MAVEN

Managing Automated Vehicles Enhances Network

WP7 Assessment and demonstration

Deliverable nº: D7.2

Impact Assessment – Technical Report

Dissemination Level: PU

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Abbreviations and definitions

Abbreviation / Term	Definition
ADAS	Advanced Driver Assistance Systems
C-ITS	Cooperative Intelligent Transport Systems
CAM	Cooperative Awareness Message
CAV	Cooperative Automated Vehicle
CTU	Company: Czech Technical University in Prague
DLR	Company: Deutsche Zentrum für Luft- und Raumfahrt (DLR)
EC	European Commission
GLOSA	Green Light Optimised Speed Advisory
GPS	Global Positioning System
HAD map	Highly Automated Driving map
HMETC	Company: Hyundai Motor Europe Technical Center GmbH
HMI	Human Machine Interface
HYU	Company: Hyundai Motor Europe Technical Center GmbH
HW	(Hardware) Articles made of material, such as cabinets, tools, computers, vehicles, fittings, and their components [mechanical, electrical and electronic]. Computer software and technical documentation are excluded.
KPI	Key Performance Indicator
MAVEN	Managing Automated Vehicles Enhances Network
OBU	On-board Unit
RSU	Road Side Unit
SPaT	Signal Phase and Time message
Stakeholders	The people for whom the system is being built, as well as anyone who will manage, develop, operate, maintain, use, benefit from, or otherwise be affected by the system.
SUMO	Simulation software (Simulation of Urban Mobility)

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SW	(Software). Computer programmes and computer databases.
VRU	Vulnerable road user
WP	Work Package

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Executive Summary

This deliverable focuses on an important topic within the MAVEN project – evaluation of the project impact. This is an important step that will allow us to say what the results and impact of the different technologies, functionalities as well as assumptions are. It covers different dimensions of the impact assessment as stated in the Deliverable D7.1 – Impact assessment plan [10].

The field tests proved that the technology in the vehicle works together with the infrastructure and the solution is technically feasible. This was demonstrated also during particular events and is reported in the attached test protocols. At the same time, the emulation and simulation in Dominion software proved the functionality, for example with respect to the cooperative perception or safety indicators. The tests also proved that the key performance indicator "*minimum time to the collision"* decreases when applying the cooperative sensing. Also, the number of human interventions needed was zero in all the tests.

This deliverable also discussed selected results of a detailed user survey aiming at understanding the expected impacts and transition of automated vehicles. The overall number of respondents reached 209. The responses have revealed some interesting facts. For example, over 80% of the respondents believe that CAVs will decrease the number of traffic accidents. Similarly, about 70% of the respondents expect improvements in traffic congestions. Over 82% of respondents declared that they would accept some detour when driving if it helps the overall traffic situation.

The literature review, however, indicated that autonomous vehicles will have either a positive or a negative effect on the environment, depending on the policies. For example, opening cars as a mode of transport to new user groups (seniors, children etc.) together with improvements of the traffic, flow parameters can increase the traffic volume on roads. Policy makers shall focus on the integration of the CAVs into a broader policy concept including car or ride-sharing, electromobility and others.

In order to evaluate the transition, for example, the influence of different penetration rates of CAVs on the performance, a microscopic traffic simulation was performed. Here the particular MAVEN use cases, as well as their combination, was addressed. The results of the simulation are rather promising. The potential for improvements in traffic performance is clearly there. It was demonstrated that a proper integration of CAVs into city traffic management can, for example, help with respect to the environmental goals (Climate Action of the European Commission) and reduce CO_2 emissions by up to 12 % (a combination of GLOSA and signal optimization). On corridors with a green wave, a capacity increase of up to 34% was achieved.

The conclusions from this project can be used not only by other researchers but mainly by traffic managers and decision-makers in cities. The findings can get a better idea about the real impacts of particular use cases (such as green wave, GLOSA and others) in the cities. An important added value is also the focus on the transition phase. It was demonstrated that already for lower penetration rates (even 20% penetration of automated vehicles), there are significant improvements in traffic performance. For example, the platooning leads to a decrease of CO_2 emissions of 2,6% or the impact indicator by 17,7%.

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1 Introduction

1.1 Objectives of the document

Autonomous vehicles will influence many different aspects of human life [11][1]. Within the MAVEN project, several use cases were specified (in deliverable D2.1 [1]) and implemented in the later phases of the project.

The main objective of this deliverable is to document and discuss the results of the particular MAVEN use cases as well as the entire MAVEN project. The focus is mainly on the potential impact on the city environment, but the expectation of general city public and potential to meet these expectations are also provided. Nowadays, the penetration of automated vehicles is low. The focus within the MAVEN project is on demonstrating the potential of autonomous driving and preparing the road authorities with systems that can help them with a smooth transition towards a higher penetration of automated vehicles. For these several vehicles- as well as intersection-system prototypes were built within the MAVEN project. This allowed us to verify the technical possibilities and limitations of the technology. and determine the impact of higher penetration rates can be evaluated. Finally, the project also aims at the involvement of citizens, road authorities and other external stakeholders. Several workshops were organized and different dissemination activities were conducted to raise the awareness but also to learn about opinions and expectations of the general public. Altogether, these different measures allow us to provide the impact assessment, which is the objective of this deliverable.

The detailed Impact Assessment Plan was provided in deliverable D7.1 [10], where the methodology, major steps roles and time plan are described in details. This document follows the methodology and provides the results according to the process and quality described in deliverable D7.1 [10].

1.2 The process and tools

The MAVEN project aims to demonstrate the impact of autonomous driving in a wider scope. For this reason, we focus on four different dimensions, as stated in D7.1 [10].

Technical assessment – aims at verification through testing of requirements in field tests. There will be system prototypes ready and the technical functionality (for example performance of communication devices, functions of ADAS and others) will be verified. During the technical assessment, the different assessment tools will be used to verify the requirements stated in Deliverable D2.1 [1] are really fulfilled. Within the MAVEN project, there are different verification methods such as Analysis, Demonstration and Test. Appendix assigns each requirement to the verification method that ensures meeting of the requirements.

Functional assessment - allows functional assessment and to extend impact assessment in real-world environments. The particular use cases will be validated using simulation as well as emulation techniques. Also here, the function assessment will result in validation of certain requirements, as described in D7.1 [10].

Impact assessment – aims at evaluating the impact of platoon organization, negotiation algorithms, adaptive traffic light optimization, and trajectory and manoeuvre planning on traffic performance and emissions. This step will also evaluate the different parameters of the network or for example traffic demand on the key performance indicators. The microscopic simulation will be used, particularly the SUMO Simulation model.

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User assessment – addresses the acceptance and compliance of drivers and citizens of the particular MAVEN use cases and its results. Different target groups will be addressed, for example, the drivers of equipped vehicles and unequipped vehicles, as well as citizens of the pilot cities, guests, passengers. User surveys will be used to address this issue.

