MAVEN

Managing Automated Vehicles Enhances Network

WP6 Integration, implementation and test
Deliverable nº: D6.4

Integration final report

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Authors

Beneficiary No.	Name and Organisation	Country
1	Julian Schindler, DLR	Germany
2	Robbin Blokpoel, DYN	The Netherlands
3	Michele Rondinone, HMETC	Germany
3	Thomas Walter, HMETC	Germany
4	Ondřej Přibyl, CTU	Czech Republic
5	Hagen Saul, DLR	Germany
6	Andreas Leich, DLR	Germany
7	Daniel Wesemeyer, DLR	Germany

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List of Acronyms and Terms

Acronym / term	Full name / description
EU	European Union
C-ITS	Cooperative Intelligent Transport Systems
CAV	Cooperative Automated Vehicle
MAVEN	Managing Automated Vehicles Enhances Network
V2X	Vehicle-to-Anything communication
WP	Work Package
DoA	Description of Action
UC	Use Case
GLOSA	Green Light Optimal Speed Advisory
I2V	Infrastructure to Vehicle Communication
AD	Automated Driving
AD_SW	Automated Driving Software
TRL	Technology Readiness Level
DLR	German Aerospace Center
HMETC	Hyundai Motors Europe Technical Center
SUMO	Simulation of Urban Mobility
LDM	Local Dynamic Map
CAM	Cooperative Awareness Message
OBU	On Board Unit
V2V	Vehicle to Vehicle Communication
V2X	Vehicle to Anything Communication
CPM	Collective Perception Message
TLC	Traffic Light Controller
TC	Test Case
SPaT	Signal Phase and Timing
MAP	Message containing map information
UDP	User Datagram Protocol
SW	Software
HD	High Definition
SCH0	Service Channel 0

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SCHx	Service Channel X
LAM	Lane Advice Message
ROS	Robot Operating System
DMM	Decision Making Module
AGLOSA	Combination of Adaptive TLC and GLOSA
RSU	Road Side Unit
IF	Interface
OF	Object Fusion
OT	Object Tracking
SI	Système international d'unités
GPS	Global Positioning System
LIDAR	Light Detection and Ranging
RTSP	Real times streaming protocol
CNN	Convolutional Neural Network
R-CNN	Region Convolutional Neural Network
CPU	Central Processing Unit
UTM	Universal Transverse Mercator
SSM	Surrogate Safety Measures
TTC	Time to Collision
TCT	Traffic Conflict Technique
PCA	Principal Component Analysis
SOM	Self-Organizing Maps
ANN	Artificial Neural Network
RNN	Recurrent Neural Network
LSTM	Long-Short-Term Memory
ReLU	Rectified Linear Unit
MSE	Mean Squared Error
FoKr	DLR research intersection located in Braunschweig, Germany
fps	Frames per second
iVRI	intelligente verkeersregelinstallaties (Intelligent Traffic Controllers)
LLR	Local Level Routing

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Table of Contents

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 690727. The content of this document reflects only the authors' view and the European Commission is not responsible for any use that may be made of the information it contains.

List of Figures

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List of Tables

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1 Introduction

Highly and fully automated vehicles, especially when connected to the C-ITS infrastructure, can significantly contribute to meeting the EU objective of effectively accommodating growing mobility demands while still ensuring lower environmental impacts and increased road safety. An increase of driving automation functions in newly released car models is already a visible trend. Moreover, the deployment of C-ITS technology is about to start in 2019 [1]. The combination of automated driving and C-ITS is expected to be a key enabler for distributed coordination of highly automated vehicles [2], and will eventually permit the road infrastructure to monitor, support and orchestrate their movements.

In this context, the MAVEN project (Managing Automated Vehicles Enhances Network) will deliver C-ITS-assisted solutions for managing Cooperative Automated Vehicles (CAVs) at signalised intersections and urban intersection corridors with the aim of increasing traffic efficiency and safety. For this purpose, traffic management algorithms for the inclusion and control of automated vehicles are developed at the infrastructure side. Thanks to V2X communications, these algorithms exchange information with automated vehicle systems that are in turn extended to include the V2X received information into the logic of their environmental perception and trajectory/manoeuvre planning modules. The MAVEN C-ITS assisted solutions include, among others, Infrastructure-to-Vehicle (I2V) interactions for optimal coordination of vehicle transit at intersections, consideration of small vehicle platoons and application of collective perception mechanisms.

While the work packages 3, 4 and 5 of the MAVEN project are dealing with different subsets of the MAVEN system approach, work package 6, to which this deliverable belongs, is in charge of bringing the different developments together, integrating them into real infrastructure and vehicle prototypes (see Figure 1). The work package is therefore consisting of six consecutive integration sprints.

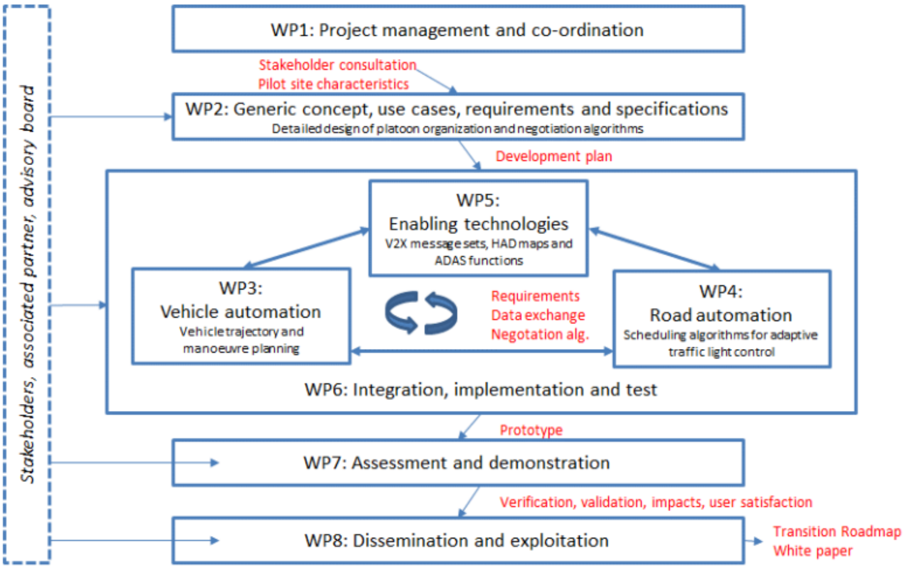

Figure 1: MAVEN WP interrelation

1.1 Purpose of this document

This document presents the work that has been performed in WP6 after D6.3 [3], and therefore focussing on the integration sprints 3-6. It describes which parts of the system are implemented and how they are put together. To do so, it builds upon the deliverables created so far, esp. D6.3 and all other deliverables of the underlying work packages 3, 4 and 5. Another important aspect for understanding the content of this deliverable is D2.1 [4] for the scenario definition of the whole

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MAVEN project, and the deliverables D6.1 [5] and D6.2 [6], which give an overview on the existing infrastructure and vehicles used in MAVEN.
This deliverable will only summarize the integrations done so far and will not go into details about the results and the validation of those actions, as this will be part of the upcoming D7.2.

1.2 Document structure

As a starting point, this document will repeat the content of D6.3 [3] to allow better understanding of the performed work. This includes to revisit the use cases introduced in D2.1 [4], describing in detail necessary modifications and decisions made on each of them since D2.1 [4] has been submitted.
Afterwards, the MAVEN integration sprints are described in detail, starting from the broader view given in the Description of Action (DoA) and leading to an explicit time table with events, which is used as central theme of the MAVEN project.
This section is followed by a brief section about the verification methodology used in MAVEN, which is used to already establish a link to the upcoming D7.2, as integration and validation need to go hand in hand.
Afterwards, a detailed description of the completed integration sprints is given (starting at integration sprint 3 since the details up to integration sprint 2 can be found in D6.3 [3]), before this deliverable ends with summarized conclusions.

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2 Review of Use Cases

MAVEN released D2.1 [4], "User needs, conceptual design and requirements" in the 5th month of the project. While the ambitions of the use cases are still the same, the results of the technical work in WP3 and WP4 led to some changes in the use cases to be able to achieve better or more robust results. This chapter describes the deviations when compared to this initial document.

2.1 MAVEN vision

As also described in the DoA and in D2.1 [3], MAVEN has an overall vision of how automated vehicles are cooperating with each other and with the infrastructure. This vision has slightly altered in the first half of the project. The updated vision is shown in Figure 1: Your automated vehicle turns onto an urban signalized corridor. While gaining speed your vehicle finds itself driving in parallel of a platoon of six vehicles coming from an upstream intersection (A). As your vehicle is also able to platoon, it starts communicating with the platoon members. Because the first four vehicles of the platoon share the same route on the upcoming intersection with you, your vehicle is deciding to join the platoon at the fifth position. Your vehicle slightly decreases speed while the fifth vehicle in the platoon increases its headway to allow your vehicle to merge (B). Immediately after completing the merge your vehicle turns to following mode. The platoon leader registers the new platoon formation at the intersection controller, which in turn reiterates the start and duration of the green phase and returns updated platoon progression instructions. A few seconds later and due to a right of way situation involving pedestrians, traffic flow on the right lane will be impeded. Therefore, the intersection controller instructs the platoon leader to move to the left lane (C). The platoon leader cascades the instruction and initiates the lane change manoeuvre. The last two vehicles continue driving on the right lane, leave the platoon and return to individual mode. Shortly before reaching the intersection your vehicle slows down and stops (D). The intersection controller has given priority to an emergency vehicle coming from the left, now safely passing the green light. Right at the onset of green the platoon departs from the intersection with minimum start delay, heading for the next intersection.

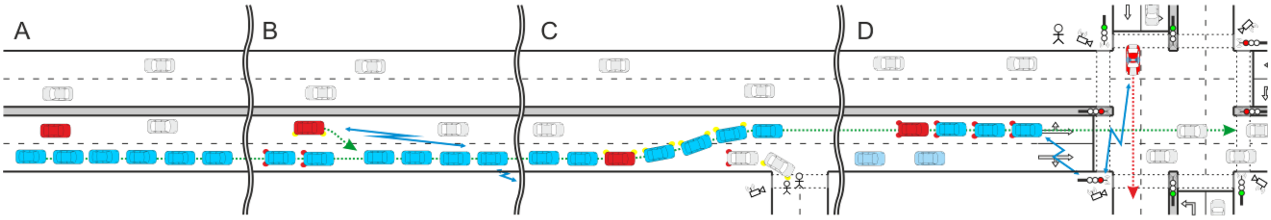

Figure 2: MAVEN vision

2.2 MAVEN use cases

In D2.1 [3] the MAVEN vision has been divided into sixteen use cases:

- Platoon management
  - UC1: Platoon initialisation
  - UC2: Joining a platoon
  - UC3: Travelling in a platoon
  - UC4: Leaving a platoon
  - UC5: Platoon break-up
  - UC6: Platoon termination
- UC7: Speed change advisory (GLOSA)

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- UC8: Lane change advisory
- UC9: Emergency situations
- Signal optimisation
  - UC10: Priority management
  - UC11: Queue length estimation
  - UC12: Local level routing
  - UC13: Network coordination – green wave
  - UC14: Signal optimisation
- UC15: Negotiation
- UC16: Detect non-cooperative road users

All of these use cases are described in detail in D2.1 [3], including separate requirements, scenarios and situations. The use cases are tested individually, but also in a combined way to reach the overall vision. During the discussion and implementation of the use cases, some adaptations had to be made to ensure higher quality and robustness of the developed systems. These adaptations are shown in the following. They also let to slightly changed, updated requirements, which are elaborated in combination with the test procedures and the validation in D7.2 later on in the project.

2.2.1 Platooning Use Cases (UC1-6)

This cluster of use cases has been redesigned during the first phase of WP3. While in the beginning of the project it was planned to give the infrastructure a major role in combining vehicles to platoons, it has been found that urban platooning needs to be done in a very flexible and dynamic way, as decisions have to be made very quickly. To ensure this, the platoon logic is implemented in a distributed way where each vehicle can decide on its own about where and how it would like to participate in platooning. Details about this are given in D3.1 [7] and in [8]. Nevertheless, the infrastructure is not entirely out of the loop. It still can provide speed and lane advisories (UC7 and UC8), which will implicitly affect the behaviour of the platoon or its members in terms of parameter changes, updated trajectories or even splitting up of the platoon.

2.2.2 Speed change advisory (UC7)

This use case is implemented unchanged when compared to the initial descriptions. However the link to UC14, signal optimization, has become stronger as the traffic light controller can actively stabilize the green planning for signal groups with GLOSA.

2.2.3 Lane change advisory (UC8)

No major changes are foreseen for this use case either. There are two scenarios defined. The first deals with a longer queue on one of the lanes without any given reason, the second one deals with a longer queue on the right lane due to permissive green. Since both lead to the same input condition for the implementation of the system (it measures queue on all lanes and triggers advice when there is a difference), these scenarios are identical. Only the first will therefore be tested due to ease of reproducibility.
The link to UC14 was presented as optional and consisted of using lane advice as a control variable. However, there is no case when a non-optimal lane distribution would be meaningful and impact of this will be very low at expected low penetration rates. Therefore, there will be no link with UC14.

2.2.4 Emergency situations (UC9)

No changes are foreseen for this use case. Scenario 1 of this use case (system failure of platoon participant) is better addressed due to the more flexible approach of platooning, which has been chosen. Scenario 2 (vulnerable road user suddenly entering the road) is taken into account by cooperative perception and individual reaction of automated vehicles. Scenario 3 (emergency vehicle approaching) is only implicitly taken into account, as connected automated vehicles will react individually to this by using Day-1 messages.

2.2.5 Priority management (UC10)

No changes are foreseen for this use case, but it is important to discuss priority levels with other stakeholders, especially road operators.

2.2.6 Queue length estimation (UC11)

No changes are foreseen for this use case.

2.2.7 Local level routing (UC12)

No changes are foreseen for this use case.

2.2.8 Network coordination – green wave (UC13)

No changes are foreseen for this use case. It should be noted that D2.2 [9] also includes the Traffic Management level to steer the green wave, This was an option that was held open, but ongoing work in WP4 concluded that this is most likely not necessary. Only policy parameters can be set as was already mentioned in D2.1 [4].

2.2.9 Signal optimisation (UC14)

No changes are foreseen for this use case.

2.2.10 Negotiation (UC15)

This use case remains the same from a functional point of view. Some minor changes originate both from ongoing signal optimization work in WP4, and the I2V interaction process and message sets as defined in Deliverable D5.1 [10]. In D2.1 [4] it is written the vehicle communicates the estimated time of arrival at the intersection, this is done by communicating the position, speed and desired speed (see Section 4.1.4 of D5.1 [10]). With this information, the traffic light controller can calculate its expected arrival. In addition, the intersection will not directly suggest platoon formation or leaving/brake-up, as it was considered more effective to let this kind of decisions to vehicles in UC1-2. Nevertheless, application of UC8 (lane change advice) to a given vehicle can indirectly generate platoon formation when the suggested vehicle changes to a lane where other vehicles meet the conditions for platoon initialization. Similar considerations apply when a lane change advice to an individual vehicle indirectly leads to situation of platoon leaving/brake-up. In addition to what mentioned in D2.1 [4], the negotiation process is closed when the vehicle acknowledges the compliance (or not) to the speed or lane changes advices received by the intersection. As explained in D5.1 [10], this allows the intersection to give priority to the validity of the provided advices, which ensures a stable time to green prediction. If this would not be prioritized, the traffic light controller would recalculate the timing schedule/speed advices every second, resulting in constant acceleration and deceleration for the addressed vehicles.

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2.2.11 Detect non-cooperative road users (UC16)

This use case also stays the same from a functional point of view with the following minor modifications. In scenarios 1 and 2 described in D2.1 [4] the intersection is not reacting to traffic light status changes as reactions are already implemented by vehicles in their automated driving (AD) Software (SW) logics: simultaneous reactions at traffic lights would overcomplicate the AD_SW logic decisions.

3 Integration Sprints

Already in the DoA, a very specific work plan has been provided showing six different integration sprints, each with a duration of three month and with the focus of adding more complexity and with the goal of reaching a higher technology readiness level (TRL). The MAVEN concept will gradually pass desk, laboratory and field tests which incrementally will lead to a system prototype of the MAVEN concept.

The integration sprint plan also takes into account the different milestones in the project, divided over the different work packages. Due to the integrative nature of WP6, each milestone of WP6, i.e. MS6.1 to MS6.6, is based on several milestones and deliverables of other work packages, as shown in Figure 3. Please refer to the DoA, the MAVEN website or to the different deliverables of each work package to get more detailed insights into the respective content.

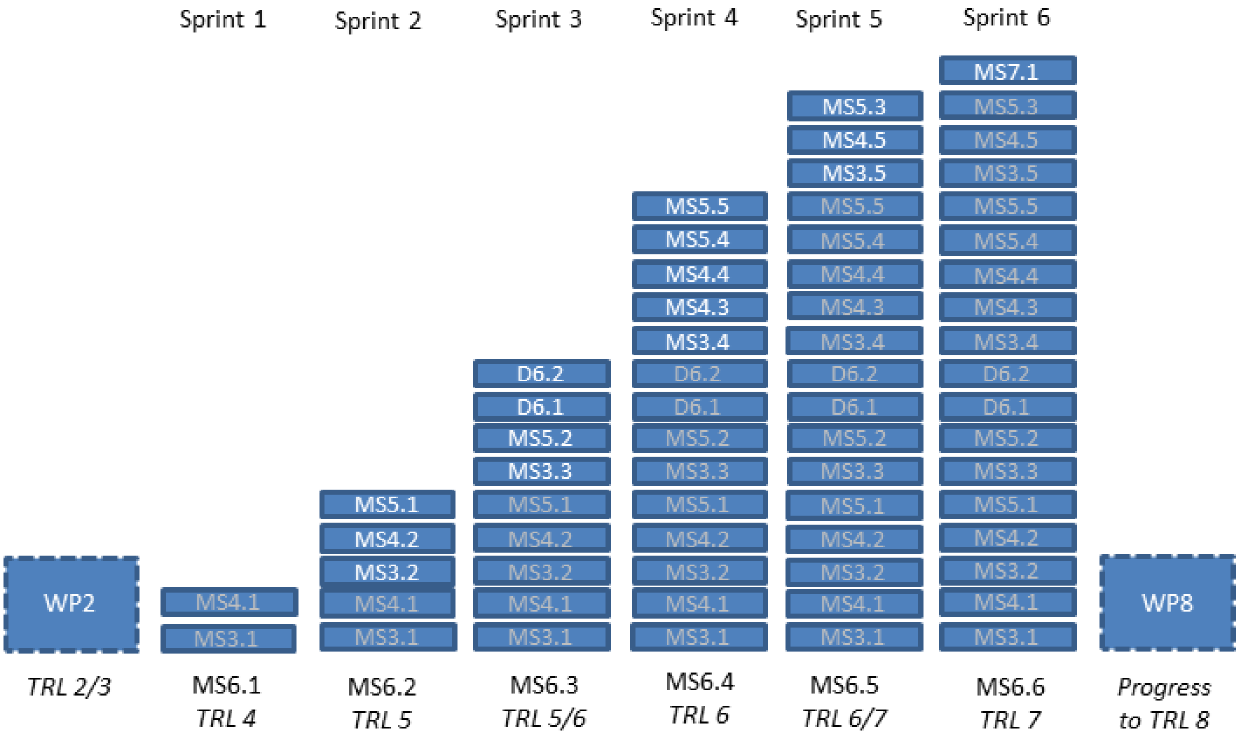

Figure 3: The initial integration sprint plan including targeted TRL and related milestones.

By taking into account the developments of the project, and especially the derived use cases described in D2.1 [4], the available test vehicles and infrastructure as shown in D6.1 [5] and D6.2 [6], and the respective system architectures shown in D4.1 [11] and in D3.1 [7], the integration sprint plan has been concretised compared to Figure 3. As shown in Figure 5, the integration sprints now start with simulations showing the basic behaviour. Afterwards, the systems get integrated into simulation and real world prototypes, which are tested on closed test tracks first, followed by more challenging tests on public roads. Implicitly, the milestone plan shown above is still followed. Nevertheless, the plan had to be rescheduled, Figure 5. This was due to various circumstances, esp. hardware problems on the Tostmannplatz intersection which needed unexpected road works and availability problems of DLR's research vehicles.

Each integration sprint consists of partner specific actions and test events leading to the fulfilment of the requirements (explained in more detail in section 4).

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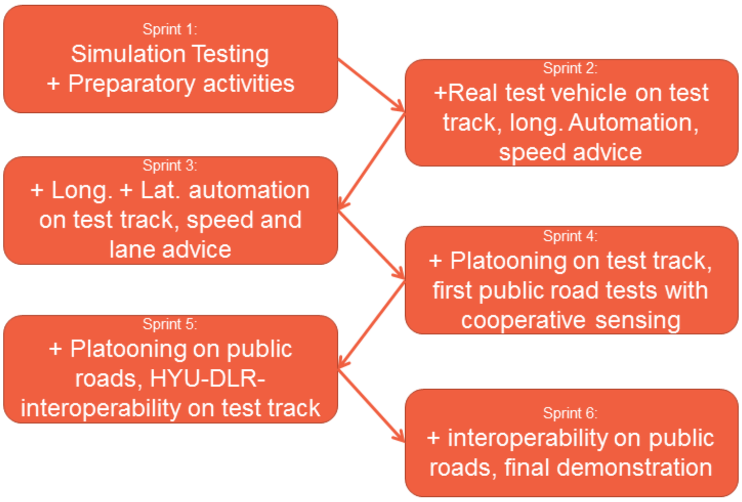

Figure 4: Each integration sprint adds functionality and complexity to the MAVEN prototypes. Sprint planning as planned in D6.3 **[3]**

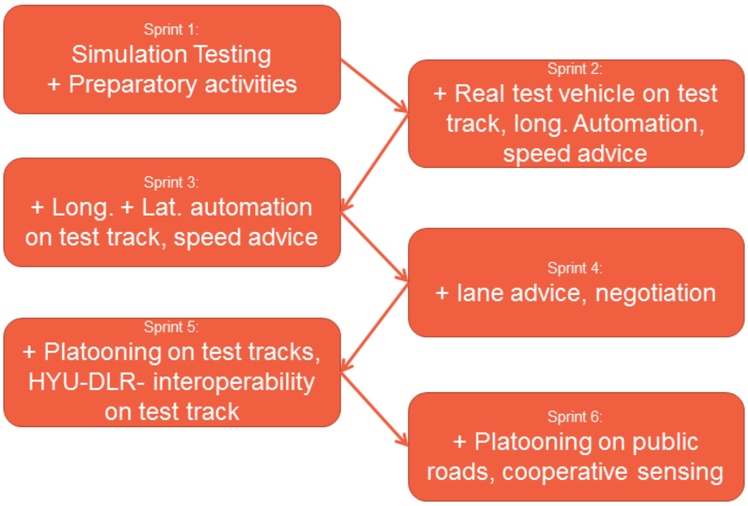

Figure 5: Modified sprint planning showing the finally achieved sprint content

The test events – also slightly modified if compared to the similar table in D6.3 [3] – have been summarized in the following Table 1.
Each test event is taking place in a specific environment. This can be a simulation environment, a test track or on public roads. There are two simulation environments: SUMO is used for simulations of various vehicles on larger road networks, while DLR's Dominion is simulating the exact behaviour of a few automated vehicles and includes the automated driving software which is also used in the DLR test vehicles (see D3.1 [7] for details). Additionally, some communication tests are performed using communication hardware and external ASN.1 decoders. With regard to test tracks, MAVEN makes use of the DLR and HMETC facilities and of two air ports (Griesheim and Edemissen). Final testing on public roads is done in Helmond, The Netherlands, and on Tostmannplatz in Braunschweig, Germany. Further details are shown in D6.2 [6].
DLR and HMETC are using their test vehicles, FASCarE, ViewCar2 and a Hyundai Ioniq during the road tests. The vehicles are described in detail in D6.1 [5].

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Table 1: Integration sprint overview

Sprint	Duration	Event		Environment
		No.	Title	
Integration Sprint 1	09/17 -11/17	1*	Basic speed advice scenario and longitudinally automated UC1/3/6	Dominion Simulation
		2*	Basic platooning and LDM	SUMO Simulation
		3*	V2V platoon messages and V2I negotiation messages (CAM extensions)	V2X OBU
Integration Sprint 2	12/17 -02/18	4*	Installation of camera and hardware	Tostmannplatz public roads
		5*	Installation of camera and hardware	Helmond public roads
		6*	V2X cooperative sensing messages (CPM)	V2X OBU
		7*	UC1/3/6/7/8 in simulation	Dominion simulation
		8*	Longitudinally automated UC1/3/6 with emulation on test track	DLR test track
		9*	I2V negotiation message encoding by infrastructure	Helmond simulation network
		10*	Adjusted ImFlow application in TLC, UC7/14	SUMO simulation
		11*	Green wave integration	SUMO simulation
Integration Sprint 3	03/18 -05/18	12	UC7 longitudinally and laterally automated with emulated infra messages or mobile traffic light on test track	Edemissen test track
Integration Sprint 4	06/18 -08/18	13	UC1-8 in simulation	Dominion simulation
		14	UC7/8/10/14/15 simulated on public roads	SUMO simulation with Helmond network
		15	UC7/8/15 on test track	Griesheim test track
Integration Sprint 5	09/18 -11/18	16	UC1/3/6/8/9 with two DLR cars on test track	Edemissen test track
		17	Platoon Logic integration on HMETC car	Griesheim test track

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		18	UC1/3/6 with two cars (DLR and HMETC) on test track	Griesheim test track
Integration Sprint 6	12/18 -04/19	19	UC13 Green Wave	SUMO simulation with Helmond network
		20	UC1-6 with three cars (DLR and HMETC) on test track	Griesheim test track
		21	UC 7 with DLR and HMETC cars on public roads	Tostmannplatz public roads
		22	UC 8 on public roads	Tostmannplatz public roads
		23	UC7/8/10/14/15 on public roads	Helmond public roads
		24	UC 11 Queue estimation + UC 12 route advice	SUMO simulation with Prague network
		25	UC 7/8/10/13/14/15 for impact assessment	SUMO simulation
		26	UC1-7 & 16 with three cars (DLR and HMETC) on public roads	Tostmannplatz public roads

As shown in the table, the integration events start in simulation environments. Afterwards, first driving tests are performed on closed test tracks. At the end of the project, nearly all use cases are shown on public roads and in large scale SUMO simulations allowing to get insights into the effects of the MAVEN system when not only implemented in single vehicles.
The events marked with * are not described in this deliverable, but in earlier D6.3 [3].

Besides the specific events, there are also ongoing activities in WP6, including software integrations and updates in the vehicles and in the infrastructure. These activities are not limited to specific events and integration sprints and therefore do not appear in the table above.

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4 Verification overview

The previous section of this deliverable focused on description of the particular integration sprints. The main objective of the Integration Sprints (or events as part of the integration sprints) is to verify that the prototypes fulfil the objectives of particular Use Cases stated in D2.1 [4]. It is important to maintain traceability among the particular objects.

In this section, the process that verifies whether the objectives of the Integration Sprints are met is provided and discussed. This section also describes the principles of traceability among different objects. This is a formal process that extends the state-of-the-art processes of requirements management [12].

Use Cases and Requirements
D2.1 [4] defined and described the individual Use Cases of MAVEN project. They focus on the basic high level functionality as well as the Situations and Scenarios under which the use case is supposed to perform (for more explanations please see D2.1 [4]).

For each Use Case, in order to fulfil its objectives, a set of Requirements is defined. There are several criteria on the requirements [13], such as that they are *Unambiguous*, *Verifiable*, *Clear* (concise, terse, simple, precise), *Correct*, *Feasible* (realistic, possible), *Necessary* and *Complete*. They are from design *atomic* and *verifiable* so that it is possible to decidedly state whether the prototype (the system) fulfils the given Requirement or not. If we assure that the Requirements completely cover every given Use Case, we can assume that fulfilling those Requirements assures that the entire Use Case meets its objectives. The verification through Requirements is a formal process documenting clearly all steps of the process. Apart from that, the expected behaviour will be also assessed by visual inspection during the field tests.

The MAVEN project identified 106 requirements for the 16 MAVEN Use Cases in D2.1 [4].

Test Cases
In order to ensure that every Requirement is fulfilled, each Requirement must have a verification method. Appendix A of D7.1 [14] provides a list of all requirements together with their verification method. In general there are three types of verification supported in MAVEN: A – Analysis, D – Demonstration and T – Test.

As part of work in WP7, for each Requirement with the verification method: Test, one or more test cases were defined. They are summarized in a working document MAVEN Verification Matrix.

Verification process

The Integration Sprints as defined in the previous sections of this deliverable each consists of one or more Events. These Events denote activities in the field or within a simulation environment aiming on verification of different use cases (can be more than one, but can be also only a partial evaluation of a use cases, especially during the early sprints).

First, the Test Cases relevant for particular Event are identified and put into a dedicated list, which is part of a test protocol. Each Test Case (TC) consists of the following attributes:

- TC ID
- TC Name
- TC Description
- Pre-condition
- Post-condition

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- TC Comment
- Test Result (Not executed, Pass, Fail, inconclusive)
- Test Result - Comment

The relevant Test Cases are identified through filtering the Requirements according to their relation to Use Cases and the Events.

The Test Cases will be executed during particular Events and the results will be reported in predefined test protocols as depicted in Figure 7. In this way, the traceability from Test Cases through Requirements back to the original Use Cases is ensured. This traceability and particular links among objects are depicted in Figure 6.

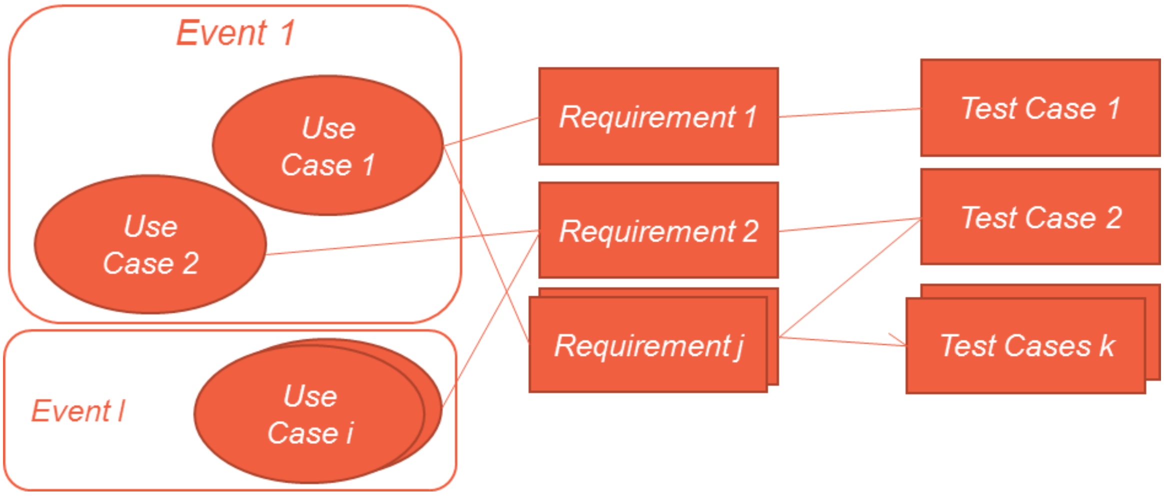

Figure 6: Traceability and links between Use Cases, Requirements, Test Cases and Events

This methodology was prepared based on the state-of-the-art analysis of the requirements management process to fulfil all needs of the MAVEN project. It was very important to manage the traceability and thus to ensure meeting of the project objectives. The advantages of this methodology cover among others the following:

- It is possible to trace the origin for each test case in the entire process and thus identify the origin of the particular requirement.
- Using Requirements as the basic verification unit follows the best practices [15] and ensures that we can clearly and unambiguously verify its impact. They are atomic and verifiable with clear *pass* or *fail* results.
- Due to the project focus on completeness of the Requirement coverage of the particular Use Cases, fulfilling all Requirements for given Use Case also ensures that a given Use Case is fulfilled. The fact that events always cover a number of complete use cases also ensures that the overall MAVEN vision is evaluated as well.
- The fulfilment of the overall MAVEN vision (part of Use Cases) is further identified by the Test manager and/or other Test witnesses during the field test and clearly written in the test protocol. Here the focus is on the “big picture” for the scenarios.

