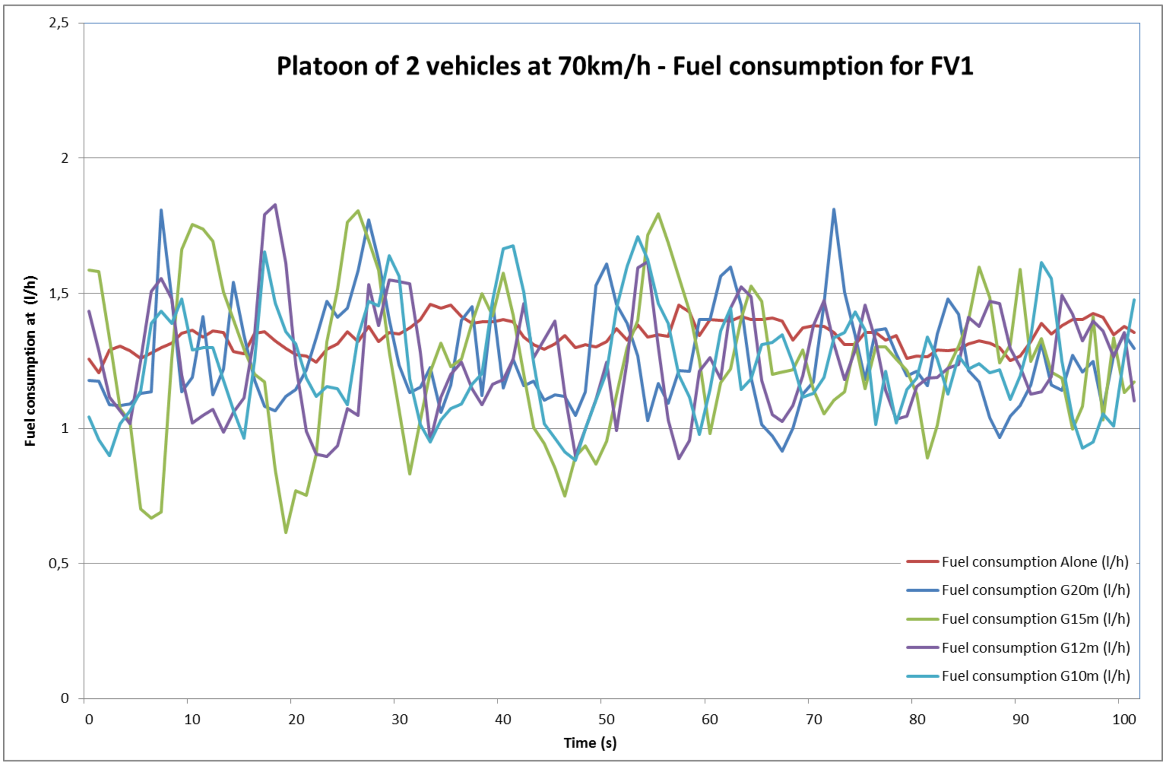


Figure 34. FV1 fuel consumption

The following graph shows the speed and fuel consumption behaviour of the FV1 at 70km/h in Platooning of **three vehicles** for the different tested gaps:

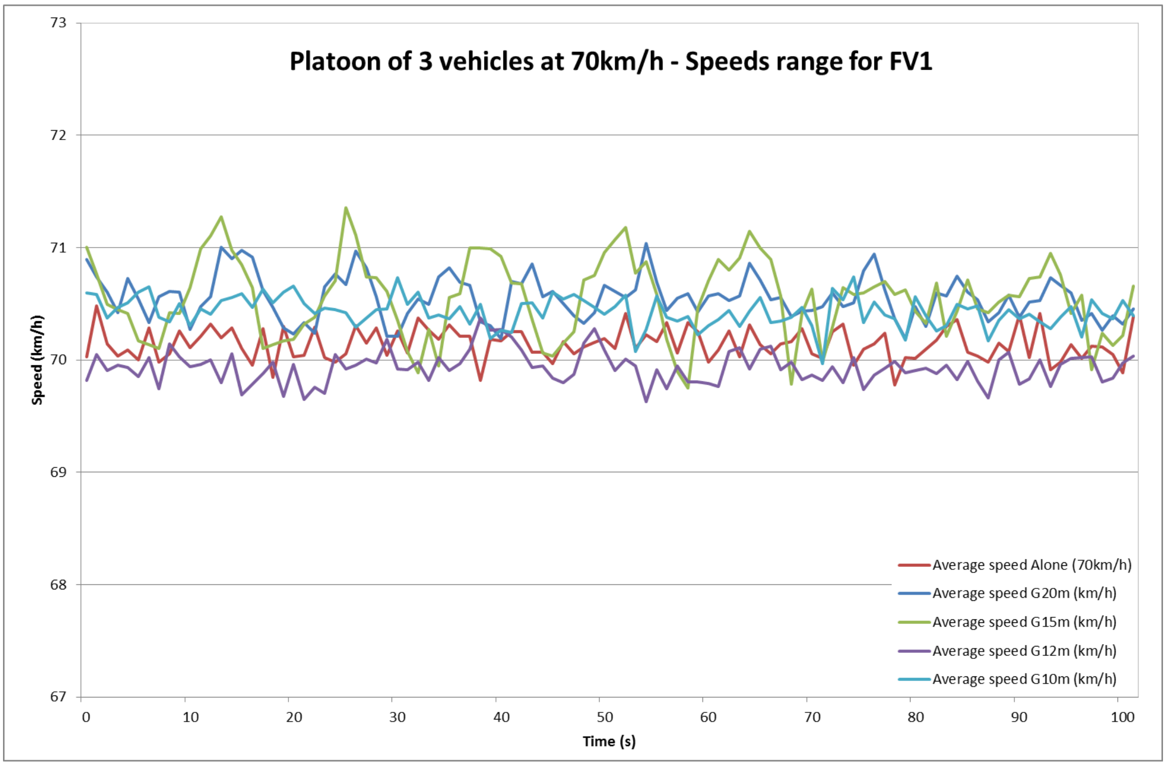


Figure 35. FV1 speed range

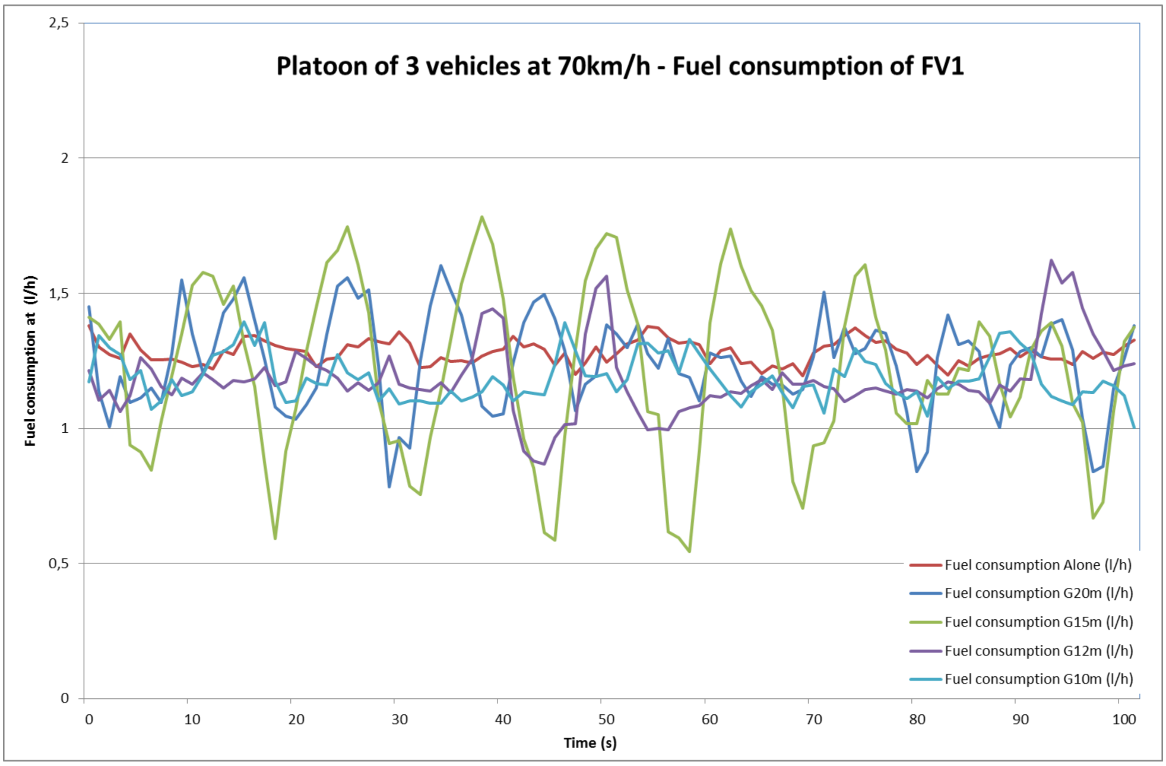


Figure 36. FV1 fuel consumption

4.3.3. Fuel consumption tests results at 70km/h FV2 vehicle.

Third day 13/08/2015 – FV2 at 70km/h – Platooning of **three vehicles**

The following table shows the fuel consumption results obtained on the FV2 at 70km/h at different distance gaps:

Hour	Theoretical Gap (m)	Real Mean Gap (m)	Mean Lateral offset (m)	Down straight (l/100km)	Speed (km/h)	Up straight (l/100km)	Speed (km/h)	Average (l/100km)	Speed km/h	KPI Fuel efficiency
0:15	Alone	Alone	Alone	14,1	69,89	21,3	70,01	**17,7**	69,95	---
1:37	20	19,71	0,71	13,0	70,40	20,0	70,42	**16,5**	70,41	**6,8%**
2:14	15	16,33	0,10	13,2	70,41	20,1	70,46	**16,6**	70,43	6,1%
3:31	*12*	*12,79*	*0,19*	*15,6*	*70,00*	*20,5*	*69,90*	***18,0****	*69,95*	*-1,9%**
4:10	10	10,64	0,02	12,9	70,77	20,1	70,61	**16,5**	70,69	6,7%

Table 6. FV2 fuel consumption results at 70km/h

**The fuel consumption results obtained in gap of 12 meters is higher than the expected. Using the information available, it is not possible to determine the origin of this incidence.*

The following graph shows the speed and fuel consumption behaviour of the FV2 at 70km/h in Platooning of **three vehicles** for the different tested gaps:

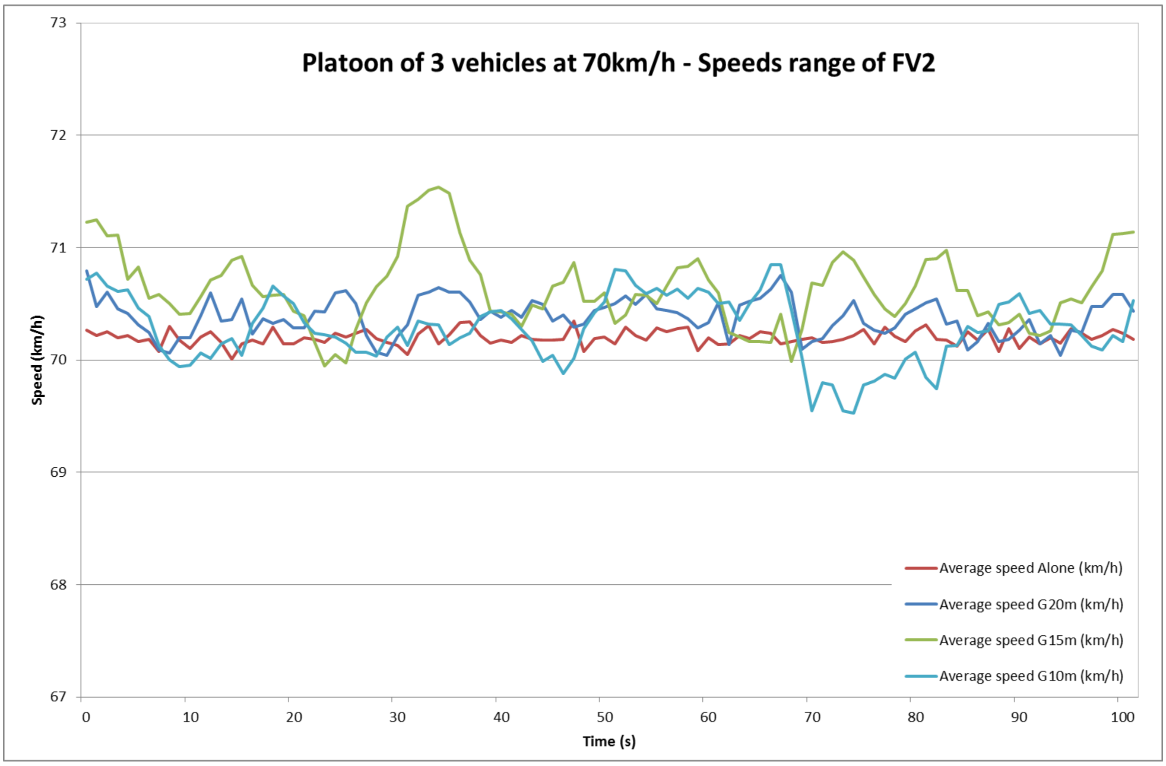


Figure 37. FV2 speed range

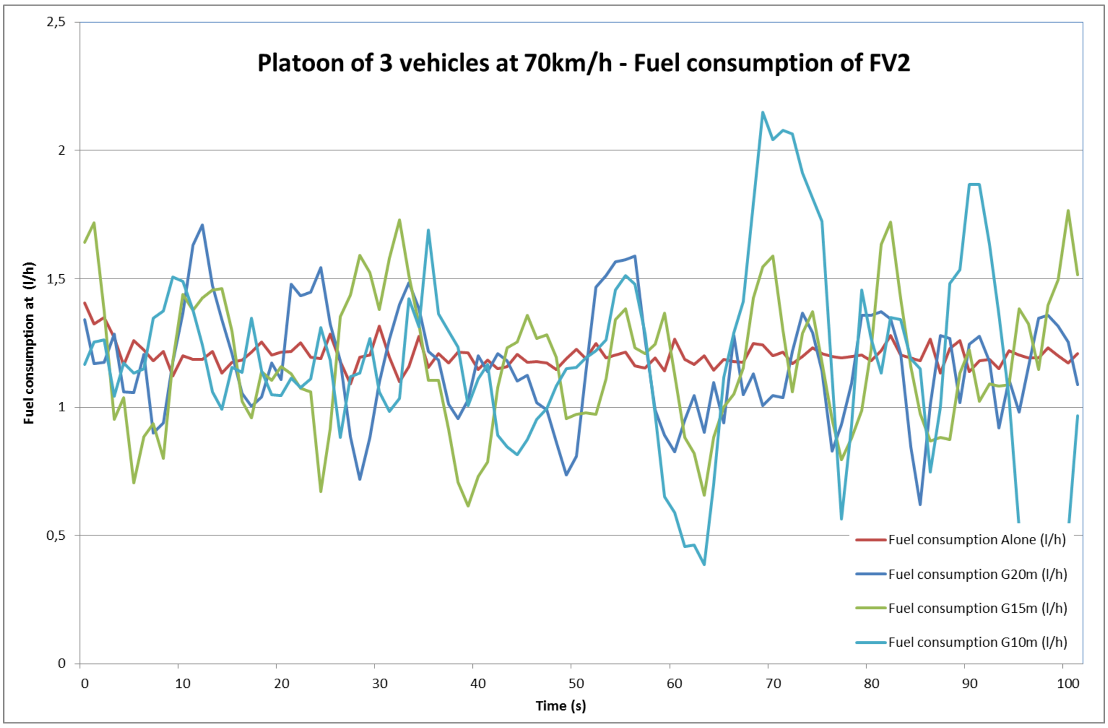


Figure 38. FV2 fuel consumption

4.3.4. Fuel consumption tests results at 80km/h FV1 vehicle.

Second day 12/08/2015 – FV1 at 80km/h – Platooning of **two vehicles**

The following table shows the fuel consumption results obtained on the FV1 at 80km/h at different distance gaps:

Hour	Theoretical Gap (m)	Real Mean Gap (m)	Mean Lateral offset (m)	Down straight (l/100km)	Speed (km/h)	Up straight (l/100km)	Speed (km/h)	Average (l/100km)	Speed km/h	KPI Fuel efficiency
0:23	Alone	Alone	Alone	17,1	79,56	25,0	79,52	**21,0**	79,54	---
0:57	20	19,22	0,48	15,9	79,90	22,5	79,80	**19,2**	79,85	**8,6%**
3:32	15	15,82	0,02	16,4	80,04	22,4	79,94	**19,4**	79,99	7,8%
1:59	12	11,68	0,11	15,8	79,61	22,7	79,52	**19,3**	79,56	8,5%

Table 7. FV1 fuel consumption results at 80km/h

Third 14/08/2015 – FV1 at 80km/h – Platooning of **three vehicles**

The following table shows the fuel consumption results obtained on the FV1 at 80km/h at different distance gaps:

Hour	Theoretical Gap (m)	Real Mean Gap (m)	Mean Lateral offset (m)	Down straight (l/100km)	Speed (km/h)	Up straight (l/100km)	Speed (km/h)	Average (l/100km)	Speed km/h	KPI Fuel efficiency
0:02	Alone	Alone	Alone	18,1	79,80	23,9	79,68	**21,0**	79,74	---
0:35	20	20,62	0,21	15,7	80,50	22,5	80,40	**19,1**	80,45	9,0%
1:31	15	15,83	0,23	14,7	80,04	23,4	79,90	**19,1**	79,97	9,2%
2:05	12	13,66	0,37	14,4	80,04	23,5	79,90	**18,9**	79,97	**9,9%**

Table 8. FV1 fuel consumption results at 80km/h

The following graph shows the speed, lateral offset and fuel consumption behaviour of the FV1 at 80km/h in Platooning of **two vehicles** for the different tested gaps:

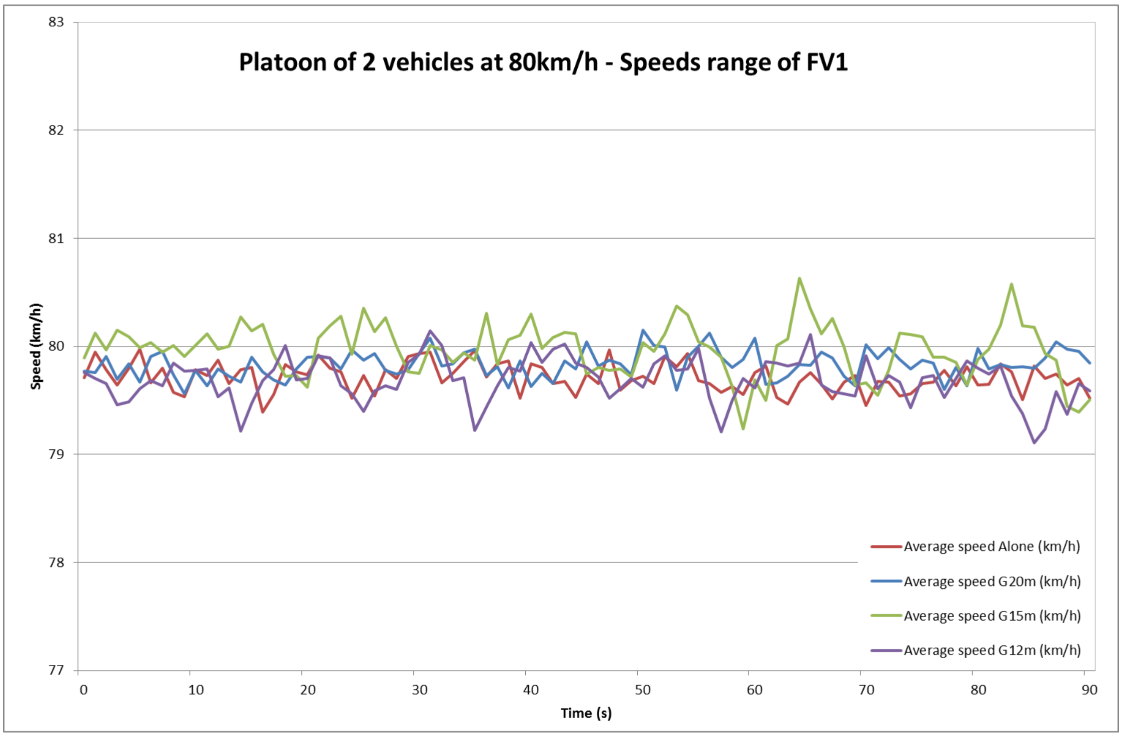


Figure 39. FV1 speed range

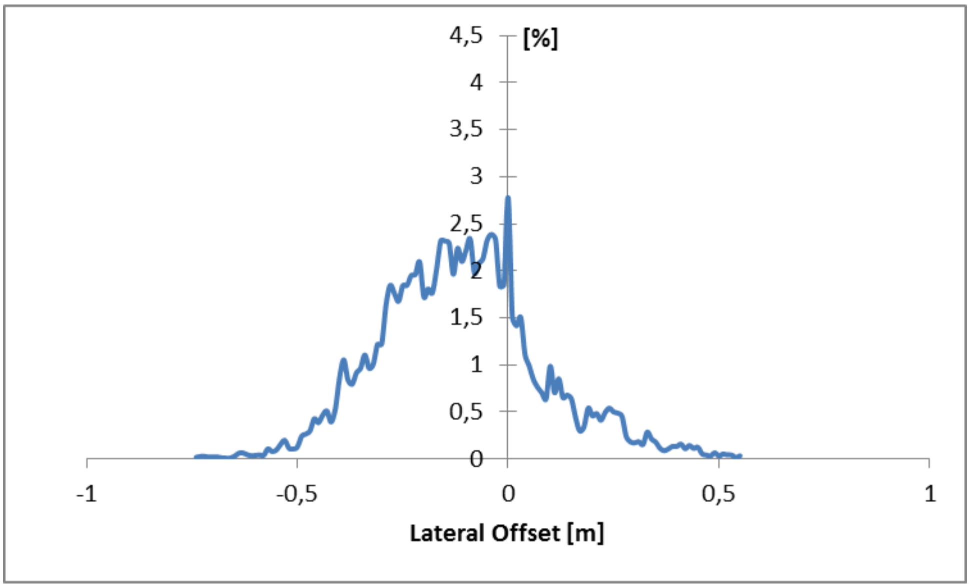
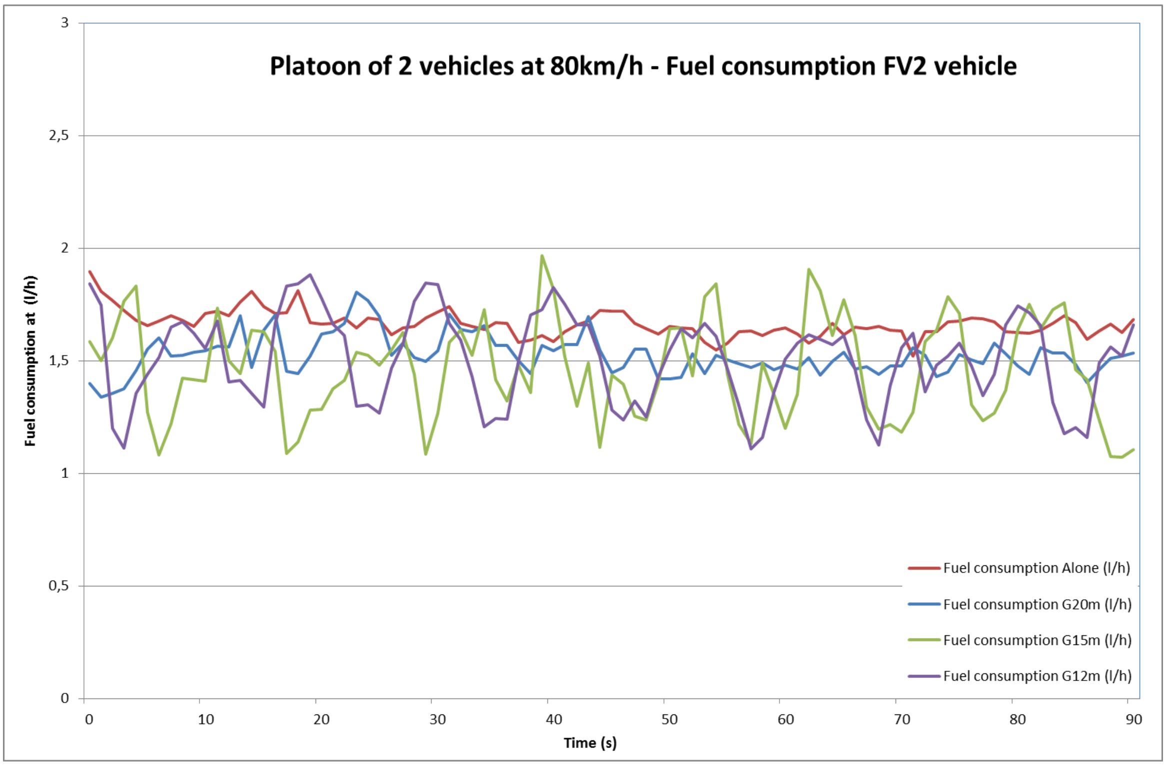


Figure 40. FV1 lateral offset



,

Figure 41. FV1 fuel consumption

The following graph shows the speed and fuel consumption behaviour of the FV1 at 80km/h in Platooning of **three vehicles** for the different tested gaps:

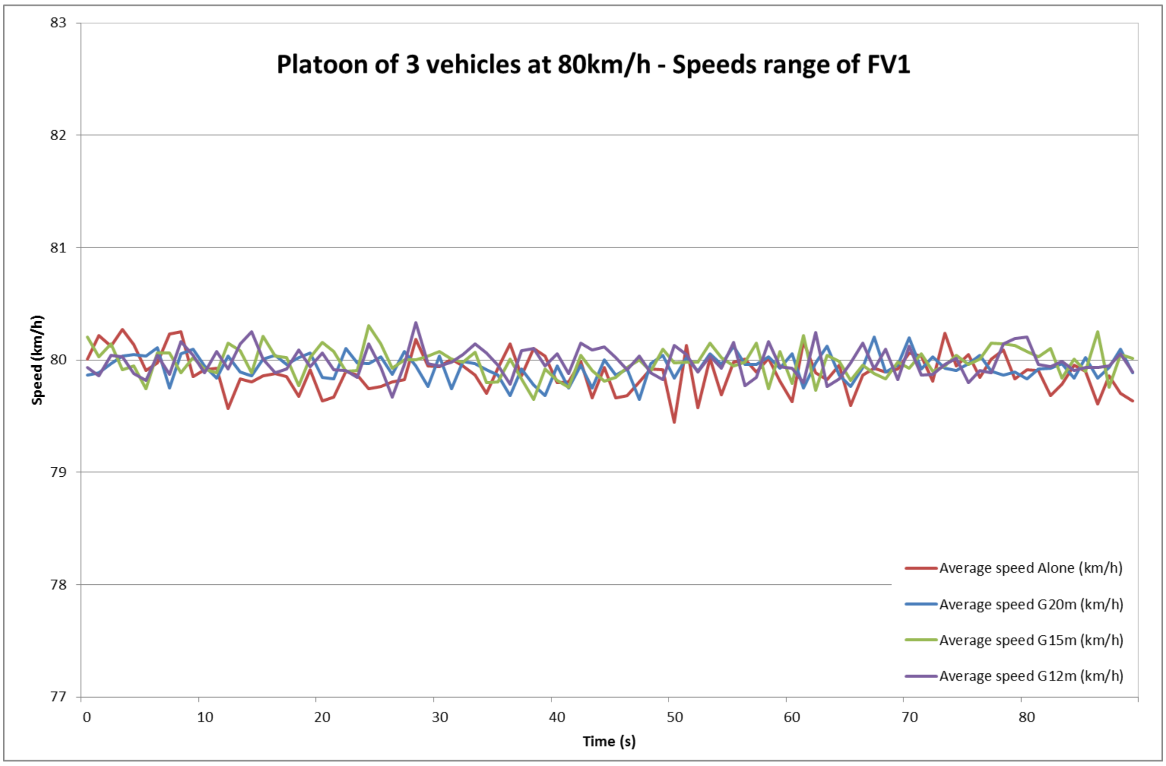


Figure 42. FV1 speed range

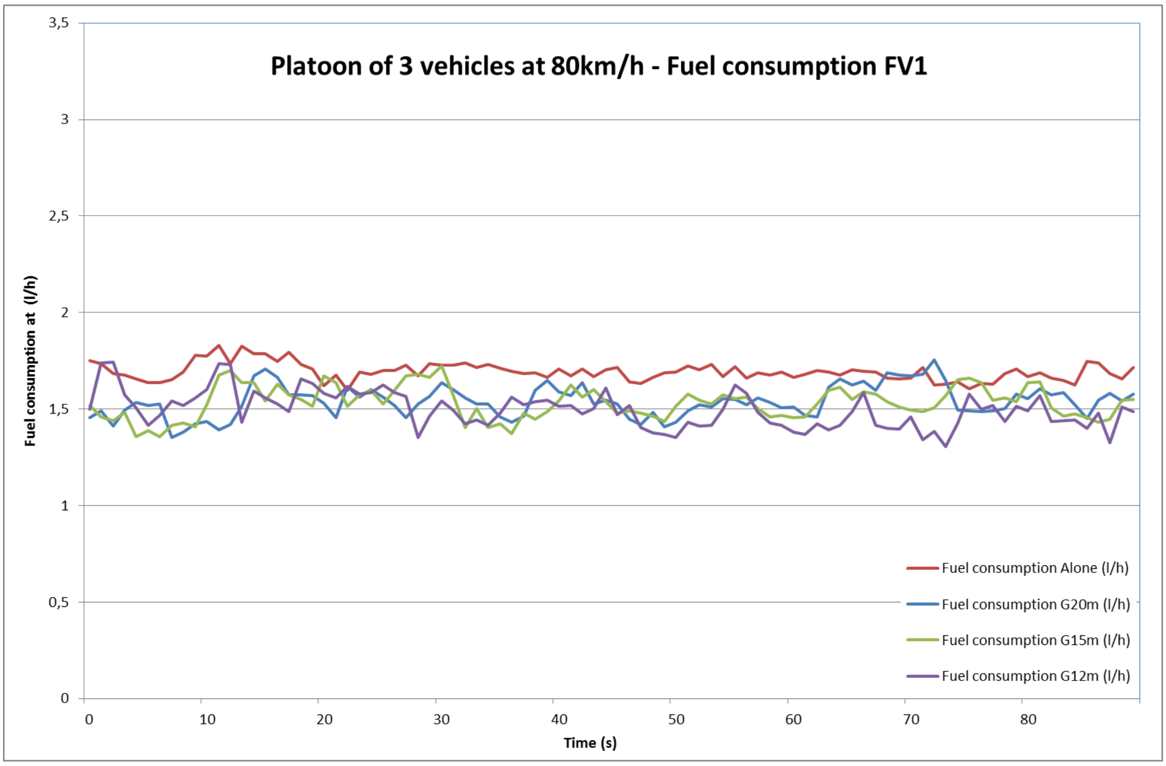


Figure 43. FV1 fuel consumption

4.3.5. Fuel consumption tests results at 80km/h.

Fourth day 14/08/2015 – FV2 at 80km/h

The following table shows the fuel consumption results obtained on the FV2 at 80km/h at different distance gaps:

Hour	Theoretical Gap (m)	Real Mean Gap (m)	Mean Lateral offset (m)	Down straight (l/100km)	Speed (km/h)	Up straight (l/100km)	Speed (km/h)	Average (l/100km)	Speed km/h	KPI Fuel efficiency
0:23	Alone	Alone	Alone	16,9	79,20	22,9	79,01	**19,9**	79,11	--
0:57	20	20,07	0,09	15,1	80,60	21,7	80,40	**18,4**	80,50	**7,2%**
3:32	15	15,70	0,15	15,6	80,04	22,6	79,90	**19,1**	79,97	3,8%
1:59	12	13,54	0,10	14,3	79,98	23,4	80	**18,9**	79,99	5,0%

Table 9. FV2 fuel consumption results at 80km/h

The following graph shows the speed and fuel consumption behaviour of the FV2 at 80km/h in Platooning of **three vehicles** for the different tested gaps:

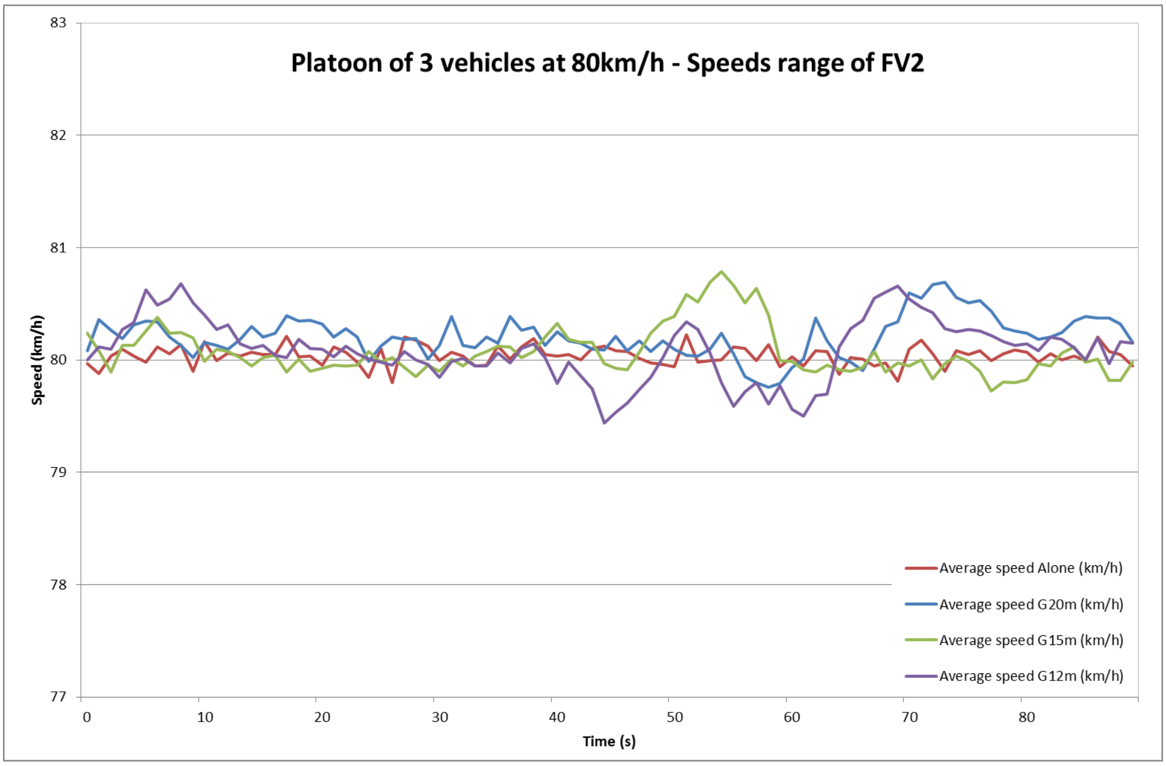


Figure 44. FV2 speed range

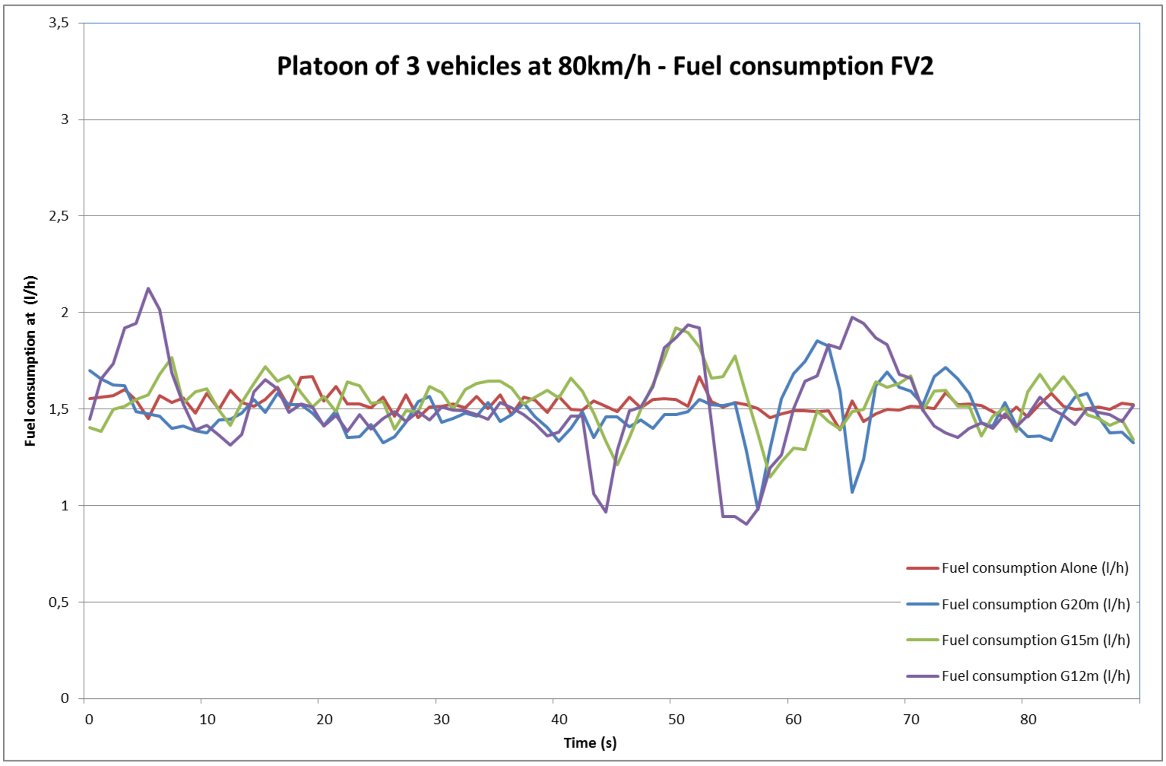


Figure 45. FV2 fuel consumption

4.4. Fuel consumption conclusions

4.4.1. LV vehicle

The fuel consumption results obtained on the FV in all configurations (alone and platooning) are quite similar. Although the fuel consumed seems lower in platooning mode, this difference is too small (around 1%) to specifically provide this value as reference. At the same time, in a few tests the fuel consumption in platoon is slightly higher so it indicates that the vehicle behaviour and weather conditions generate a test uncertainty inside the possible fuel consumption benefits of the LV.

4.4.2. FV1 vehicle.

The fuel consumption results of the FV1 in platoon mode at 70km/h are better than the reference fuel consumption measured. The first reduction appears in the gap of 20 meters that depending on the number of vehicles in platoon (two or three), it is possible to obtain a reduction from 5,4 to 8,3%.

The fuel consumption reduction is quite similar between the gaps of 15, 12 and 10 meters so it is difficult to notice a big impact on the fuel consumption reduction inside this distance range. If we calculate the average of the fuel consumption reduction percentages for these 3 gaps, we obtain a reduction of 7,6% for two vehicles in platoon and 11,5% for three vehicles in platoon.

The fuel consumption behaviour running at 80km/s is similar but in this case the reduction improvement between the gaps of 20, 15 and 12 meters is not noticed. The average of the fuel consumption reduction percentages for two vehicles in platoon is 8,3% and for three vehicles in platoon is 9,4%.

The reductions is always higher in the FV1 in three vehicles in platoon mode so seems that the position of the FV2 helps in the reduction of the FV1 fuel consumption but the differences are too low and it will be necessary to increase the number of tests to quantify its benefit.

4.4.3. **FV2 vehicle.**

The fuel consumption values of the FV2 are lower than the reference tests but this reduction is lower than the FV1 and there is not an important reduction impact between the gaps of 20, 15 and 12 meters. The results show that the average fuel consumption between the different gaps at 70km/h is 6,5% and for 80km/h is 5,4%.

In this situation the difficulty of keeping the leader target speed is higher so the benefits in the fuel consumption are lower.

If we test the vehicle alone, the fuel consumption and vehicle speed behaviour is more stable than in platooning mode, for this reason we consider that it is possible to obtain higher fuel consumption reductions optimizing the vehicles behaviour in platoon mode.

4.4.4. **CO_2 emissions results.**

The percentage of the CO_2 emissions reduction is proportional to the fuel consumption reduction.

4.5. KPIs

This section provides an overview of the Key Performance Indicators (KPIs) identified to assess the performance of the COMPANION system from the fuel consumption perspective.

4.5.1. **CO_2 Emissions**

This KPI is in charge to calculate the saving CO_2 emissions due to driving in platoon versus to driving alone.

$$KPI = \frac{CO_2\ Emissions\ before\ Platooning - CO_2\ Emissions\ after\ Platooning}{CO_2\ Emissions\ before\ Platooning} \cdot 100\ [\%]$$

4.5.2. **Fuel Efficiency**

This KPI estimates the percentage improve of the platoon compared to the vehicles driven alone.

$$KPI = \frac{Average\ consumption\ of\ vehicles\ in\ a\ platoon}{Average\ consumption\ of\ vehicles\ out\ from\ a\ platoon} \cdot 100\ [\%]$$

5. Driver Acceptance Tests

5.1. Methodology

To assure the usability of the on-board HMI of COMPANION system, usability tests were ran on the first working prototype. This prototype is a graphical user interface (GUI) that is displayed on a monitor, which is mounted in the instrument cluster of the vehicle (see Figure 46). The GUI software integrated with the on-board hardware and software infrastructure system of the truck. Due to the small number of drivers, limited time and resources available, the tests were performed in a qualitative way. The objective was to assess the usability, efficiency, and effectiveness of the HMI in main platooning scenarios, as defined in D2.1 [2].

Figure 46. Cockpit with OFFIS HMI

In the following sections, an overview is given about the test participants and the applied procedure.

5.1.1. Test participants

Our participants were three male pilot drivers provided by APPLUS IDIADA with 25, 40, and 62 years of age. They had 2, 18, and 30 years of truck driving experience, respectively. All of them use cruise control and navigation systems regularly when driving, and drive a minimum of 30 hours in a week.

5.1.2. Training Session

Because the platooning concept and the manoeuvres which are performed while driving are new to drivers, a training session was conducted. Here, the drivers had the chance to get to know the system and the test procedure in order to circumvent misconceptions and unwanted surprises during the tests. The drivers were given a one-hour training session. In this session, they were introduced to the platooning manoeuvres, and their corresponding HMI views. For each view, the details of each information item in the view and the required actions at each manoeuvre were explained. The drivers were free to ask questions in cases of confusion.

5.1.3. Pre and Post-test Questionnaires

To be able to compare the first impression of the drivers of the on board HMI with their impression of it after having used it, two questionnaires were designed. These questionnaires were called pre-test and post-test questionnaire. The questionnaires were completely identical, the difference was the time, in which they were given to the drivers. The pre-test questionnaires were handed out right after training session to the drivers, before they used the system for the first time to evaluate their first impression of the system. The post-test questionnaires were spread distributed on the last day of the tests, after the drives used the HMI in all platooning scenarios.

5.1.4. Description of the HMI

In platooning, there are four main states: single driving (platooning plan present, the vehicle is guided to the platoon), merging (a vehicle reached a platoon and joins), platooning (a vehicle is part of the platoon and drives with close distance), and splitting (a vehicle dissolves from the platoon to return to individual driving). The drivers used the integrated user interface, depicted in Figure 47. For single driving, the drivers were presented with (a). Here, the driver is informed about the time and the distance until the platoon is reached. Further, the future role (leader or member), and the future position (e.g. 2 of 3) are shown. In the middle, the plan speeds are shown which represent the current (bottom), next (middle) and next (top) requested speed values. The speed values are applied to the vehicle automatically in order to catch up to the platoon in front. In the bottom, there are three elements: and ascending triangle, a descending triangle, and a steady bar. Only one element is shown at a time to indicate how the current vehicle speed differs from the planned speed.

After the vehicle has caught up to the platoon, the view (b) is presented. Here, the merging process is supported. In this case, the ego vehicle merges from behind to a vehicle in front. The top element represents the truck to merge to, whereas the green cubical element represents the ego vehicle. Between the front and ego vehicle, two arrows visualise the merging process by animation. Here, the distance between the vehicles is shown in meters. Similar to (a), the distance until platooning (which is the next status after merging), the future role, and the future position in the platoon is shown. Figure 48. shows the merging manoeuvre and the view presented to the driver.