In order to be able to cover the different dimensions, several tools as provided in Figure 1 and described in the following paragraphs.

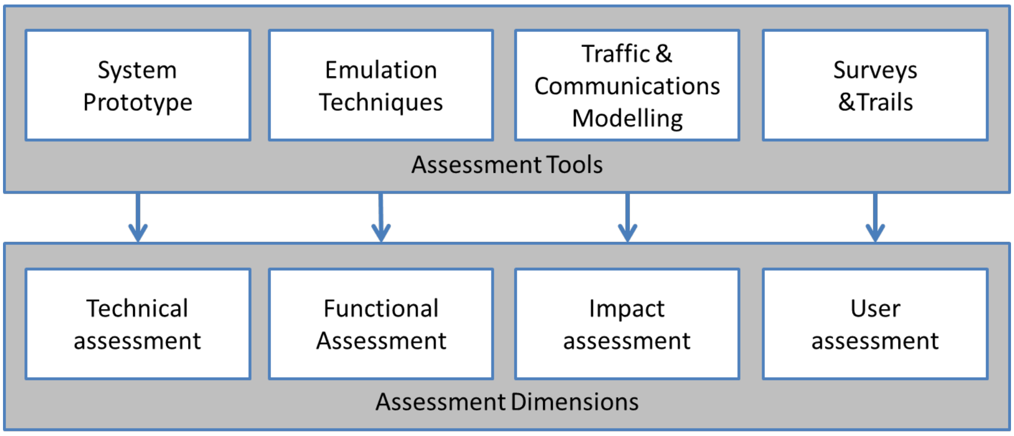

Figure 1 MAVEN assessment methodology (Source: D7.1 [10])

System prototype - MAVEN will develop an operational system prototype, including both vehicle and infrastructure elements, to be assessed in real-life conditions. Already equipped urban roads in Braunschweig (D) and Helmond (NL) will serve as proving grounds, primarily for the technical assessment of the system prototype, but not exclusively as will be described later. Both sites consist of a corridor of intersections equipped with communication and sensor hardware which are configurable by the consortium. It allows for modifications to traffic light control algorithms and V2X communication protocols. In Braunschweig sets of cameras for the online detection of vehicles and vulnerable road users are present. Highly automated vehicles from DLR and Hyundai will be used for a feasibility study of the platoon organization and negotiation algorithms developed in MAVEN. Additionally, MAVEN will strongly interact with automated vehicle initiatives in Greenwich and the wider smart city community to learn from each other and to position the MAVEN concept in a wider perspective. This is particularly relevant in the context of passenger transport and mobility service delivery.

Emulation techniques - To overcome limitations related to low market penetration of automation and cooperative vehicles, emulation techniques will be used to allow functional assessment and to some extend impact assessment in real-world environments. Using hybrid evaluation methods real test vehicles (with and without automation) can interact with virtual surrounding vehicles. The method combines a real-life test track with a traffic simulation model of that same test track, which allows the test vehicles to interact with vehicles in the simulation model. As the MAVEN algorithms will also be applied in the virtual traffic network, actual negotiations can take effect and the outcomes such as speed and lane changes or platoon formation can be directly experienced in the test vehicles. As the assessment of systems like the MAVEN concept is still a very new and novel topic, especially in real-world conditions, emulation techniques could become a key component in system assessment.

Traffic and communications modelling - Additionally, an important part of MAVEN will be traffic and communications modelling tools for an impact assessment on the traffic network. For this task, the open-source traffic simulation model SUMO will be used and extended with V2X

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communications and emission modules [11]. MAVEN will evaluate the impact of platoon organization, negotiation algorithms, adaptive traffic light optimization, and trajectory and manoeuvre planning on traffic performance and emissions. The impact will be evaluated for different intersection and corridor geographies, traffic demands and rates of penetration and compliance, relative to currently implemented control algorithms. Finally, MAVEN will include an assessment of the related V2X communications schemes through suitable simulation tools like iTETRIS, as communication aspects may drive the design of the MAVEN negotiation algorithms and protocols. Already modelled and calibrated networks of Helmond and Braunschweig will be used, whereas Prague will offer an additional case to study network effects as rich data from different sensors such as inductive loops, video detection, RFID tag detection or dedicated V2I communication is readily available.

Surveys and trials - The acceptance and compliance of drivers are crucial and MAVEN will address user assessment in several ways. An online survey will be prepared including video material that captures the concepts of MAVEN to evaluate the opinion of the general audience. Additionally, citizens of the pilot cities will be invited to drive in the test vehicles as a passenger. Finally, the acceptance of drivers in unequipped vehicles surrounding the automated ones will be assessed by asking participants to follow and observe the behaviour of the test vehicles.

1.3 Expectations of the MAVEN project

Before we provide a description of the actual results, let us summarize the expectation collected from the literature review at the beginning of the project. The following paragraphs are adopted from the deliverable D2.1. [1] we do not aim to repeat them but to highlight the most relevant ones.

Improved efficiency, safety and traffic flow and reduction of emissions

Balancing a traffic network is well established in theory. User-equilibrium is, however, by its nature non-optimal, while system-equilibrium has been a non-achievable target. Automation can shift network balancing towards system-equilibrium, which leads to better use of the existing infrastructure capacity and increasing it while reducing environment impact.

Earlier research as part of the eCoMove project as well as other projects showed that adaptive (cooperative) traffic light control and trajectory and manoeuvre planning can reduce fuel consumption considerably. Moreover, a simulation study showed that when combined, assuming a 100% penetration rate and perfect user compliance, the impact was considerably larger than the sum of both systems alone.

Platoon organization in parallel to signal timing negotiation will lead to denser vehicle platoons passing traffic lights in more effectively utilised green windows. This will increase lane utilisation and reduce the delay time.

Trajectory and manoeuvre planning result in more homogenous driving and a reduction in the number of stops at traffic lights. This primarily decreases emission but also reduces delay time and benefits the comfort of individual vehicle drivers and passengers.

The combined intelligence of infrastructure and vehicles can decide on a very low-latency response which will benefit the safety of VRU’s in particular.

The MAVEN approach improves the prediction of the traffic state significantly, which will decrease time-lost due to non-optimum decision making by the intersection control.

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Robustness and performance of sensor and data analysis systems

The distributed and cooperative sensing approach envisioned by MAVEN will overcome the intrinsic limitations of the current on-board sensor technologies such as occlusion, especially in case of vulnerable road users. Cooperative use of vehicle and infrastructure sensing capabilities will ensure more robust and reliable decisions exploitable by ADAS and automated driving.

From a road operator's viewpoint, several projects have explored advice and hazard information based on a cooperative infrastructure. With increasing automation and MAVEN's negotiation approach, warnings can evolve into directives as the probability of improper responses diminish.