All requirements, test protocols and results are summarized in the upcoming D7.2.

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MAVEN - Managing Automated Vehicles Enhances Network

Test Protocol

Event identification

Event Name:		Event ID:	
Event location:		Date:	

	Major	*Minor*	*Internal*
Event significance	☐	☐	☐

	Name	*Organization*	*Role*
Participants			

Introduction and prerequisites

Event objectives	
HW and SW configurations	

Test results

	Number	*Proposed measure*
Fail	1	
Pass	1	
Inconclusive	1	
Not executed	**3**	

Conclusions	

Figure 7: Test protocol template

.

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5 Final achievements

Due to the aim of this deliverable to report the achievements of the integration work done in WP6 after D6.3 [3], the following sections give an overview on the last 4 integration sprints. A detailed overview is given for each of the events linked to those integration sprints. Besides, as mentioned before, there has been continuous work done by the partners (Dynniq, DLR, HMETC and CTU) which is not linked to specific events. This work is also summarized in the “General achievements” sub-section of each integration sprint. Please note that not all partners contributed to all integration sprints, therefore not every partner is represented in each sprint. Please also note that some of the work has already been presented in dedicated deliverables, e.g. in terms of vehicle automation in the deliverables of WP3 or in terms of road side algorithms in the deliverables of WP4. Not all details are repeated here.

5.1 Integration Sprint 3

Integration sprint 3 (M19-M21) was according to the DoA planned to lead to integration level 3 of the MAVEN project:

<u>MS6.3, MAVEN validated in field environment</u> Vehicle and roadside software algorithms and hardware will be integrated in the test vehicles, and roadside stations and traffic light controllers in the field. Vehicle and roadside stations will transmit C-ITS messages. One vehicle will be capable of interaction with traffic lights with automation capabilities activated. TRL 5/6.

This milestone has been reached in M21. Vehicles and the roadside have been integrated in a closed test track environment. Both, vehicle and roadside stations are transmitting C-ITS messages, esp. SPaT and MAP (see D5.1 [10]). A single vehicle (DLR and HMETC) is responding to these advices correctly.

5.1.1 General achievements

5.1.1.1 HMETC

HMETC was not involved in any specific events in this integration sprint. Instead, several components needed for the upcoming integration sprints have been developed, esp. in terms of communication and automated driving. Both aspects are described in the following.

5.1.1.1.1 Communication integration

As explained in D6.3 [3], the MAVEN cars are equipped with a V2X communication module whose SW has been extended with a MAVEN application to handle bidirectional communications with the Automated Driving Software (AD_SW) modules. These communications are done through dedicated interfaces where suitable data structures are exchanged via UDP sockets. In D6.3 [3] it has been described how the V2X communication module SW extensions have been performed and tested to handle reception of relevant V2X traffic light data from the cooperative intersections, and transmit ego-vehicle-specific data to other cars and infrastructure (V2X communications for I2V interactions). In this integration sprint, further V2X communication integration has been done. In particular, the V2X communication module SW has been extended to support transmission of ego-vehicle data structures for platooning, and reception of such information from other platoon cars (see Figure 8).

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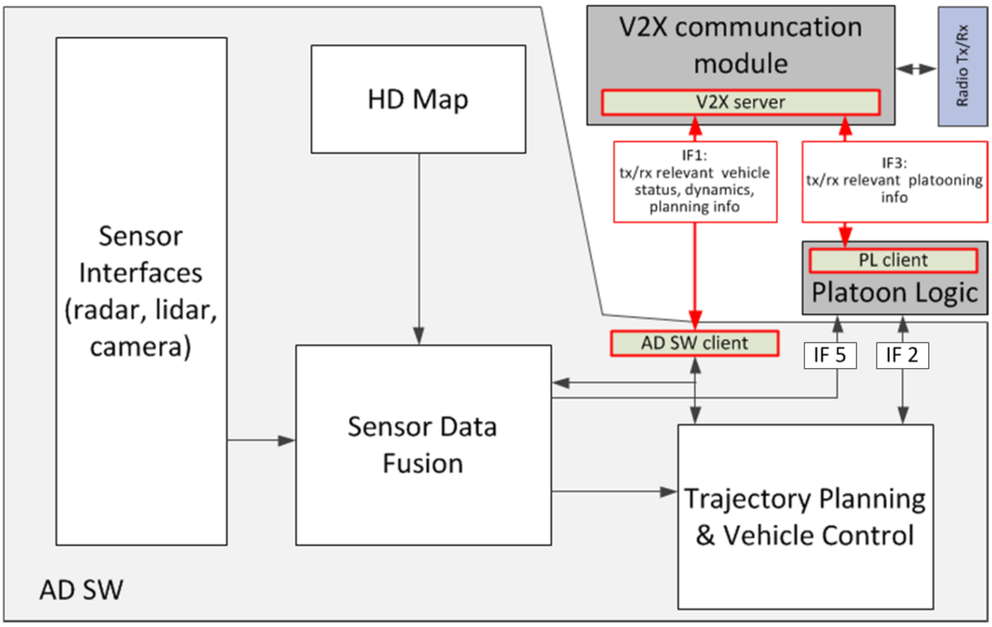

Figure 8: General AD Software modules and MAVEN V2X system integration scheme for V2V platooning communications in the vehicle

This figure shows the interfacing with the AD_SW implemented at Hyundai and DLR vehicles, and with the Platoon logic. Over the interface IF1 (AD→V2X), the AD_SW continuously provides the V2X communication module with data needed to be V2V exchanged in order to detect opportunities for initializing or joining a platoon. This data is used by the V2X module for populating CAMs on Service Channel 0 (SCH0, see D5.1 [10]). In the other direction (V2X→AD), the AD_SW receives the data relative to CAMs on SCH0 received by other CAVs and used by the AD_SW sensor fusion modules to increase the environmental awareness of the ego vehicle. Over IF3 (V2X→PL), the Platoon logic receives data structures relative to CAMs received from other CAVs on both SCH0 and SCHx. These structures are needed for the platooning state machine to check the conditions for platoon initialization and state changes (e.g. presence of vehicle behind/ahead with similar route/speed/acceleration capability, platoon ID, Platoon followers and state machine flags (see D3.1 [7])

In the other direction (PL→V2X), IF3 is used when the Platoon Logic wants to activate the V2V transmission of CAMs on the SCHx (e.g. the conditions are met to initialize a platoon between two CAVs). Moreover, this interface is used to advertise the ability of a vehicle to drive in a platoon. This info is received by the V2X module and transmitted in SCH0 CAMs.

To verify that the above mentioned integration between AD and V2X SW works properly, the validation scheme depicted in Figure 9 is used.

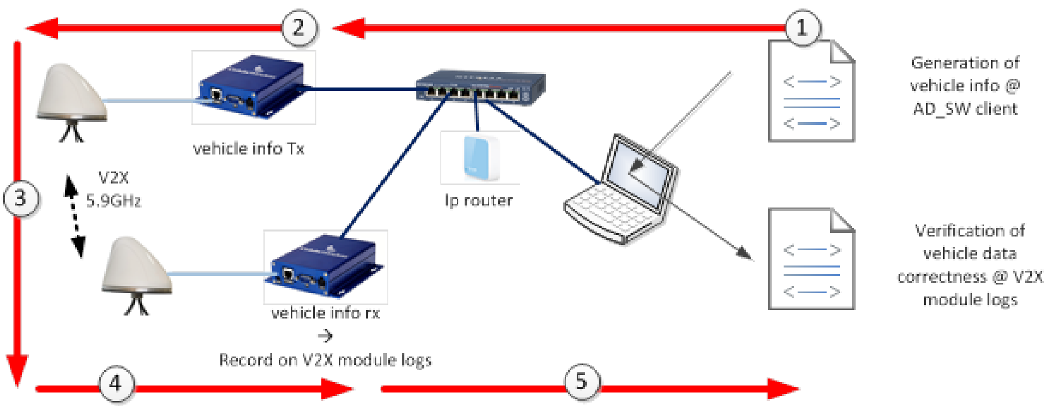

Figure 9: Verification scheme for V2X integration implementation of platooning communications

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The same test bench setup as described in section 5.1.1.1.2 of D6.3 [3] is used. The AD_SW client application running at the tester PC is used to populate the above mentioned data structures with test data (step 1). When running, this client application transmits the structures to the V2X module over UDP using the above mentioned IF1 and IF3 interfaces (step 2). The transmitting V2X module runs the V2X MAVEN application that extracts data from the structures and includes it in extended MAVEN CAM messages that are continuously broadcasted over the 5.9GHz ITS SCH0 and SCHx channel (step 3). The transmitted CAMs are received at a receiving V2X module running a V2X application capable to decode the extended MAVEN CAMs and log the reception results (step 4). Finally, the receiving V2X application extracts relevant data structures and forwards them to the client modules running on the tester PC over the above mentioned interfaces (step 5). The next figure show an example of the logs recorded at the receiving V2X module.

Figure 10: Logs of receiving V2X module

The log lines highlighted proves a correspondence with the data structures received by the AD_SW over IF3 (V2X→PL), data elements used by the platoon algorithms are framed into red boxes.

Another very important communication integration step performed in this sprint by HMETC is the implementation of a V2X emulation approach for preparation of the next real-road tests. A V2X emulation approach is used to emulate V2X receptions in absence of other cooperative automated vehicles or infrastructure. This is very important for HMETC, as only one AD car is available and no traffic light controller providing LAM or SPaT/MAP messages can be used on the adopted test track. The V2X emulation module can be used to generate or record data structures relative to V2X messages from real infrastructure (e.g. speed or lane change advices of a given traffic light). These generated or recorded data structures are converted into Robot Operating System (ROS) bag files and stored in the format as they would be received over the above mentioned UDP interfaces. The ROS bag files can be then "replayed" within the AD_SW logic of the ego-vehicle when performing tests on the test track. Replaying the bag file emulates receptions of V2X messages from the infrastructure (virtual stations in this case).

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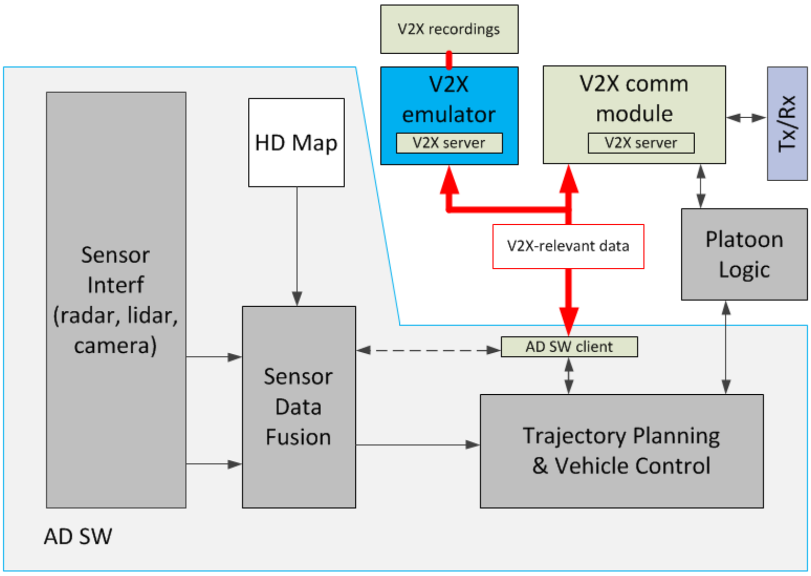

Figure 11: HMETC framework including V2X emulation approach

The recording functionality has been adopted in May 2018 by HMETC for recording V2X SPaT and MAPs messages at the Helmond intersection test site. SPaT and MAPs messages convey real-road phase/timing and speed information as transmitted by the Road Side Unit (RSU) attached to the traffic light controller. Figure 12 shows a picture of the Hyundai car during these recording sessions. The V2X communication module converts SPaTs and MAPs messages into a data structure suitable for the AD_SW module in terms of GLOSA handling. This data structure is forwarded to the AD_SW via UDP over the already mentioned IF1 interface and logged. These recordings represent the dynamic evolution of the traffic light phases and speed advices over a given time window and can be replayed by the AD_SW as an additional emulated input for the vehicle automation (see figure above). Adopting traffic light controller data collected in real-road scenarios when performing tests on proving ground is very important because in the reality this data is changing dynamically in a non-deterministic way to adapt to actual traffic demands. As a consequence, GLOSA adaptation algorithms in the AD_SW should be adequately “trained” with samples of this data to adapt to patterns as likely to be experienced in real-road scenarios at later integration sprints.

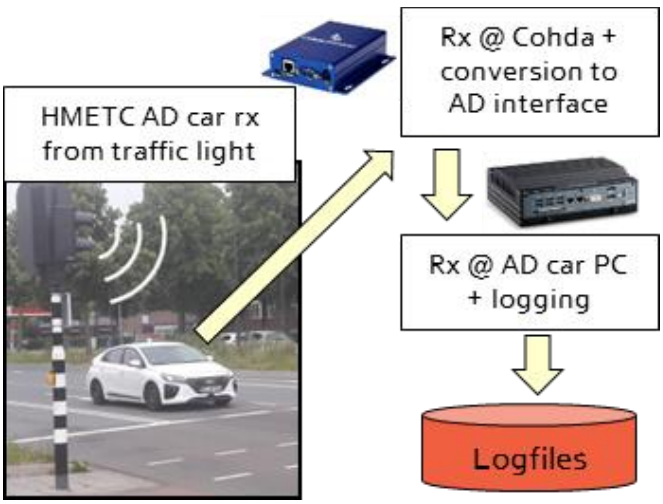

Figure 12: SPaT and MAP recording in Helmond

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5.1.1.1.2 Automation integration

During integration sprint 3 the focus was to enhance the vehicle prototype's base AD functionality described in D6.3 [3] to support lane change requests triggered by I2V Lane Advice Messages (LAM) from the infrastructure. The complete logic to handle execution of such lane change requests is implemented at the Decision Making Module (DMM) of the AD_SW and described in D3.3 [16]. In particular, the execution of a lane change request is subject to availability of safe gaps with the surrounding vehicles. If such gaps are not available at the triggering moment, the *DMM* will try to execute the lane change at later instants along the planned route. As a consequence, a very important piece of automated software integration happened in this sprint is the extension of the decision module logic to take into account events originated by the sensor fusion (presence of objects in the surrounding) in combinations with triggers coming via V2X lane change advices. To verify in real-time that the AD logic is behaving as expected at every moment of a test run, a debugging HMI providing visual indication of the status of relevant use case variables has been realized. This debugging HMI is displayed on a monitor installed in front of the co-driver's seat so that the co-driver can monitor the AD logic operation while the driver is engaged in checking the car's surrounding to assess if he needs to take the control over in case of risks. The current values of the variables considered for automated lane change in response to a LAM request during a test run are visualized in the next figure. As it can be seen, the LAM indicates to move to the lane 3 (left lane) starting from a point which is 180m far from the stop line ("target distance to lane change" in the figure). At the moment of the snapshot, the vehicle is 18m far from that point in its direction of travel ("distance to initiate lane change") and detects the presence of a car behind it on the left lane ("left lane follower"). As this car is at a safe distance, the gap is considered safe (green colour in the figure). If such a gap is maintained at the lane change point, the lane change is executed.

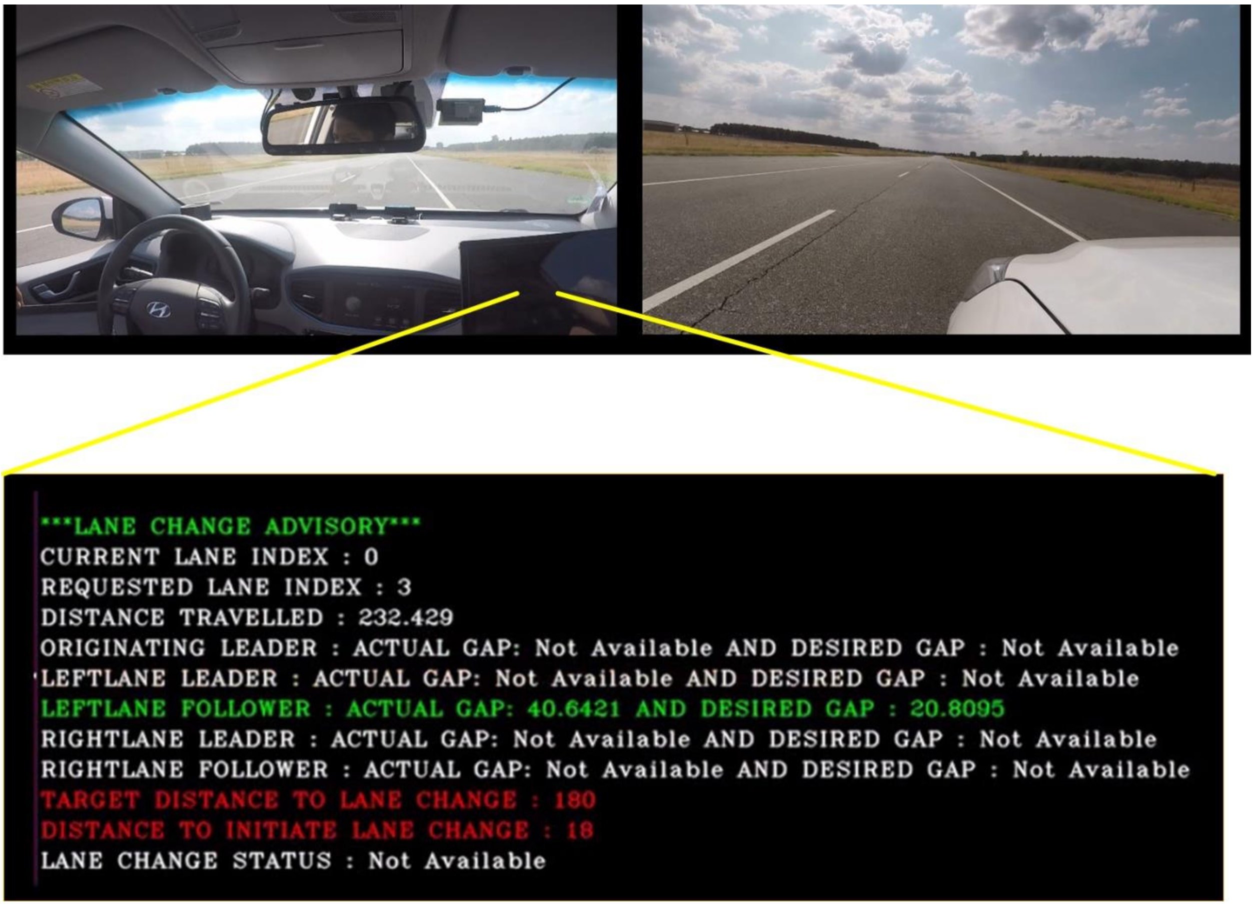

Figure 13: Debugging HMI outputs for lane change monitoring

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The adaptation to I2V lane change advices has been extensively tested by HMETC on the Griesheim test track using a LAM emulation compliant in its concept to the scheme described in the previous section. Several scenarios are reproduced in which a lane change is triggered in different conditions of obstacle vehicles present around the ego-car (see Figure 14).

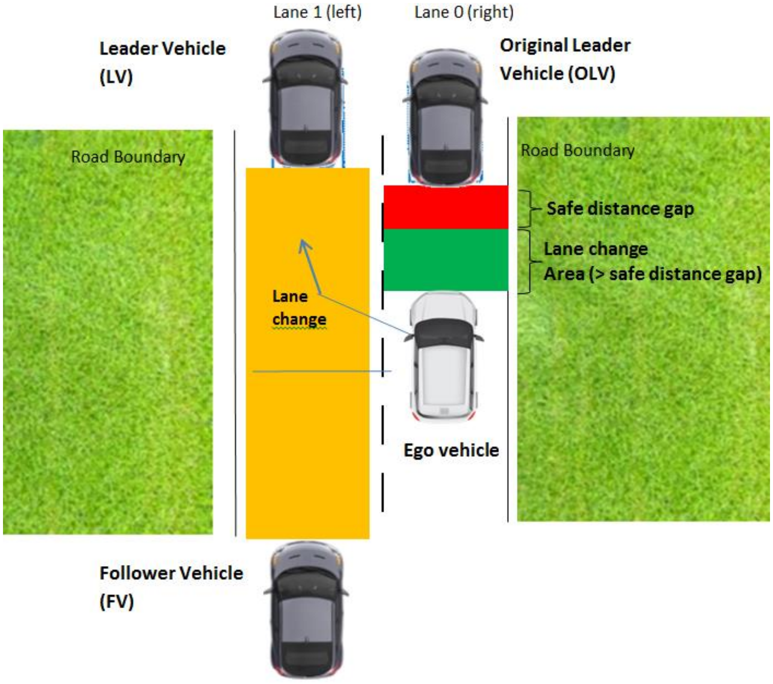

Figure 14: Obstacle vehicles considered for automated lane change decisions

First, tests with only one obstacle vehicle opening and closing the gap are performed to check if the ego-vehicle correctly executes or rejects the lane change advice, respectively. Later, multiple obstacle vehicles (also in different combinations of static and dynamic ones) are adopted to verify the ego-vehicle reaction in random scenarios as likely to be experienced in real road-traffic conditions. The performed tests were subsequently executed in order to fine tune the adopted safe gaps as well as the lane change trajectory. The objective of this was to achieve a comfortable experience for the ego-car passengers, as well as for the drivers of the obstacle cars, which is very important in preparation of the real-road tests happening at later integration sprints.
The lane change adaptation tests made at Griesheim have been recorded on sample videos that have been shown at the MAVEN consortium meeting in Berlin in September 2018. The next figure represents a snapshot of some of these videos.

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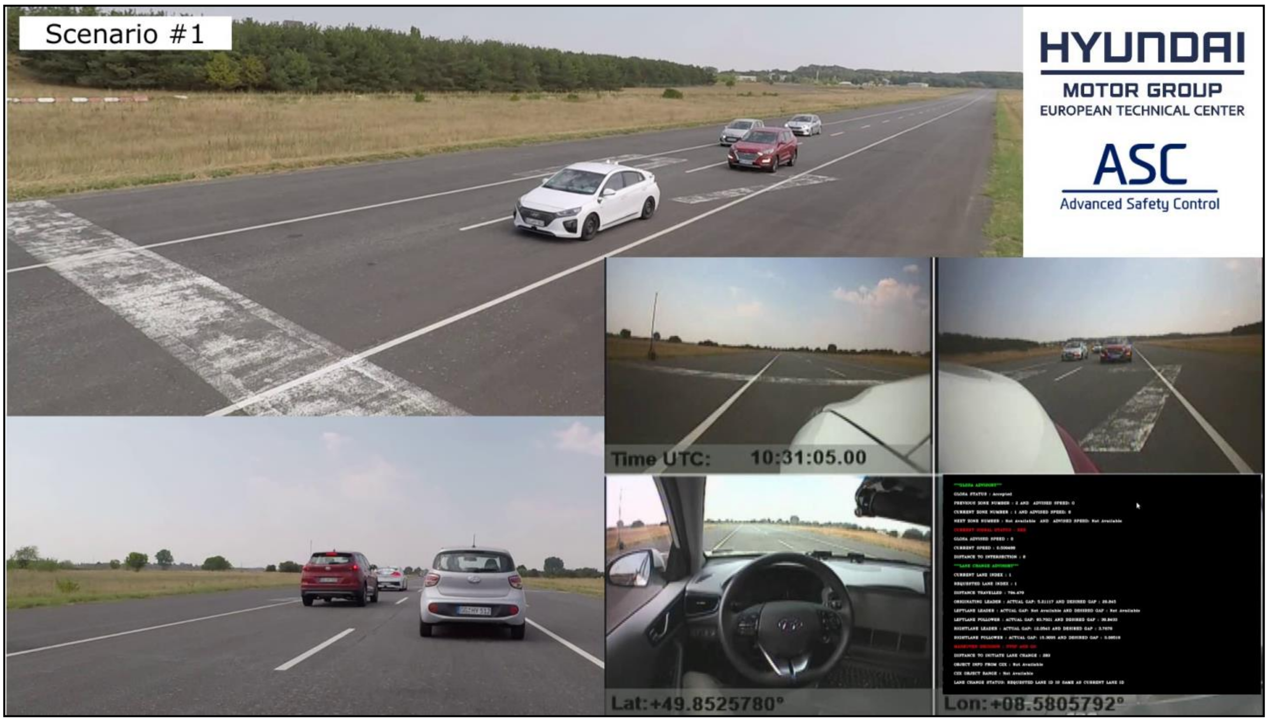

Figure 15: test-track-based verification of LC functionality (2)

5.1.1.2 DLR

In integration sprint 3, DLR was working mostly on Event 12. In that time, DLR suffered a lot from the unavailability of its second test vehicle, the ViewCar2, which could not been put into service on time due to several issues. As several research projects where planned to take place during that time, the left test vehicle was not usable for MAVEN in the desired way. Therefore, work on the prototype was delayed in that phase. Nevertheless, some general achievements could be made, shown below.

5.1.1.2.1 Automation integration

The vehicle automation, and mainly the cooperative trajectory planner of DLR at this stage was already able to plan a real-time collision free trajectory, and to calculate the longitudinal and lateral reference value of the planned trajectory used as input by the vehicle controller. The software modules have been enriched, updated and revised, resulting in the components shown in Figure 16. The DLR vehicle automation receives the environment information from its sensor data fusion. Before planning a trajectory, the “Tactical Decision” module analyses the vehicle surrounding and defines a task for the trajectory planner allowing it to plan a trajectory. The planning itself is using an optimal control based approach. The vehicle model used inside the trajectory planner is simplified and it cannot reflect the complete behaviour of the real vehicle. On the other hand it is not possible to consider all external disturbances and effects inside the trajectory planner due to their complexity and calculation time expenses. Hence, the driven trajectory after applying the actuator values, found by the trajectory planner does not match the planned trajectory. Therefore, a closed loop controller is used to minimize the error and difference between calculated trajectory and the driven one.

All further details of the steps taken in the vehicle automation at this time are summarized in D3.3 [16].

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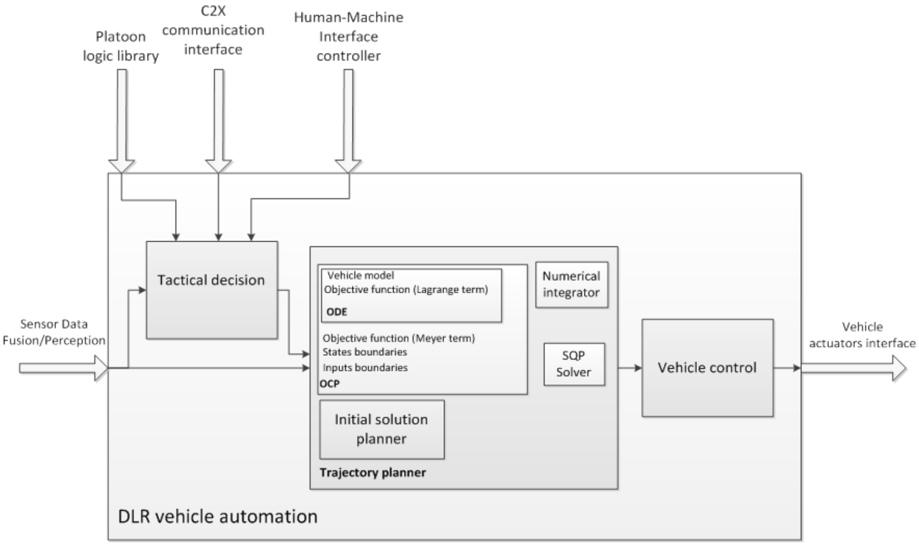

Figure 16: DLR vehicle automation software detailed architecture

Besides, the interpretation of received SPaT and MAP messages has been refactored and generalized. As result, stop lines of all traffic lights and the different speed advice zones per lane are visualized, as shown in Figure 17. The vehicle does a zone matching to know the zone it is currently driving in. When the vehicle is driving in a red zone, it needs to stop at the upcoming stop line. In case it is in a green area, it is possible to reach the traffic light at green. A small number in the print is showing the optimal speed in m/s as received from the infrastructure in the SPaT message.

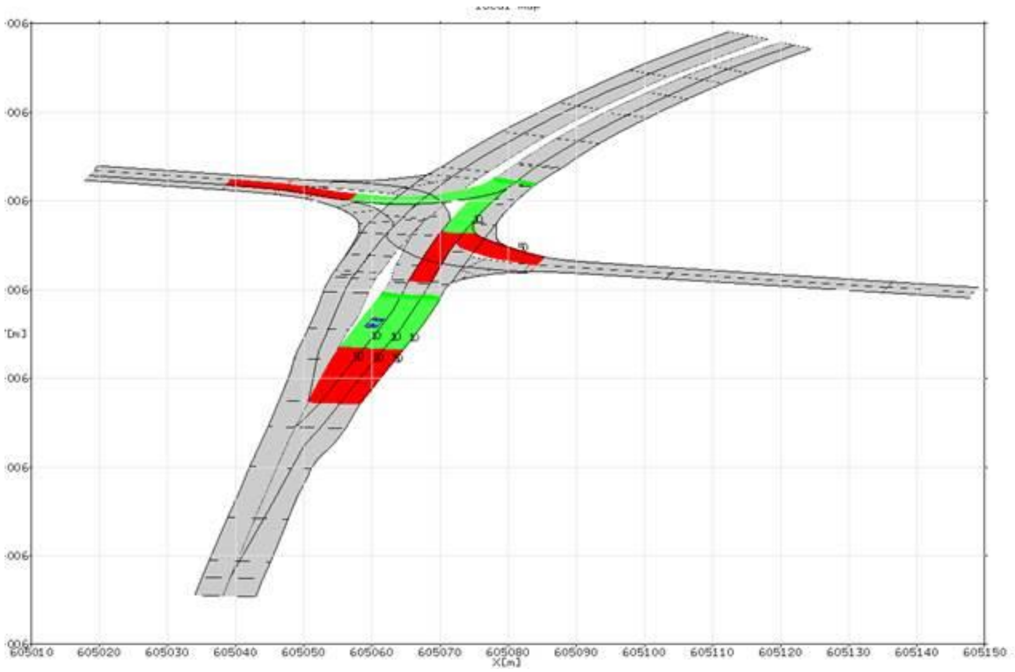

Figure 17: Speed advices visualisation on Tostmannplatz for a subset of lanes.