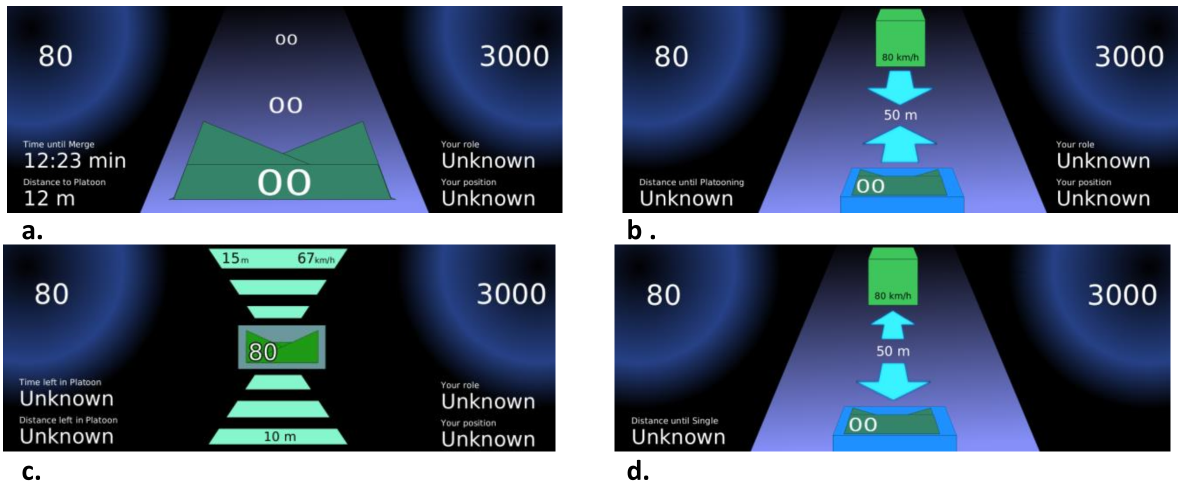


Figure 47 - On-board HMI views: a. Driving alone view, b. Merging view, c. driving in platoon view, d. Splitting view

In the next view (c), the platooning status is presented. The rectangle in the middle represents the ego vehicle. The planned optimal speed, and also the triangular and static shapes for the difference between the optimal speed and the current vehicle speed are presented. On the top, there is the distance and the current speed of the front truck. If there is a vehicle behind the ego vehicle, the bottom part is presented, which shows the equivalent information for that vehicle.

For the splitting manoeuvre, view (d) is used. Similar to the merging view, the splitting is represented by two arrows pointing in opposite directions. The current distance to the front vehicle is to be found in the middle, while current optimal speed and the speed of the front vehicle are placed in a similar manner as in the other views.

Figure 48 – Merging into the platoon manoeuvre

5.1.5. Situation Awareness Rating Technique Questionnaire

One objective in designing the on-board HMI of COMPANION system, is to increase the Situation Awareness (SA) of the driver in all platooning stages. To do so, it was decided to use the Situation Awareness Rating Technique (SART) questionnaire [5]. This method is commonly used in dynamic contexts, and has been found to be valid for contexts such as in COMPANION. Due to the small number of participants, the results of these questionnaires cannot be used as a proper statistical reference, but they help to estimate the SA of the drivers in different manoeuvres. SART questionnaires were spread among drivers after each test block (which was dedicated to specific platooning manoeuvres).

5.1.6. System Usability Scale Questionnaire (SUS)

The System usability scale (SUS) [6] is a reliable tool used widely for measuring usability of a system. This questionnaire consists of ten statements which ask for participant’s agreement in a 5-Likert scale from “strongly agree” to “strongly disagree”. Due to the small number of participants, the results of these questionnaires cannot be used as a proper statistical reference. However, the standard statements of this questionnaire help to find the weak and strong points of the HMI.

5.1.7. Think Aloud Technique

The main objective in running this usability test was to collect drivers’ feedback on the HMI in different platooning manoeuvres. Therefore, a think aloud technique was used. In this approach, the user is encouraged to talk all the time while using the system about the ideas that come to her mind every time a new screen pops up or an action has to be performed. Two cameras were installed in the truck, one facing the driver and one the HMI. Several hours of user interaction with the system and their feedback on various platooning views were recorded. One of the testers was also sitting in the truck to encourage or remind the drivers to talk, if they became silent.

5.1.8. Interviews

The last step of the usability test consisted of an interview session with drivers. Here, they could give general feedback on the HMI and bring up the problems they had while driving in the platoon. These interviews were also audio-recorded.

5.2. Results

In this section, the results from different stages of the usability tests are presented. These results were collected within a period of five days of testing on the proving grounds of APPLUS IDIADA. Three drivers participated in the tests including driving in various platooning manoeuvres, filling in questionnaires, and taking part in interviews. As the development of the on-board HMI is still in progress, during driving blocks, the driver of the lead truck in platoon did not have an on-board HMI unlike the following vehicles. All drivers signed an agreement for recording and utilizing the data collected during these test for COMPANION project objectives and scientific work.

5.2.1. Pre and Post-test Questionnaires

Results from comparison between pre and post-test questionnaires showed that all drivers found the system easy to learn in both conditions, although none of them have used a similar HMI before. The drivers were asked to rate the difficulty of understanding of each view of the HMI. The results show that drivers found the driving alone view more difficult and the merging and platooning views less difficult after using them in comparison with pre-test conditions. The platooning view in both cases was rated easy to understand by all drivers.

5.2.2. Situation Awareness Rating Technique Questionnaire

After each test block (manoeuvre), the drivers were asked to fill in the Situation Awareness Rating Technique (SART) questionnaire. This questionnaire which is a post-trial subjective rating technique, uses ten dimensions to measure situation awareness: familiarity of the situation, focusing of attention, information quantity, information quality, instability of the situation, concentration of attention, complexity of the situation, variability of the situation, arousal, and spare mental capacity. Participants are asked to rate each dimension on a seven point scale (1= Low, 7=high) based on their experience with the system. We used a quicker version of SART which groups the aforementioned ten dimensions into three groups:

- Demand on attentional resources = Instability + Variability + Complexity
- Supply of attentional resource s= Arousal + Spare Mental Capacity + Concentration + Division of Attention
- Understanding of the situation = Information Quantity + Information Quality + Familiarity

The table below shows the collected scores from drivers in different platooning manoeuvres. Based on their position in the platoon demand (D) and supply (S) of information resources, understanding (U) of situation and situation awareness (SA) in each manoeuvre is calculated.

Manoeuvre	Position in Platoon	D	S	U	SA
Merging, platooning, splitting	2 of 2	5	16	8	19

Merging, platooning, splitting	2 of 3	6	16	8	18
Merging, platooning, splitting	3 of 3	8	10	5	7
Speed change 60→70→80	1 of 3	6	9	5	8
Speed change 60→70→80	2 of 3	6	13	7	14
Speed change 60→70→80	3 of 3	7	21	5	19
Vehicle intruding in platoon of 2	1 of 2	7	11	6	10
Vehicle intruding in platoon of 2	2 of 2	6	20	5	19
Emergency braking	1 of 2	13	16	6	9
Emergency braking	1 of 2	7	15	6	14

Table 10 - Results collected from SART questionnaire during different platooning manoeuvres

The results from Table 10 show that in all platooning manoeuvres, the situation awareness of the following truck drivers that were using the on-board HMI is relatively higher than the driver of the platoon leader truck. These results support the assumption that the benefit from information provided by the HMI makes drivers more aware of the situation in different manoeuvres.

5.2.3. System Usability Scale Questionnaire (SUS)

The system usability scale questionnaire consists of ten statements which are rated in 5-Likert scale from *strongly agree* to *strongly disagree.* The statements of this questionnaire are as below:

1) I think that I would like to use this system frequently
2) I found the system unnecessarily complex
3) I thought the system was easy to use
4) I think that I would need the support of a technical person to be able to use this system
5) I found the various functions in this system were well integrated
6) I thought there was too much inconsistency in this system
7) I would imagine that most people would learn to use this system very quickly
8) I found the system very cumbersome to use
9) I felt very confident using the system
10) I needed to learn a lot of things before I could get going with this system

Results from the questionnaires show that the overall SUS was 71.66, which can be interpreted in the way that the system is usable (over 68%). However, due to the small number of participants, this score cannot be confirmed with full confidence. Therefore, we decided to analyse the results on each statement to determine strong and weak points. The graph in Figure 49 shows these results.

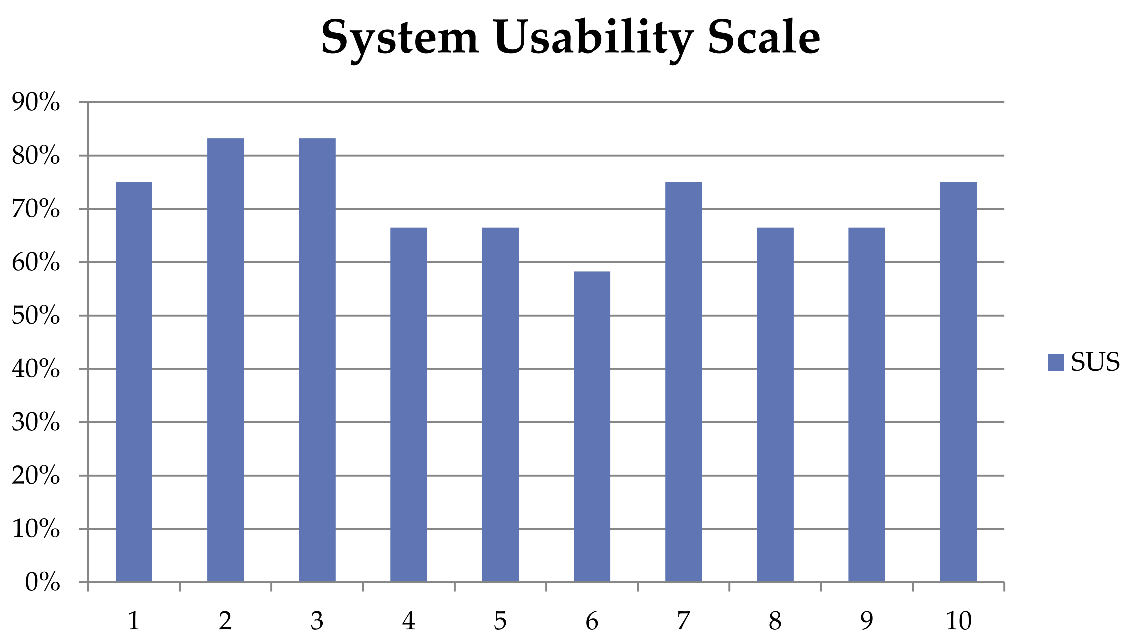


Figure 49- System Usability Scale results

The highest rating in this graph belongs to the statements 1, 7, and 10, which address the learnability of the system and frequent use. All drivers agreed that they would like to use the system frequently and found it easy to learn. The lowest rating was for statement 6, which addresses the inconsistency of the system. Through the comments of the drivers it was understood that due to the behaviour of the vehicle in use cases where the system is not fully developed, they could not map what they saw on the screen with what they observed on the road.