Optimised HMI and advice strategies

The MAVEN approach will enhance the range of the vehicle sensors and therefore enhance the "situation awareness" of the automated vehicles. This leads to a broader scope of action for the individual automated vehicle and therefore to better informed and more effective advice strategies.

Accessibility

The implementation of AVs will have a great impact on what people are able to do in the urban environment and beyond. By offering mobility to new user groups, decoupling travels from fixed schedules and increasing spatial availability by offering pick-up services, it will become easier to reach more locations in the urban area than before. One major benefit can be seen if AVs are regarded as a means of covering the last mile between a public transit facility and peoples' homes or workplaces. On one hand, as described before, this will lead to induced demand and might have the negative effect of slowing down travelling. On the other hand, increased accessibility is a huge societal benefit of AVs. In that regard, both developments can be seen as antagonists if no infrastructural changes are being made. Therefore, from a societal perspective, it will be a challenge to balance expected gains in accessibility (among the other benefits of AVs) with expected losses in speed through congestion. Finally, one needs to think about how the increased accessibility will change the behaviours and decision making of the people. One likely development is that AVs will heavily encourage urban sprawl, giving the motivation to move outside of crowded city centres into the neighbouring areas. This, if no tailored policy decisions are made, will drastically change how the urban environment changes and what can actually be considered as the "urban environment".

1.4 MAVEN Ambition

The main ambition of MAVEN is to pave the way from automated driving and automated vehicles towards the wider concept of "automated road transport" in the challenging conditions of urban scenarios. Former European FP6 and FP7 have provided important contributions to highly or partially automated driving in less complex scenarios like highways. In most of these activities, automated driving has been studied on individual and isolated vehicles, and relatively little effort has been spent in exploiting the potential of V2X cooperation. At the same time, the Car-to-Car Communication Consortium has been leading the standardization and profiling of V2V systems and applications for traffic safety. However, such applications have been conceived for non-automated vehicles, and are basically aimed at providing drivers with additional warning functions. More recently, Compass4D and the C-ITS corridor projects are setting the basis for the deployment of similar warning and/or information services using V2X communications from the road infrastructure. Even if V2X communications will enable in these cases traffic data collection from vehicles, this information will be generally used for the provision of more precise traffic updates, and not in the short term, automatic road infrastructure decisions or reactions as foreseen by MAVEN. As can be seen, there is a gap to fill between vehicle automation, collaborating behaviour for automated driving and cooperative sensing, and cooperative communications with

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the road infrastructure to enable efficient adaptive traffic management and safety solutions, especially in urban areas. In fact, traffic management services and fully automated driving features are nowadays working almost independently; especially the missing bidirectional real-time data exchange is one of the biggest draw-backs for traffic flow optimizations and enhanced vehicle safety. Current navigation systems, for example, are not taking road operator traffic light or traffic flow data into account or make only limited use of this data (historic traffic flow database). In any case, these solutions do not provide a feedback channel to inform about vehicle manoeuvres. This channel is missing or restricted to a single OEM (e.g. Mercedes "Real Life Safety" wrong-way driver information). Finally, current ADAS functions are not covering all urban scenarios and do not integrate any automated off-board vehicle control or manoeuvre recommendation function. To fill these gaps, MAVEN proposes a comprehensive framework linking automated driving functions on vehicles with automated coordination capabilities at the road infrastructure. The real-time interaction between vehicles and infrastructure will enable new automated mobility concepts even beyond the scope of this project.

MAVEN envisions a safe, environmentally friendly, high-capacity network with a high level of user comfort as a result of state-of-the-art adaptive network-optimization algorithms and street-level vehicle-organisation enabled by vehicle automation. Network-wide optimization orchestrates locally-optimal behaviour of highly or fully automated vehicles through a C-ITS network of vehicles and intelligent infrastructure nodes. MAVEN aspires to demonstrate this vision by:

- Showing the viability of orchestrating vehicle movements at the intersection level;
- Developing platoon organization algorithms at the city corridor level;
- Detailing the supporting architecture and building on C-ITS technology;
- Using state-of-the-art traffic state acquisition, and
- Defining necessary additions to C-ITS standardisation.

Finally, MAVEN strives to improve the road authorities' and municipalities' understanding of future network performance when highly automated vehicles are deployed in volume. Moreover, the MAVEN project aims to become a reference for road authorities and policy makers to start thinking about the traffic management aspects of automation.

1.5 Key performance indicators (KPIs)

Based on the expectations and ambitions summarized above, the deliverable D7.1 [10] (Impact Assessment Plan) provided a list of KPIs that have been used in the MAVEN project to evaluate the results of particular use cases. The overview and definitions are provided in the following paragraphs.

In general, all KPIs will be reported on network averages for impact assessment purposes. However, the evaluation methodology will first determine them on a per signal group level. This means all delay, stops, etc. incurred by a vehicle upon entry of the network up to the passage of the first traffic light, will be attributed to the signal group it passed there. The next sub-trip is from passing that intersection up to the next and so on. From the last intersection up to exiting the network, vehicles should travel free flow, but data will still be collected as a control. If a significant delay is incurred after the last intersection, the network probably has a configuration problem.

The reason for collecting the data per signal group is to allow deeper analysis when unexpected effects are observed. For instance, it enables the researchers to check if a certain use case works better on a left turn than on a right turn, or the data can be filtered per intersection type. To keep the validation reports comprehensible, only interesting findings from the deeper analysis will be reported.

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KPI 1) Number of stops at traffic lights (-)

It should be noted that a vehicle is considered stopped once its speed is lower than 5 km/h. This is to prevent long coasting from distorting the data. The threshold of 5 km/h has been used by traffic engineers for decades.

KPI 2) Control delay time (s)

The delay time is derived from the travel time, which is defined as follows:

$$t_{travel} = t_{arrival} - t_{depart}$$

Using this the delay time is:

$$t_{delay} = t_{travel} - t_{free\ flow},$$

where free flow means that no interactions with other vehicles are disturbing the journey and the driver is following the maximum speed limit.

Travel time seems to be a more intuitive KPI to determine the performance of a traffic network. However, travel time also includes a large share of free flow travel and will distort comparisons. If a certain simulation network has 10 kilometres of the road leading towards and intersection, while another only has 1 kilometre, the effects of a change in a control plan will be relatively higher in the second network, while all other factors are the same. Therefore, the delay time is a much better KPI, because it filters out the part of the trip that was spent in free flow conditions. Waiting time is also occasionally used in literature, but this KPI does not include time lost due to acceleration and deceleration after a stop and optimizing for waiting time may encourage stop-and-go traffic.

KPI 3) Produced emissions (g)

SUMO can couple to the PHEMlight (*Passenger Car and Heavy Duty Emission Model*) model, which contains many different vehicle classes (approximately 200) with a variation for EU0 – EU6 emission regulation compliance and different types of fuel, including hybrid electric, and different weight categories for trucks. More importantly, there are also distributions available for the percentage of traffic that falls in all those categories. These distributions are available for 2016, but also for the future, e.g. 2020. The *PHEMlight* model is made by extensive analysis of TU Graz with advanced sensors in the exhaust of real vehicles on a roller bank.