In addition to this, a set of virtual test tracks have been created for testing on the Edemissen test track. While first tests were only using a straight lane with a traffic light and stop line at one end, the grade of realism was raised step by step, to finally allow tests on the real Tostmannplatz in Braunschweig. As the real maps of the Tostmannplatz and Research intersections located in Braunschweig do not fit onto the real Edemissen test track, another procedure had to be used. Therefore, the intersection topologies of the intersections have been analysed and a virtual track resembling the original topology but in a straightened way has been created, see Figure 18.

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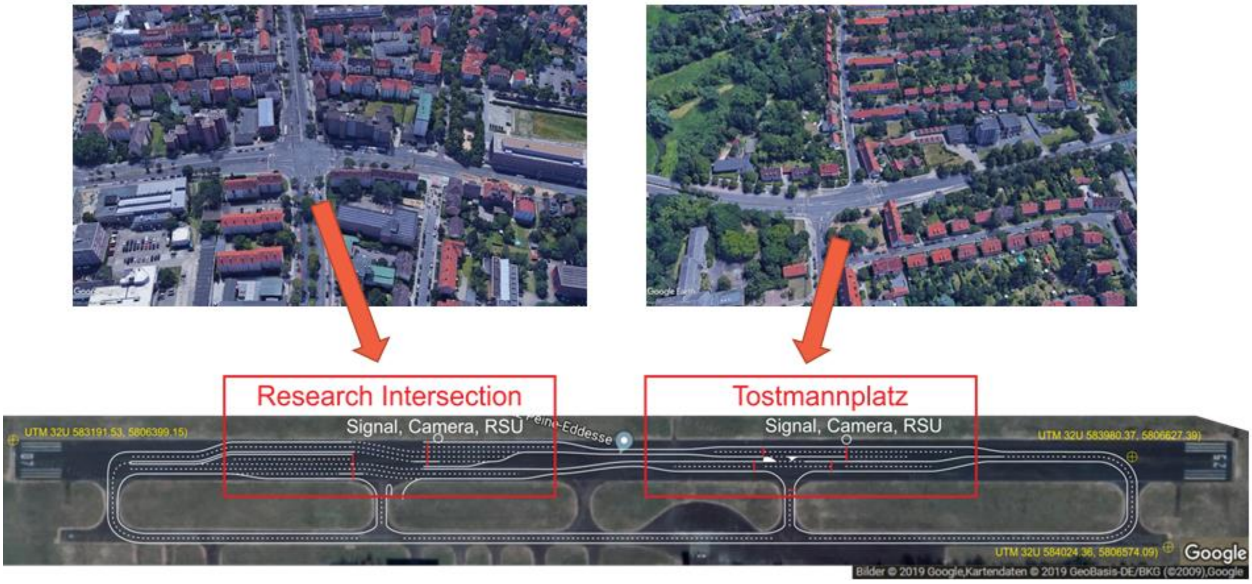

Figure 18: Two real intersections located in Braunschweig, Germany, straightened and virtually placed onto the Edemissen test track.

While implementation continues, the test track needs to be as close to reality as possible. Therefore, a third virtual test track has been created in which a section of the original Tostmannplatz map without any distortion has been placed on the Edemissen test track, see Figure 19. For the Tostmannplatz, this was only possible by using the southern part of the real intersection, since the northern part includes a curve which would exceed the existing runway in Edemissen. In addition, all the branching roads had to be removed.

Figure 19: A section of the real undistorted Tostmannplatz map virtually placed on the Edemissen test track.

5.1.1.2.2 Infrastructure integration

For all of the created virtual roads also the virtual map included in the mobile traffic light had to be created, see Figure 20. This map is used by the AGLOSA algorithm, see D4.4 [17]. Same goes for the content of the MAP message, which had to be implemented reflecting the lane layout.

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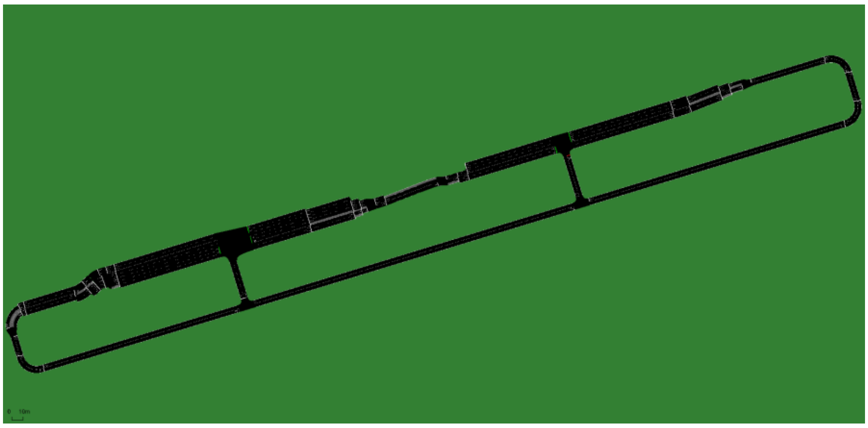

Figure 20: SUMO track included in the mobile traffic light used for the AGLOSA algorithm, showing the virtual map

In addition, several improvements of the SPaT and MAP senders have been implemented in this integration sprint, allowing the quick switching between the different underlying maps for the test purpose. Therefore, the road side system had to be restarted with different parameter sets, which was impossible before.

Figure 21: Mobile traffic light located on the DLR test track in Braunschweig (left) and in Edemissen (right), here adapted for the straight virtual road layout

5.1.1.3 Dynniq

Dynniq developed the necessary software for the RSU in Helmond in May 2018 for the communication test that was described in 5.1.1.1.1. In preparation, the messages were shared in raw binary and decoded JSON format between all partners to verify they were filled in correctly. The implementation details are described in detail in D5.1 [10] section 4.3, lane specific GLOSA. The main challenge was to define the MAP with a higher quality than was currently required in the state-of-the-art to make it suitable for automated driving and lane specific speed advice. This meant that the existing MAP configuration had to be replaced by a new more accurate one. In order to keep the existing system operational, the MAVEN messages were put on a different BTP port number in the Geonetworking stack. Thanks to the careful preparations, the test could be executed successfully at once.

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5.1.2 Event-based achievements

5.1.2.1 Event 12: UC7 longitudinally and laterally automated with emulated infra messages or mobile traffic light on test track

Integration Sprint		3
Date of achievement		May 2018
Importance		medium
Setting	Software	Dominion
	Test site	Straight road on Edemissen test track
	Vehicles	FASCarE
Goal		Show GLOSA behaviour, related to UC 7

To complete UC7, the DLR vehicle automation receives via the “V2X communication interface” module (see Figure 16) SPaT and MAP messages. The “Tactical Decision” module checks the received speed advices included in the SPaT message as shown in Figure 17 and matches the ego vehicle position to the relevant speed advice. This speed advice is forwarded to the trajectory planner as desired speed. The whole procedure has been shown already in D6.3 [3] at Event 8, but is repeated here for convenience, since the recordings in Edemissen with regard to speed adaptation are nearly similar to those recorded in that Event earlier:

Figure 22 shows the corresponding velocity profile of one test drive. At (a) the vehicle started to drive, accelerating to the desired speed. At (b) a speed limit is reached. At (c) a speed advice has been received resulting in an adaptation of the currently driven speed. This speed is reached at (d). After passing the traffic light, the test track is continued only for a few meters. Therefore, the speed needs to be reduced again (e) and the vehicle is coming to a full stop (f) at the end of the test track.

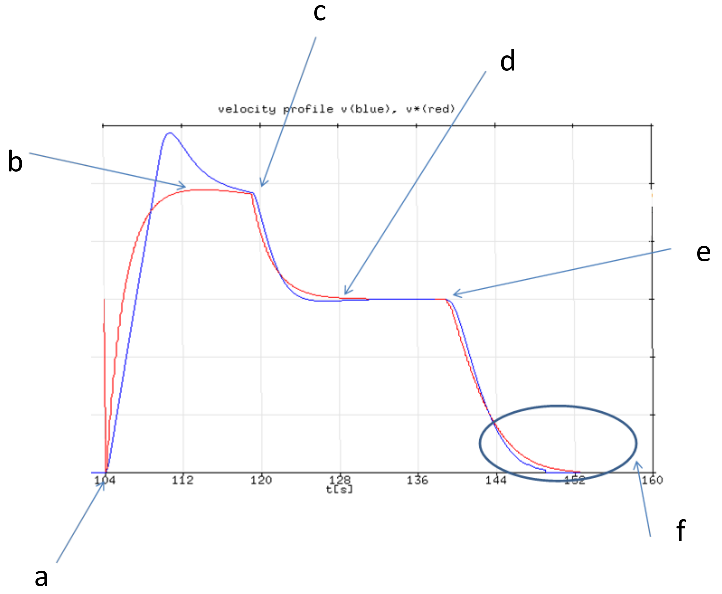

Figure 22: Velocity profile on while driving on the DLR grounds while receiving SPaT messages, planned velocity (blue) and actual velocity (red) of the vehicle

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The additional requirements of this event compared to Event 8 are mostly related to

- Higher driven speeds of max. 13.6 m/s
- Lateral control of the vehicle

The vehicle automation software was already able to cope with both requirements before, but the Event 8 test track (DLR grounds) does not allow lateral control and only speeds up to 8 m/s for security reasons (it is a parking area for DLR employees with a lot of pedestrians). Therefore, the most important aspects for this Event was the beginning of the operation of the Edemissen test track for MAVEN, the inclusion of virtual test tracks as stated before and the provision of the mobile traffic light.

5.2 Integration Sprint 4

Integration sprint 4 (M22-M24) was according to the DoA planned to lead to integration level 4 of the MAVEN project:

MS6.4, MAVEN extensions validated in field environment Vehicle sensor data, cooperative sensor data and necessary V2X communication will be integrated to the vehicle and roadside stations. The roadside algorithms will be extended to be capable of including presence of special category road users in their optimization and to consider multi-intersections in the platoon organization and negotiation. TRL 6.

The content of this milestone has been slightly adapted to cope with the defined use cases in D2.1 and the planned implementations. According to project decisions, the "special category road users" are only addressed in real world scenarios as being vulnerable road users (now included in UC 16). In addition, public transport vehicles are included in simulation only, esp. Event 14 in this sprint. Emergency vehicles are only included implicitly (see chapter 2.2.4) and are not part of the integration activities any more. More details about "special category road users" can be found in D4.4 [17] and simulation results are shown in the upcoming D7.2.
The validity of multi-intersection platoon organization and negotiation is addressed in simulation only, also in Event 14.

5.2.1 General achievements

5.2.1.1 HMETC

HMETC was involved in several activities related to communication and automated driving. Both aspects are described in the following.

5.2.1.1.1 Communication integration

In this integration sprint the V2X communication module SW has been extended to handle bidirectional UDP socket communications with the AD_SW modules for transmission and reception of cooperative sensing data. The following figure shows the interfacing with the AD_SW implemented at Hyundai and DLR vehicles for this purpose. As detailed in Deliverable D5.1 [10], over the interface IF4 (AD→V2X), the AD_SW continuously provides the V2X communication module with data relative to objects detected by the sensor fusion module, which must be included in transmitted Collective Perception Messages (CPM, see D5.1 [10]). In the other direction IF6 (V2X→AD) provides the AD_SW with the data relative to CPM received by other CAVs and

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cooperative intersections. This data contains descriptions of objects detected by the sensor fusion of those remote stations. These descriptions are then reused by the ego-vehicle's sensor fusion to improve its environmental awareness beyond the field of view of the ego-vehicle's sensors.

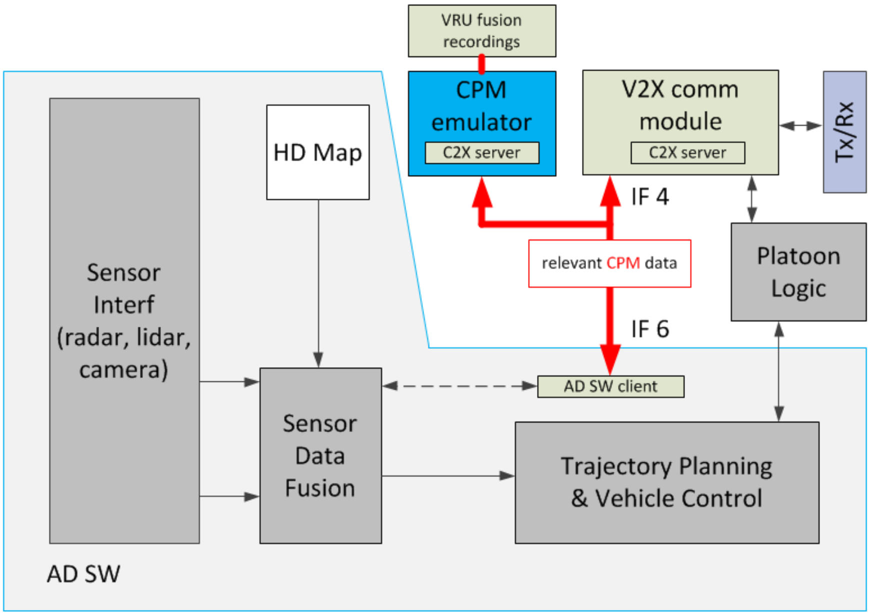

Figure 23: General AD Software modules and MAVEN V2X system integration scheme for cooperative sensing, including the HMETC emulation approach

To verify that the above mentioned integration between AD and V2X SW works properly, the same validation scheme as depicted in Figure 9 is used. The AD_SW client application running at the tester PC is used to populate CPM-relevant data structures and transmit them to the V2X module over UDP using the above mentioned IF4 interface. The transmitting V2X Module runs the V2X MAVEN application that extracts data from the structures and includes it in CPMs that are continuously broadcasted in the 5.9GHz band. The transmitted CPMs are received at a receiving V2X module running the MAVEN V2X application capable to decode CPMs and forward the extracted relevant data structures back to the AD client application on the tester PC via IF6. Using the tester PC, the logs of the transmitting as well as the receiving V2X modules are analysed to verify that they correspond to the data generated and processed at the AD Client application.
As Figure 23 shows, a V2X emulation approach for CPM has been realized too in order to emulate CPM receptions from other CAVs or cooperative intersections (Deliverable D5.2 [18]), which is necessary given that HMETC only has one automated vehicle equipped with sensors and supporting V2X capabilities. The V2X emulation module can be used here to record UDP data structures relative to ego-vehicle detections of real objects to be disseminated via V2X CPMs. In addition, the V2X emulation module can replay those UDP structure at the AD_SW as the ego-vehicle would get them upon receptions of V2X CPMs.

5.2.1.1.2 Automation integration

During integration sprint 4 the AD_SW has been extended to handle the capability to automatically adapt to GLOSA speed advices received by the infrastructure, and to implement automated reactions in response to V2V collective perception message receptions.
The successful integration of GLOSA adaptation capability is highlighted in the following section 5.2.2.3 by describing the achievements of event 15. A description of the logic to handle execution of such GLOSA adaptation requests is given in D3.3 [16]. This logic is implemented at the Decision Making Module (DMM) of the AD_SW. Similarly to the case of lane change advices, the execution of a speed adaptation request depends on environmental conditions like for example absence of slower vehicles in front when the GLOSA is requesting for increasing the ego-speed compared to the actual one. Hence, also in this sprint the AD_SW decision module logic has been

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extended to take into account presence of objects from the sensor fusion in combination with triggers coming via V2X GLOSA advices. In absence of GLOSA advices, the AD_SW continuously considers the V2X received current phase of the traffic light to safely prepare a stop by red or just keep the actual ego-speed by green (further details on the relationships between SPaT/MAP information and expected automated vehicle reactions are given in D5.1 [10]).
To verify in real-time that the AD logic is behaving as expected at every moment of a test run, the debugging HMI described in section 5.1.1.1.2 has been extended to show the current values of the variables considered for GLOSA adaptation (Figure 24).

Figure 24: Debugging HMI outputs for GLOSA lane change monitoring

As it can be seen in the example, the SPaT/MAP messages indicate that at the distance to the stop line where the ego-vehicle currently is (“distance to intersection: 87” which corresponds to “Current zone number: 0”) there is no speed advice (“GLOSA advised speed: 0”, “advised speed: 0”), and that the current signal status is red. As a consequence, the ego vehicle will accept the traffic light status by slowing down for stopping at the stop line once arrived there (“GLOSA status: Accepted”).
Another very important piece of integration happened in this sprint is the inclusion of functionalities to operate automated reactions to V2V CPM receptions (MAVEN use case 16). To handle such reactions, both the environmental perception and the guidance, navigation and control parts of the AD_SW needed to be extended. As described in Deliverable D3.2 [19], the environmental object perception’s modules for object fusion (OF) and tracking (OT) incorporated new logic for considering objects detected via receptions of CPM messages, fuse them with inputs from other sensors and track them over time. The following figures shows the OF/OT outputs when the HMETC vehicle receives emulated CPMs including information about a pedestrian dummy crossing the road in a section where it is not still detectable by the ego-vehicle on-board sensors

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(experiments done on the Griesheim test track). As it can be seen, the dummy's presence is correctly acknowledged by the OF/OT and represented in a visualization tool as a yellow dot.

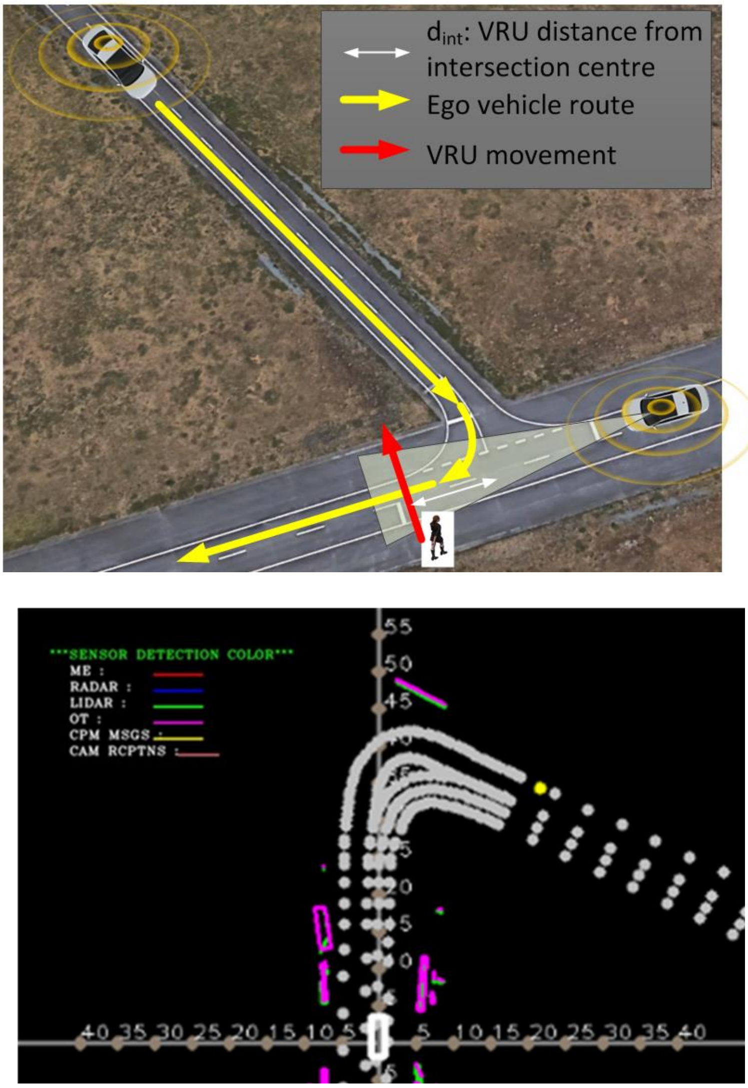

Figure 25: HMETC AD_SW OF/OT performance in presence of CPM receptions (the yellow dot represents the pedestrian detected via CPMs)

At the same time, the DMM incorporated new algorithms to consider presence of such CPM-detected obstacles. As explained in Deliverable 5.2 [18], such CPM objects are additional inputs for the DMM to perform its threat assessment. The DMM is informed about the presence of objects along its route much before they enter in the field of view of the on-board sensors, and can decide to slow down/change lane earlier according to the relative speed between the ego-vehicle and the obstacle. In the above figures, the ego vehicle is turning right and is going to collide with a crossing pedestrian. Nevertheless, thanks to the early consideration of CPM messages' content, the DMM decides to slow down to approach the curve in a safer way. Slowing down allows the ego vehicle to turn at the curve when the pedestrian has already crossed as demonstrated by the vehicle's speed profile shown in the next Figure 26. The ego vehicle slows down to 10kmph without braking or stopping because of the presence of the pedestrian, and then it can smoothly ramp up once the pedestrian has crossed the road.

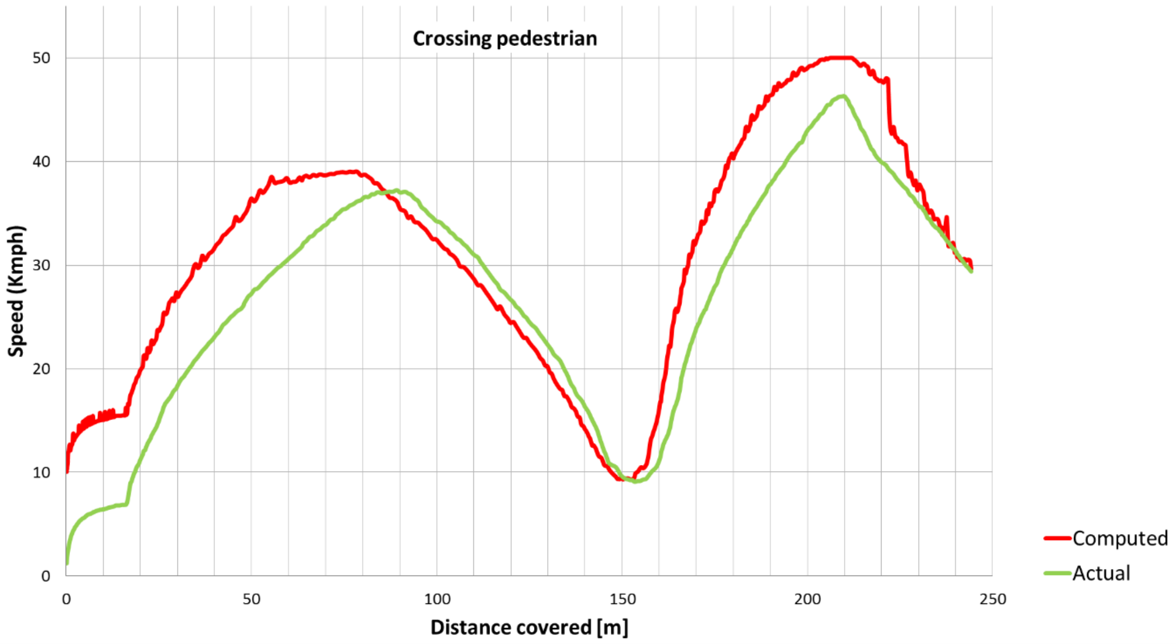

Figure 26: AD vehicle motion profile in case of no risk of collision with crossing pedestrian detected via CPM information consideration [18]

Further details on the execution of UC16 tests on the Griesheim test track can be found in Deliverable D5.2 [18], some pictures of the executed tests are in the following Figure 27.

Figure 27: HMETC UC 16 tests at the Griesheim test track

5.2.1.2 DLR

During integration sprint 4, the integration work has been continued:

5.2.1.2.1 Automation integration

Without being linked to specific events this integration sprint dealt mostly with debugging of the Platoon Logic library and with enhancements of the lateral control of the vehicle. In terms of the Platoon Logic minor errors have been found related to threading and interaction with the real hardware, and with platoons of more than two vehicles, which has not been tested before.
In terms of lateral control, the reception of Lane Advice Messages has been implemented, extending the much simpler approach followed in Event 7 (described in D6.3 [3]). For this purpose, the V2X-Communication Hardware “Cohda-Box” [20] in the vehicle is receiving the message and forwards it to a created Dominion application, which converts the message to a readable format including SI units. This advice is than forwarded to the vehicle automation software and respected by the tactical decision module (see Figure 16 earlier in this document).

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As each automated vehicle is responsible of its trajectory, the planner must analyse the vehicle surroundings when a lane change is advised. If all safety criteria are satisfied, the lane can be changed. In order to do this, the DLR trajectory planner - after receiving LAM messages - analyses the lane changing situation by looking at possible gaps at desired lane. Although the LAM also includes information about desired predecessor and successor vehicles (if this information is available), the vehicle may decide to use another gap. Therefore, a cost is assigned to each gap which is lowered by the indication from the infrastructure, and a lane change is performed in the gap with the lowest cost. Figure 28 illustrates the gap analysis by trajectory planner after receiving LAM.

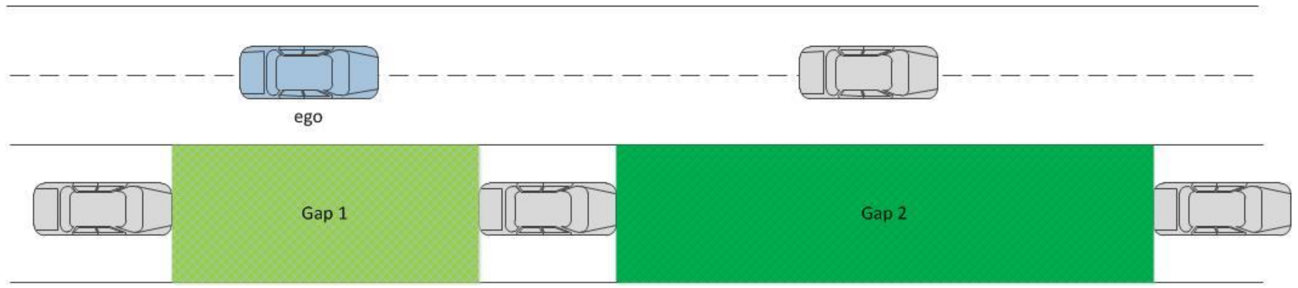

Figure 28: Lane change preparation: gap analysis. Gap 2 is currently preferred. This may change dynamically and lead to another preference.

The testing of this approach was done in Event 13 in simulation, Event 16 on test track (integration sprint 5) and Event 22 on public roads (integration sprint 6).

Another very important aspect of this integration sprint was that the new DLR research vehicle ViewCar2 went into service on test tracks in general. This step also required a lot of resources since the vehicle had to be brought into the same level of operation as the FASCarE, which was doing all DLR tests up to now. This work had to be concluded within only a few weeks as the ViewCar2 needed to be ready for use case testing directly at the beginning of integration sprint 5. As several components in this car are basically identical to the FASCarE, but included in a much newer version, it turned out that the vehicle itself is acting more stable and accurate than the FASCarE.

5.2.1.2.2 Infrastructure integration

The infrastructure was also addressing the sending of the Lane Advice Message in this integration sprint. Therefore, the AGLOSA component (see D4.4 [17]) running on the traffic light has been extended. As it comprises of a SUMO simulation running in the background, where all detected vehicles (via V2X or induction loops or any other source) are included and further simulated (see D4.4 [17] for details), the number of vehicles waiting in one lane can easily be taken directly from SUMO. If the automated vehicle is arriving on the lane with the longer queue (detected by received CAMs from that vehicle in the infrastructure), this information is used to generate a LAM for this vehicle which is directly been sent out. In this implementation, there is no acknowledgment from the vehicle included. If the vehicle is not changing its lane, the advice is repeated once per second. While there are several induction loops for detection of the vehicles available on Tostmannplatz, this is not the case for the Edemissen test track. Therefore, the behaviour has been reproduced on the test track by putting a single vehicle able to send CAM messages on one of the lanes. Results of this action can be seen in integration sprint 5 / Event 16 later on.

Besides the LAM component, the Tostmannplatz was in focus during this sprint. The hemispheric camera was activated and the physical and software links between the camera and the image server, as well as the link between the image server, the application unit and the road side unit on

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Tostmannplatz have been established. This also included the link to remotely control the different units and PCs directly from DLR Berlin and related to this the adaptation of the firewall rules.

Figure 29 shows the integration work on Tostmannplatz during this integration sprint, including the setup of the MAP message used later on in integration sprint 6 / Event 21.