5.2.4. **Think Aloud Technique**

During all test blocks, the drivers were asked to think aloud, and say what comes to their mind when looking at the HMI. Below, these comments are presented under two criteria: general comments and manoeuvre-related comments.

5.2.4.1. General Comments

- The contrast of the colours on the HMI should be increased to make it more salient
- Other information items which exist on the information cluster of all vehicles such as fuel gauge, engine oil temperature, and gear indicator are needed.
- It is good to have the name of the manoeuvre that is currently performed, on top of the screen.
- Sound signals, when the manoeuvre switches to another, are useful for the driver.
- The display for speed profile is changing too frequently addressing the target speed.
- Drivers are more relaxed when they can read the speed of the front truck.
- Information about rear truck such as gap size and speed are required.
- When the platoon was driving with 40 km/h speed, drivers felt bored and mentioned that his attention loses focus from driving.

- When the driver drove for the first times as the follower, they found the distance too close but got used it through time. They found the information sufficient but the distance scary for the first trials.
- In drive alone view, the distance to the platoon is needed.
- Drivers said that they find the interface simple and easy to understand and they trust the system much more using the HMI.
- Younger drivers mentioned that having the distance and speed information of the front truck, they can reduce the gap as close until they see the back lights of the front truck.
- The font size of the free driving view is too small.
- Driver confirms the system is comfortable for long time driving.

5.2.4.2. Manoeuvre-related Comments

- Merging to platoon
  - When approaching to the platoon, if there is more than one truck on the highway at the merging point, it is not easy to distinguish which one is the target truck to merge with.
  - Drivers had the feeling of losing control when merging to the platoon, one thing that they mentioned that could help is to have the target distance to the front truck displayed (so they would know how close they should get)
  - Drivers mentioned that having an audio alert once they have completed merging to the platoon or when another truck merges to a platoon they are a member of, would increase their Situation Awareness.
- Driving in platoon: According to the drivers, the most important information needed while driving in a platoon, are distance and speed of the front and rear truck, the speed profile, and gear indicator of ego vehicle.

- Splitting from platoon
  - When splitting from behind, the target distance until you are out of platoon is required.
  - Audio alert when splitting manoeuvre for ego or rear truck is completed, is needed.
  - Position in platoon after the rear truck has split should be highlighted after being updated.

- Intruding vehicle manoeuvre
  - The square representing the intruding vehicle on the HMI and the text alert should be more salient and with more contrast to the background.
  - Audio alerts are needed when intruding vehicle approaches
  - Distance to the front truck in the platoon is needed while the intruding vehicle drives in present
  - When an intruding vehicle is in the platoon behind the ego truck, a text notification with its distance is needed
  - Audio alerts needed when intruding vehicle leaves the platoon and gap starts to close again

    - Position of the ego truck is needed in the intruding view

- Emergency braking manoeuvre:
    - Audio alert and salient signs on the display is needed to attract drivers attention immediately

5.2.5. Interviews

After the drivers have performed all the tests, we invited them to a short interview session to give their general feedback about the pros and cons of the on-board HMI. Following is a brief overview of the answers collected:

All drivers agreed that the system was very easy to learn and the information is clear. They liked the fact that their role was to monitor the display and not to input or confirm information regularly. They liked all three views for merging, platooning and splitting, and they found the information helpful. They preferred to have information about the vehicle such as the gear indicator or oil temperature. They also added that having more colour contrast on the display and also audio signals will help the saliency of information.

On the negative side, all drivers pointed that audio signals were missing in intruding vehicle and emergency braking manoeuvres to shift their attention immediately; also when you complete a manoeuvre it is better to have an audio notification because they don't always have their eyes on the display. Due to the short distance between the trucks they found it scary and difficult to trust the system. But this feeling was reduced day by day as they drove more in the platoon and monitored the information on the HMI.

All three drivers mentioned that in case they are certain that the system is responsive in cases of hazard they can easily drive in platoon for long time intervals and trust the system with the information provided.

6. Conclusions

COMPANION aims to reduce fuel consumption in heavy duty vehicles through the benefits of the reduced aerodynamic drag that platooning generates and therefore reduce CO_2.

As part of the COMPANION system, the on-board unit was validated focused on the platoon performance that is exposed to driver taking into account the relevant use cases implemented for the actual development phase of the system. The overall picture shows that the system made progress between the test sessions. The biggest challenge was the tune of the on-board control system in order to maintain a stable speed without compromising the gap between the vehicles. In general, the system was able to perform create platoon, merge to platoon, split from platoon, dissolve platoon, lane changes, detect an intruder in the platoon, modify the speed of the platoon and modify the gap. Special mention deservers the emergency braking manoeuvre, due to the fact that there are some limitations in order to apply all force on the braking pedal, the following vehicles cannot safely brake at relative high speeds (70-80 Km/h), thus the system still needs to improve. The KPI values show a good performance of the system. The *Duration of Platooning Manoeuvre* it lasts on average between 12 to 20 seconds to merge or split depending on the speed and number of the vehicles involved in the test. Concerning the *Level of Smoothness, the* KPI denotes very specific results about speed harmony with values between 0.7 and 1.1 km/h. Regarding the quality of the link, the KPIs show that over 99% of the packages are received. And finally, the *Longitudinal Position Accuracy* shows average values ranging between 0.9 and 1.8 meters.

For the fuel consumption tests, stability tests were performed since the fuel consumption tests require the system to work properly for hours and maintain a very strict longitudinal gap. The theoretical longitudinal gap was compared with the actual longitudinal gap. This was also achieved and the fuel consumption tests were valid and showed an important drag reduction and consequently fuel savings. Results show that the system maintains in average a gap value close to the theoretical one and regarding the mean lateral offset, the figures show that the misalignment due the manual control of the steering wheel can reach up to 0,5 m per test. The final figures show that the reduction in consumption ranges from 5,4% and 8.3%. If the misalignments are corrected and the control system is improved, it is foreseen higher fuel savings, however, no values can be estimated.

During all stages of our usability test we collected valuable qualitative data which can be used as requirements for our final on-board HMI prototype. All our test participants found the HMI usable (SUS= 71.66) and very easy to learn and understand. They also mentioned that they would like to use it in the future. The data collected from think aloud and interview sessions helps improving the system in the future. Some of these comments were already implemented during test days in a in a participatory design approach: different concepts were proposed to the drivers and the preferred ones were implemented for the next test block.

7. References

[1] *Description of Work*. COMPANION project.

[2] *D2.1 Potential scenarios for new platooning concepts*. COMPANION project

[3] *D2.3 Final user requirements*. COMPANION project

[4] *D2.4 Technical requirements*. COMPANION project

[5] Taylor, R. M. (1990). *Situation awareness rating technique (SART): the development of a tool for aircrew systems design. In Situational Awareness in Aerospace Operations* (Chapter 3). France: Neuilly sur-Seine, NATO-AGARD-CP-478.

[6] Brooke, J. (1986). *SUS: a "quick and dirty" usability scale*. In P. W. Jordan, B. Thomas, B. A. Weerdmeester, & A. L. McClelland. Usability Evaluation in Industry. London: Taylor and Francis.

