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

D7.3 Limited validation results of the integrated system

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Executive summary

This document reports the work within the task T7.3 – Limited validation results of the integrated system belonging to work package 7 – System Integration, Validation, Deployment and Demonstration in the COMPANION project.

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. Task 7.3 implements the final demonstration of the COMPANION system in real environments, integrating the platoon capabilities of the vehicles, with the off-board platoon coordination system.

Driving trials with three vehicles platooning have been implemented in public highways. The platoon operator coordinates the formation and merging of the platoons driving in the designated public roads test areas.

A total of four demonstrations have been done so far in months 18, 24, 28 and 32; two more are planned for month 34 and month 36.

These open road tests have also been used to evaluate the driver acceptance of the system. The demonstration has been evaluated on highways and interurban roads of three different EU countries according to availability regarding legal issues output from WP2. These tests allowed COMPANION to demonstrate the feasibility of international transportation platoons as well as assess interoperability and scalability of the system to the EU.
D7.3 – Limited validation results of the integrated system

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Introduction

One of the objectives of this deliverable is to demonstrate the potential of the COMPANION system and validate in the scope of the demonstrations that it can be operated safely and meet all of the requirements previously defined in the respective confidential deliverables “D2.3 – Final User Requirements” and “D2.4 – Technical Requirements”.

The different User Requirements (UR) and Technical Requirements (TR) have been verified through the different demonstrations, and the purpose of this document is to describe the events that have been organised to show the capabilities of the system and provide a brief overview of the tests and results of the demos. For a more detailed picture of the outcome of the tests done during the different demos see the confidential deliverable “3.4 Result of System Compliance and Integration”.

Figure 1 shows the different demonstration milestones (x-axis) and a schematic overview of the tests to be done/validations that has taken place (y-axis). In M34 and subsequently M36 all tests should have been validated.

Figure 1 is a good representation of how the different demonstrations (M18, M24, M28, and M32) have validated the project’s requirements. The M34 demonstration is an intermediate demo that will be used to test the final version of the COMPANION system, allowing to verify the last requirement and hence, to freeze the COMPANION implementation status. M36 will be the final demo, a general case to showcase the performance and benefits of the COMPANION system. Currently, the M36 scenario is not chosen yet since M34, which will be the basis and is still under discussion.
Demonstrations

1.1. M18 demonstration

1.1.1. Presentation
The month 18 demonstration consisted in a proof of concept; the architecture skeleton integration of the COMPANION system was tested. The main idea behind was to test the end-to-end connectivity of the COMPANION system and to make sure that all the different interfaces between the partners modules were implemented.

The demonstration was a simulation based one. No real trucks were used in this case.

Basically, the demonstration consisted in entering an assignment in the off-board HMI (Human Machine Interface). The simulated vehicle was programmed to realise that it could not fulfil the assignment. Thus, that information was shown to the driver on the on-board HMI and the dispatcher on the off-board HMI.

1.1.2. Test results
All parameters were correctly entered in the system through the off-board HMI. The tests showed that the drivers will not have to interact much with the on-board HMI. Indeed, it was designed to avoid them being disturbed whilst driving. The off-board HMI seems to be easily used by the dispatchers, reducing the needed time to use it, hence their interactions with the off-board HMI. In case of disconnection of the vehicle to the network, the messages were correctly stored in the message queue. Regarding the routes, they were successfully calculated during the tests.

As the project had quite strict deadlines, it was necessary to make sure some features were correctly implemented. Hence, some non-fulfil requirements were tested outside the demo, such as verifying the user still has a good control of the vehicle after breaking manually.

1.1.3. User requirements
In the scope of the demonstration, some user requirements were tested and validated. Below it is briefly summarized the outcome of those:

- Checking that all parameters are correctly entered into the system
- Checking that the system correctly controls the speed of the truck and the distance to the vehicle in front of it, whilst attempting to platoon.
- Observing that the driver does not spend too much time interacting with the HMI, for concentration sake.
- Examining whether the HMI is fast enough to be used and whether the proposed functions are fast enough to be performed.

1.1.4. Technical requirements
In the same way, the demonstration had to test and to validate some technical requirements for the on-board and off-board platforms; below, a brief description of the TR tests is given:

- Checking that the off-board system runs on a specific platform and that the services have certain properties
- Checking the proper buffering of messages
- Verifying the calculation of assignments

1.2. M24 demonstration

1.2.1. Presentation
The demonstration on month 24 consisted of a road demo. The three planned scenarios consisted in the fulfilment of the below-mentioned assignments, taking into account different traffic conditions.