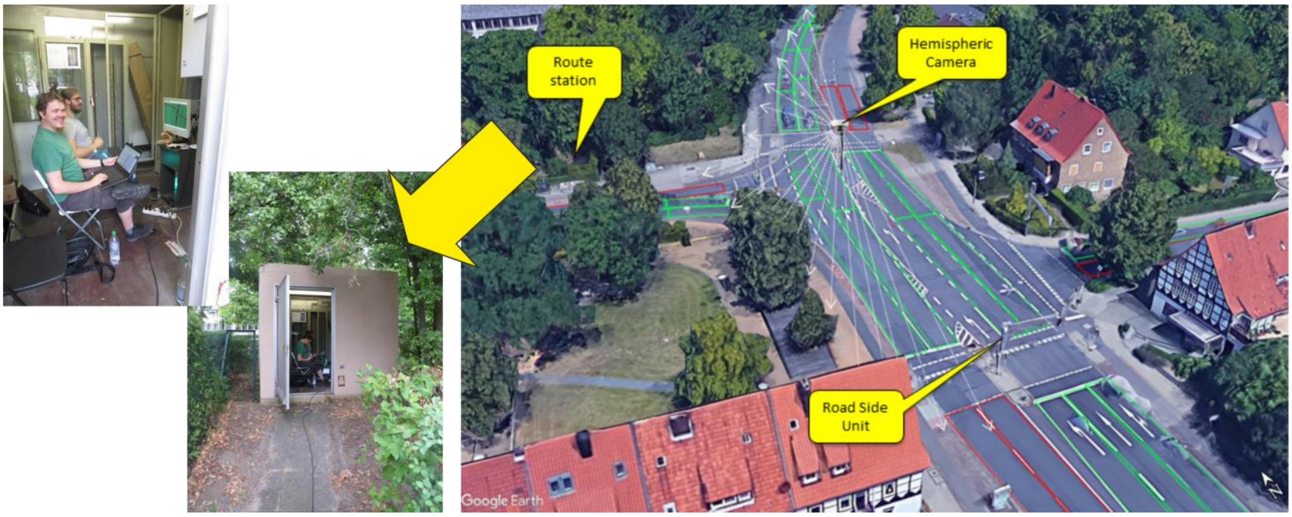

Figure 29: Integration work on Tostmannplatz, configuring the hemispheric camera and several servers in the route station. The Tostmannplatz image on the right also shows the ingressing and egressing lanes included in the MAP message

5.2.1.3 Dynniq

At the infrastructure in Helmond an important event took place where the WP4 traffic control algorithms were connected to the output of the new MAVEN message sets. This combines the use cases of speed advice, lane advice, queue estimation, signal optimization and negotiation in one integrated test event. The architecture setup is shown in Figure 30:

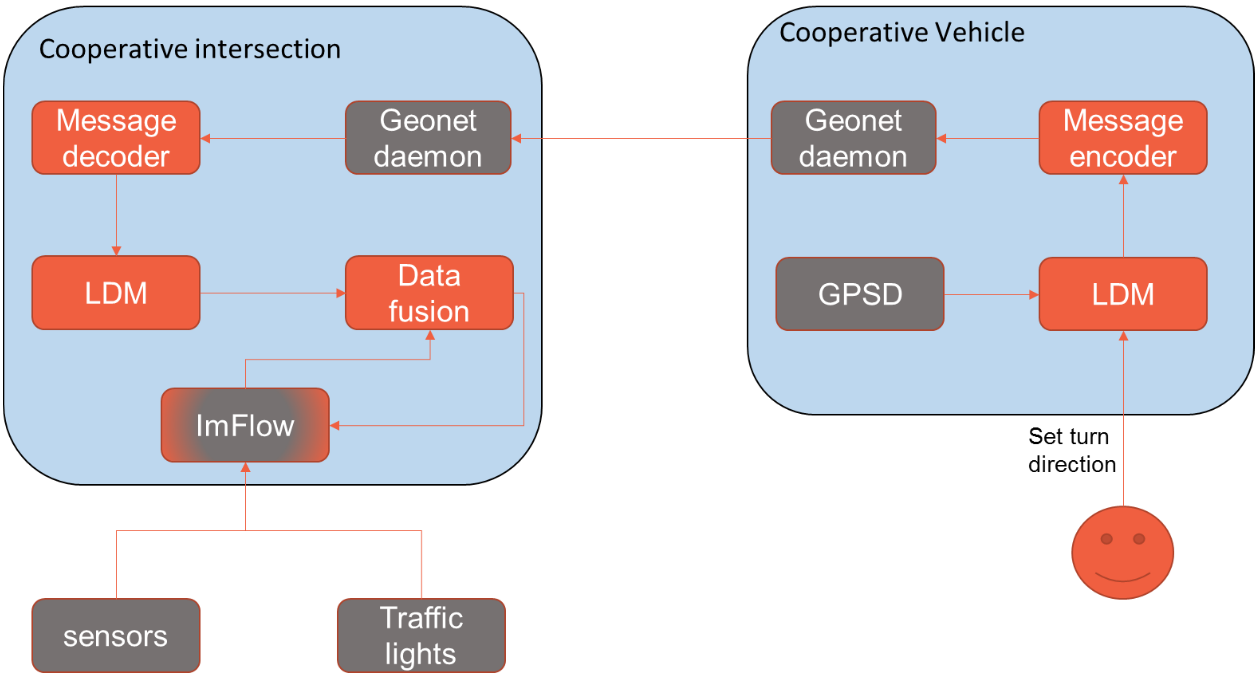

Figure 30: Trial setup for UC 7/8/10/14/15 tests in August 2018 in Helmond

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The orange elements are new for MAVEN while the grey elements already exist in the current product line of Dynniq. ImFlow [21] is a special case as it has the adaptations developed in WP4 included, while the core is still the same as on regular intersections. Since there was no automated vehicle present, a Dynniq vehicle emulated its behaviour, feeding its CAM messages by its real GPS position. The only manual action that had to be taken for this test was to set the turn direction at the intersection. Using that together with the GPS position and the received MAP and SPaT messages (not in the figure) from the RSU, the LDM could send all required inputs to the message encoder. This encoder was specifically developed for this test to support the MAVEN message extensions. Both the Dynniq On Board Unit (OBU) and RSU run a Geonet Daemon by default that supports exchanging raw binary messages at the application layer of the OSI model [22]. This was very useful for quick integration of new messages.

On the infrastructure side a decoder was required to interpret the MAVEN message extensions, the extended set of parameters were added to the LDM as well and fused with traffic control and sensor data (interfaced via the traffic controller). This enabled the traffic controller to take the fused data for improved queue modelling (UC10) and use the extra parameters for negotiation (UC15). Together with plan stabilization developed in WP4, it completed the full signal optimization use case (UC14), resulting in enhanced GLOSA (UC7) and lane advice (UC8) performance.

5.2.2 Event-based achievements

5.2.2.1 Event 13: UC1-8 in simulation

Integration Sprint		4
Date of achievement		June 2018
Importance		medium
Setting	Software	Dominion
	Test site	Virtual straight road as used on Edemissen test track, and others
	Vehicles	Simulated
Goal		Platooning use cases in combination with GLOSA and lane advice shown in simulation

In terms of use cases, the functioning of UC1 (Platoon initialisation), UC3 (Travelling in a platoon), UC6 (Platoon termination), UC7 (Speed change advisory) and UC8 (Lane change advisory) have already been shown in Event 7 during integration sprint 2.
UC8 has been extended in integration sprint 4 as described before. Figure 31 illustrates the new lane change behaviour implemented in DLR's Dominion framework simulation. (I) shows that the automated vehicle (right lane) receives a LAM messages. It analyses the lane change situation on the left lane (II) and selects the second gap. Therefore, it increases its velocity as an action to be taken in order to change lane into the selected gap and then starts to perform lane change manoeuvre (III). At (IV) the lane is changed and the vehicle continues driving.

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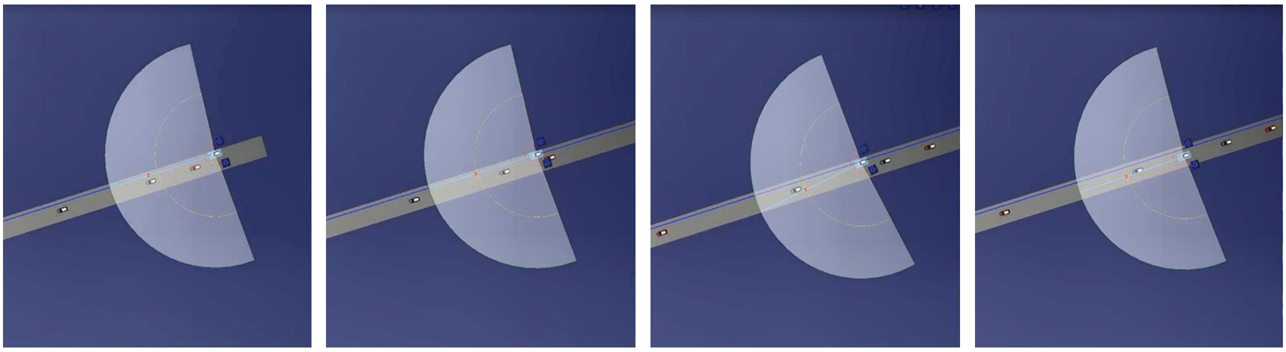

I II III IV

Figure 31: Lane change behaviour in simulation

In addition to this enhancement of UC8, the focus of this Event was on the one hand to get closer to the real setup by introducing hardware-in-the-loop simulations and on the other to include a third vehicle in the simulation tests. Esp. the second aspect allowed to also address UC2 (Platoon joining), UC4 (Leaving a platoon), which both are only possible with three automated MAVEN vehicles. In addition, UC5 (platoon break-up) was addressed as a more complex use case taking into account also the traffic on adjacent lanes (see D3.1 [7] for details).

In order to simulate platooning use-cases, the vehicle automation (including all aspects from sensor fusion to tactical and trajectory planning) has been instantiated in two or even three vehicle simulations in the same Dominion framework, following the MoSAIC approach [23]. If the simulation included only two automated vehicles the communication between these two has been implemented by using two real Cohda boxes, one per vehicle, as hardware-in-the-loop simulation. Figure 32 illustrates the simulation setup with two automated vehicles driving on the virtual map of the Griesheim test track, currently involved in UC 5, platoon break-up. In this case, a Cohda Road Side Unit (RSU, A) was used for the platoon leader and an On Board Unit (OBU, B) was used for the follower. Both modules are acting in a similar way, so choosing RSUs and OBUs was only a matter of availability. As it is shown, all automation modules are running in Dominion including a 3D simulation of the scenario on a single laptop computer.

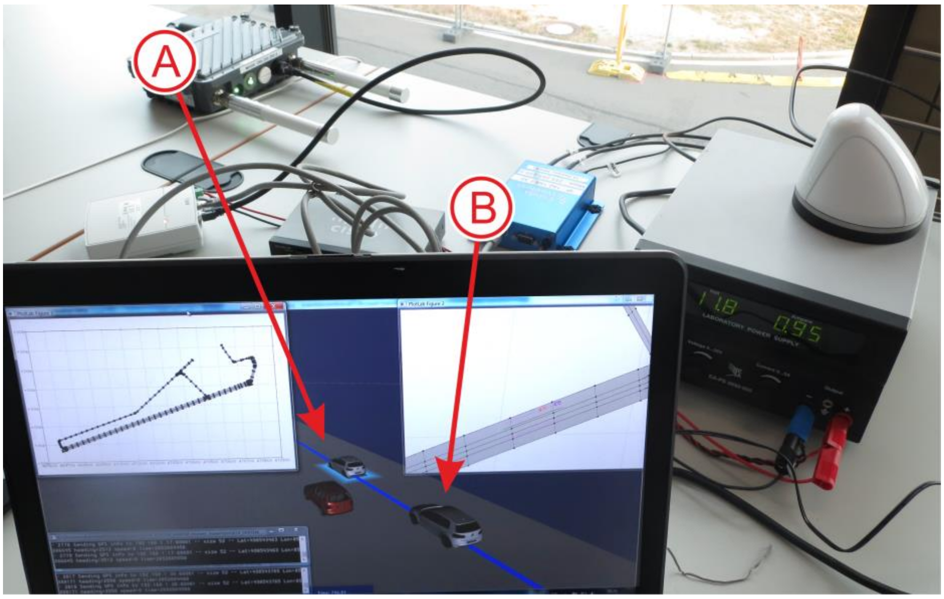

Figure 32: Hardware-in-the-loop simulation with two Cohda-Boxes, allowing platooning on the virtual Griesheim test track with real V2X messages

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In case there was a third vehicle, the communication is handled directly without any hardware in the loop and therefore is assumed to be optimal. The simple reason for this is that only two Cohda boxes were available during the tests. Still, all simulations ran on a single laptop computer.

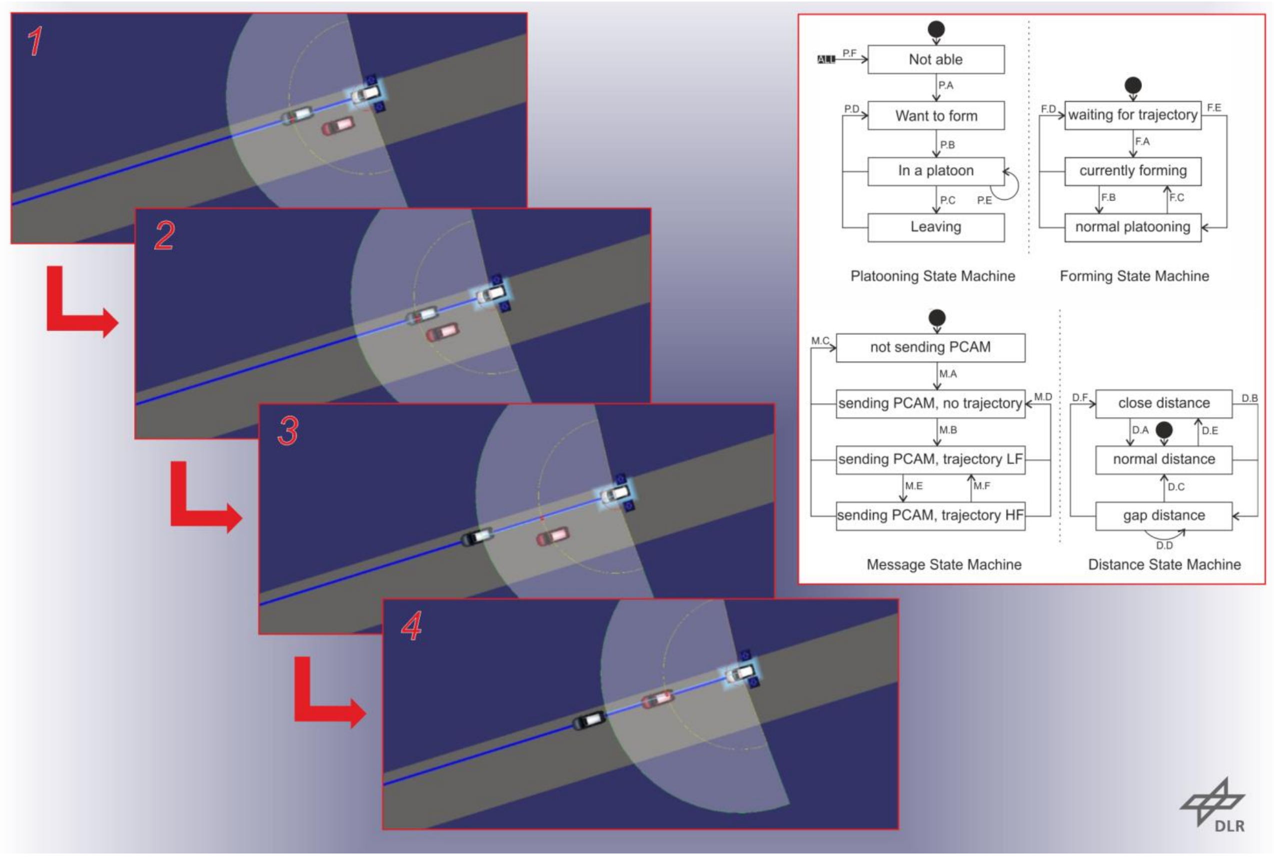

Figure 33: UC 5, platoon break-up, simulated in Dominion. The right side of the image shows the four state machines implemented in the platoon logic, see D3.1 **[7]**

As mentioned in D3.1 [7], platooning vehicles must interact and consider the normal vehicles. As an example a platoon can be broken up if a non-cooperative vehicle wants to perform a lane change where a platoon is driving. Figure 33 illustrates a platoon break-up use case in which on the right lane a platoon of two vehicles is driving and a manually driven vehicle (red vehicle, controlled in the simulation by the vehicle simulation software and the scenario control) is driving on the left lane (1), In (2), the red vehicle is indicating that it wants to change lane by enabling its turn indicator. Since this vehicle is not automated, the platoon needs to make room for this vehicle. Therefore, the turn indicator is detected by the following vehicle in the platoon in its sensor data fusion, which is leading to a transition D.B in the Distance State Machine (in the same figure on the right, taken from D3.1) from “close distance” to “gap distance”. As result, the trajectory planner of the following vehicle opens the gap (3). Whenever the manually driven vehicle agrees on the gap size, it changes lane. As consequence, the platoon is interrupted, and both formerly platooning vehicles change its platooning state from “in a platoon” to “want to form”, by triggering transition P.D. This also includes a change of the Distance State Machine, which now is in state “normal distance” since no platooning vehicle is driving directly ahead. Now, all three vehicles are driving on the right lane (4). The formerly platooning vehicles remain in the state “want to form”, waiting for a new opportunity to form a platoon,

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5.2.2.2 Event 14: UC7/8/10/14/15 simulated on public roads

Integration Sprint		4
Date of achievement		22nd of August 2018
Importance		High
Setting	Software	ImFlow, RSU and OBU software kit
	Test site	Helmond
	Vehicles	Dynniq vehicle
Goal		Show that all traffic efficiency use cases that are applicable to intersections without green wave are properly integrated.

All tests were successful and a short vlog (output of a junction controller) was recorded demonstrating the results. It can be found on the MAVEN website. It is basically a real-world implementation of the results previously shown in D4.2 [24], the demonstrator of WP4. Figure 34 shows a screenshot of the video, demonstrating the queue estimation. The red circle indicates that the MAVEN vehicle already has its turn direction known before reaching a loop detector at the stop line. Having the "#" showing instead of "1", "7" and "2" spread over the different turn directions. Even though no extra priority was granted to the vehicle, positive effects could be observed at the controller in three test runs that could be attributed to the extra information provided by the MAVEN vehicle. More details on the results will be reported in D7.2.

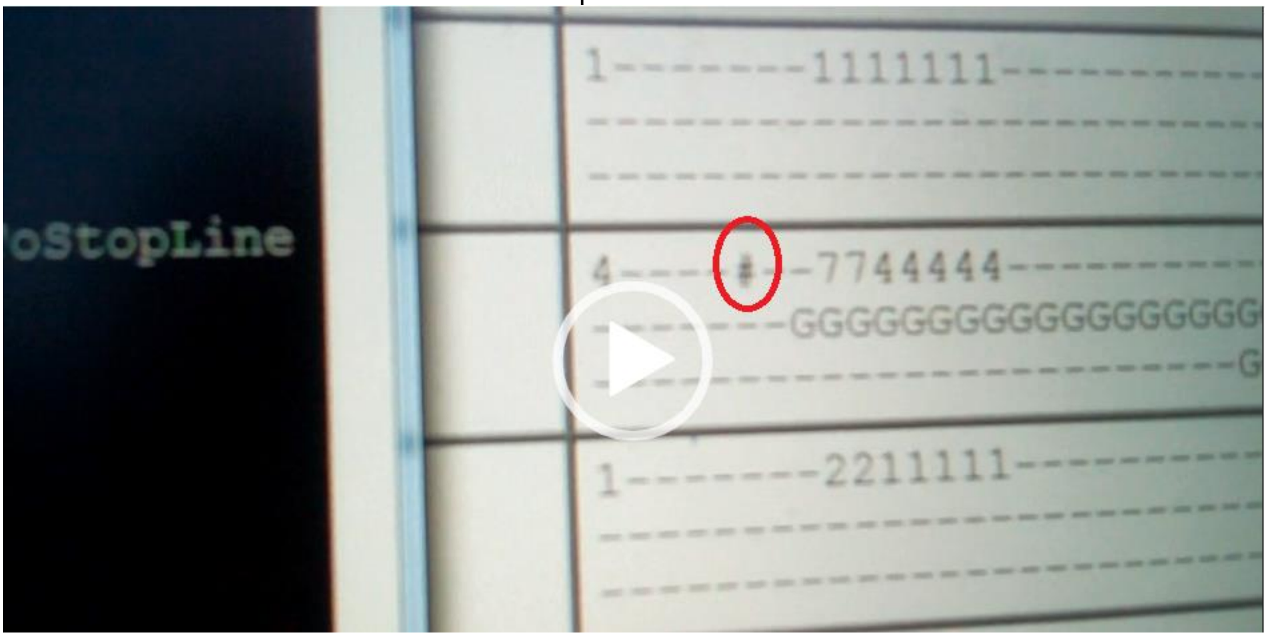

Figure 34: The MAVEN vehicle turn information known before the stop line

5.2.2.3 Event 15: UC7/8/15 on test track

Integration Sprint		4
Date of achievement		September 2018
Importance		high
Setting	Software	Hyundai-AD
	Test site	Griesheim test track
	Vehicles	Ioniq
Goal		Verify the functionality of GLOSA, lane advice and I2V negotiation at the

	Hyundai vehicle prototype on test track. These tests are necessary for training the AD_SW planning and control modules to adapt the ego speed to the GLOSA dynamically suggested by the traffic light controllers running at the Tostmannplatz and Helmond signalized intersections. Moreover, combination of speed adaptation with concurrent adaptation to lane change advices in presence of surrounding traffic shall be verified to emulate as much as possible traffic conditions to be experienced in real-road tests. Finally, provision of correct V2X data for I2V negotiation shall be correctly executed in order to prepare meaningful I2V interactions with real traffic lights controllers available at the MAVEN test sites

This test event was executed at the Griesheim proving ground by reproducing on the track the layout of one approach of the MAVEN test intersection in Helmond. As indicated in Figure 35, a virtual stop line with two parallel ingressing lanes is considered. When driving along these ingressing lanes, the V2X emulation module running on the vehicle AD_SW replays the GLOSA data structures recorded at the Helmond test site (see section 5.1.1.1.1).

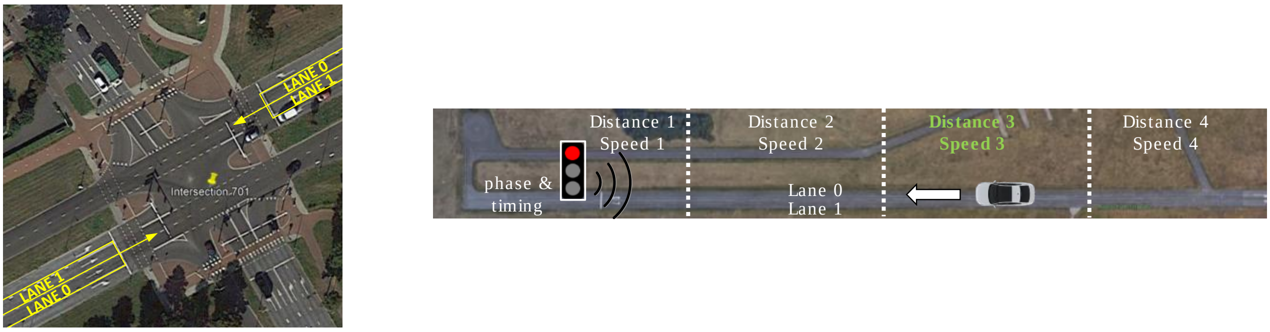

Figure 35: MAVEN test intersection at Helmond (left) and its reproduction at the Griesheim test track (right)

These recordings represent the dynamic evolution of the traffic light phases and speed advices over a given time window. Speed advices are provided at different distances that are dynamically moving towards the intersection as the current traffic light signal phases expire. This implies that the AD_SW needs to understand at what distance from the stop line it currently is to try to adapt to the right speed. The speed adaptation of the automation system has been successfully verified for different combinations of starting vehicle distances from the stop line and GLOSA recordings. Figure 36 shows one example of driving automated on the Griesheim track while replaying the above mentioned Helmond GLOSA recordings. As we can see, the automated car‘s speed adapts dynamically to the GLOSA speed while approaching the stop line (placed at approximately 800m from the starting point). Please notice that a GLOSA speed equal to zero means that no speed advice is present in the recordings at that moment. By following the current value of the GLOSA (35 kph after driving 500m), the vehicle drives at a lower speed than the maximum allowed (50 kph). Then the vehicle ramps up again when receiving a GLOSA of 50kph. This procedure allows crossing the stop line without stopping after the green phase has started.

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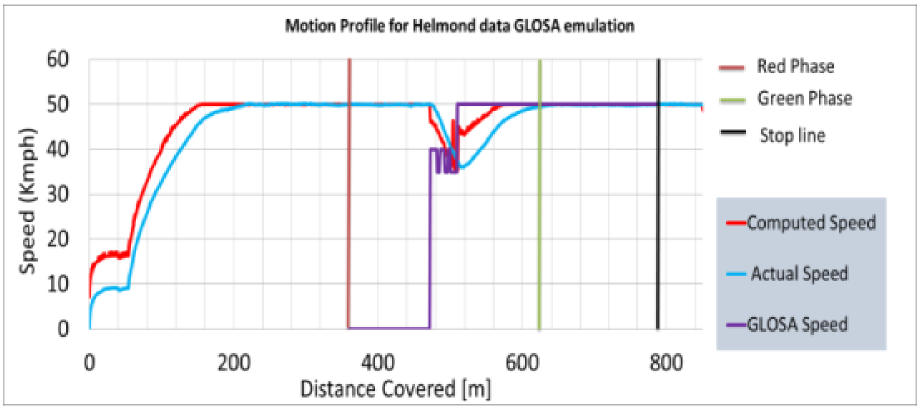

Figure 36: speed adaptation to Helmond GLOSA at the Griesheim test track

To challenge the reaction of the AD_SW under varying conditions, the same tests have been run for different recorded data sets, and in presence of other cars jeopardizing the possibility to adapt to the GLOSA speed. In all these scenarios, the capability of the car to automatically and safely stop at the stop line when the traffic light phase is red has been verified.
As a next step, the combination of GLOSA and lane change advices has been verified. As explained in section 5.1.1.1.2, lane change advices are automatically executed only in presence of open gaps to surrounding obstacles vehicles. To verify the simultaneous functionality of the GLOSA and lane change adaptations, the debugging HMI described in Section 5.2.1.1.2 is used. Thanks to this HMI, the co-driver is informed at any moment about the reason for advice adaptation or rejection (e.g. due to presence of surrounding traffic). The next figure shows a snapshot of a video shown by HMETC at the Berlin Consortium meeting, and represents the execution of a simultaneous GLOSA and lane change adaptation test. In the video, it is possible to observe the automated vehicle reactions to the inputs of the emulated GLOSA and Lane change advices as well as the status of the gaps with surrounding vehicles. As the gaps are open, the lane change is executed while the vehicle is considering GLOSA data. As for the GLOSA tests, also in this case lane change adaptations have been tested in many different configuration of surrounding traffic and GLOSA inputs to challenge the system to be ready for real-road tests.

Figure 37: Test execution of automated adaptation to GLOSA and lane change advices (UC7 and UC8) at the HMETC car

Finally, during these tests, it was important to verify that the AD_SW correctly provides meaningful inputs to the V2X communication module for transmission of V2X information needed for

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negotiation with the infrastructure. The successful verification of this functionality can be observed in the next figure, which depicts logging of the V2X messages transmitted by the V2X communication module installed on the vehicle. As it can be seen, the mavenAutomatedVehicleContainer of the transmitted CAM messages contains the HMETC car's RouteAtIntersection information reflecting the planned route for crossing the MAVEN test intersection in Helmond as well as the status of compliance to the received speed advice. The data RouteAtIntersection refers to the Helmond test intersection 701 in its ingressing, egressing lanes and signal groups, which is meaningful and needed by the traffic light controller for the execution of its signal timing and phasing optimization algorithms.

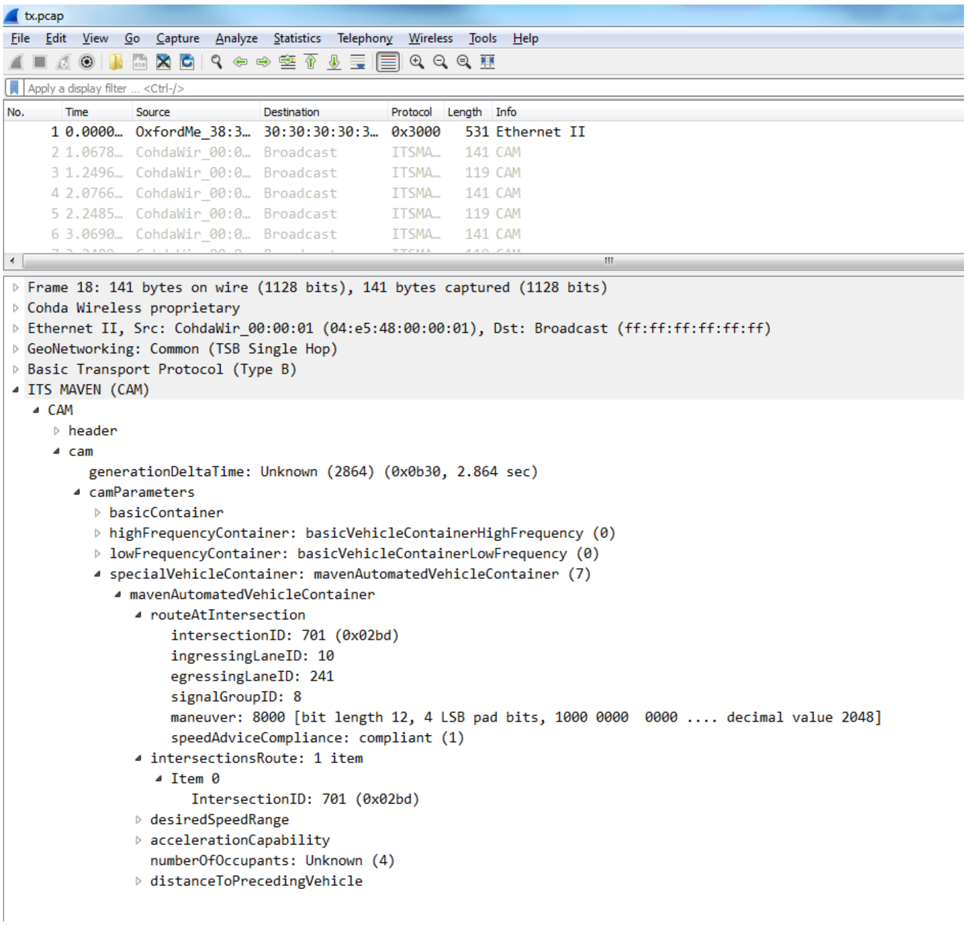

Figure 38: verification of V2X functionality for I2V negotiation (UC15) at the HMETC car

5.3 Integration Sprint 5

Integration sprint 5 (M25-M27) was according to the DoA planned to lead to integration level 5 of the MAVEN project:

MS6.5 MAVEN technology demonstration in field environment Multiple vehicles will be involved for the integration of platoon organisation algorithms. These will simultaneously interact with the roadside algorithms. TRL 6/7.

This milestone has been reached with both DLR and HMETC vehicles since several tests on the test tracks in Griesheim and Edemissen showed already or show in this sprint the successful platoon interaction in UC1/3/6 and the interaction with the road side in UC7/8/15.

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5.3.1 General achievements

The most important general achievement of this integration sprint is that this has been the first time where HMETC and DLR vehicles met on the test track. By doing this, the correctness of the implementations in both company's cars could be tested in terms of compliancy to the defined message set and proposed vehicle reactions.

5.3.1.1 HMETC

In this integration sprint the HMETC AD car prototype was tested for the first time in cooperation with the DLR vehicles to execute the platooning tests on the Griesheim test track (Event 18). In preparation for these tests, the HMETC vehicle AD_SW was extended to let it's OF/OT modules consider remote vehicles' detections as results of V2X CAM messages from other CAVs. In addition, the HMETC AD_SW incorporated the platoon logic (PL) developed and provided by DLR according to the specifications of deliverable D3.1 [7] and the interfacing scheme of D5.1 [10]. Figure 8in section 5.1.1.1.1 can be used to describe the integration architecture realized for this purpose. The UDP data structures relative to V2X CAM receptions from remote CAVs are received by the OF/OT modules of the sensor fusion block over interface IF1. On the contrary, the DLR platoon Logic block is integrated in the ROS-based HMETC AD_SW as an additional library, where the interfaces IF2 and IF5 are used to exchange data with the interfaced modules as parameters of predefined set/get functions. In particular, IF2 is used by the trajectory planning and vehicle control module to provide the PL with the necessary ego-vehicle status, dynamic as well as manoeuvre and trajectory planning information necessary for letting the PL populate transmitted V2X platoon messages (CAMs on SCHx). On the other direction, IF2 is used by the trajectory planning module to get from PL the remote vehicles' dynamics and planning information received via V2X, which is needed to drive as a platoon follower. Through IF5, the sensor fusion module continuously informs the PL about obstacles detected in the surrounding, and whether those obstacles are results of V2X receptions or simply detections made by on-board sensors. This information is crossed by the PL with the information received via V2X over interface IF3 to perform platoon management decision like forming or breaking-up a platoon. As an example, let us assume that the PL receives over IF5 information about two following vehicles A and B. B is a non-cooperative vehicle directly after the ego-vehicle and hence detected via on-board sensors only. A is a cooperative automated vehicle further behind and detected via V2X CAM receptions. In this scenario, PL receives via IF3 information about the presence of vehicle A (V2X reception). With this information available, the platoon logic will not form a platoon with vehicle A because of the perceived presence of the "obstacle" non-cooperative vehicle B in between. The results of the verification of the DLR platoon logic integration on the HMETC vehicle are described in section 5.3.2.3.
In this integration sprint, HMETC also performed tests on the Griesheim test track training the AD_SW planning and control modules to adapt the ego speed to the one dynamically suggested by the AGLOSA traffic light controller running at the Tostmannplatz signalized intersection in Braunschweig. Similarly as done for Helmond, this was in preparation to the real road tests of the next integration sprint on the Braunschweig test site. For this purpose, a preliminary task was the collection/recording of traffic light's phase/timing and speed information transmitted by the Tostmannplatz RSU via V2X SPaT/MAP messages. Figure 39shows a picture of the Hyundai car during these recording sessions.