SUMO can be started with a special option to output the current emission values of each vehicle 10 times per second. These can be summed again for each signal group approach and reported on a total network level.

KPI 4) Fuel consumption (l)

This KPI is obtained in the same way as the produced emissions using the same *PHEMlight* model.

KPI 5) Throughput (veh)

Throughput is measured again per signal group and is defined by the number of vehicles passing the intersection for a specific (set of) turn direction(s). It can be acquired by simply counting this in the simulation output. However, if the network is under saturation application of a use case will most likely not increase the throughput, simply because all vehicles could already pass the intersection. Stochastic effects can influence the total throughput depending on at what point in a traffic light cycle the simulation has ended. Therefore, if the throughput of a signal group in one

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scenario does not differ more than the maximum number of vehicles that pass a signal group during a green phase, it cannot be concluded that there is a significant difference.

To determine the capacity, the traffic demand has to be gradually increased for all origin-destination pairs. Once the throughput of a single signal group is significantly smaller than expected by the configured demand, it can be concluded that the capacity has been reached.

KPI 6) Travel times (s)

This KPI is intended for field tests in which delay time cannot be determined due to the absence of a free flow travel time value. Curves and road quality also impact this, so simply dividing the distance by the speed limit will not result in the free-flow travel time.

KPI 7) Minimum time to collision (s)

Time to the collision is defined as the time it takes before two traffic participants collide if their current speed is not adjusted. This is a safety measure, where a higher value is better. However, aiming for a value that is too high, will negatively impact traffic efficiency and will not add any safety. Therefore, a predefined threshold is used in MAVEN above which the time to collision is not taken into the analysis anymore.

KPI 8) Number of human interventions for safety (-)

The ultimate safety measure would be the number of accidents and while MAVEN will of course report on it should an accident happen, the project does not expect any accidents to happen during the tests. Especially because trained human drivers will closely watch the vehicle's behaviour and intervene if necessary. Therefore, the number of human interventions for safety reasons is a measure that is more likely to show differences.

The following table provides an overview of the KPIs together with the expected impact of MAVEN use cases.

KPI ID	KPI description with units	Expected impact
KPI 1	Number of stops at traffic lights (-)	Reduction
KPI 2	Control delay time (s)	Reduction
KPI 3	Produced emissions (g)	Decrease
KPI 4	Fuel consumption (l)	Reduction

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KPI 5	Throughput (veh)	Increase
KPI 6	Travel times (s)	Reduction
KPI 7	Minimum time to collision (s)	Increase
KPI 8	Number of human interventions for safety (-)	Decrease

Table 1 Overview of key performance indicators

1.6 Structure of the deliverable D7.2

This document is structured in the following way:

First, this introduction mainly summarised the expectations stated in previous deliverables shaping the objectives and ambitions of the MAVEN project. This covers the different tools and dimensions, as well as the impact on particular user groups as identified at the project start. Also, the KPIs used in the validation are provided here.

Second chapter provides a literature review focusing on the autonomous vehicles in general. As the particular use cases focus on a small portion of the problem only (and this cannot be different), this section should provide the big picture and place the results of particular MAVEN use cases into a broader perspective.

The third chapter provides the actual results and their discussion with respect to user impact. Different approaches (e.g. stakeholder workshops, field test surveys and online survey) are discussed and the results presented.

The fourth chapter focuses on a field test evaluation and emulation using Dominion software. This chapter builds on the deliverable D6.4 [12] and elaborates on the obtained results.

The sixth chapter provides the impact analysis for a particular use based on microscopic traffic simulation in SUMO. Here the main contribution is on allowing measuring impact for the transition phase and different traffic conditions.

The final section concludes the impact assessment deliverable and provides a final discussion of the results and the way how the objectives were met.

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2 Reported impact of autonomous vehicles – literature review

The autonomous driving is experiencing a huge boom. It is linked together with developments in technology, but also with a strong focus on Smart Cities, where automated vehicles, shared economy, as well as for example electromobility shall play an essential role. Many activities have been finished during the last years, i.e. duration of the MAVEN project. This section provides an updated literature review with a focus on the new developments and projects.

Before the year 2016, most researchers expected a mainly positive impact of automated vehicles. A selection of such expected impact adopted from Chan [13] is provided in the following list:

1.Vehicle user perspective

- Fewer traffic collisions, due to elimination or minimization of human errors.
- More smooth and comfortable, and less stressful, rides.
- Greater mobility freedom for the disabled, fatigued, drunk, inattentive, senior, or children.
- More productive vehicle riders, and gains in personal productivity and/or pleasure.
- Alternative and possibly more efficient mode of transportation.
- Less demanding or unnecessary ownership for individuals.
- Feasible automated event handling in vehicle failure or incapacitated users.

2.Transportation operation perspective

- Reduced congestion due to reduced incidents and better managed traffic flows.
- More effective real-time navigation, trip assignment, and dynamic routing.
- More accessible, reliable and flexible shared rides for personal transit and mobility service.
- Reduced number of on-road vehicles via ride sharing or car sharing of automated vehicles.
- More efficient infrastructure, because of better vehicle control and coordinated operations.
- More affordable mobility services and less subsidized transit operations for public agencies.
- Improved economic returns and business models for private investors.
- More savings of resources needed for infrastructure, including parking and roadway constructions

3.Society perspective

- Less burden on those providing support services to mobility-challenged groups.
- Greater incentives for the transition from personal ownership into the car- and ride-sharing services.
- Mitigated issue of driver shortage for certain countries and regions.
- Reduced insurance and related ownership costs.
- Reduced accident rates and less societal losses.
- More environmentally friendly vehicles and infrastructure.

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– Increasingly feasible transportation services of enhanced safety, reliability, security, and productivity

This was supported by several researchers as well as results from a survey focusing on expectation from the general public as well as policy makers, see Figure 2 [14].