1.2.2. Test scenario
The complete test scenario for this demonstration included two different assignments (Figure 2 and Figure 3) in the Södertälje area in three different scenarios:

Scenario 1: The trucks that drive according to the assignments 1 and 2 need to arrive at the same time in Nyköping. The departure time is given to the vehicles in such a long time in advance that they are able to merge in Södertälje, and to be still on time in Nyköping. In that case, there is no deviation reported.

Scenario 2: Same as Scenario 1, but due to an unscheduled stop for truck 1 (Assignment shown in Figure 2), a new speed profile is calculated for the two trucks. They still merge in Södertälje and arrive on time in Nyköping.

Scenario 3: Same as Scenario 1, but due to a long unscheduled stop for truck 1 (Assignment shown in Figure 2), a new speed profile is calculated for that truck. However, Truck 1 will not arrive on time and there are no longer possibilities for platooning. Truck 2 will continue according to the speed profile that allows it to arrive on time.

Due to a lack of time (the re-planning feature for the monitoring engine was not implemented yet), only Scenario 1 was performed.
Figure 2 is the first assignment, from Nykvarn to Nyköping, driven by truck 1.

![Route from Nykvarn to Nyköping](image1)

Figure 2 – Route from Nykvarn to Nyköping

Figure 3 is the second assignment, from Rönninge to Nyköping, driven by truck 2.

![Route from Rönninge to Nyköping](image2)

Figure 3 – Route from Rönninge to Nyköping
1.2.3. Test results

The platooning plan was successfully generated and translated into an assignment plan; truck 2 was going to be the platoon leader.

The confirmation of the assignment by the dispatcher triggered the off-board system to send the plan to the trucks. Information about the estimated effects of platooning, and the platooning segments were transferred. In addition, the status field in the off-board HMI was set to “confirmed”.

Both trucks confirmed that they received a plan and that they were able to execute it.

Each truck started driving according to the specified starting time without any delay and they both sent a “start” status when they immediately started driving the plan.

For the segment Nykvarn-Södertälje (Figure 2), truck 1 reported an unexpected deviation. Despite this delay, the system could correctly calculate an alternative so that the trucks still could platoon.

The merge was successful despite the reported delay (200m gap when the trucks were on the same road). The on-board-HMI informed the driver throughout the assignment by symbols and messages about the different events related to the platooning actions.

Both trucks experienced a similar delay (ever bigger than before), while driving down to Nyköping.

Both trucks successfully split just before Nyköping.

Truck 1 arrived at 10:10:30 and Truck 2 arrived at 10:06:56 while both had a planned arrival time of 10:05:00 according to the assignment. Both of them reported a delay of about five minutes.

Finally, the M24 was a feasible platooning generated plan. Both trucks have been able to execute the plan and to merge with success. The web interface was sufficient to manage and monitor the demo.

The demo was not an entire success as a couple of points had to be improved. Indeed, some troubles with the Route Calculation Engine (RCE) have been identified. (The RCE returned wrongly the ordered link positions, the ETA time seemed incorrect. In the same way, the five-minute delay was caused by a bad conversion from the algorithm of the velocity and time, to which are applied a coefficient by the Monitoring Engine (KTH)

Other troubles regarding the information displayed were also detected; those were not impacting directly on the obtained results.

In addition, the whole scenarios could not be executed. As mentioned, only scenario 1 was implemented. Hence, it was not possible to observe every planned case. Nevertheless, this was the first demonstration using the entire integrated and up and running system with real trucks.

1.2.4. User requirements

The demonstration had to test and to validate some of the user requirements. Below the different tests performed are described

- Verifying that the dispatcher is aware of the current state of the assignments (to be confirmed/confirmed...)
- Verifying that assistance is correctly provided to the drivers whilst platooning
- Verifying that the distance between two communicating vehicles increases if one of them turns off the communication.
- Verifying that in the case of a new plan calculation, the driver is well informed.
- Verifying that the dispatcher is well informed in case of a route modification, and informed about the reasons
- Verifying that the drivers have access to the platoon effects

1.2.5. Technical requirements

The demonstration had to test and to validate a series of technical requirements for the on-board and off-board platforms. Below, follows a list of tests and short descriptions

- Verifying that the off-board system stores a unique identifier per vehicle, so that only this specific vehicle receives the message sent from the off-board system.
- Verifying that the assignment status works properly.
- Verifying that the system proposes different road profiles (“Short”, “fast”, “economic”).
- Verifying that the routes are only calculated for highways and valid truck routes.
- Verifying that the system correctly saves the data from the vehicle.
- Verifying the impact of the speed or the departure/arrival time parameters on the resulting routes.
- Verifying through simulation that the system is capable of detection deviations due to weather conditions.
- Verifying that the COMPANION systems has real-time traffic information.
- Verifying that deviations are properly calculated.
- Verifying that the fuel consumption estimation are correctly estimated.
- Verifying that the on-board system can detect vehicles not belonging to the platoon.
- Verifying the good communication between the platooning trucks.
- Verifying that the plan contains all relevant information for every joining vehicle.