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Figure 39: Recording of SPaT/MAP messages on the Braunschweig Tostmannplatz test site

The speed adaptation of the automation system has been successfully verified on the Griesheim test track, where the layout of the MAVEN Tostmannplatz test intersection is replicated. As indicated in Figure 40, differently from the Helmond test intersection, in the Tostmannplatz intersection two consecutive stop lines and traffic lights per approach must be considered. On each approach, two lanes can be driven. In the figure, it can be seen how this topology has been reflected in the Griesheim track, where two virtual stop lines are considered for speed adaptation experiments.

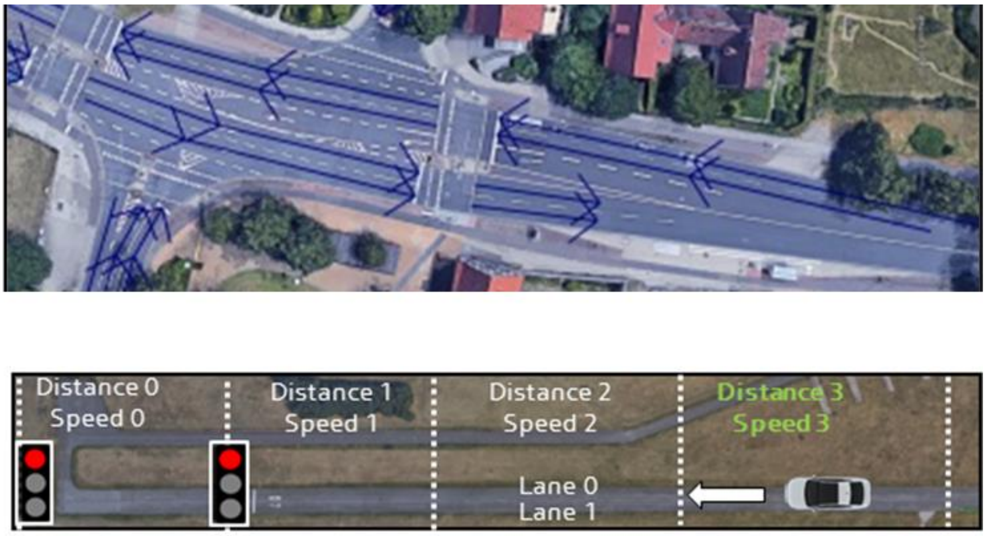

Figure 40: MAVEN test intersection at Braunschweig (top), and its reproduction at the Griesheim test track (bottom)

Also in this case, the speed adaptation experiments have been performed for different combinations of initial vehicle distances from the stop line and by replying different GLOSA recordings in the V2X emulation module. Figure 41 shows the results of one of these experiments. As we can see, the automated car‘s speed adapts dynamically to the GLOSA speed while approaching the first stop line (placed at approximately 800m driven distance from the starting point). Please notice that the GLOSA speed equal to zero means that no speed advice is present in the recordings at that moment. By following the current value of the GLOSA, the vehicle drives at a lower speed than the maximum allowed (50 kph) which allows crossing the first stop line without stopping after the green phase has started.

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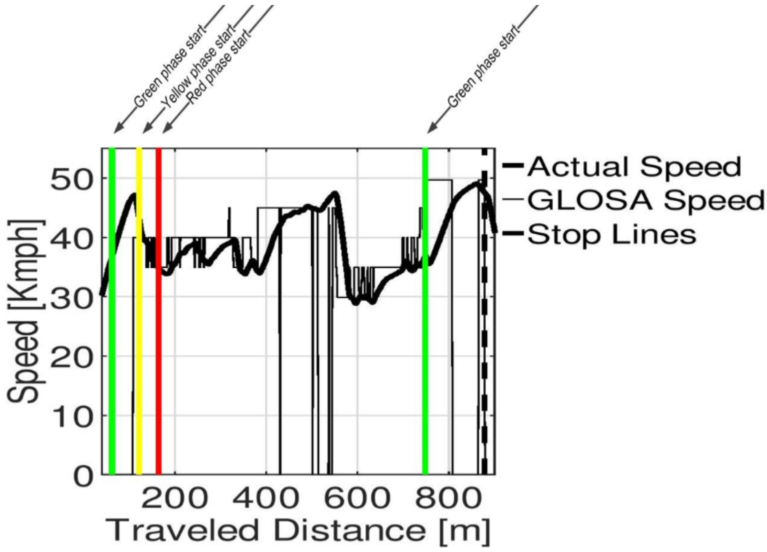

Figure 41: Speed adaptation to Tostmannplatz GLOSA at the Griesheim test track

5.3.1.2 DLR

During integration sprint 5, the integration work has been continued:

5.3.1.2.1 Automation integration

At this integration sprint special focus was taken on the upcoming integrations on the test track and also for being able to cope with the public road tests of integration sprint 6 later on. As the software modules of the vehicle automation itself were already in a quite good shape, this mostly meant that a lot of effort was spent in the sensor data fusion and robustness of the overall system.
At the sensor data fusion, the required fusion with object data received not from the vehicle internal sensors but via V2X was in focus. Figure 42 shows the resulting visualisation of detected objects from the different sources, here LIDAR and CAM reception. In addition, further work has been done in integrating CPM related object data which is going to be used later on in integration sprint 6.

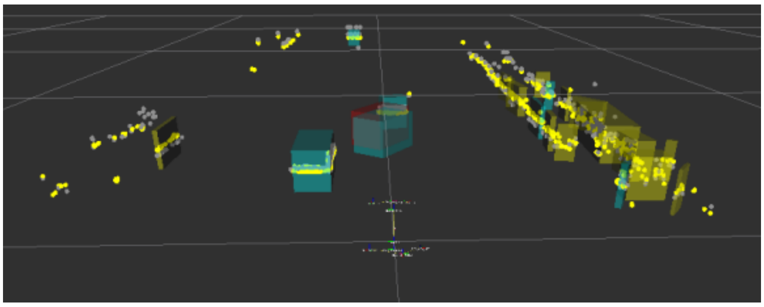

Figure 42: Sensor data fusion in the DLR automated vehicles, the green boxes are vehicles detected by LIDAR, the red box is the not yet fused object received via V2X (by CAM in this case)

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5.3.2 Event-based achievements

5.3.2.1 Event 16 UC1/3/6/8/9 with two DLR cars on test track

Integration Sprint		5
Date of achievement		September 2018
Importance		High
Setting	Software	Dominion
	Test site	Edemissen
	Vehicles	FASCarE
Goal		Platooning, lane advice and emergency handling working on test track.

For DLR, this event was one of the most important steps forward, as it was the first time were FASCarE and ViewCar2 were tested together on the Edemissen test track.
First of all, the combination of UC7 and UC8 was tested, as shown in **Figure 43**. In (A), the ViewCar2 is standing at the red traffic light on the right lane. It is constantly transmitting CAMs leading to the corresponding placement of the vehicle on the right lane of the AGLOSA algorithm. The FASCarE is also driving on the right lane, but still in a given distance. Besides sending out GLOSA advices via the RSU, the AGLOSA algorithm detects that the FASCarE should better drive on the left lane, as the queue there is shorter. Therefore, a LAM is sent out addressed to the FASCarE. In (B) the FASCarE is already adapting to the GLOSA advices while also checking the left lane as described earlier, before finally changing the lane (C). Thanks to the GLOSA advices, the FASCarE reaches the traffic light shortly after it switches to green, so it can pass the intersection without coming to a stop behind the now also accelerating ViewCar2.

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Figure 43: Combined UC7 and UC8 use case, showing a lane advice coupled with GLOSA functionality on the test track

Besides the lane change, also the platooning has been tested with both cars in combination with the GLOSA advices. As shown in Figure 44, the vehicles were driving in a platoon on their way to the traffic light. Both cars were receiving the GLOSA advices. Since the AGLOSA algorithm on the traffic light also receives the platoon information, the duration of the phase is adapted to allow the platoon to pass as a unit. Therefore, the GLOSA advice does not lead to a splitting of the platoon, since the advice is not in conflict with the platoon behaviour of the vehicles. Whenever the GLOSA advice is in conflict, the platoon members individually decide on splitting up. Therefore, the GLOSA advice has priority over the platooning, as crossing the traffic light not at green is not an option for the automated vehicle.

Since driving in a platoon (UC3) also includes platoon initialisation (UC1) and platoon termination (UC6) when only two vehicles are present, those use cases could be tested in the very same test runs.

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Figure 44: Platooning combined with GLOSA advices

In addition, also emergency situations (UC9) were tested. As described in the beginning of this document (section 2.2.4), UC9 is mostly focussing on correct behaviour of platoon members in case of a sudden event. In our tests, those events have had two different origins. First of all, detected objects between the platoon leading FASCarE and the following ViewCar2 directly lead to braking of the ViewCar2 and platoon termination. As stated in D3.1 [7], the platooning is always stopped whenever there is any object between the vehicle and its predecessor. In case of the test runs, this effect could be seen several times at the very beginning of the integration event, when the ViewCar2 was detecting false positives several times.

The second kind of sudden event was the induced malfunction of an automated driving component. In our tests, we disabled the communication unit while driving, resulting in the loss of messages and esp. loss of the reception of platoon related messages from the platoon leader. Without such information, the platoon is instantly terminated and the distance to the vehicle ahead is enlarged.

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5.3.2.2 Event 17: Platoon Logic integration on HMETC car

Integration Sprint		5
Date of achievement		September 2018
Importance		high
Setting	Software	Hyundai-AD_SW + DLR platoon logic
	Test site	Griesheim test track
	Vehicles	Ioniq
Goal		Verify that the DLR platoon logic is correctly integrated in the overall HMETC AD_SW. These tests are an essential preliminary step for the execution of cooperative platooning tests involving multiple CAVs, given that only with a fully functional platoon logic integration at both vehicles allows this capability.

The DLR platoon logic has been integrated in the HMETC AD_SW at subsequent steps in the period June-August 2018 as received by DLR at subsequent development iterations. As a consequence, these tests have been prepared in the ROS-based HMETC AD_SW simulation environment and finally verified at the Griesheim test track during the Event 18, right after the final version of the platoon logic was delivered. The tests for verifying the correctness of the platoon logic integration are performed by letting the HMETC AD_SW modules call the platoon logic functions for setting and getting reference data for platoon state machine decisions' implementation. As this verification is strictly related to the execution of Platooning test cases, the outcomes are described in Section 5.3.2.3.

5.3.2.3 Event 18: UC1/3/6 with two cars (DLR and HMETC) on test track

Integration Sprint		5
Date of achievement		September 2018
Importance		high
Setting	Software	Dominion + Hyundai-AD_SW + DLR platoon logic
	Test site	Griesheim
	Vehicles	Ioniq, ViewCar2
Goal		Verify the functionality of basic platooning use cases ("initialization", "travelling", and "termination") involving two vehicle prototypes from different partners. Both prototypes include AD_SW extensions for platoon logic and V2X integration, hence this is the first test verifying cooperation between two complete MAVEN CAVs subsystems. The whole end-to-end data generation and communication chain used for platooning algorithms and involving the AD_SW, platoon logic, and V2X communication module at two test vehicles is intended to be verified.

During the tests, the vehicles were initially static or driving manually along a predefined route between points (A) and (B) shown in Figure 45 below.

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Figure 45: Griesheim test track with route for initial platooning tests

The DLR vehicle ViewCar2 is behind the Hyundai one over the stretch A to B. As depicted in Figure 46, at each vehicle, the AD_SW is configured to generate the same planned manoeuvre/route information and transmit it over the UDP IF1 interface for inclusion in the V2X CAMs (both vehicles are heading towards a virtual intersection at point B). The same manoeuvre/route information is set to the platoon logic using interface IF2. Also, at each vehicle the AD_SW continuously generates position and dynamics (speed, acceleration, etc.) that are passed through IF1 for V2X CAM transmission and through IF2 for platoon logic setting. Finally, the AD_SW sets the platoon logic with information about vehicles currently detected at the sensor fusion via IF5. Moreover, the platooning logic running at both vehicles is configured to indicate the ability for platooning over the UDP IF3 interface. With this configuration, the objective of the performed tests is to verify an end-to-end communication as follows: the data generated at the AD_SW modules of the transmitting vehicle is correctly received at AD_SW modules of the receiving one (both from the DLR car to the HMETC one and vice-versa). Moreover, when the conditions for platoon initialization are met (in brief, both vehicles detect via V2V to have the same route, with no other vehicle in between), the platoon logic module shall start forwarding over IF3 the vehicle planned trajectory set by the AD_SW via IF2. The IF3 data is expected to be transmitted via V2V and received at the platoon logic of the receiving car.

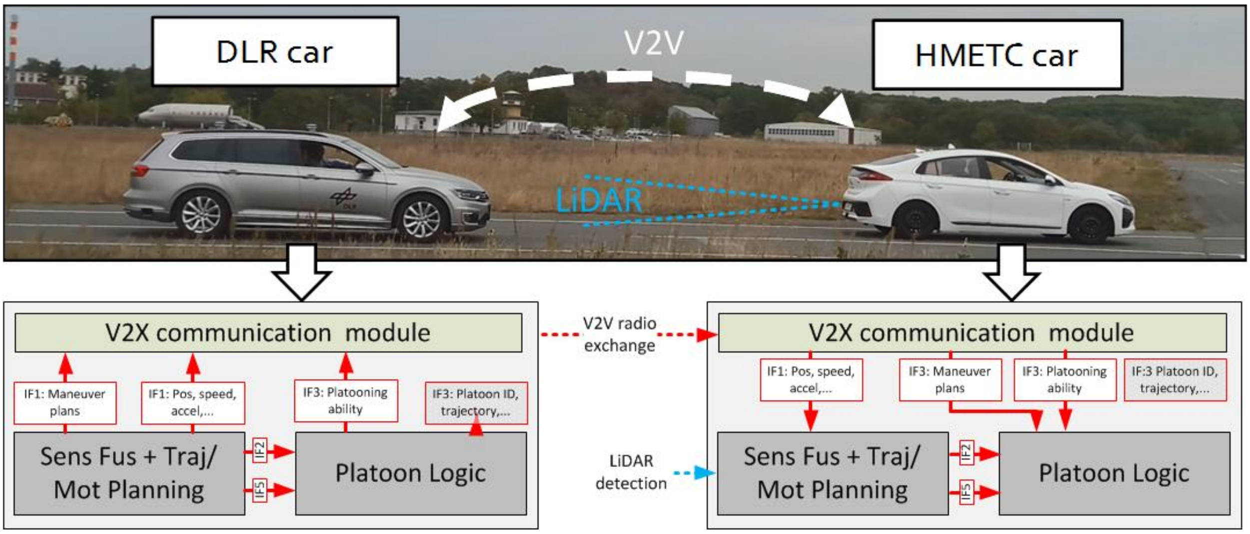

Figure 46: Schematic representation of the end-to-end communication for initial platooning tests on the Griesheim test track

On this basis, the results of these first platooning tests are summarized in the following table:

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	Description	Result
Platooning	Maneuver plans info V2V exchanged	✓
	Received maneuver plans reused in platoon logic module → other car gets considered for platoon forming	✓
	Platooning ability info V2V exchanged	✓
	Received info reused in platoon logic module →other car considered able to form platoon	✓
	Platoon info (ID, trajectory to follow, etc.) V2V exchanged	✗
	Received info reused in platoon logic → other car gets considered for platoon driving	✗
Sensor fusion	Position, speed, accelaration, heading V2V exchanged	✓
	Received info reused in ego-vehicle sensor fusion → other car gets detected	✓

Figure 47: Summary of results for initial platooning tests on the Griesheim test track

In general, most of the data generated at the AD_SW modules of the transmitting car is received at the addressed modules of the receiving car. The sensor fusion modules of the receiving cars acquire knowledge of the presence of a remote vehicle upon reception of the MAVEN CAMs. By analysing visual sensor fusion representations of the ego-vehicle surrounding at both the DLR and the HMETC car, it can be concluded that the positioning information contained in the received CAMs is correctly converted into the local coordinates systems (Figure 48).

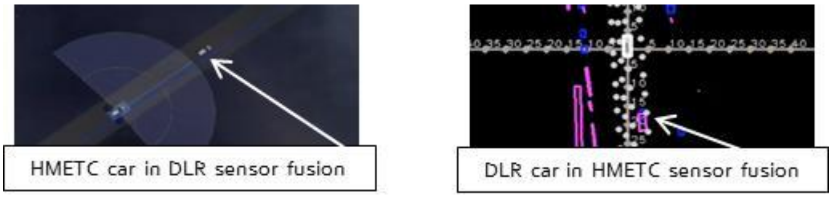

Figure 48: remote car representation in receiving cars' sensor fusion visualization systems

Moreover, the platoon logic of the receiving car gets aware that the transmitting car is able to platoon and has the same route as the ego vehicle (achieved via IF3). As IF2 informs the platoon logic that there is no vehicle between the ego- and the transmitting vehicle, the conditions for platoon logic initialization are met. As a consequence, the platoon logic shall forward over IF3 the ego vehicle current planned trajectory received via IF2. Nevertheless, the communication over IF3 was not successful in the tests (depicted as a shaded IF3 box in Figure 46) and could not be fixed by the end of the event. It was hence decided to repeat this test event on the Griesheim test track in January 2018 right before the public road tests in Braunschweig.

5.4 Integration Sprint 6

Integration sprint 6 (M28-M30, extended to M32) was according to the DoA planned to lead to integration level 6:

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MS6.6 MAVEN system prototype demonstration Systematic verification of MAVEN system prototype for all use case scenarios that will be selected for field demonstrations and assessment. TRL 7.

This final integration sprint was bringing all selected use cases to public roads. These include (according to D7.1 [14]) the platooning use cases UC1-6 as well as the speed and lane advices (UC7-8). It also includes priority management (UC10), signal optimization (UC14), negotiation (UC15) and the detection of non-cooperative road users (UC16). The other use cases queue length estimation (UC11), local level routing (UC12) and network coordination/green wave (UC13) are shown in simulation only. UC9 has already been shown in the last integration sprint at event 16. Also according to D7.1 [14], all events have been distributed to the partners and the respective locations/road networks, so not all use cases are shown at all locations with all vehicles.

5.4.1 General achievements

5.4.1.1 HMETC

As most of the communications and automation integration has been executed in previous sprints, at integration sprint 6 the HMETC vehicle had already reached a complete and verified functionality level allowing real road tests. Nevertheless, before performing test events in the Braunschweig and Helmond test sites, further platooning tests were necessary on the Griesheim test track. These tests were needed to verify the fixes to the newly integrated platoon logic to cope the issues that prevented test platooning of automated cars in the previous integration sprint.
During these tests, some adjustments to the sensor fusion module of the HMETC AD_SW were found to be necessary to optimize fusion and tracking of a moving CAV (preceding or following the ego-vehicle) when detected simultaneously via CAM V2X receptions and lidar samples. Since the frequency of V2X receptions is irregular and much lower compared to lidar samples, it can happen that the same moving vehicle is detected as two separate objects till the next V2X reception, where lidar and V2X detections are aligned again and result in one single object. Having one physical vehicle detected intermittently as two vehicles results in the platoon logic intermittently matching the conditions for platoon break up, which in turn provokes instability of the platoon formation. The methodology to fix this issue at the HMETC AD_SW is described in Deliverable D3.2 [19] and has been verified during the test Event 22. In the next figure it can be seen how the above mentioned method helps the HMETC sensor fusion not to duplicate detections of remote CAVs when combined with lidar detections. Figure 49 represents the objects detected by the different sensors as shown in the visualization tool. The brown box behind the ego-vehicle (where the coordinates system is centred) corresponds to the remote DLR vehicle detected via CAM receptions and well overlapped with the lidar detections of the same car.

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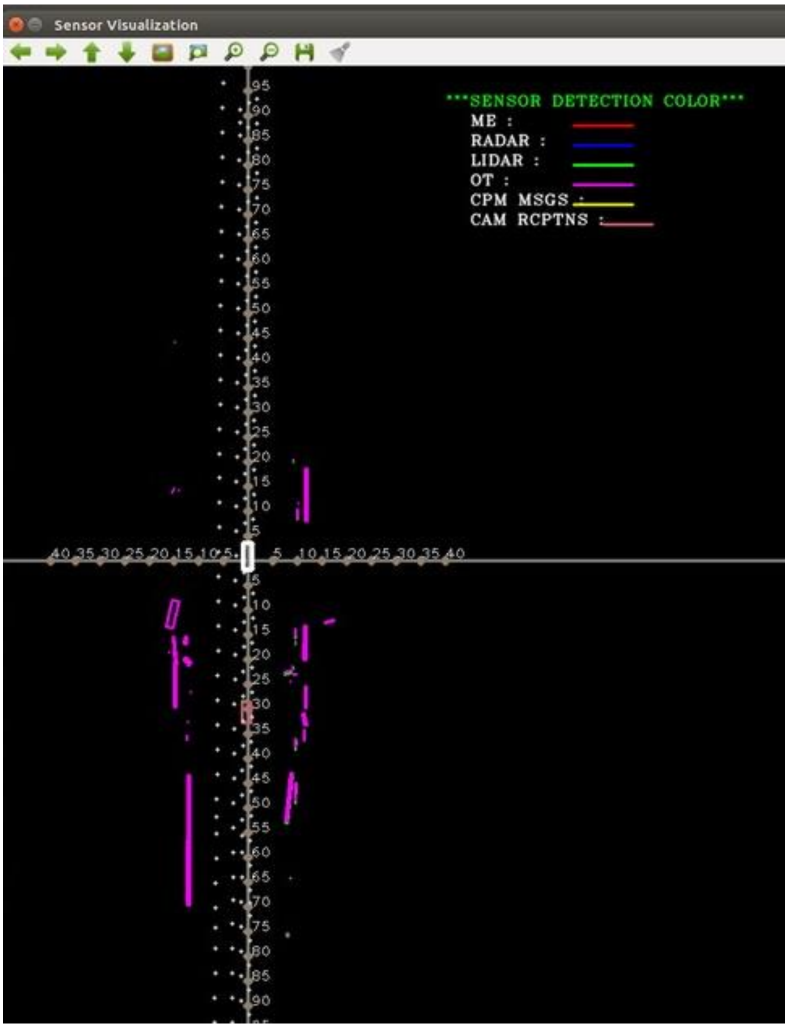

Figure 49: HMETC AD_SW OF/OT performance in presence of CAM receptions. Here, an object is received by CAM approx. 30m behind the ego in the middle.

5.4.1.2 DLR

During integration sprint 6, the integration work has been finalized. The corresponding preparatory work is described in the following sub sections.

5.4.1.2.1 Automation integration

At this final step, the vehicle automation was only fine-tuned and parametrized to cope with the current weather conditions, esp. in winter. In addition to this, some debugging effort at the platoon logic needed to be done as well as some steps for including the CPM in the sensor data fusion.

5.4.1.2.2 Hemispheric Camera and Communication integration

The generation of Collective Perception Messages (CPM) was integrated and successfully tested (see Figure 54). For this purpose a processing pipeline was issued in ROS. The following software modules were implemented and tested:

- video_player node for interfacing with the RTSP video stream of the hemispheric camera PNM 9020V

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- object_detector node for computing faster R-CNN object detection on the Nvidia GTX 1080 Ti CPU of the road site unit computer
- camera2world node for projection of the detected vehicles to UTM-coordinates
- v2x_cpm_rsu_node for compiling CPM messages

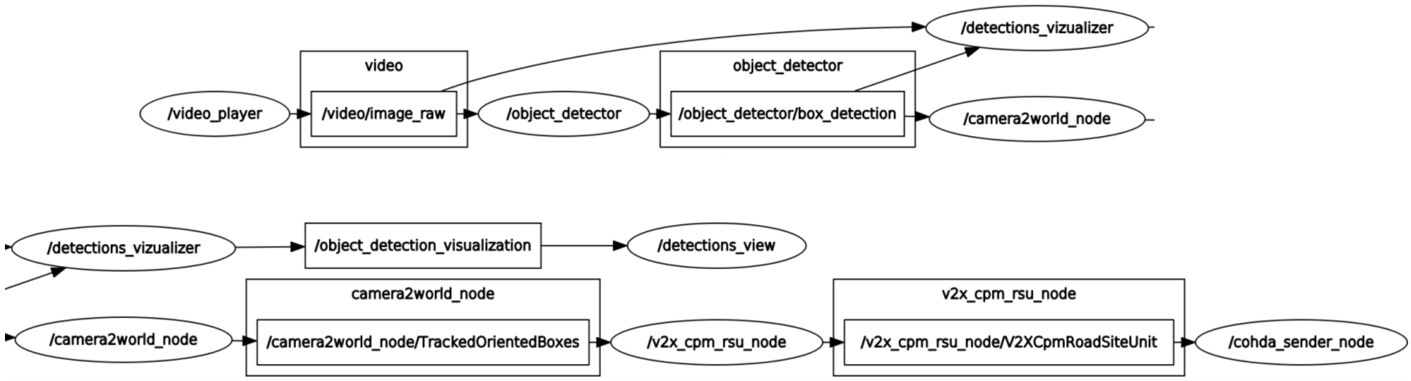

Figure 50: Building blocks of the hemispheric camera to CPM processing pipeline

The PNM 9020V is a multi-sensor camera system. It consists of four single cameras. The images of the single cameras are stitched within the camera, the result is a 180° view image. Accordingly, the algorithms for re-projection from camera to world coordinate systems were extended (see Figure 51).

The following development goals were achieved in the course of integration:

- In order to be able to calibrate the hemispheric camera, dedicated calibration and projection features were added to the pipeline and the image processing toolset BoB-ROS. BoB-ROS is a software framework for sensor data processing in ROS. It is designed for use in research for ITS and is under active development at DLR.
- The R-CNN integrated and retrained in order to improve detection accuracy and tracking performance. As a result, the number of fragmented and broken trajectories was significantly reduced. The CNN was trained to distinguish the following road user classes: motorbike, car, van, car_with_trailer, lorry, lorry_with_trailer, bus. Pedestrian and bicycle. It was found that classification and detection accuracy varies over the classes. Especially pedestrians were often confused with bicycles, bicycles with motorcycles and vans with cars. A more detailed evaluation of detection quality and implications for the related use cases of connected driving was beyond the scope of MAVEN.
- A CPM message profile was issued. It implements specific properties of the camera sensor and the processing pipeline. The field of view of the camera sensor is pictured implemented as a polygon.

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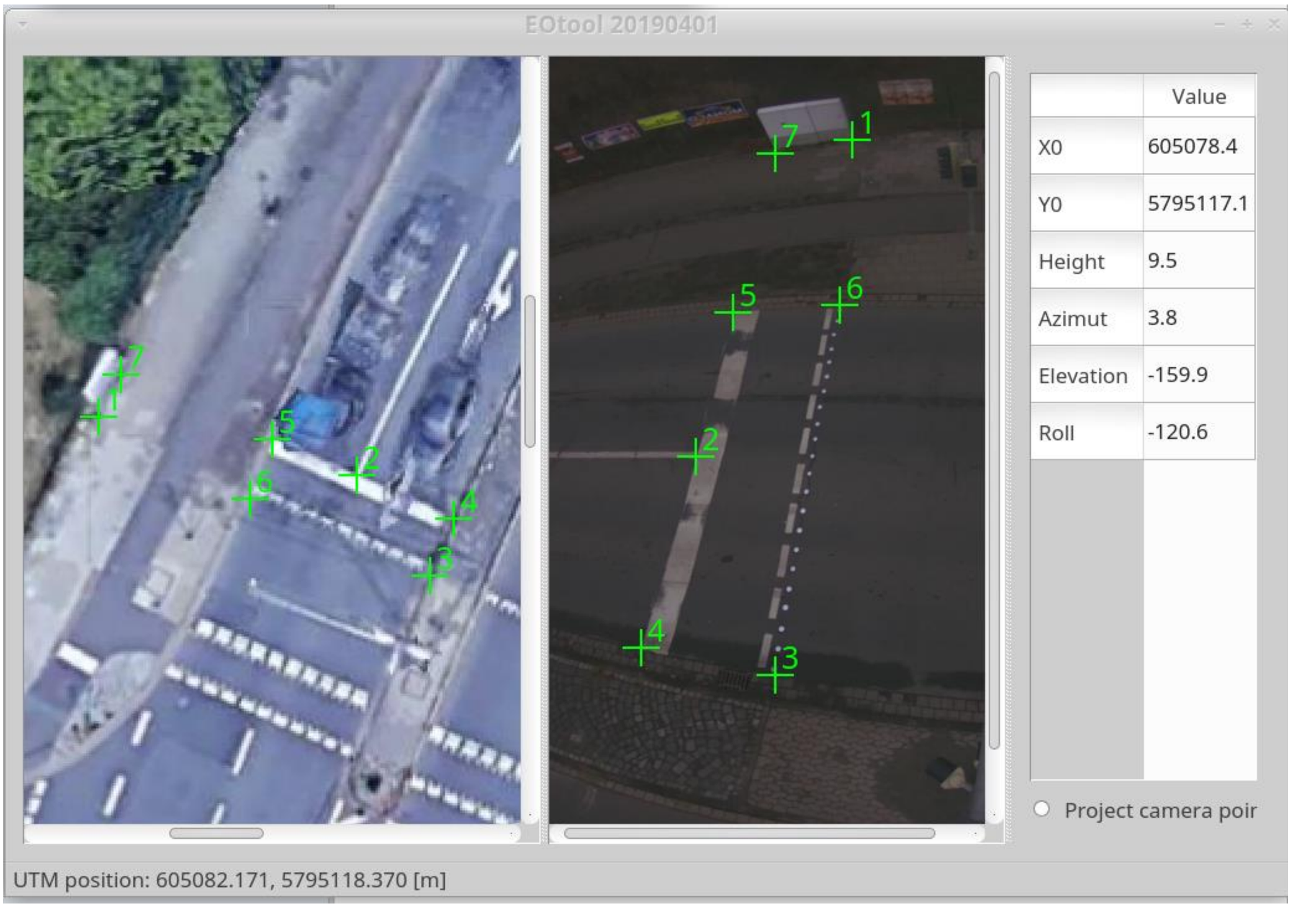

Figure 51: Screenshot from calibration tool “eo_tool” with added features for multi-sensor camera calibration. Here, one of the four cameras of PNM 9020V on Tostmannplatz is calibrated with marker points.