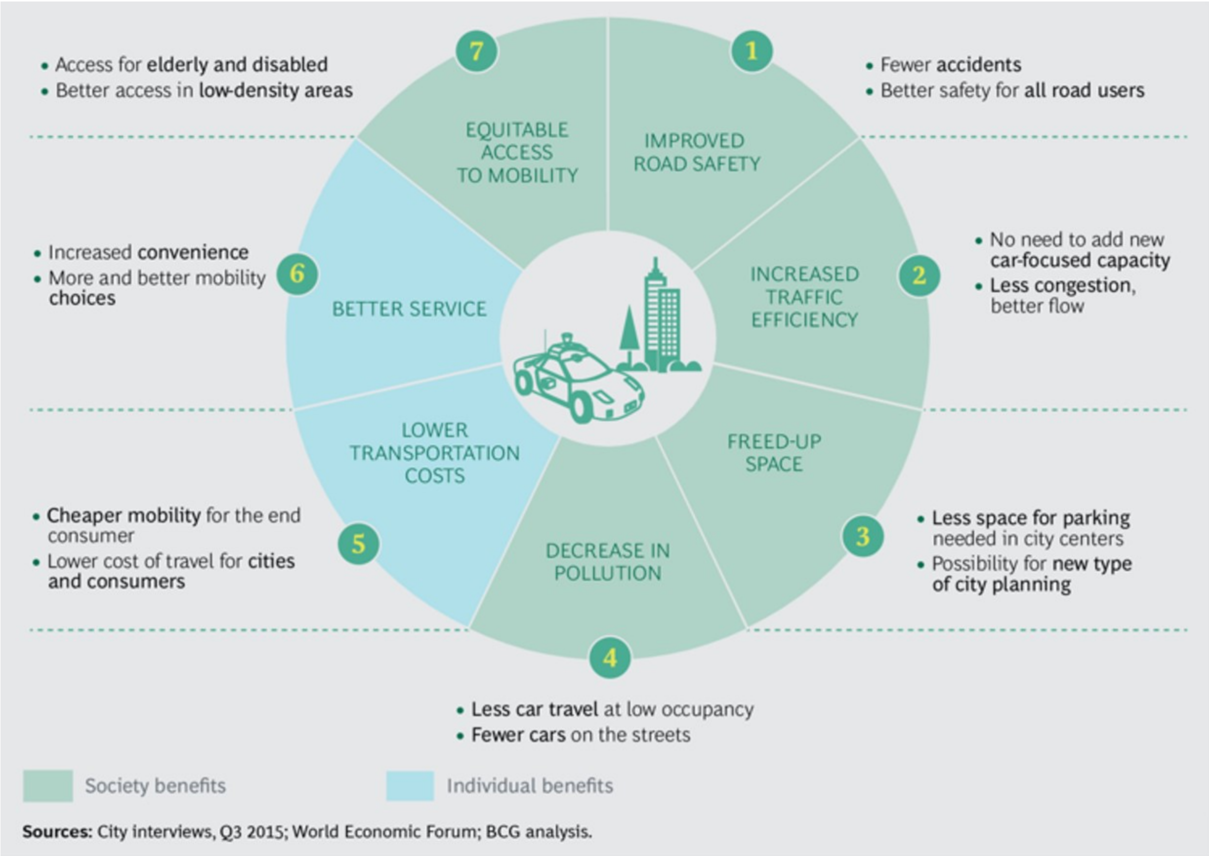

Figure 2 Impact of AVs on individuals and society as expected by policymakers

Even some early simulation research suggested a similar trend. Atkins [15] developed a simulation model and tested different penetrations rates to demonstrate its impact on-road performance. Based on the simulations, he confirmed the potential for significant benefits to network performance, particularly in high-speed, high-flow, congested situations. This is a reasonable assumption as at low penetration rates, the AVs are limited by the behaviour of other vehicles. His results indicate **improvements in the delay of 7% for a 50% penetration of CAVs, increasing to 17% for 75% penetration and as high as 40% for a fully automated vehicle fleet**. This is certainly a very ambitious conclusion.

To summarize, it was expected that autonomous vehicles will improve safety, reduce congestions, harmonize traffic, reduce the number of vehicles on roads, allow for savings in infrastructure incl. parking or for example make more affordable mobility services.

Only a few factors were typically named by experts as a possible source of negative influence on the smooth deployment of automated vehicles. Sousa et. Al [16] named among others the following challenging factors:

– Slow progress of technological development,

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– high cost of the AV vehicles,
– limited scale of production,
– the fact that consumers are not ready for automated driving, and finally
– the lack of regulations.

This was the most common perception of the future impact of autonomous vehicles.

In the last years, however, researchers started to doubt the expected positive impacts and often refer back to them as “wishful thinking”. Even when the challenges from above are overcome, the impact on, for example, traffic flow can be really different. At best, there is much uncertainty about the impact of AVs as it is demonstrated in the following paragraphs [17].

2.1 Increase in the vehicle miles travelled

Sousa et al. [16] stated that since automated vehicles can provide mobility for new groups of users, travel demand may increase.

This statement was supported by the work of Sivak and Schoettle [18], who analysed the reasons for not having a driving license and estimated this increase in new mobility users to go as high as 11% when AVs become widely accessible. Harper et al. [19] used the data from the 2009 National Household Transportation Survey to study this phenomenon. His results suggest that in the USA, the increase in vehicle miles travelled is expected to be 14%.

2.2 Parking and land use – a positive or negative impact?

The cities and the entire land use will need to be changed to address another important aspect of autonomous vehicles. Nowadays, cars in cities are used only for short periods of time. People typically drive to work in the morning and back home in the late afternoon. In the meantime, they stay parked.

Finding a parking spot may, in addition to fuel and time waste and increase in the overall stress, increase traffic up to 15% [20].

AVs address these problems by driving passengers to their destination, and then driving to a dedicated parking place at home or outside of the city centre. This can reduce the need for parking places in the centre, but introduces new challenges. The empty AVs would be negatively influencing the overall traffic flow, using extra fuel and polluting while looking for parking far away [21].

Additionally, the city would need changes in the entire land use, for example, an additional space and solution for drop-off and pick up by AVs [22].

Automated vehicles should save space not only by reducing the number of parked vehicles but also by reducing the space required for parking them. AVs allow parking in so-called depots where the space needed to park such vehicles can be reduced to half the space needed with conventional parking lot designs [23].

2.3 Impact on congestions

David Metz [24] confirms the expectations that the impact of AVs cannot be simply just positive or just negative. He addresses the concept of autonomous driving with respect to other new trends – the topic of vehicle ownership and ride-sharing. He puts together the partial conclusions from previous sections and concludes that it is to be expected that individually owned AVs will add

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significantly to the overall distance travelled by car and hence to increased traffic levels. In contrast, AVs operating as robotic taxis would not be expected to have such an impact, given that conventional taxis travel without passengers between paid trips.

There is however much more significant impact of shared use. Shared use increases car occupancy, which would be expected to reduce the number of cars needed to meet the travel needs of a given population and hence would reduce traffic congestion.

Even this very promising expectations, however, introduce another negative impact – so-called induced travel demand [25]. Decreased congestion tends to attract trips previously deterred by anticipated delays. Additionally, the lower travel costs associated with using shared vehicles can attract passengers from public transport, increasing the demand for a private car or taxi use.

This effect was also in details elaborated by Wadud et al., [26]. The authors explore the effects of automation on congestions, energy consumption and emissions through several illustrative scenarios, finding that automation might plausibly reduce road transport emissions and energy use by nearly half; or nearly double them; depending on which effects come to dominate. The effect of particular factors is demonstrated in Figure 3.