1.3. M28 demonstration

1.3.1. Presentation

The month 28 demonstration consisted of a simulation demo. The purpose was to evaluate the performance of the off-board system and validate that about one hundred routes could be randomly generated in the area of Stockholm. As this kind of test could not be performed on public roads, the demonstration was a simulation.

For more information regarding this demonstration we refer you to the public deliverable “7.2 Limited results of the off-board platoon coordination system via simulation”

1.3.2. Test scenario

The simulation performed in M28 had the purpose to show a working system with recalculation and feedback of fleet state. The time required for those calculations had to be measured to fulfil the concerned requirements.

The simulation could simulate traffic. Hence, it was possible to generate traffic jam, deviation, vehicle platooning, or disturbing the trucks.
Figure 4 - 102 assignments around Mälaren

Figure 4 represents the result of 102 assignments generated between highways exits of the following cities:

- Västerås
- Örebro
- Södertälje
- Eskilstuna
- Uppsala
- Nyköping
- Norrtälje
- Enköping
- Stockholm
- Sala
- Nynäshamn

Those assignments depended on different parameters such as the arrival time value (resolution of 1 hour), the total weight of the truck (from 2000kg to 30000kg), and the type of goods (Dangerous or not).

1.3.3. Test results

The calculation of a hundred assignments (Figure 4) has been done in less than five minutes. Still regarding the execution time, less than sixty seconds were necessary for a truck to confirm a plan.

Those execution times fulfilled the below requirements. Indeed, despite the amount of assignments to calculate, the system could easily calculate the routes in a short delay.
1.3.4. User requirements
The demonstration had to test and to validate some user requirements. The two following tests were performed:

- Verifying that on-board system correctly detects failures of the system, and informs the driver.
- Verifying that roles are correctly managed in the platoon, if for example, a new truck joins or leaves.

1.3.5. Technical requirements
The demonstration had to test and validate a series of technical requirements for the on-board and off-board system. Below follows a list and short description of the technical requirements tested:

- Evaluate the performance of the COMPANION system to calculate the routes.
- Verifying the impact of the weather on the application.
- Verifying that the system can handle all its current assignments and optimise those routes.
- Evaluate the performance of the COMPANION system handling 100 assignments.
- Validating that less than sixties seconds are necessary to send a plan to a truck, and for it to confirm it.
1.4. M32 demonstration

1.4.1. Presentation
The demonstration from month 32 consisted in a real environment demo. It took place in Sweden. The purpose was to validate that the COMPANION system could manage the platooning of three trucks driving on public roads. One sub goal of this demo was to minimize the fuel necessary to complete the three defined routes.

1.4.2. Test scenario
Three trucks are assigned to leave from three different cities: Järna, Nykvarn, and Salem. The final destination for the three trucks was Botkyrka. Two scenarios were originally proposed, but thanks to the success of them, a third one was improvised. The latter was not related to platoon forming as the formers, but related to experiencing the behaviour of the system in a huge traffic environment.

Scenario 1: The assignments 1 and 2 (Figure 5 and Figure 6) are performed. The trucks merge in Södertälje. It can be considered as a first step before performing scenario 2.

Scenario 2: In that case, the assignments 1, 2 and 3 (Figure 5, Figure 6 and Figure 7 – Route from Salem to Botkyrka) are performed. Trucks 1 and 2 merge in Södertälje and the platoon merges with Truck 3 in Salem.

Scenario 3: A truck goes alone on a trip through Stockholm, following the fourth assignment. (Figure 8) The purpose is to see how well the route calculation engine including historical and real-time traffic information performs. Through Stockholm there is always a lot of traffic so the scenario was a good evaluation.

Figure 5 is the first assignment, from Järna to Botkyrka.