Findings:

- A multi-camera device like PNM 9020V is a better match with the requirements of road user surveillance. This is the result of testing with the Sony SNC-HM662 single camera device. The reason is that the resolution of single camera devices quickly detoriates near the border of the image (see Figure 53). However, the border of the image is of special interest because it covers a wider area than the centre.
- The PNM 9020V did not completely satisfy the needs of intersection monitoring and CPM generation. However, the scope of MAVEN was not to develop dedicated camera hardware but instead to investigate what can be achieved with existing commercially available products. Therefore the following list of requirements was derived:
  - While the resolution in the 0° and 180° observation angles is not as bad as with SNC-HM 662, a field of view of >180° is desirable.
  - The coverage of a true hemisphere is desirable. PNM 9020V has a field of view of 84° x 180°. The best camera orientation on Tostmannplatz covered the road “Bienroder Weg” in the north-south direction. Already the south-north lanes were not sufficiently covered. The 84° field of view angle is too narrow. Extending the field of view to the complete hemisphere would also allow observing of junction areas with the roads “Mergesstraße” and “Riekestraße”.
  - Image stitching of PNM 9020V was not correct. Especially in the borders of the image, artefacts from image stitching were apparent (see Figure 52). Future

developments should enable seamless stitching of the images. Another projection approach might be reasonable, e.g. cylindrical camera projection. Note: Stitching four rectified images with four concentric pinhole camera models is favourable, when we assume that CNNs work best on rectified images.
    - PNM 9020V delivers H264 and MJPEG compressed image streams. For CPM generation, only the latter option can be used because H264 causes a delay in the order of magnitude of 1s. The delay of MJPEG is only ~200ms. However, the resolution in MSPEG mode is 1536x672 pixels. This is far below the rated resolution of PNM 9020V, which is 4096 x 1800 pixels.
- A pretrained Faster R-RCNN was deployed and re-trained with additional vehicle training samples from Tostmannplatz. Standard data augmentation algorithms were applied. These include mirroring and rotation by 90°. It was observed, that in the hemispheric camera image there is a tendency to lose detections of vehicles that appear tilted. Therefore, rotation in 5° steps when augmenting training data is recommended.
- In the concept phase, timing issues were anticipated, because the camera itself causes a delay for image compression and the following processing steps, especially the object detection with a CNN object detector may cause significant timing delays. Therefore, time stamps were evaluated and it was found that CNN processing on the Nvidia Geforce GTX 1080Ti graphics card did not consume more than 50 ms and the GPU load was ~30%. The delay for CPM transmission was within 300 ms which is acceptable for data fusion in the vehicle.
- It was assumed that performing image rectification before object detection would yield the best detection accuracy possible. However, seamless image stitching was not working on the camera firmware. Therefore, applying this approach in practice would have resulted in splitting the output image, rectifying the four sub-images and performing object detection on the sub-images. In the image transition regions this gave by far worse results than processing the whole unrectified image. Therefore it was concluded, that processing the whole image gives more advantage in object detection than image rectification.

Figure 52: Image stitching artefact of PNM 9020V

It can be concluded, that using a hemispherical camera for traffic data acquisition and CPM generation is a feasible approach and works well with established camera technology that is commercially available. However, a multi-sensor camera was found to be a better match with the requirements that than a single sensor fisheye camera model. Object detection algorithms did

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perform well on the image of the hemispheric camera. Adoption of camera calibration procedures was necessary.

Future work after the end of MAVEN will include:

- Adding another PNM 9020V to the road observation setup on the same mounting position. This will cover the whole hemisphere and allow observing critical situations. However, this will require the application of trajectory stitching algorithms, because a blind spot directly below the mounting position will occur.
- Implementation of advanced data augmentation including rotation in 5° steps for better detection results for vehicles in hemispheric camera images.
- Experimenting with seamless stitching algorithms for rectified images and evaluating the impact on detection accuracy.

Figure 53: Object detection and tracking for the single sensor hemispheric camera Sony SNC-HM662 on a reference test site Berlin Ernst-Ruska-Ufer. Although the field of view is true 180° x 180°, the resolution in the image regions that correspond to 0° and 180° viewing angles is too poor for object detection.

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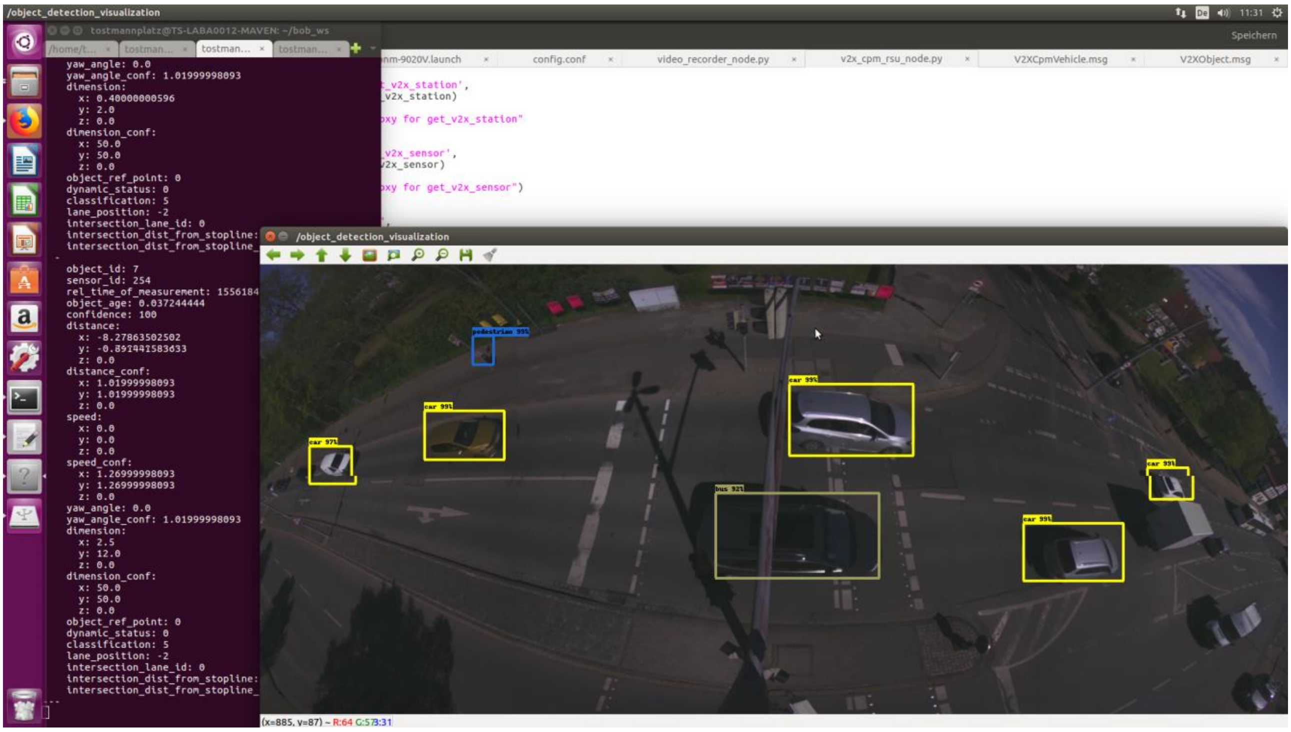

Figure 54: CPM generation for the hemispheric camera on Tostmannplatz. Left: CPM contents, Right: Object detections. Note: the camera view is mirrored

Figure 55: PNM 9020V hemispheric surveillance camera (source: [25])

5.4.1.2.3 Detection of anomalous situations

The part of the detection of anomalous situations has been already addressed in WP5. On top of the desired outcomes of that WP, DLR decided to also spend more effort on algorithms detecting anomalous situations, as described in the DoA. As result, the following work has been performed.

It needs to be noted that this work has just started in MAVEN and could neither be included in the trajectory planning of the automated vehicles so far, nor on the infrastructure part for an online warning of the automated vehicles in the vicinity. Nevertheless, this topic is very much related to the CPM generation explained above and in D3.2 [19], and therefore included here.

5.4.1.2.3.1 Introduction

Safety critical situations in road traffic can be detected in different ways. Conflicts between road users can be detected or forecasted by calculating Surrogate Safety Measures (SSM) like Time-to-Collision (TTC), where low values indicate a conflict. Low TTC values based on a path prediction for the interacting traffic participants allow hardly any reaction time in case the vehicle driving ahead is abruptly changing its speed, for example. The disadvantage of the Traffic Conflict Technique (TCT) and using SSM is, that interacting traffic participants are a prerequisite for measuring and determining a risk of collision; but in some cases it is important to adjust its own behavior and be aware of potential risks arising from unusual behavior of other participants without a direct interaction.

For example, potholes on the cycle path can cause the cyclist to fall or do expansive sudden maneuvers to avoid a fall and regain balance—such situations can lead to sudden safety-critical situations without preannouncement. In order to detect such locations an analysis of cyclist trajectories has to be conducted. Another unusual behaviour can be using shortcuts increasing the potential risk of collision: unusual or abnormal behaviour needs special attention due to its rare occurrence thus higher safety risk. The capability to detect abnormal behaviour and abnormal trajectories enables to be prepared for higher risk situations and to defuse them by adjusting reactions.

In the following an approach to detect atypical situations is described.

5.4.1.2.3.2 Approach

The approach to detect anomalies is to model typical behaviour and motion of pedestrians and determine the deviation from this model. The underlying assumption is, that by modelling the behaviour with a suited algorithm like neural networks typical behaviour can be learned. The model cannot capture the whole variety of the data and thus exceptional behaviour is not part of it. Algorithms like Principal Component Analysis (PCA), Self-Organizing Maps (SOM) or deep learning networks in a way compress the data and model the data by finding its best describing features. The algorithm chosen to predict trajectories is a deep-learning based architecture of an artificial neural net (ANN). An anomaly, i.e. a point or part of a trajectory which is considered abnormal, can then defined as deviation too far from expected or predicted next trajectory points. In order to define a border between normal and abnormal behaviour a threshold is defined, which is derived from comparison of actual next trajectory points and forecasted trajectory points on the training data. See section 5.4.1.2.3.2.1.2 for details.

5.4.1.2.3.2.1 Methodology

5.4.1.2.3.2.1.1 Trajectory Prediction

The trajectory prediction problem is formulated as a sequence to sequence problem, where we want to predict a sequence from an observed sequence.

The input data is therefore created by splitting each trajectory into sequences of n last points (observation length) and the next n points to be predicted. This corresponds to an n-to-m-sequence prediction problem. In order to have a generalizing approach the position in UTM coordinates is discarded and only the velocity vector (vx,vy) used as features describing a sequence. The velocity vector encodes the absolute velocity and the direction/heading of the traffic participant. Note, that as a first examination further features are not taken into account, which are, e.g. static objects and obstacles, surrounding traffic participants etc. which affect trajectories. Only the motion itself is modelled.

The network architecture is adapted from [26] and [27], who use Recurrent Neural Networks (RNN) or LSTM encoder-Decoder architecture for predicting vehicle trajectories.

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A RNN is an artificial neural network with the ability to learn temporal dynamics in the time-series data. Since a road user's trajectory is time-series data and because there are dependencies within these sequences between the time-steps we want to capture RNNs are a suited class of ANNs to solve the problem.

The Long-Short-Term Memory (LSTM) is a RNN variant which has a special internal structure to overcome the vanishing or exploding gradient problem, which often RNNs suffer from and make it hard to train them. The LSTM consists of a memory storing a summary of the past sequence and a gating mechanism controlling the information flow between input, memory and output and is responsible for "memorizing" and "forgetting" information.

The network architecture can be divided into three parts:

The first part consists of three stacked fully connected layers, which transform the 2-dimensional input data into a 512-dimensional, then 256 and finally 128 dimensional feature. In this way, the data is consistent with the LSTM cell dimension and the network is extended to capture the complexity of the trajectory data. The fully connected layers are time distributed, which means the whole layer is applied to each data sample of the input sequence. Thus, the FC layers can only "see" and encode a part of the sequence and not the whole sequence.

The next part consists of two stacked LSTM layers each having 128 cells. The LSTM layers model the sequence capturing its time dependencies between the sequence's data points.

The third part is the decoder-like part following the LSTM layers, where – again – symmetrically to the first part of the network – FC layers in a time distributed manner, having as output the predicted sequence. In the last layer or output layer, a linear activation function is used to do regression on the predicted sequence. The values of the predicted sequence can be directly compared to the ground truth sequence.

LSTM dropout is 0.8, learned as regression problem with Adam optimizer and mean squared error as loss function.

Table 2: Network architecture. "Samples" denotes the number of sequences in a batch.

Layer name or type	Units or size	Activation function
Input layer	(samples, observation sequence length, feature vector length)	
Fully connected / time distributed	512 units	ReLU
Fully connected / time distributed	256 units	ReLU
Fully connected / time distributed	128 units	ReLU
LSTM	128 units	Softsign, inner activation: sigmoid
LSTM	128 units	Softsign, inner activation: sigmoid
Fully connected / time distributed	128 units	ReLU
Fully connected / time distributed	256 units	ReLU
Fully connected / time distributed	512 units	ReLU
Output layer, Fully connected	Prediction sequence length * feature vector length	Linear

The implementation of reading the raw trajectory data, creating input data for the ANN from it and training the network was done in Python and with the help of Tflearn/Tensorflow libraries.

5.4.1.2.3.2.1.2 Anomaly Detection

The idea behind the detection of anomalies in trajectory data is to use the motion model for pedestrians to identify abnormal behaviour like abrupt stops or slalom. Of course, this work discards the position itself and surrounding traffic participants, so site-specific behaviour cannot be learnt, e.g. a pedestrian may walk in a normal manner but uses a cycle path, which can be considered as abnormal behaviour.

The method predicts at every time step the expected next steps and evaluates the deviation of the actual next steps and the predicted ones. The deviation can be measured by calculating the Mean Squared Error (MSE) between predicted and ground truth sequence. With $\hat{y}_i$ the predicted value of the i-th sample and y_i the true value, the MSE can be formulated in as:

$$MSE(y,\hat{y})\frac{1}{n_{samples}}\sum_{i=0}^{n_{samples}-1}|y_i-\hat{y}_i|_1^2$$

Note, that $\hat{y}_i$ and y_i are two-dimensional vectors containing the velocity vector $\binom{v_x}{v_y}$; and because a single value is desired as outcome the l_1-norm is used as error.

The MSE between predicted and ground truth sequence is used as loss to be minimized by the trajectory prediction network during its training phase.

Since we want to find anomalies in an unsupervised way, i.e. without data labelled as normal or abnormal behaviour, we have to find a way to define what an anomaly is based on the capabilities of the trajectory prediction algorithm. The distribution of the prediction loss on the training data shows how good the algorithm performs on known data. By defining a threshold regarding this known distribution we can control what an anomaly is for a certain part of a trajectory. Looking at the prediction loss distribution in Figure 56, we can see a peak at a loss of 0.7. The choice of for an anomaly threshold based on this distribution depends (1) on “how big” the anomaly we want to detect should be and (2) how good the trajectory prediction algorithm generalizes, which means, how good it is on unseen data. If the prediction loss on the training data is low, and on unseen test data is how, maybe a threshold $t = \max(loss_{prediction})$ or higher should be chosen. To ensure the generalization ability to a certain degree is common to split the data into training/validation and test data or use cross validation to find the best model. If the distribution on all data sets is similar, it may be better to use a percentile of this distribution as a threshold.

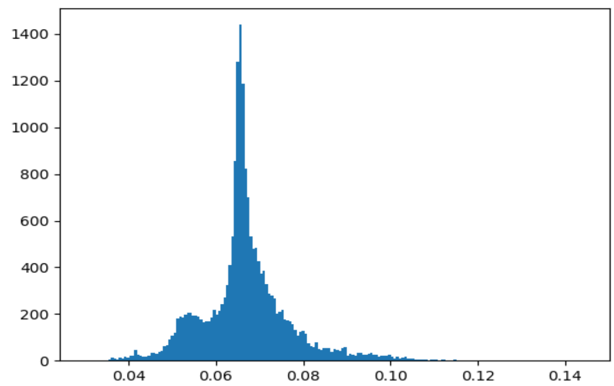

Figure 56: Distribution of prediction loss on training data.

The prediction loss distribution on the test data can be seen in Figure 57 and is very similar to the distribution of the training data. Almost no sequence is exceeding the value of 0.10 in training or test set and thus almost no trajectory would be classifiable as abnormal.

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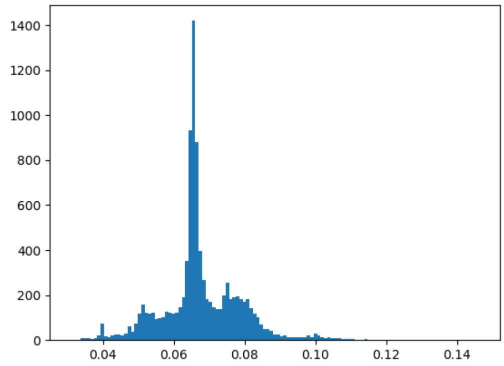

Figure 57: Prediction loss at each trajectory point of test set trajectories.

Because there are no examples of abnormal behaviour available for this data set we are required to find anomalies in an unsupervised way. In order to validate the anomaly detection method we first pick a threshold not too high to find some abnormal behaviour (according to this first “guessed” threshold). Subsequently, the samples identified as anomalies can be examined and the threshold can be (a) set to a lower threshold, if all samples found are verified as anomaly by an expert or (b) set to a higher threshold, if there are already samples wrongly classified as anomaly (false positive). The type of anomaly which is detectable may further depend on the features used for trajectory prediction and thus for anomaly detection (and not only the threshold itself).
The threshold for an input sequence on the DLR research intersection FoKr (Braunschweig, Germany) dataset to be considered as anomaly is set to the 90th percentile of the training distribution P90 = 0.081 (P90 on test set: 0.0783).

5.4.1.2.3.3 Results

In this section the results are shown. First, the results of the trajectory prediction algorithm and then, based on this prediction the results of the anomaly detection method.

5.4.1.2.3.3.1 Trajectory Prediction

The prediction algorithm was first applied to the public data set “BIWI walking pedestrian dataset” of ETH Zürich [28] because of its lower complexity than the data of the DLR research intersection (FoKr) and the manual annotation data available for it. The annotation data provides a ground truth with less noise and no detection failures or other problems full automatic detection systems have to cope with. Therefore, training and testing the trajectory prediction algorithm on the ETH BIWI data set gives good evaluation possibilities on a more ideal data set than with trajectory data from FoKr, where problems occur like (1) wrong traffic participant classification (a cyclist may be wrongly classified as pedestrian), or (2) sensor noise and object detection and tracking errors leading to errors in position, velocity and acceleration estimation.

5.4.1.2.3.3.1.1 Results on ETH BiWi data set

The trajectory data is annotated at a frequency of 2.5 Hz and the video is recorded with 25 fps. A prediction length of 5 points is desired, i.e. the prediction of the next 2s of the pedestrian trajectories. An observation length of the last 5 trajectory points showed to be enough information and more observation points do not result in higher prediction accuracy. The trajectories are split randomly into 60% for training, and 20% each for validation and testing. After creating input data from the trajectories and scaling to [0,1]-interval the training was conducted for 200 epochs. The model converges, which can be seen in Figure 58, which shows the loss while training.

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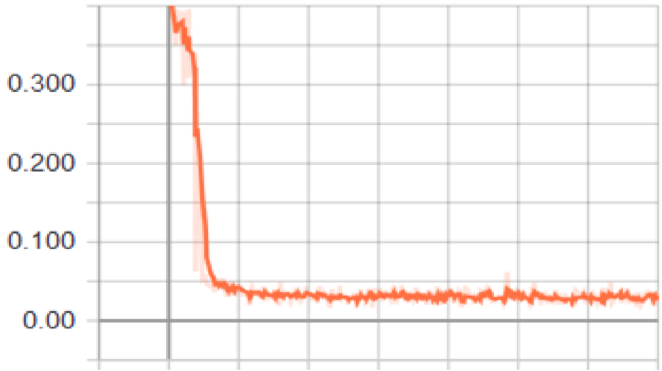

Figure 58: Training loss on ETH BiWi data set.

The resulting predictions are exemplary shown in Figure 59 left and right the last five observations are linked to a grey trajectory, the five predicted points are linked to a red trajectory and in green are the next actual ground truth positions.

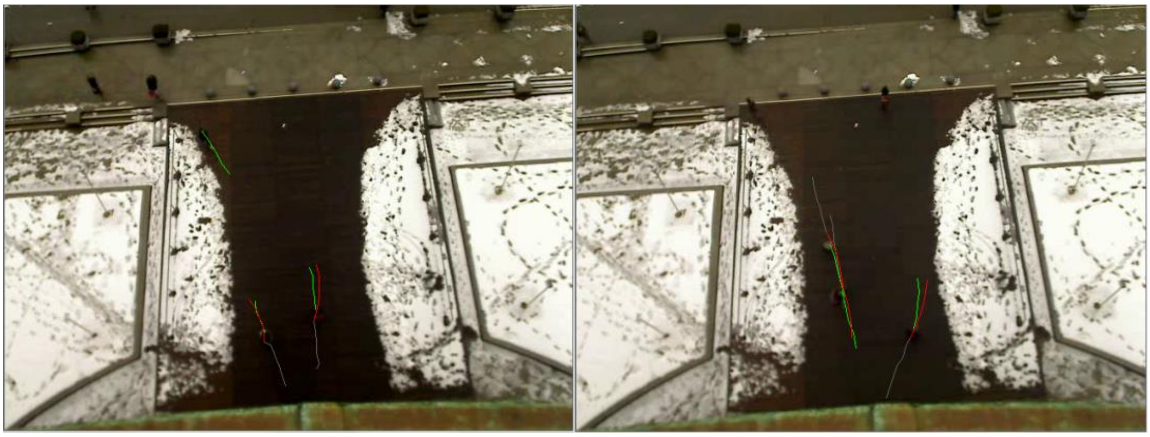

Figure 59: Exemplary video frames from ETH BIWI dataset showing last 5 annotated observations (grey), next 5 trajectory points predicted (red) and groundtruth (green).

The results show (1) the prediction length is very accurate, but (2) the shape was not captured exactly of the trajectories' next points. This may be due to restricted amount of training trajectories and some overweight of trajectories coming from the upper left corner. Nevertheless, the results on ETH BIWI data set prove the ability of the proposed RNN to predict pedestrian trajectories only by using their velocity vector.

5.4.1.2.3.3.1.2 Results on DLR FoKr data set

There have been taken two hours of trajectory data from 2019-01-23 from 2-4 p.m. In this set contained are 249 trajectories classified as belonging to a pedestrian. Again, these trajectories have been split randomly into three parts of 60%/20%/20% of the total amount of 249. The training set as the biggest set and the validation set are used for training purposes. The test set can be used to see how the model performs on unknown data – either for trajectory prediction or for anomaly detection. The creation of input sequences of observation length of 10 points and prediction length of 10 points results in 90,123 training sequences, 31,423 validation sequences and 39187 test sequences. There has been chosen a sequence length twice as long as for the ETH BIWI data set, since the FoKr trajectory data is recorded at 15 fps. Hence, a higher sequence length the RNN has to forecast, but less time (10 time steps equals to 0.66s at 15 fps). The sequence consists of the velocity vector between subsequent positions and is measured in m. All sequences are scaled, so that all features are within the range [0,1].

The neural net has been trained for 20 epochs. As can be seen in Figure 60, the model converges successfully, but slowly to the value of 0.0002, after a steep decline at the beginning.

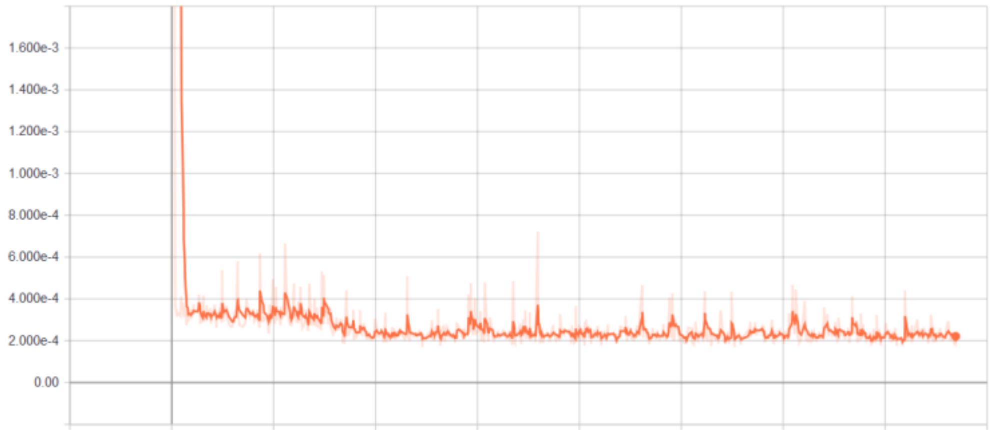

Figure 60: Training loss for FoKr trajectory data.

5.4.1.2.3.3.2 Anomaly Detection

In order to find anomalies in the test set the sequences of 10 points observation length and 10 points prediction length and examined and each prediction compared with the ground truth. The resulting loss is compared to the anomaly threshold for a sequence at a trajectory time step, which is 0.081 (see section [method anomaly detection]). As a next step to classify a trajectory as anomaly we can look at the percentage of points or sequences which are considered as abnormal of a whole trajectory:

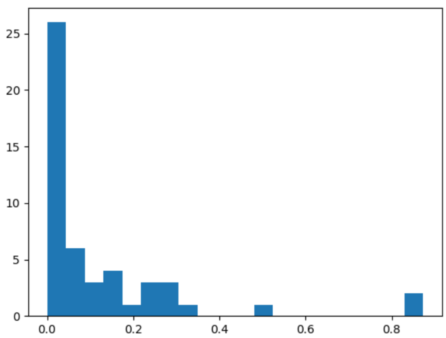

Figure 61: Number of trajectories with certain percentage of anomaly.

In the set, which consists of 50 pedestrian trajectories, only three trajectories have a percentage of over 50% classified as abnormal and clearly stand out of the set and are candidates for anomalies. If a trajectory has a length of 20s on total, 50% determined as abnormal means that for 10s (not necessarily subsequently) the trajectory could not be accurately predicted, or at least worse than 90% of the training data for the trajectory prediction algorithm.

In Figure 62 the set trajectories are projected onto a schematic map of the research intersection where they have been recorded. Normal trajectories in blue and the three strong candidates with over 50% abnormal trajectory points are shown in red.

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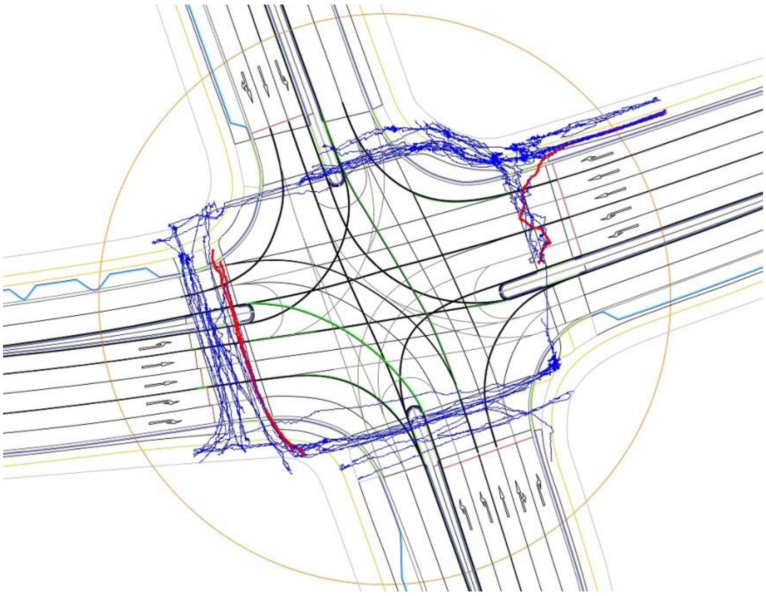

Figure 62: Test set trajectories. Blue trajectories are classified as normal, in red are abnormal trajectories.

In order to find the reason for the abnormal behaviour we examined the three trajectories visually on the video recordings.

The first trajectory is a cyclist, which is at the beginning correctly detected as a cyclist. But as the cyclist turns to the left and crosses the road the object detection system gets problems in correctly detecting the position and class of the road user: the classification changes to “pedestrian” and the object box is in front or behind the cyclist and moves abruptly. Conclusively, this trajectory has been correctly identified as anomaly (although not being abnormal pedestrian behaviour but a severe detection error, see Figure 63).

Figure 63: Abnormal trajectory: cyclist correctly classified (left), but later classification changes to “pedestrian” and object localisation has big errors (right).

The other two candidates are also classified as anomaly due to a wrong classification as pedestrian, but are cyclists actually. The object boxes capture the persons correctly, but still for pedestrians this velocity vector is unusual and hence correctly detected as anomaly (see Figure 64).

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Figure 64: Abnormal cyclist trajectories due to misclassification as pedestrian.

An anomaly regarding the velocity can also be an abrupt braking or a seldom pattern to an avoidance manoeuvre and may last only 1-2s. Thus, looking at the whole trajectory may not show these anomalies. Instead, a sliding window with 50% of its points classified as abnormal is proposed with a length of 2s, but pending to be tested.

5.4.1.2.3.4 Discussion

It has been shown that it is possible to model the motion of pedestrians and to derive a measure to define abnormal behaviour. To method to detect anomalies compares at each trajectory point the prediction accuracy with a threshold derived from training data. Analysing whole trajectories this way results in an "Anomaly percentage" which tells what percentage of a trajectory is considered to be abnormal. The three trajectories with more than 50% abnormal are shown to be errors of the object detection system which is the basis for the data. Misclassifications of cyclists as pedestrians and positioning errors leading to abrupt velocity changes physically impossible were detected correctly as anomalies.

5.4.1.2.3.4.1.1 How to improve?

In order to find real behavioural anomalies like abrupt velocity changes from strong braking or driving sharp curves or using unusual paths it is shown in this work that it is essential to filter out those anomalies which are caused by errors of the underlying road user detection system. An obvious point is to improve this object detection and tracking system. An alternative way is to pre-preprocess the data before feeding it to trajectory prediction or anomaly detection system. For example, trajectories with severe position errors can be detected and ignored (test for physical plausibility and remove trajectories with accelerations higher than 1g). Or additional Kalman filtering can fix trajectories.

Another aspect is the choice of observation length and prediction length for trajectory prediction and thus also for anomaly detection: The choice of 10 points for both observation length and prediction length is a good choice for prediction length, but systematic examination regarding the best sequence length for anomaly detection is pending. It may be possible to capture some abnormal behaviour only when the algorithm sees a sufficient long part of the trajectories, e.g. 50 time-steps long. A pedestrian walking in an unusual way and doing slaloms requires vehicle drivers to pay special attention to in order to react fast if the pedestrian takes an unexpected and dangerous walking path. Such slaloms may not be detectable from looking at the last 0.66 seconds but rather at the last 5 or 10 seconds.