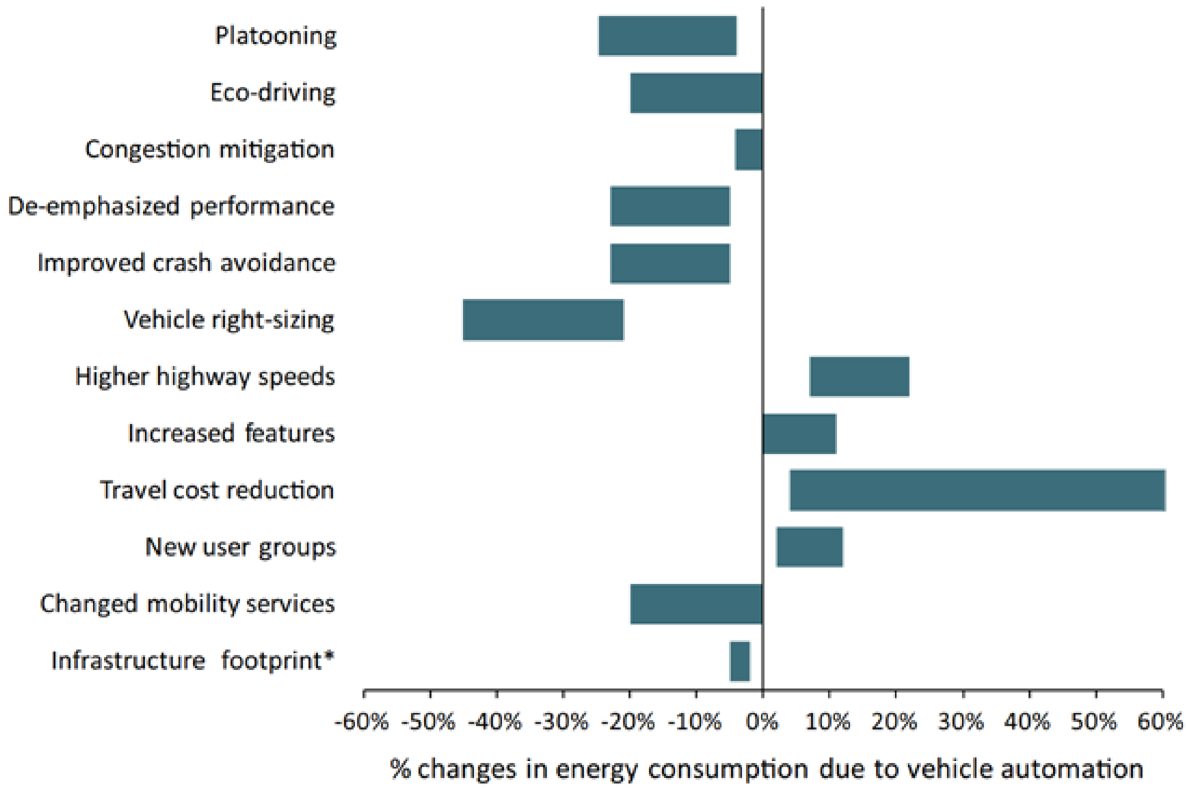

Figure 3 Factors affecting the energy consumption of CAVs (Source:[16])

We can see that AVs offers the potential for substantial reductions in energy consumption and emissions, for example by introducing vehicle platooning, increase in safety or vehicle right-sizing. On the other hand, they will most likely lead to changes in vehicle operations, changes in the cost of travel, or changes in transportation system design and thus introduce induced travel demand and thus also increase in emissions.

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The results summarized in the figure however also demonstrate another interesting aspect. **The most potential energy-reduction benefits may be realized through partial automation, while the major energy/emission downside risks appear more likely at full automation.**

The negative impacts – the vehicle-miles travelled and associated fuel consumption - could increase significantly, if automation sharply reduces the cost of drivers' time but at the same, the energy efficiency benefits are not implemented.

Similar conclusions were confirmed in the same year by Gruel and Stanford [27]. The authors consider three speculative scenarios, defined primarily by different behavioural responses to the availability of autonomous driving. The scenarios build on an established system dynamics model that represents the major forces and influencers involved in transportation systems. In this paper, three different scenarios were presented. The author demonstrates that in all three scenarios, driving will become safer, time spent in the car can be used differently, and the situation of people with limited access to mobility would improve. Furthermore, per-mile-cost and energy consumption would decrease.

However, in all three scenarios, the vehicle miles travelled is likely to increase, leading to a potential increase in energy consumption and emissions. The level of increase, however, appears to differ significantly among the scenarios (modelling different behavioural changes). The authors conclude, that in order to reach positive impact of AVs, the municipalities must actively develop ways to make the usage of public transport more attractive, discourage urban sprawl, and if possible limit the amount of driving that people can do using some form of incentives.

This recommendation is also in the conclusion of a paper providing a detailed literature review with respect to modelling of the impact of AVs on land use by Soteropoulos et al. [28].

2.4 Impact on traffic safety

Probably less discussion is led with respect to the expected impact of AVs on traffic safety [29]. There is no doubt, that human error contributes to about 90% of all car accidents [30]. Some authors expect so high reduction in car crashes [31], they, however, do not take into consideration new sources of errors or risks that the new these technologies can introduce [32], such as Hardware and software failures, malicious hacking [33] or even reduced investment in conventional safety strategies. When travellers feel safer they often take additional risks, called offsetting behaviour or risk compensation. For example, if autonomous vehicles are considered very safe, passengers may reduce seatbelt use, and other road users may take greater risks [34], what Toyota Research Institute Director Gill Pratt describes as "over-trusting" technology [35].

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Can it work? A detailed case study in Boston

In June 2018, World Economic Forum and The Boston Consulting Group (BCG) presented a report summarizing findings from a three-year collaboration between these two groups exploring how autonomous vehicles could reshape the future of urban mobility [36]. The study uses different methods to obtain results, among others large consumer survey, series of detailed focus groups with residents of the Greater Boston area as well as the development of own agent-based simulation model of traffic and vehicle-to-vehicle interaction for the entire Boston city [37].

Five of the major findings are summarized below:

- Mobility-on-demand will grow to account for one-third of trips in Boston
- Mass-transit ridership will drop in urban areas
- AV adoption – the indication by those surveyed that they would ride in autonomous vehicles – will vary considerably across city neighbourhoods
- Age and income are significant drivers of AV adoption
- The shorter the trip, the higher the AV adoption

The conclusions are demonstrated in Figure 4.