![Figure 5 – Route from Järna to Botkyrka](image)

Figure 6 is the second assignment, from Nykvarn to Botkyrka.
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**Figure 6 – Route from Nykvarn to Botkyrka**

Figure 7 is the third assignment, from Salem to Botkyrka

**Figure 7 – Route from Salem to Botkyrka**
1.4.3. Test results

All 3 scenarios were performed with success. The defined goals were reached. All routes have been calculated by the RCE correctly. The OE aligned the speed profiles correctly, so that platoon formation was possible. As below are presented the scenario 2 and 3 results, where scenario 2 is scenario 1 with an additional assigned truck.

At first, two vehicles started to drive accordingly to the schedule in the plan. The on-board HMI showed the departure time to the driver. The merge segment was reached by the two vehicles in a proper timing without re-planning. Whilst passing through the merging section, a distance of 90-100 meters was separating the two vehicles; a vehicle was interfering the platooning. Once the vehicle was gone, the vehicle could correctly merge. Every information about merging and up-coming platooning events were successfully shown in the on-board HMI.

The third vehicle started at designed mark and time. It merged with the other vehicles and was planned to merge to the platoon as the last member. Its merge to the platoon has been successfully completed by the COMPANION on-board system. No time deviations were reported during the whole demo run.

Regarding scenario 3, a truck drove from Södertälje to Upplands Väsby. It was about three minutes late at the departure point. Fourteen deviations happened during the trip which caused a re-planning by the off-board system.

Finally, the vehicle arrived with one minute late. The re-planning could hence compensate two of the three minutes the truck was late at the start.
1.4.4. User requirements

The demonstration had to test and to validate a couple of user requirements. Bellow follows a list and short description of what has been tested.

- Verifying that the off-board HMI provides all information needed for the fleet operator
- Verifying that the estimation of fuel savings are shown in the off-board HMI

1.4.5. Technical requirements

The demonstration had to test and to validate a series of technical requirements for the on-board and off-board systems. Below, follows a list and short description of what has been tested in the scope of the demo.

- Verifying that the off-board HMI provides clear and precise information about the assignments and that they are shown on a map
- Verifying that the assignment plans contain information about the future manoeuvres

1.5. M34 demonstration

1.5.1. Presentation

Due to some of the functionality not being implemented in time for the M32 demo, it has been decided to add the M34 demo to validate the last set of requirements to finally freeze the implementation of the COMPANION system, and allow making the final demonstration.

As below are the last requirements to fulfil:

- The truck driver must be guided by a turn-by-turn navigation from his stating point to his destination.
- The vehicle should have the possibility to access a short horizon speed profile that utilises the topography in order to minimise the fuel consumption.

1.6. M36 demonstration

1.6.1. Presentation

The final demonstration of the COMPANION system, for month 36, will consist of a demo on public roads in Spain. The purpose is to demonstrate and showcase the potential of the COMPANION system for the attendees of the final project conference at Applus IDIADA.

In this case, three different assignments have been defined for three trucks. Two trucks will be confronted by highways with tolls. Hence, the COMPANION system will have to take into account that deviations due to queuing and passing toll stations will occur. The monitoring engine has to detect those deviations from the optimised plan and update the platooning plan.

Two trucks will leave from different points in the region of Martorell. One of the trucks will have to drive a longer distance. Both trucks will have to pass tolling stations and merge directly after them. A third truck will join the platoon entering the highway from a resting area. The third truck will join the platoon and the three trucks will platoon on the AP7 to Applus IDIADA.
Conclusion
A total of four demonstrations were performed, most of the tests cases in the scope of the demo were successful. Two simulation based demonstrations and two on public roads permitted to verify almost all of the requirements.

The M18 simulation demo allowed verifying the end-to-end communication of the COMPANION system, that the on-board HMI was well designed, and forecast to not disturb the driver much. They were not interacting too much with it, and understood easily how to use it. Every route was successfully calculated.

In M24 demonstration, despite only one scenario could be performed of the three originally planned ones, the system has been validated correctly as it correctly informed the trucks, which could platoon and arrive as planned in the city towards which they were heading, with a short delay of five minutes.

The calculation of a hundred assignments (Figure 4) during M28 were performed in less than five minutes. Still regarding the execution time, less than sixty seconds were necessary for a truck to confirm a plan. Those times fulfilled the concerned requirements. It could fast enough calculate a route from a point to another; optimise it, in a short time, despite the amount of assignments to calculate.

The M32 scenarios were a success. The trucks could merge correctly and arrive at the arrival point without any delay. Plus, the truck going alone through Stockholm could manage correctly the different re-planning and arrive with a delay of only one minute despite the heavy traffic through Stockholm.

The last non-verified requirements shall be verified in the demonstration of Month 34, to permit finally, to make the final demonstration with the final implementation, on Month 36.