Regarding anomaly detection based on single trajectory points it is not trivial to find a suitable threshold enabling to find all true positive anomalies but none or only few false positives. There are two thresholds in the proposed method to be adjusted: (1) the threshold to classify a sequence of 20 points (10 points serving as prediction input and 10 future points to for comparison of the prediction with the actual next points) and (2) the threshold for considering a trajectory as abnormal. A single point of the trajectory being abnormal may be due to data noise, but the higher

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the number of abnormal points of a trajectory the higher the probability to be abnormal. One problem with the proposed method is, that short actions can be abnormal but only take a small percentage of a whole trajectory. One way to improve the proposed method is to express “anomaly” as probability. Another solution would be to use a sliding window instead and e.g. classify a trajectory as anomaly if within a 2-seconds-windows more than 50% of the trajectory points have been classified as abnormal. This may also be a solution to find different anomalies: on different time-window-scales different behaviour anomalies may be likelier to identify.

Moreover, in this work only the velocity vectors between trajectory points have been used, which encode heading and absolute velocity. This feature vector restricts the method and unusual paths may not be found. Imagine a pedestrian walking across an intersection and not taking the designated crossings, which may be an abnormal situation not detectable by the proposed method. A disadvantage would be less generalization: if an anomaly detection system learns specifics about certain intersections and cannot be applied to other intersections without learning again the typical pathways of road users.

Other traffic participant classes have to be examined as well: the proposed anomaly detection method was only applied to pedestrians. Future work has to test what is a better solution: Create a prediction for every class of road user (i.e. train separate neural network) or combine in one single neural network and feed the class (pedestrian, cyclist, vehicle etc.) as an additional feature. This work revealed some road user classification problems of the object detection system; as a countermeasure one may consider to learn the motion of pedestrians and cyclists in a common neural net in order to compensate such weaknesses. The assumptions would be then, that the neural net is able to identify the observed motion pattern and create a prediction based on the hidden implicit classification.

The trajectory prediction has to be further improved by taking into account static objects and other road users as in [29].

An important point to do systematic research regarding anomalies in road traffic is to have a data set of such anomalies. It can consist of synthetic trajectories but better of real-world scenarios. Such a data set may help to improve anomaly detection by serving as a benchmark and making various anomaly detection systems comparable (use as validation set to measure performance). Another advantage would be to be able to train (semi-) supervised methods.

5.4.1.3 Dynniq

5.4.1.3.1 Final field integration

During the last integration sprint, the focus was on including the automated vehicle from Hyundai in the tests. However, an unexpected problem was that the traffic light controller was upgraded to a new software version of the “iVRI” standard in the meantime. This meant that the controller software of WP4 had to be merged and rebuilt for this new version. Additionally, the possibilities for swapping processor boards running the control algorithm were impeded. Taking out the processor board would endanger the safety at the intersection because there was no back-up control plan anymore. Therefore, the special MAVEN software had to be installed on an additional processor board that runs in parallel with the original board, which posed some challenges with regards to communication with neighbouring intersections for the multi-intersection optimizations. These were solved with a 3 step swapping procedure that allowed swapping ports while maintaining at least one controller operational and freeing up ports that were required for communication.

Compared to the tests in August 2018 of IS4, the acknowledgements of the speed and lane advice were new. This would have been too much manual action during driving for a non-automated vehicle.

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Tooling was also developed to log and track the behaviour of the automated vehicle in detail. An example of a logging entry is shown below:

```
21/02/19 14:25:52 CAM decoder:
stationID=120,lat=514747190,lon=56333813,heading=2412,speed=1111,inLaneID=3,outLaneID=143
,SG=2,speedComp=Y,int=701,occupants=4,distanceBack=15,LAMComp=Y2
```

Here the vehicle is acknowledging both the speed and the lane advice, while indicating its intended turn direction (SG2, going out on lane 143 from the MAP). There are 4 occupants in the vehicle and there is a vehicle following the automated vehicle at 15 meter distance.

5.4.1.3.2 Green wave integration

The green wave solution that was designed in WP4 and extensively reported in D4.4 [17], also required some final integration steps. During the requirements phase of WP2, it was thought that putting green windows as external input to an adaptive controller would be the best solution. However, as the deliverable explained, this would be negatively affected by adding GLOSA. This was concluded after successful integration and simulations.

Therefore, a new static control design methodology was developed in WP4 that could work well together with speed advice. However, the existing coupling between adaptive control and speed advice was not sufficient anymore. Even though speed advice on static control is simpler, the new feature of splitting platoons before the first intersection had to be added. For effective speed advice queue modelling is of course also a prerequisite and therefore integrated as well. A demonstration video of this integration was made and can be found on the MAVEN website

Due to the high dependency on the synergy between speed advice and green wave for effective deployment, this use case was not deployed in the field. Most vehicles would not be able to receive the speed advice, and there would not be any new insight gained from deployment.

5.4.2 Event-based achievements

5.4.2.1 Event 19: UC13 Green Wave

Integration Sprint		4
Date of achievement		07-12-2018
Importance		low
Setting	Software	SUMO
	Test site	Helmond (large network 101-104)
	Vehicles	Simulated
Goal		The goal of this event was to prove that the requirement of being able to take external green wave input into an adaptive controller.

This test was successful, but as already indicated a negative influence from speed advice was found. Therefore, an extra event, number 25, was added.

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5.4.2.2 Event 20: UC1-6 with three cars (DLR and HMETC) on test track

Integration Sprint		6
Date of achievement		January 2019
Importance		High
Setting	Software	Dominion + Hyundai-AD_SW + DLR platoon logic
	Test site	Griesheim
	Vehicles	FASCarE, ViewCar2, Ioniq driving automated and cooperatively
Goal		Verify the functionality of all the platooning use cases involving three vehicle prototypes from different partners. All prototypes include AD_SW extensions for platoon logic and V2X integration, hence this is the first test verifying cooperation between three complete MAVEN CAVs subsystems for the sake of automated driving and platooning implementation. The whole end-to-end data generation and communication chain used for platooning algorithms at three test vehicles, as well as their automated systems' according reaction want to be verified.

These tests were executed on the Griesheim test track driving automated along the same predefined route between points (A) and (B) shown in Figure 45. Initially, only two vehicles are tested to verify the fixes to the platoon logic. With both vehicles driving automated, the DLR vehicle drives behind the Hyundai one over the stretch A to B. A schematic representation of these tests is depicted in Figure 65. At each vehicle, the AD_SW is configured to generate the same planned manoeuvre/route information and transmit it over the UDP IF1 interface for inclusion in the V2X CAMs (both vehicles are heading towards a virtual intersection at point B). The same manoeuvre/route information is set to the platoon logic using interface IF2. Also, at each vehicle the AD_SW continuously generates position and dynamics (speed, acceleration, etc.) that are passed through IF1 for V2X CAM transmission and through IF2 for platoon logic setting. Finally, the AD_SW sets the platoon logic with the currently planned trajectory over IF2 and with information about vehicles currently detected at the sensor fusion via IF5. Moreover, the platooning logic running at both vehicles is configured to indicate the ability for platooning over the UDP IF3 interface. With this configuration, the test verifies that the following three steps are executed correctly (please also refer to Figure 65):

1) the AD_SW at the DLR car sends its status, dynamics and manoeuvre/route planning data over IF1 and its ability to platoon over the IF3 interface to the V2X communication module. The V2X module accordingly populates CAMs on the SCH0. These CAMs are received by the Hyundai vehicle's V2X module. The V2X module forwards the IF3 data to the Hyundai platoon logic as well as the IF1 data to the AD_SW via UDP communication.

2) the platoon logic at the Hyundai car identifies a matching between the manoeuvre/route data received and its own data (crossing IF3 and IF2 data). Also, it learns that the DLR vehicle is able to platoon (IF3 data). As the DLR car is detected (IF5) to be behind at a valid distance to initiate a platoon, CAMs transmissions on SCHx for platooning management and control can be initiated. For this purpose, the Platoon logic on the Hyundai car starts sending platooning data over the UDP IF3 interface. This data is received by the V2X module, which starts transmitting CAMs on the SCHx in addition to those transmitted on the SCH0. Both CAM types are received by the DLR vehicle. The receiving V2X module forwards the received Hyundai car's manoeuvre/route plans and platooning information over the UDP IF3 interface to the platoon logic.

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3) the platoon logic on the DLR car processes all the received information (IF1, IF3, IF2 and IF5) and acknowledges the initialization of the platoon by starting transmitting its own platooning information over the UDP IF3 interface. This information is received by the V2X communication module that starts transmitting CAMs on the SCHx on the DLR car as well. The CAMs are received by the Hyundai vehicle (IF3): from this moment on the platoon is formed and get controlled thanks to the exchanged V2V information.

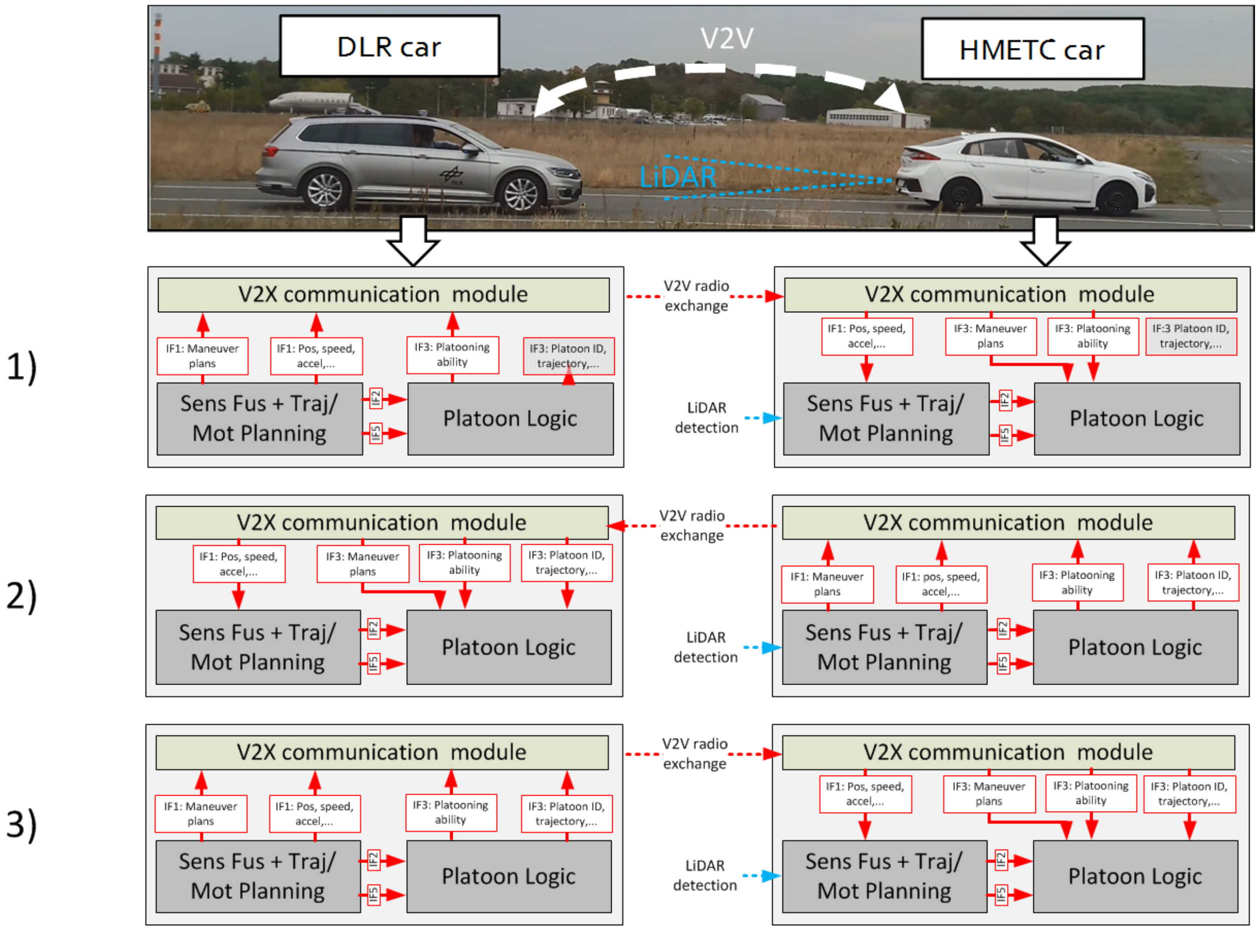

Figure 65: Schematic V2X interaction during platoon tests in Griesheim

The above described results are also summarized in the next table.

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	Tests description	Result
Platooning logic	DLR planned maneuver & ability to platoon rx @ HMETC car and forwarded to platoon logic → cars have same route	✓
	DLR position, speed, acc, rx @ HMETC car and forwarded to sensor fusion	✓
	DLR V2X rx data fused with back LiDAR data @ HMETC car → no obstacle between DLR and HMETC car → platoon is initialized @ HMETC car	✓
	Platoon info (ID, trajectory to follow, etc.) tx from HMETC car and rx @ DLR car	✓
	HMETC platoon info rx at DLR car and forwarded to platoon logic → cars have same route → platoon is initialized @ DLR car	✓
	Platoon info (ID, trajectory to follow, etc.) tx from DLR car and rx @ HMETC car → Both cars drive in platoon with DLR following HMETC car	✓

Figure 66: Summary of results for final platooning tests on the Griesheim test track

The next step was testing the inclusion of the third platoon vehicle in the tests for evaluation of the other platooning use cases. Unfortunately, these tests needed to be interrupted because of ego localization issues related the reception of correction data at the FASCarE. As result, the use cases platoon joining (UC2), platoon leaving (UC4) and platoon break-up (UC5) could not be verified. After the end of this integration event, a problem was found in the reception unit for the correction data, which is only working in the northern part of Germany and not in the area of Griesheim.
Nevertheless, the overall integration activity at this event was very fruitful, since the general platooning of two vehicles could be fully shown.

Figure 67: Platooning and sensor data fusion tests in Griesheim

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5.4.2.3 Event 21: UC 7 with DLR and HMETC cars on public roads

Integration Sprint		6
Date of achievement		January 2019
Importance		High
Setting	Software	Dominion and Hyundai-AD
	Test site	Tostmannplatz
	Vehicles	FASCarE, Ioniq
Goal		GLOSA test on public roads successful in Braunschweig

Event 21 is about implementing UC 7 "Speed change advisory (GLOSA)" with DLR and HMETC vehicles on public road. During this event, the DLR vehicle FASCarE was used and the scenario to fullfill this experiment was to drive from south to north and cross Tostmannplatz intersection. The traffic light sent continiously SPaT and MAP (see D.5.1 [10]) messages which contains several dynamic zones and a velocity assigned to each of those zones. As explained in section 5.1.1.2.1, the "Tactical decision module" of the DLR vehicle automation estimates the advise zone and sends the velocity of that zone to the trajectory planner.
Important point to be mentioned here is that driving in simulation and closed test track without other road users means that vehicle automation follows the GLOSA velocity as it is the only calculated velocity, as described in e.g. event 12. But in an urban scenario with public traffic, "Tactical decision" calculates other velocities such as collision free velocity with front man. And the minimum velocity is sent to trajectory planner.

Figure 68 illustrates one of the experiments done at Tostmannplatz and as it is shown, the vehicle approaching the intersection and for the first part there is no advised velocity because the vehicle is far away from the intersection. While approaching, via V2X, the vehicle automation receives the "STOP velocity" which is defined as "50 m/s" and means that vehicle reaches the intersection when traffic light is red. Therefore the "Tactical decision" based on the current distance of the vehicle to the stop line of the traffic light and current lane situation, suggests to smoothly decelerate till stand-still at the stop line.
When the traffic light switches to green, a new speed advised is sent from traffic light and received by the DLR vehicle resulting in an acceleration and the crossing of the intersection.

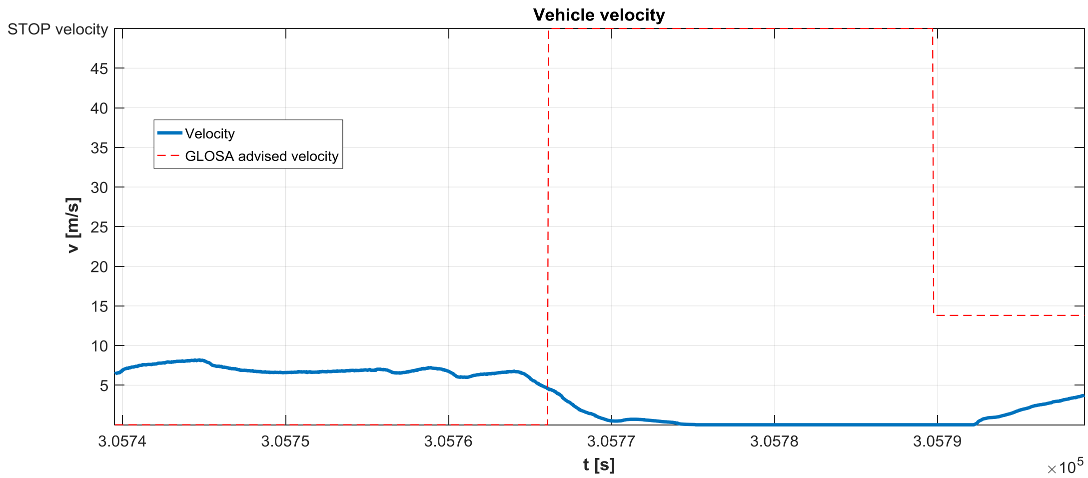

Figure 68: Tostmannplatz experiment 1, Driving with GLOSA advised velocity

Figure 69 illustrates another scenario. This time, while approaching the intersection, the DLR vehicle receives "13.8 m/s" advised velocity and not the "STOP velocity" as in the previous

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example. This means if the vehicle follows the suggested speed advice it can cross the intersection when the traffic light is still green. In this experiment run another non-cooperative vehicle drove in front of the DLR vehicle at lower speeds. As result, the driven velocity could not be the same as advised. In this case, the DLR vehicle was not able to keep up with the movement of the zones and finally reached the succeeding zone, which is including an advised speed of “STOP velocity”. Therefore, like in the previous example, a smooth deceleration is calculated, bringing the vehicle to a stand-still at the stop line, and afterwards accelerating again when the light turns green and a new advice is received.

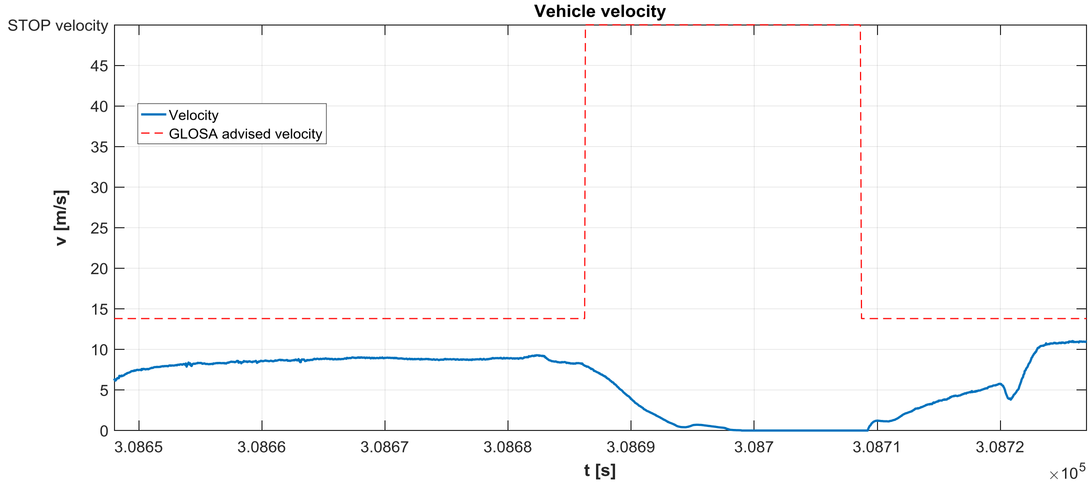

Figure 69: Tostmannplatz experiment 2, Driving with GLOSA advised velocity

The HMETC was also reacting to the GLOSA advices in the same way, as it was basically already shown during event 15 and during integration sprint 5, see section 5.3.1.1.

5.4.2.4 Event 22: UC8 on public roads

Integration Sprint		6
Date of achievement		February 2019
Importance		Medium
Setting	Software	Dominion
	Test site	Tostmannplatz
	Vehicles	FASCarE
Goal		Lane advice performed on Tostmannplatz

The lane change advisory scenario has been done in a complex urban scenario at Tostmannplatz intersection. As it is shown in Figure 70, the DLR automated vehicle FASCarE drives autonomous from south to north. The red lines on the HD map are the rear axle GPS positions of the automated vehicle. The traffic light sent LAM messages advising to the left lane to the DLR automated vehicle. After detecting and analysing the gaps on the desired lane, a lane change is effectuated.
Figure 71 illustrates the velocity profile for the same scenario, as it is shown, when the automated vehicle is approaching the traffic light. At a given time, it receives the LAM message from road side unit installed at Tostmannplatz because the traffic flow is less at left lane, shown with violet line. Therefore the “tactical decision” module analyses the gaps and evaluate the required action to change the lane. As already mentioned in the vehicle automation chapter, the DLR vehicle, despite the lane change suggestion from RSU,

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analyses the situation to make sure that based on its current states, lane change is possible or not. For this test case the lane change was possible and the required action to merge to the selected gap is reducing velocity. The vehicle merges to the gap and increases its velocity. Then the vehicle reaches the stop zone defined by GLOSA, shown with the red line in the figure, and therefore it reduces its velocity till reaching a stand-still behind the stop line. When the traffic light turns to green, shown with the green line, the vehicle accelerates and crosses the intersection.

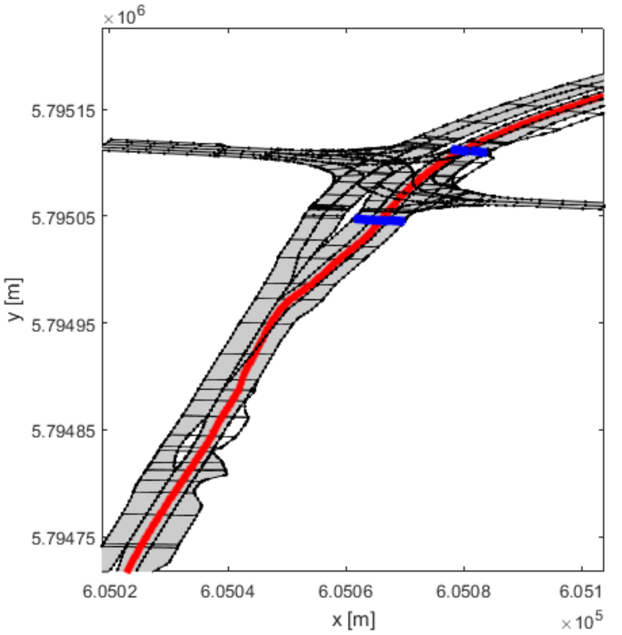

Figure 70: Lane changing scenario triggered from traffic light via LAM at Braunschweig Tostmannplatz

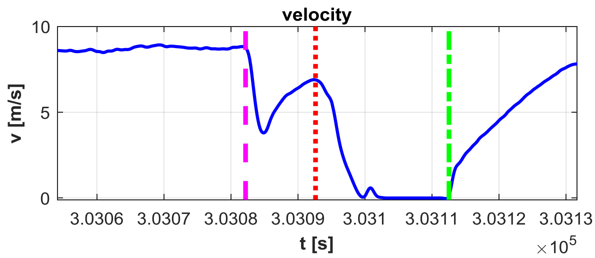

Figure 71: Velocity profile of lane changing scenario

5.4.2.5 Event 23: UC7/8/10/14/15 on public roads

Integration Sprint		6
Date of achievement		February 2019
Importance		High
Setting	Software	Hyundai-AD_SW, Dynniq ImFlow (with MAVEN extensions)
	Test site	Helmond
	Vehicles	Ioniq
Goal		Verify, for the first time on real roads and urban traffic, the MAVEN use cases for infrastructure-assisted automated driving using the HMETC

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	automated vehicle prototype and the Dynniq traffic light controller. For this verification, a precondition is that the Hyundai automated vehicle prototype performs V2X interaction with the Dynniq traffic light controller. The HMETC vehicle shall broadcast its intended route, manoeuvre and vehicle characteristics; in response the Dynniq traffic light controller shall broadcast meaningful speed and lane change advices from the RSU operating at the test intersection. It must be verified that with the received information, the HMETC vehicle implements correct automated adaptation to lane-change and speed advices to cross the test intersection in real-life traffic conditions. In addition, the HMETC automated vehicle shall automatically inform back the traffic light controller about the actual status of compliance to the received advices, which enables further optimization of the traffic light controller's phase and timing calculations.

The preparation of these use cases was done on the test track as described in Sections 5.1.1 and 5.2.1. Moreover, to obtain an exemption for driving automated on the real road test site, HMETC underwent a process with the RDW (Netherlands Vehicle Authority for vehicle licensing, supervision, enforcement and registration) which included provision and explanation of vehicle prototype documentation, detailed test description, associated hazard analysis and risk assessment (HARA), as well as a vehicle inspection and testing by RDW experts at the Griesheim test track.
Finally, the real road tests were executed at the Helmond test intersection 701 driving towards the intersection from both the east and west direction (see Figure 72). The tests were executed in such a way to verify individual functionalities in a separate way, and to increase stepwise the complexity of the tasks assigned to the vehicle automation.

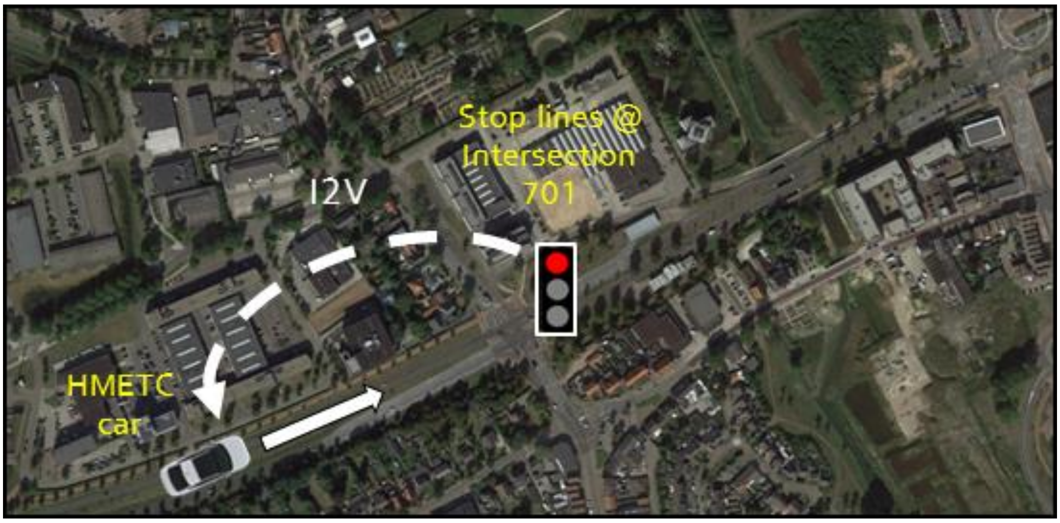

Figure 72: MAVEN test intersection at Helmond

First, the vehicle was driven manually for verifying the reception of I2V SPaT/MAP and LAM messages from the infrastructure and its consideration in the AD_SW by using the debug HMI described in section 5.2.2.1. At the same time, the correctness of the V2I data sent to the infrastructure could be verified by analysing logs at the V2X communication module of the HMETC car. This information includes the vehicle route in terms of ingressing and egressing lanes at the intersection as currently driven and planned by the HMETC vehicle. This was not a trivial task, as it implies the AD_SW to localize the current vehicle position on the driven lanes extracted by the HAD map, which is then converted into a SPaT/MAP-like lane index representations understandable by the infrastructure. The initial manual drives also permitted to check the functionality of the AD-SW sensor fusion and tracking in correctly recognising surrounding objects

that must then be considered as obstacles for later automated driving runs. This functionality could be tested and verified by observing the output of the visualization tool of Figure 49.
As a second step, the AD_SW was activated only in the longitudinal direction and without considering I2V message receptions. This was done to prove that the vehicle follows the preceding cars at a safe distance and stops safely behind them.
As a third step, the AD_SW was activated both longitudinally and laterally, still without consideration of I2V messages. This was done to verify the correct automated driving along the lanes of the test site HAD maps, where the vehicle has to drive automated being well cantered between the real lane markings. Such tests were successfully executed along both lanes of the west and east intersection approaches but sometimes required some manual adjustments of the HAD map lane coordinates where mismatches with the DGPS-calculated vehicle trajectory were identified. As I2V SPaT and MAP messages are not considered by the AD_SW at this stage, the AD_SW cannot know when to stop at the signalized intersection, hence the driver had to take back the control of the car in case of getting close to the stop line when the traffic light is red.
After the previous tests were successfully executed, the next step was to activate the lateral and longitudinal automation with consideration of I2V messages for GLOSA adaptation (SPaT/MAPs). The successful results of these tests have been recorded in videos depicting the HMETC car from the inside as well as from the outside while executing the GLOSA adaptation use case. These videos have been shown to the MAVEN consortium during the March 2019 meeting at Rüsselsheim and presented at the MAVEN stand during the EUCAD conference in April 2019. A snapshot of some of these videos can be seen in Figure 73, where the images of the HMETC car are synchronized with the status of the debugging HMI showing the compliance of the AD_SW to the information V2X received from the infrastructure.

Figure 73: HMETC GLOSA adaptation at the Helmond test intersection (1)

Another proof of the GLOSA adaptation functionality at the HMETC car can be seen in Figure 74, which represents the speed profile of the car while approaching the stop line. As it can be seen, the I2V GLOSA speed is only transmitted after start of the green phase. The car is approaching the stop line while the traffic light phase is red. As a consequence, the HMETC AD_SW correctly slows down and stops the car at the stop line behind other vehicles and waits for the green to come. When the traffic light gets green, the received SPaT/MAP messages trigger the automated restart of the car that ramps the speed up to cross the stop line at the suggested GLOSA speed.