Annex A: Test Plan

A.1. Platooning Test Plan

Test ID	Test Track	Manoeuvre	Vehicles involved			Speed [Km/h]	Gap [m]
TC_PLT_MERGE-TO-PLATOON_02_40_2.0	HST	Create platoon	LV	FV1	-	40	23
TC_PLT_SPLIT-FROM-PLATOON_02_40_2.0	HST	Dissolve platoon	LV	FV1	-	40	-
TC_PLT_MERGE-TO-PLATOON_02_70_0.6	HST	Create platoon	LV	FV1	-	70	12
TC_PLT_SPLIT-FROM-PLATOON_02_70_0.6	HST	Dissolve platoon	LV	FV1	-	70	-
TC_PLT_MERGE-TO-PLATOON_02_70_0.6	HST	Create platoon	LV	FV1	-	70	12
TC_PLT_SPLIT-FROM-PLATOON_02_70_0.6	HST	Dissolve platoon	LV	FV1	-	70	-
TC_PLT_MERGE-TO-PLATOON_02_80_0.5	HST	Create platoon	LV	FV1	-	80	12
TC_PLT_SPLIT-FROM-PLATOON_02_80_0.5	HST	Dissolve platoon	LV	FV1	-	80	-
TC_PLT_MERGE-TO-PLATOON_02_80_0.5	HST	Create platoon	LV	FV1	-	80	12
TC_PLT_SPLIT-FROM-PLATOON_02_80_0.5	HST	Dissolve platoon	LV	FV1	-	80	-
TC_PLT_MERGE-TO-PLATOON_03_60_0.8	HST	Extend platoon behind	LV	FV1	FV2	60	14
TC_PLT_SPLIT-FROM-PLATOON_03_60_0.8	HST	Leave platoon behind	LV	FV1	FV2	60	-
TC_PLT_MERGE-TO-PLATOON_03_70_0.6	HST	Extend platoon behind	LV	FV1	FV2	70	12
TC_PLT_SPLIT-FROM-PLATOON_03_70_0.6	HST	Leave platoon behind	LV	FV1	FV2	70	-
TC_PLT_MERGE-TO-PLATOON_03_80_0.5	HST	Extend platoon behind	LV	FV1	FV2	80	12
TC_PLT_SPLIT-FROM-PLATOON_03_80_0.5	HST	Leave platoon behind	LV	FV1	FV2	80	-
TC_PLT_MERGE-TO-PLATOON_03_60_0.8	HST	Extend platoon behind	LV	FV1	FV2	60	14
TC_PLT_SPLIT-FROM-PLATOON_03_60_0.8	HST	Leave platoon behind	LV	FV1	FV2	60	-
TC_PLT_MERGE-TO-PLATOON_03_70_0.6	HST	Extend platoon behind	LV	FV1	FV2	70	12
TC_PLT_SPLIT-FROM-PLATOON_03_70_0.6	HST	Leave platoon behind	LV	FV1	FV2	70	-

TC_PLT_MERGE-TO-PLATOON_03_80_0.5	HST	Extend platoon behind	LV	FV1	FV2	80	12
TC_PLT_SPLIT-FROM-PLATOON_03_80_0.5	HST	Leave platoon behind	LV	FV1	FV2	80	-
TC_PLT_INCREASE-GAP-VI_02_50	HST	Vehicle interfering	LV	FV1	-	50	40
TC_PLT_INCREASE-GAP-VI_02_80	HST	Vehicle interfering	LV	FV1	-	80	12
TC_PLT_INCREASE-GAP-VI_03_50	HST	Vehicle interfering	LV	FV1	FV2	70	10
TC_PLT_INCREASE-GAP-VI_03_80	HST	Vehicle interfering	LV	FV1	FV2	80	12
TC_PLT_DOUBLE-LANE-CHANGE_02_40_2.0	HST	Double Lane Change	LV	FV1	-	40	23
TC_PLT_DOUBLE-LANE-CHANGE_02_40_2.0	HST	Double Lane Change	LV	FV1	-	40	23
TC_PLT_DOUBLE-LANE-CHANGE_03_40_2.0	HST	Double Lane Change	LV	FV1	FV2	40	23
TC_PLT_DOUBLE-LANE-CHANGE_03_60_0.8	HST	Double Lane Change	LV	FV1	FV2	60	14
TC_PLT_DOUBLE-LANE-CHANGE_03_70_0.6	HST	Double Lane Change	LV	FV1	FV2	70	12
TC_PLT_DOUBLE-LANE-CHANGE_03_80_0.5	HST	Double Lane Change	LV	FV1	FV2	80	12
TC_PLT_MERGE-TO-PLATOON_03_60_0.8	HST	Extend platoon behind	LV	FV1	FV2	60	14
TC_PLT_SPLIT-FROM-PLATOON_03_60_0.8	HST	Leave platoon behind	LV	FV1	FV2	60	-
TC_PLT_MERGE-TO-PLATOON_03_70_0.6	HST	Extend platoon behind	LV	FV1	FV2	70	12
TC_PLT_SPLIT-FROM-PLATOON_03_70_0.6	HST	Leave platoon behind	LV	FV1	FV2	70	-
TC_PLT_MERGE-TO-PLATOON_03_80_0.5	HST	Extend platoon behind	LV	FV1	FV2	80	12
TC_PLT_SPLIT-FROM-PLATOON_03_80_0.5	HST	Leave platoon behind	LV	FV1	FV2	80	-
TC_PLT_INCREASE-SPEED_03_50_0.4	HST	Controlled acceleration	LV	FV1	FV2	50 --> 50	12
TC_PLT_INCREASE-SPEED_03_60_0.4	HST	Controlled acceleration	LV	FV1	FV2	50 --> 60	7
TC_PLT_INCREASE-SPEED_03_70_0.4	HST	Controlled acceleration	LV	FV1	FV2	60 --> 70	12
TC_PLT_INCREASE-SPEED_03_80_0.4	HST	Controlled acceleration	LV	FV1	FV2	70 --> 80	9
TC_PLT_REDUCE-SPEED_03_70_0.5	HST	Speed reduction	LV	FV1	FV2	80 --> 70	12
TC_PLT_INCREASE-SPEED_03_80_0.5	HST	Controlled acceleration	LV	FV1	FV2	70 --> 80	12

TC_PLT_REDUCE-SPEED_03_70_0.5	HST	Speed reduction	LV	FV1	FV2	80 --> 70	12
TC_PLT_EMERGENCY-BRAKING_03_40_9.0	HST	Emergency braking	LV	FV1	-	40	-
TC_PLT_EMERGENCY-BRAKING_03_40_9.0	HST	Emergency braking	LV	FV1	-	40	-
TC_PLT_EMERGENCY-BRAKING_03_50_9.0	HST	Emergency braking	LV	FV1	FV2	50	-
TC_PLT_EMERGENCY-BRAKING_03_70_9.0	HST	Emergency braking	LV	FV1	FV2	70	-
TC_PLT_EMERGENCY-BRAKING_03_70_9.0	HST	Emergency braking	LV	FV1	FV2	70	-
TC_PLT_EMERGENCY-BRAKING_03_80_9.0	HST	Emergency braking	LV	FV1	FV2	80	-
TC_PLT_EMERGENCY-BRAKING_03_80_9.0	HST	Emergency braking	LV	FV1	FV2	80	-
TC_PLT_MERGE-TO-PLATOON_03_60_0.8	HST	Create platoon	LV	FV1	FV2	60	14
TC_PLT_INCREASE-GAP-VI_03_60	HST	Vehicle interfering	LV	FV1	FV2	60	14
TC_PLT_INCREASE-SPEED_03_60_0.4	HST	Controlled acceleration	LV	FV1	FV2	60	14
TC_PLT_INCREASE-SPEED_03_70_0.4	HST	Controlled acceleration	LV	FV1	FV2	70	10
TC_PLT_INCREASE-GAP-VI_03_70	HST	Vehicle interfering	LV	FV1	FV2	70	10
TC_PLT_REDUCE-SPEED_03_65_0.4	HST	Speed reduction	LV	FV1	FV2	65	14
TC_PLT_INCREASE-SPEED_03_75_0.4	HST	Controlled acceleration	LV	FV1	FV2	75	12
TC_PLT_INCREASE-SPEED_03_80_0.4	HST	Controlled acceleration	LV	FV1	FV2	80	12
TC_PLT_INCREASE-SPEED_03_80_0.4	HST	Controlled acceleration	LV	FV1	FV2	80	12

Table 11. Platooning Test Plan

A.2. Fuel Consumption Test Plan

Test ID	Test Track	Manoeuvre	Vehicles involved			Speed [Km/h]	Gap [m]
TC_FC_DRIVE-IN-PLATOON_02_70_20>	HST	Platooning	LV	FV1	-	70	20
TC_FC_DRIVE-IN-PLATOON_02_70_14>	HST	Platooning	LV	FV1	-	70	14

TC_FC_DRIVE-IN-PLATOON_02_70_12>	HST	Platooning	LV	FV1	-	70	12
TC_FC_DRIVE-IN-PLATOON_02_70_10>	HST	Platooning	LV	FV1	-	70	10
TC_FC_DRIVE-IN-PLATOON_02_80_20>	HST	Platooning	LV	FV1	-	80	20
TC_FC_DRIVE-IN-PLATOON_02_80_14>	HST	Platooning	LV	FV1	-	80	14
TC_FC_DRIVE-IN-PLATOON_02_80_12>	HST	Platooning	LV	FV1	-	80	12
TC_FC_DRIVE-IN-PLATOON_03_70_20>	HST	Platooning	LV	FV1	FV2	70	20
TC_FC_DRIVE-IN-PLATOON_03_70_20>	HST	Platooning	LV	FV1	FV2	70	14
TC_FC_DRIVE-IN-PLATOON_03_70_20>	HST	Platooning	LV	FV1	FV2	70	12
TC_FC_DRIVE-IN-PLATOON_03_70_20>	HST	Platooning	LV	FV1	FV2	70	10
TC_FC_DRIVE-IN-PLATOON_03_80_20>	HST	Platooning	LV	FV1	FV2	80	20
TC_FC_DRIVE-IN-PLATOON_03_80_20>	HST	Platooning	LV	FV1	FV2	80	14
TC_FC_DRIVE-IN-PLATOON_03_80_20>	HST	Platooning	LV	FV1	FV2	80	12

Table 12. Fuel Consumption Test Plan