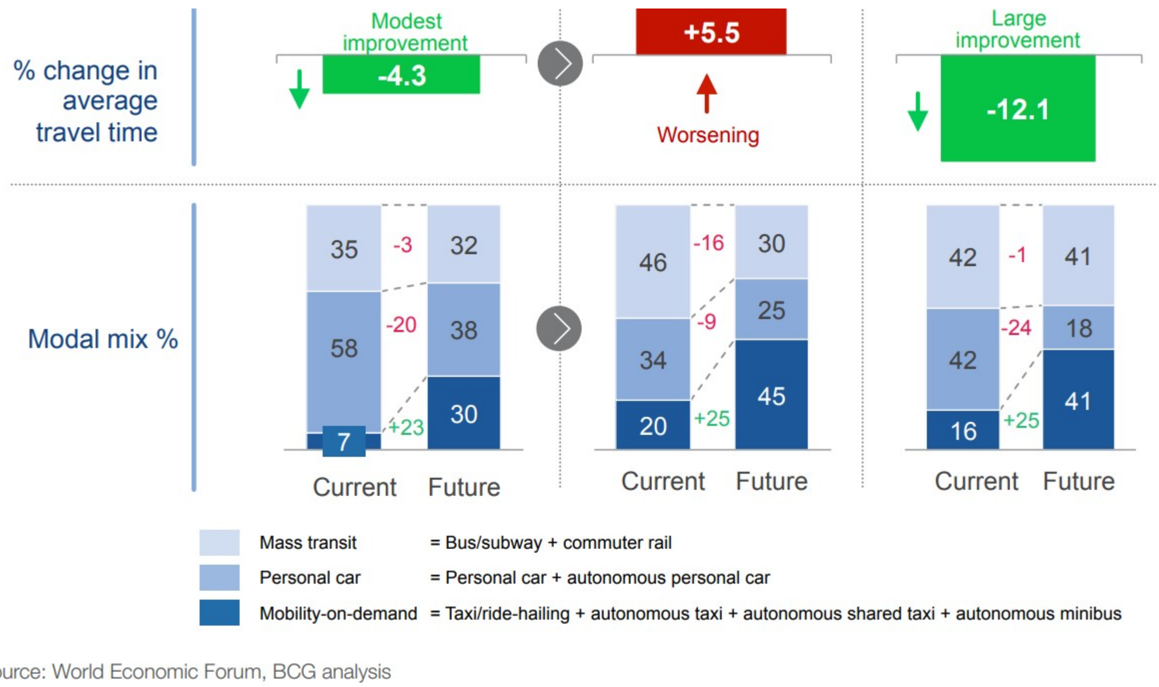

Figure 4 Factors affecting the energy consumption of CAVs (Source: [37])

The simulation study further concluded that:

- The number of vehicles on the road will decrease by 15%.
- There will be a 16% increase in the distance vehicles travelled.
- There will be a significant (48%) decrease in the number of parking spaces needed.
- The simulation predicts that average travel time will decline by 4%.

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2.5 Conclusions of the literature review

The impact of autonomous vehicles on traffic flow can be summarized as follows. Vehicles that are highly but not fully automated would probably not behave significantly differently from normal vehicles as regards their contribution to congestion.

For fully automated AVs (automation level 4 or higher) there are factors that seem likely to operate both to increase and decrease congestion. Those that may add to congestion include:

- individually owned AVs travelling unoccupied on return trips or while "parked" on the move;
- increased demand for car use arising from those unable to drive;
- increased demand arising from the relaxation of the time constraint on daily travel if work can be carried out on the move; and
- increased demand for lower-cost robotic taxis by former users of public transport.

Factors that might mitigate congestion include:

- possible scope for reduced headway and lane widths on dedicated highway lanes;
- some reduction in city curbside parking;
- shared use of robotic taxis; and
- possibly less individual car ownership.

However, all these factors would play out in the context of congestion that is self-regulating on account of the time constraints to which road users are subject, as discussed above.

A critical question is **whether autonomous vehicles increase or reduce total vehicle travel and associated external costs**. It could go either way, depending on **public policies**. By increasing travel convenience and comfort, and allowing vehicle travel by non-drivers, they could increase total vehicle mileage, but they may also facilitate vehicle sharing, which allows households to reduce vehicle ownership and therefore total driving.

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3 MAVEN Results – User impact

The main aspects of the user assessment were identified in the deliverable D7.1 – Impact Assessment Plan [10]. Different target groups were identified and have been addressed by several different means, as specified in Table 2.

First, municipality representatives and traffic managers were interviewed and responses were collected to get feedback mainly about the scope and possible impact of the MAVEN project. This was done through several Stakeholder consultation meetings. It was interesting to get feedback from professionals that could benefit from the MAVEN project. As this was repeated several times during the project, it helped to shape the MAVEN use cases.

Next, participants of the field tests were asked about their experiences. This is not a large group but could give us feedback about the experience with driving or observing an automated vehicle.

Last, in order to get more quantitative results, and an online survey for the general public was conducted. Here we asked respondents mainly about their expectations and perception of automated vehicles.

	Tools	Target group	Key user impact
1	Stakeholder meetings (Mentimeter)	Municipality representatives Traffic managers	Meeting of the research objectives Expectations on future development (transition) Changing role of traffic managers Key perceived issues
2	Field test survey	Drivers of equipped vehicles Drivers of unequipped vehicles Passengers of equipped vehicles Other indirect participants of the field test and trials	Comfort when using automated driving Trust in the automated driving Key perceived issues
3	Online questionnaire	General public	Perceived impact Expectations on future development (transition) Integration of AVs into a city Key perceived issues

Table 2 Target groups and the key user impacts (source D7.1 – Impact Assessment Plan [10])

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More detailed analysis of the three particular approaches is provided in the following sections.

3.1 Stakeholder meetings

First workshop

The stated aim of this first MAVEN stakeholder consultation workshop on the 15th of November 2016 in Barcelona, was to discuss and review the preliminary MAVEN system concept, use case descriptions, and assessment and demonstration plan. The workshop audience of 34 persons was made up primarily of local authority representatives (representing 2/3) – mainly working on traffic management - and project partners. For many participants, this workshop was the first occasion to learn about and to share views on automated driving and urban transport. Hence, the discussion largely remained at a rather general level, covering the potential advantages and disadvantages of automated vehicles in the urban environment. Nonetheless, some requirements and recommendations emerged from the discussion and the interactive Mentimeter (real-time voting and poll website) session that have bearing on the use cases, the demonstrations and impact assessment. These requirements recommendations and questions to study have been used as an input for the requirements collection step.

Use cases:

- The scenarios should be investigated at both peak and off-peak hour
- The use cases are too technical and should be linked to real-world transport problems, such as how to deal with high volumes of tourist buses along specific corridors?
- There should be use cases describing the transition between what we have now and pervasive C-ITS
- Where the business logic/demonstration is held at a higher level (control centre or zonal level), the feasibility of running the MAVEN use cases needs to be explored.
- The viewpoint of the non-automated vehicles and other road users (cyclist, pedestrian) should be described in the use cases

Demonstrations/emulation:

- The effects of different mixes of automated and non-automated vehicles should be demonstrated – especially as non-automated vehicles will predominate for many years
- The emulations should take account of many different scenarios, such as congested conditions, multiple junctions, presence of VRUs (especially cyclists) or specific fleets.
- The viewpoint of the non-automated vehicles and other road users (cyclist, pedestrian) should be described in the emulations
- The city model used for the simulation should be based on a representative network.