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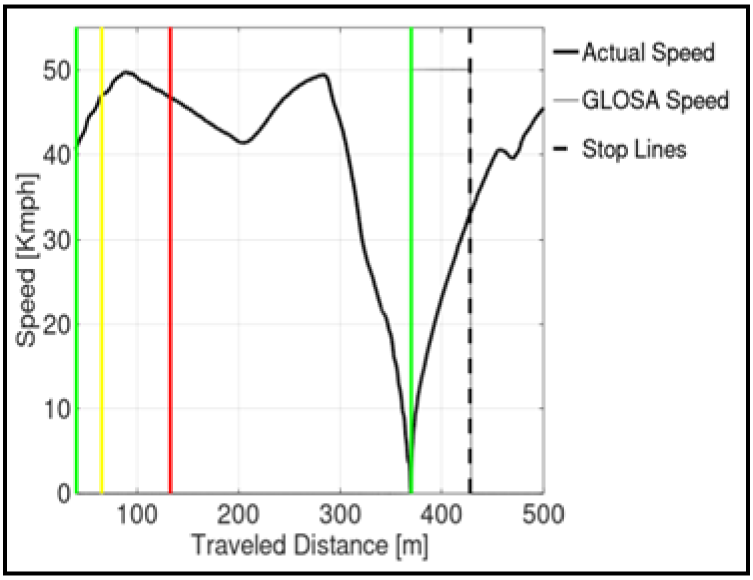

Figure 74: HMETC GLOSA adaptation at the Helmond test intersection (2)

The last step was the activation of the AD_SW for longitudinal and lateral automated driving while considering both GLOSA and lane change advices from the infrastructure. For these tests the co-drivers support the driver by reading relevant values from the AD_SW debugging HMI. In this way, the driver knows the current distance to the lane change point suggested by the infrastructure as well as the status of the gaps with the obstacle vehicles considered by the AD_SW lane change acceptance logic. By knowing this information, the driver knows in advance when and if an automated lane change is going to occur, hence he is ready to take back the control of the vehicle in case of risky situations. The successful execution of the automated adaptation to the I2V lane change advices has been also recorded in videos shown to the MAVEN consortium as well as at the EUCAD conference. A snapshot of some of these videos is depicted in Figure 75.

Figure 75: HMETC lance change advice adaptation at the Helmond test intersection (1)

The functionality of the HMETC lane change advice adaptation logic at the Helmond test site can be seen in Figure 76. The figure represents the status of the vehicle's heading as well as the status of the gaps with the obstacle vehicles considered to safely execute the lane change while

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approaching the intersection. In the top figure, the point at which the lane change should be executed upon suggestion by the infrastructure is also indicated. As it can be seen, since all the actual gaps with the surrounding vehicles are higher than the ones desired by the lane change logic, the automated lane change is actually executed. This is visible in the change of the vehicle's heading in the top graph.

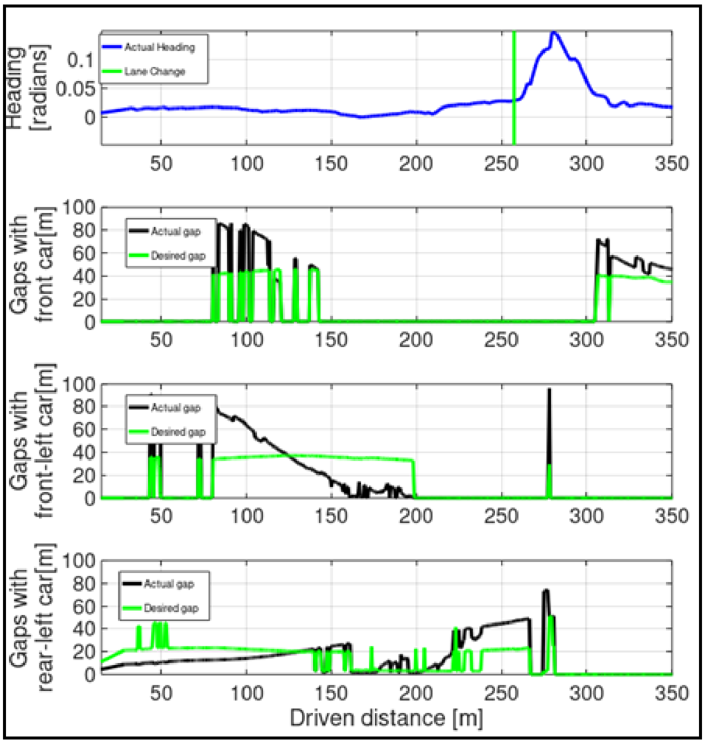

Figure 76: HMETC lance change advice adaptation at the Helmond test intersection (1)

At the test site the RSU was also capturing the messages and tracking the vehicle. An example of the logging entry (also see 5.4.1.3.1) is shown below:

```
21/02/19 14:25:52 CAM decoder:
stationID=120,lat=514747190,lon=56333813,heading=2412,speed=1111,inLaneID=3,outLaneID=143
,SG=2,speedComp=Y,int=701,occupants=4,distanceBack=15,LAMComp=Y2
```

The logging of the vehicle and the infrastructure were compared and found to be consistent. The most important element of this was of course the indicated signal group for the vehicle and its position. Correct communication of these values enabled the RSU to pass the information of the vehicle to the traffic light control software ImFlow with MAVEN extensions and have the same behaviour as in Event 18 of 22nd of August 2018.

5.4.2.6 Event 24: UC 11 Queue estimation + UC 12 route advice

Integration Sprint		6
Date of achievement		15-03-2019
Importance		medium
Setting	Software	SUMO
	Test site	Prague
	Vehicles	Simulated

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Goal	Demonstrate implementation of the queue length estimation algorithm and local level routing algorithm and evaluation in SUMO.

The goal of this test event was to demonstrate the implementation of the queue length estimation algorithm and the local level routing algorithm and evaluation in SUMO.
The queue length estimation algorithm (UC11) was tested in a simulated environment consisting of Eclipse SUMO (with “simpla” platooning module), ImFlow and custom code bindings on intersection 701 in Helmond (Hortsedijk/Europaweg). Lane change estimator was tested on the approach from 702 to 701. The test network in SUMO is a manually modified export from ImFlow tools so that all relevant intersection parameters that assure collaboration between ImFlow and SUMO are preserved. The initial test results were presented in D4.1 [11] and D4.4 [17] for the current evaluation round. The simulation covers three different flow densities (900, 1800, and 3600 vehicles per hour), five different penetration rates (0, 10, 40, 60, 80, 100% of automated personal vehicles that are platooning-capable), different detector sampling rates (1, 5, 10, 60, 90, 120 seconds) and four different layouts (isolated/downstream intersection, dedicated/shared right turn). Not all combinations were simulated, the detailed description will be provided in D7.2.
The route advice (U12), i.e. the local level routing has been tested on Žižkov street network in Prague again for three different flow densities (900, 1800, and 3600 vehicles per hour), seven different penetration rates (10, 20, 30, 50, 70, 85, 100% of automated personal vehicles), and three different route advice modes (no advice, advice based on historic travel times, full local level routing that takes into account also current traffic and signal settings). A full matrix of the above experiments was simulated with 10 replications, preliminary results were reported in D4.4 [17]. Also a video demonstrating the principle and effects of LLR will be presented at the final MAVEN event.
UC11 snapshots are shown in Figure 77 and Figure 78. UC12 is shown in Figure 79.

Figure 77: UC 11 Snapshots on the map (a) and the same section in SUMO (b)

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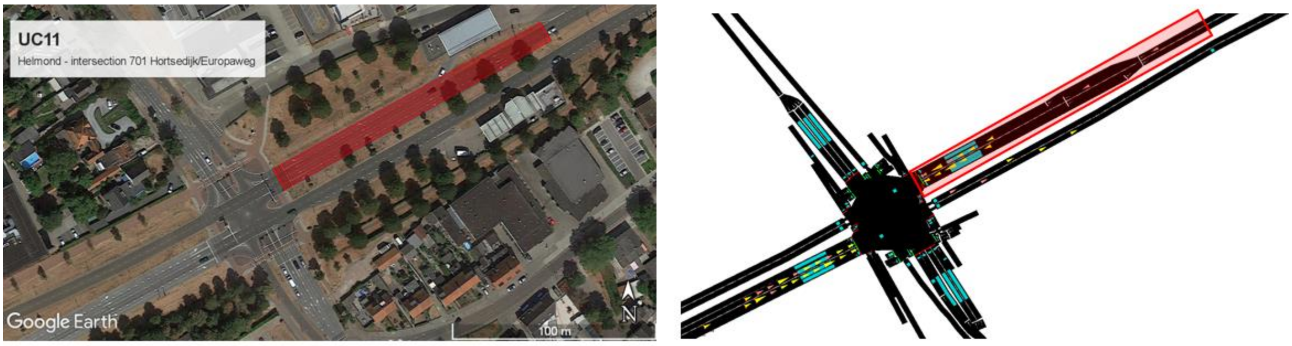

Figure 78: UC 11 in more detail

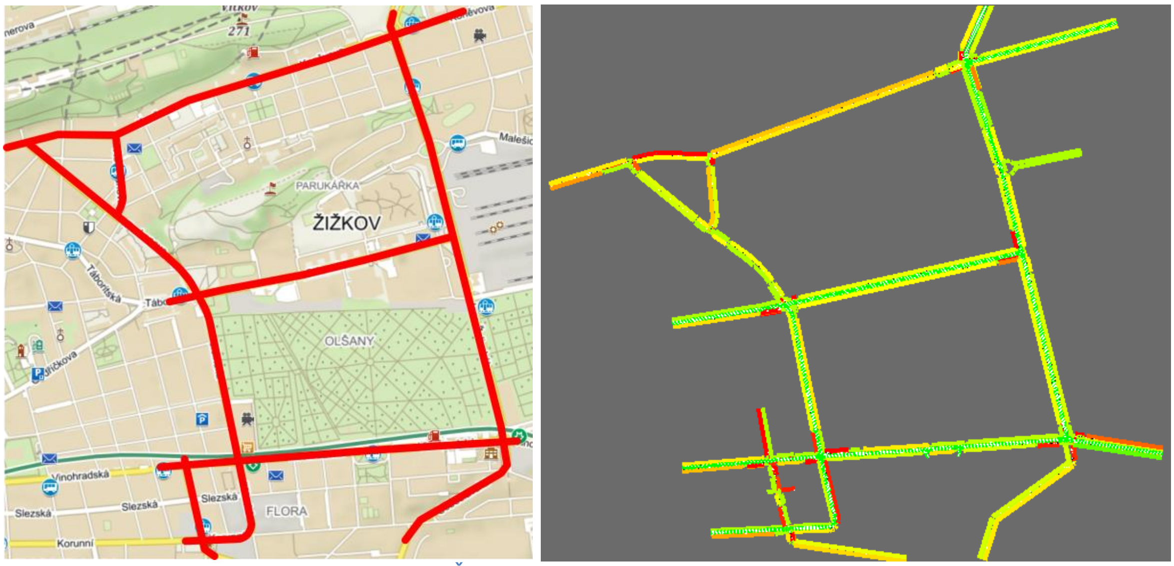

Figure 79: UC12 test polygon at Praha Žižkov (left) and a snapshot of the Eclipse SUMO simulation (right) showing actual link travel delays for the highest (i.e. circa 3600 vph) flow rate settings.

5.4.2.7 Event 25: UC 7/10/13/14 for impact assessment

Integration Sprint		6
Date of achievement		24-01-2019
Importance		Medium
Setting	Software	SUMO
	Test site	Helmond (large network 101-104)
	Vehicles	Simulated
Goal		Test the integration of GLOSA (UC7) with queue estimation (UC10) and green wave (UC13).

This test was carried out successfully and a video of the results was already linked in Section 5.4.1.3.2. Furthermore, a paper on this subject was submitted and accepted by the ITS Europe congress. The detailed assessment results will be included in D7.2.

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5.4.2.8 Event 26: UC1-7 & 16 with three cars (DLR and HMETC) on public roads

Integration Sprint		6
Date of achievement		April 2019
Importance		High
Setting	Software	Dominion / Hyundai-AD
	Test site	Tostmannplatz
	Vehicles	FASCarE, Ioniq, T5 Bus
Goal		Show all platooning use cases, GLOSA and collective perception on the Tostmannplatz public roads

The final event 26 also took place on Tostmannplatz in Braunschweig, this time with the automated vehicles FASCarE of DLR and the Ioniq of HMETC. The runs were accompanied by a manually driven T5 Bus, as the other automated DLR vehicle ViewCar2 suffered from a battery malfunction not allowing it to be used during the integration weeks. As the T5 bus is equipped with a Cohda box and an inertial platform including differential GPS as well, and thanks to the flexible approach of the Dominion framework, it was possible to run the vehicle automation software including the platoon logic etc. on the bus. Of course, as the T5 bus does not have an interface for controlling it by the automated driving vehicle controller, the software was only used passively, which is sufficient for testing the logical behaviour of the platoon logic with three vehicles.

All test runs of this event except the UC16 tests have been performed driving in northbound direction to the Tostmannplatz and crossing it. The automated driving software at DLR and HMETC was running on the long stretch of road leading to the Tostmannplatz already, and switched off right after passing the intersection, in an area where the two northbound lanes have just merged into one, see Figure 80.

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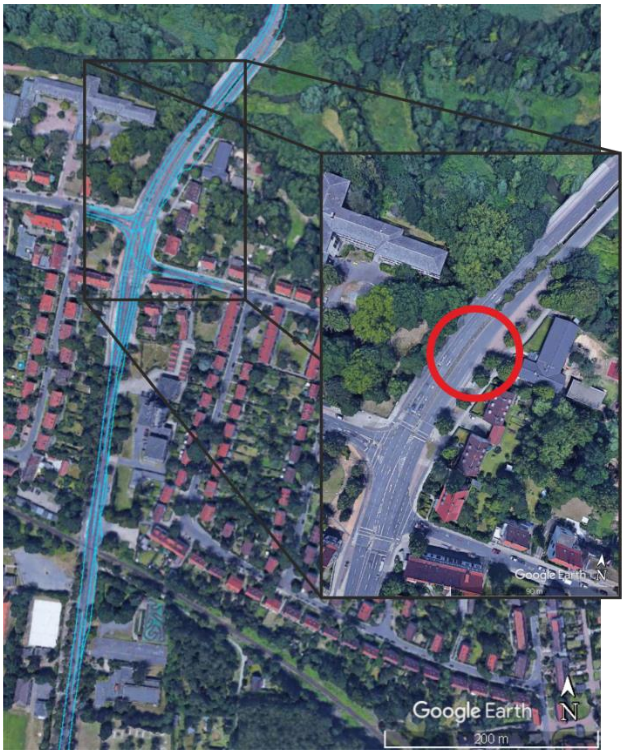

Figure 80: Tostmannplatz map showing the digital map (cyan) used by DLR vehicles. Test runs always started in at different places in the south for UC1-8. In the circle, the merging area important for UC5 is highlighted.

Figure 81: Platoon of two vehicles in combination with GLOSA

The test runs started with platoon initialization (UC1), driving in a platoon (UC3) and platoon termination (UC6) with two automated vehicles, the FASCarE and the HMETC Ioniq, as shown in Figure 81. After performing the first test runs building a stable platoon, also the crossing of the intersection in combination with GLOSA advices (UC7) was put into focus, as well shown in the figure. Figure 82 shows data recorded in the FASCarE, which always was driving in the role of the

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following vehicle in the platoon. It is shown that right after the automation is switched on (left red line in the figure), the vehicle speeds up to close the gap (green area A). Then, the vehicle is following in a stable platoon with the desired time headway of 2.5s. This headway has been chosen due to security reasons in public traffic. Then, in area B, an object has been detected between the vehicles (as false positive). As described before, this object directly leads to a splitting of the platoon, i.e. in this case to the platoon termination, resulting in braking and enlarging the distance to the leader. Since the false positive disappeared right after, the effect was rather low and the platoon has been re-initialized right after. In area C the GLOSA advices have been received and the platoon leader as well as the follower reduced their speeds in order to reach the traffic light at green. The vehicles crossed the traffic light and the automated driving software was switched off. As consequence, the distance between the platooning vehicles became larger and the platoon was terminated.

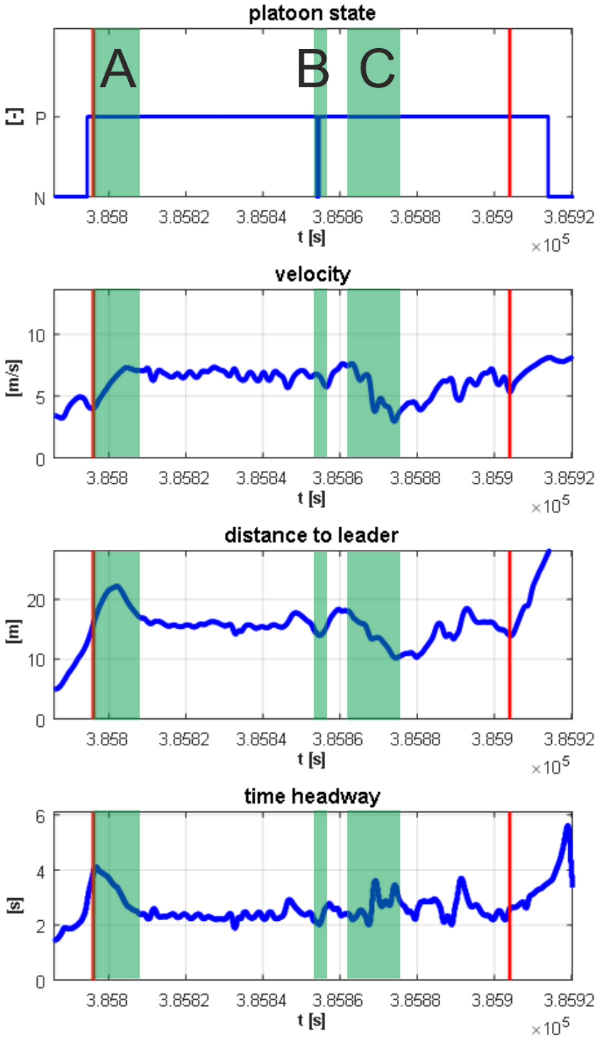

Figure 82: Platooning on Tostmannplatz with two vehicles. Red lines show enabling and disabling of automated driving. The green zones show the platoon forming (A), a very short platoon termination (B) and the GLOSA reaction (C).

During the tests, the correct behaviour of the GLOSA was also recorded by the platoon leading vehicle, shown in Figure 83. Both graphs depict the actual speed of the AD vehicle as a function of the travelled distance. In both cases, the AD mode is activated before the red light phase starts (red line). As soon as the red light phase start, the GLOSA advice is different than 0 (thin line). The vehicle continuously localizes itself in the GLOSA distance-zones and adapts to the GLOSA suggested speed of that zone, which allows in both cases to cross the stop line(s) (dotted line) after the green light phase start (green line). Please not in this context that there are two

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consecutive stop lines on Tostmannplatz. In the first figure the second stop line is not depicted as the ROS bag file is cut at the very end right before crossing it.

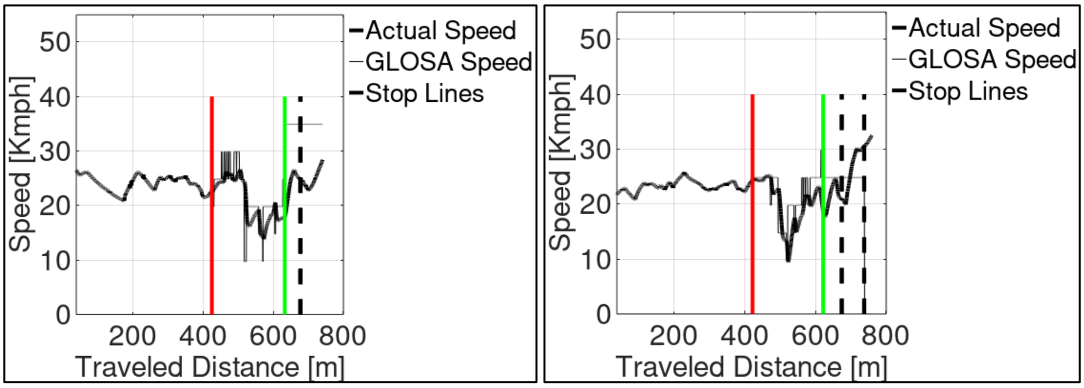

Figure 83: GLOSA reactions in the HMETC platoon lead car

In the following, the runs have been repeated, also with the third vehicle as shown in Figure 84. As shown, the debugging HMI inside the T5 Bus indicated the platooning of the three vehicles, with the Hyundai Ioniq as automated driving platoon leader (ID 100 in the HMI), the automated driving DLR FASCarE (ID 110) and the manually driven T5 Bus (ID 14, in blue as it is the ego vehicle). The HMI also shows with small arrows that the T5 is currently in “closed gap” mode. In addition, also the current signal phase (green dot) is shown together with the advised speed in the current area (49 km/h) and the time when the light is switching to red (20 seconds).
By performing these runs, it could be shown that the platoon logic implementation was able to cope with more than two vehicles as well.

Figure 84: Logical platoon of three vehicles and the respective debugging HMI (left) as shown in the third platooning vehicle, the manually driven T5 bus.

Third part of the testing was focussing on the more special cases of platooning, like the platoon break-up (UC5). One of the test drives is shown in Figure 85. At that run, both cars are driving in a stable platoon as described before, always trying to keep 2.5s time headway. At some point in time the GLOSA advice is received and the car slows down to reach the traffic light at green. Since

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there is a bus standing at the red traffic light (lane advices where switched off during this run), the platoon leader needed to reduce the speed further. To keep the 2.5s time headway, also the follower reduced the speed as shown in the diagrams. After passing the traffic light, the platoon leader constantly speeded up and the follower tried to further keep the time headway.
Then, as indicated in Figure 80, the vehicles reach a merging area where two lanes merge into one. If the platooning vehicle is detecting any vehicle on the adjacent lane in this area, it is by default opening a gap. No further algorithm for detecting the intention of the vehicle (as described e.g. in D3.1 [7]), e.g. by checking the indicator signals of those vehicles, needed to be used. The gap is opened and the non-MAVEN vehicle is merging. At one point in time during this merging, the non-MAVEN vehicle is classified as new vehicle ahead on the driven lane (leap in the distance curve). As result, the requirements for a platoon are no longer met (see D3.1 [7]) and the platoon is terminated.

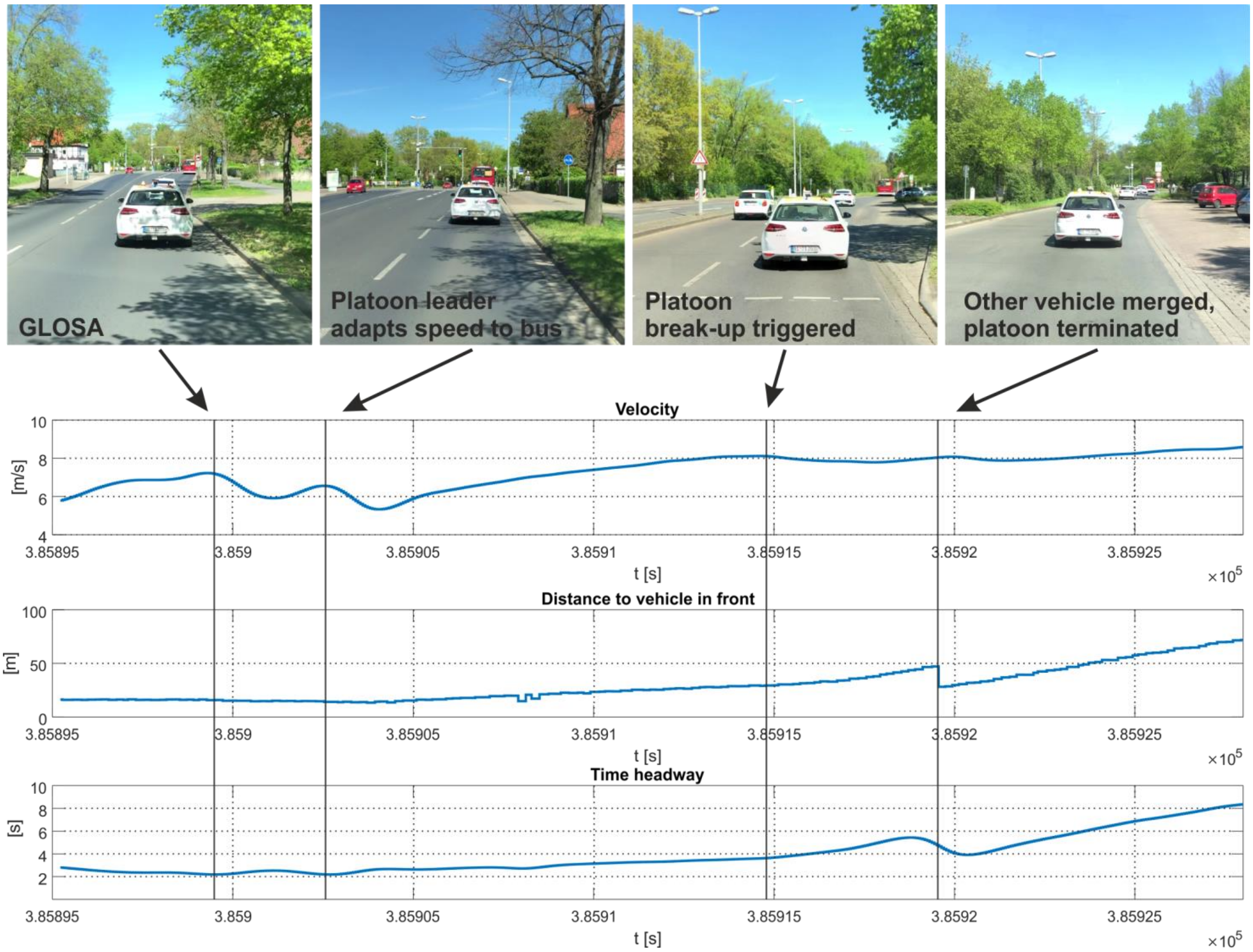

Figure 85: Platoon break up on Tostmannplatz

Finally, also UC16 needed to be investigated. Therefore, the hemispheric camera mounted on the Tostmannplatz intersection was used. As the camera's field of view is only allowing detecting objects in southbound direction (see Figure 86), the FASCarE was driving in that direction during the runs. The camera was constantly monitoring the intersection and detecting the objects, as described in 5.4.1.2.2. The detected objects have been incorporated into collective perception messages (CPM) which have been broadcasted.

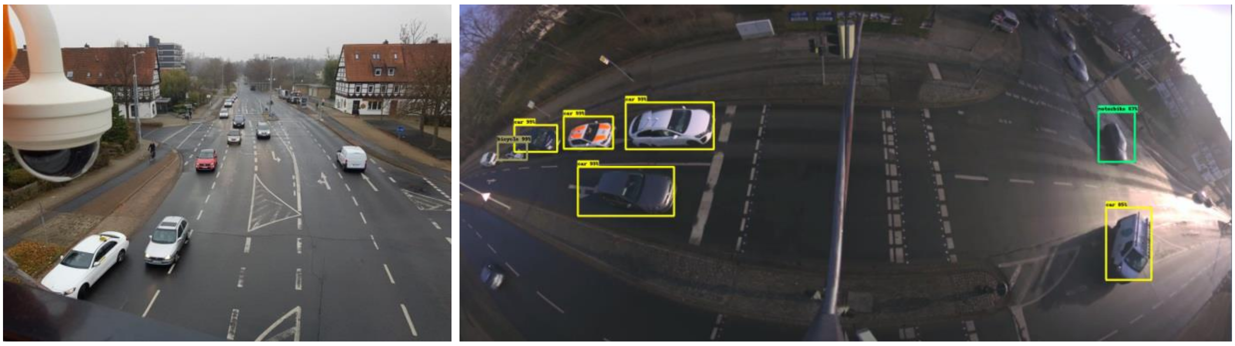

Figure 86: Hemispheric camera on Tostmannplatz (left) and detected objects of it used for CPM generation (right). Note that the right image is flipped.

When received by the DLR automated vehicle, the objects were taken into account by the sensor data fusion, but marked as objects detected only by an external device. Such objects are not used in the vehicle automation as objects detected by internal sensors, like a LIDAR. Reason for this is that the vehicle does not trust the source in the same way than it would for internal sensors. Therefore, there are two different ways of reacting to the different categories of objects. While internally detected objects are treated as really existing ones and are therefore fully taken into account, e.g. by strong braking, the externally detected objects are treated in a softer way, as they are only used to make the vehicle “more alert” of the upcoming situation and that the vehicle is already softly reacting to the possibly upcoming thread. In MAVEN, it has been decided for DLR that the vehicle is already taking obstacles into account while there are not perceivable by the internal sensors. In that case, the vehicle is starting to reduce the speed by 20%. This behavior can be seen as one example of a reaction. More research is needed beyond the end of MAVEN to design the optimal behavior in a similar case.

Figure 87 shows an example of the performed runs. As shown, the FASCarE is heading for the Tostmannplatz (A). At this point, the internal sensors of the vehicle are not able to detect any obstacle behind the curve. The hemispheric camera detects waiting vehicles as objects standing at the Tostmannplatz intersection and forwards these objects via CPM. The FASCarE receives the obstacle data and reduces speed from 10 to 8 m/s. After passing the curve (B), the obstacles come into view of the internal sensors, which now acknowledge the existence. As consequence the FASCarE is reducing speed (C) and stopping right behind the obstacle.

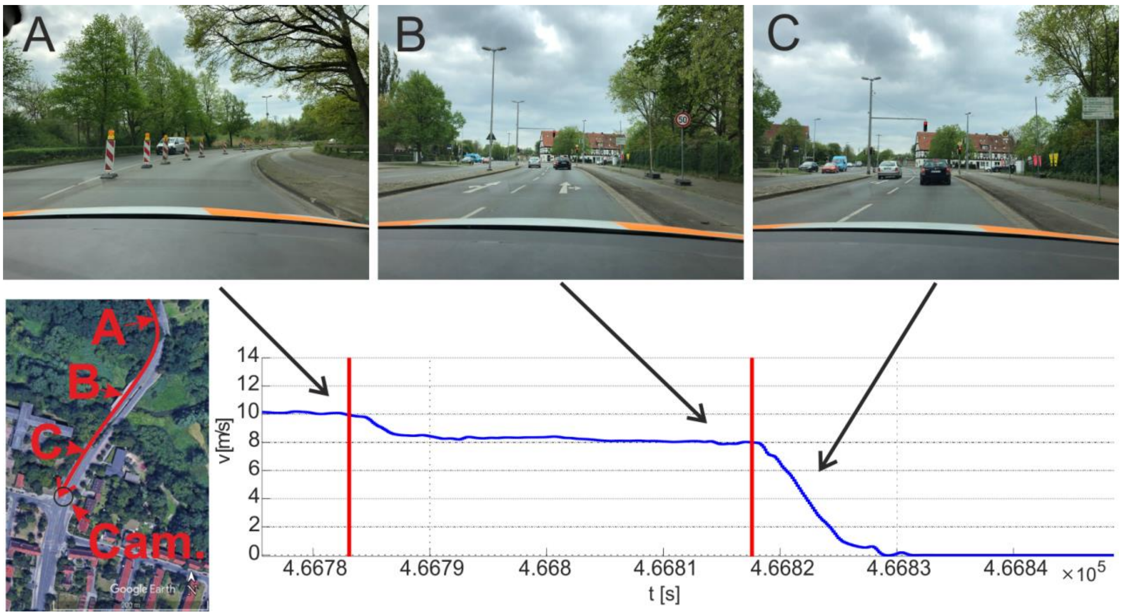

Figure 87: Soft and hard reaction of the automated vehicle FASCarE

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6 Conclusion

This deliverable shows the integration work done since D6.3 [3]. After repeating the changes done to the use cases, the integration sprints and the different test events which have been in focus are introduced.
The passed integration sprints have been described in detail, showing that all use cases have been tested. The results of the performed tests and the verification of the initially formulated requirements are shown in the upcoming D7.2

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