Impact assessment:

- The impact of automated driving is likely to beyond the mobility domain, notably toward the freight sector, land use and environmental aspects
- There is a need to have a better understanding of the benefits in terms of safety, travel time, environmental effect.
- The infrastructure needs and liability issues have to be clarified and the business case has to be spelt out.
- MAVEN should also address users' (citizens) needs

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- Scalability of MAVEN system needs to be addressed, i.e., from local junction to city-wide.

A snapshot of the other key issues that emerged from the discussion included:

- Vulnerable road users/VRU: the interaction with and impact on VRU (pedestrians and cyclists) is a key consideration for all project activities.
- Transition phase: It was agreed that it is safer to assume the co-existence of manually driven and automated cars will be the norm for many decades because some people will drive older (especially classic) cars for many years. Legislation could be used to prohibit older cars but this would need to be implemented across all Member States
- Human factors: Concerning the operation of the platoons, there was a concern that alerting other road users to the presence of automated platoons could lead to the behaviour of trying to disrupt the platoon.
- Traffic manager's role:
- Who makes platooning happen? All actors should be included in the chain
- General agreement that the traffic manager should be able to communicate directly with an automated vehicle and give directions. Opinions were more cautions on road authorities having an active role in investing to facilitate automated driving as a form of traffic management and on the need for traffic management to become simpler and requiring fewer interventions. Most agreed that the traffic manager will still be needed despite the fact that automated vehicles may manage themselves as a system.
- General support for the assertion that traffic management will become more strategic in the future, translating policy goals into operations, and that while more operational decisions will be made by systems, these will be guided by policy.
- It should not be overlooked that traffic management systems are mainly installed in big cities; smaller cities do not tend to have them.
- Deployment
- What happens at the administrative boundaries especially where one area has not implemented the system? This could be mid-way along a road.
- What happens in case of malfunction?
- Who is going to pay for automation especially as a drop in income from parking fees is anticipated when full automation is there?
- Financial resources can vary differently depending on the size of a city: generally, the bigger the city, the more resources and skills available to invest in new technology and systems.
- There was general agreement that current C-ITS investments are not a waste of money
- All investments have to be future proof. Cities are concerned about making investments now and having to upgrade systems later – standardisation link
- Overwhelming support for the potential of automation in public transport, followed by taxies and delivery services. The reality of what cities want to happen and what will happen is quite different: automated private cars will be on the road on a larger scale than public transport and technology will develop quicker than cities have time to react and quicker than they can adapt their infrastructure. Market forces will push cities down a route faster than they can follow

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Automation has to be implemented incrementally for public acceptance reasons.

Second workshop

The stated aim of the second MAVEN stakeholder consultation workshop on the 10th of October 2017 in Brussels was to gather the views and requirements of local authorities and other urban transport stakeholders on various tasks underway or planned. The workshop audience of 49 persons was urban transport stakeholders, with a particular emphasis on representatives of the local and regional government. The workshop was jointly organised by MAVEN, CoEXist and TransAID.

Overview

A quick overview from the MAVEN project was given, complemented by a presentation from Bart van Arem (TU Delft) who pulled together the results from a wide variety of other projects and studies on the topic of vehicle automation and cities. Some highlights of these findings include the following:

– Until the driver is fully relieved of the driving task, automation technology can only serve safety and comfort purposes.
– Automation should not be assessed in just transportation terms (safety, efficiency, etc.). The economics, for instance, are equally important, notably in relation to time spent in congestion doing more productive things.
– High income males are more interested in certain vehicle technologies, such as adaptive cruise control (a key enabler of vehicle automation) than other cohorts.
– Level 4 automation vehicles will not be commercially available on the roads for another 10 years.

City council presentations

After the presentation, the activities of two city councils, of Greenwich and Gothenburg, were presented and in the following discussion, a number of points were raised, notably:

1) City AV planning and policy will to some extent depend on the type of service that is offered by automation, i.e., automated private cars or automated shuttles.
2) The presentations during the morning session are missing a vision for the future. The focus has been on the car. Is this the future we want for our cities?
3) There is a need for cities and regions to reflect on how they can use automation to serve their own transport and societal goals.
4) In order to be proactive as a city or region and to engage with politicians, more information is needed about vehicle automation, notably when it will be here and what are its capabilities.

The morning plenary terminated with an overview of the main themes and points that are emerging from the Polis paper on ‘AVs and cities and regions’.

During the afternoon session, the audience was invited to join project group discussions. General comments about (C) AVs were:

– Local authorities need to deal with the arrival of AVs
– AVs could work only if they provide real public service
– uncertain=outcome of the competition between AVs and public transport

Comments about (C)AVs and traffic management

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No special traffic rules for automated cars are envisaged: they will be treated in the same way as normal cars. However, it is expected that automated cars will make diverting traffic easier, specifically where there is vehicle-infrastructure communication (i.e., C-ITS). Connected and automated vehicles (CAVs) can support other measures. the mix with traditional cars will still be a challenge. CAVs can take the green wave strategy on congested roads to a new level. How a city is able to interact with AVs will, to some extent, determine the efficiencies that can be gained.

A world of (C)AVs will rely heavily on artificial intelligence. Yet AI struggles to make sense of traffic management plans given their diversity and cultural specificity. Open transport data is another way to have a well-connected system. There is a need to give information to cars to direct them.

Specific feedback about MAVEN Transition roadmap:

- Do we need to adapt the infrastructure to AV or should it be the other way around?
- Public acceptance: is there enough trust in technology?
- How will liability be addressed in a future of CAVs?
- How to make systems sufficiently robust to prevent hacking?
- MAVEN should also look at use cases where people want to get out of an AV, e.g., parking
- How scalable is the MAVEN approach?
- The project's roadmap should limit itself to traffic management only and go deeper into one topic

Clarify the ICT infrastructure requirements: on the roads and underground (e.g., 5G network)

Third workshop

After the first two workshops, the third workshop on the 24th of October 2018 was held in Greenwich London and had an audience of 50 persons which targeted urban transport stakeholders with a particular emphasis on representatives of the local and regional government. The aims of the workshop where:

- explore in more detail how increasingly instrumented vehicles are likely to behave on city roads and how this may affect the traffic management task and wider transport goals
- provide insight into the role that communication technology can play in the shorter-term of connected transport and the longer-term of automated transport
- promote reflection among local authorities on their role and responsibility as CCAV evolves.

The workshop was jointly organised by MAVEN, CoEXist and TransAID.

Following a welcome by the workshop host and an introduction to the MAVEN project and the workshop by project partners, a live poll was introduced and first questions were put to the audience (see Figure 5 and Figure 6).

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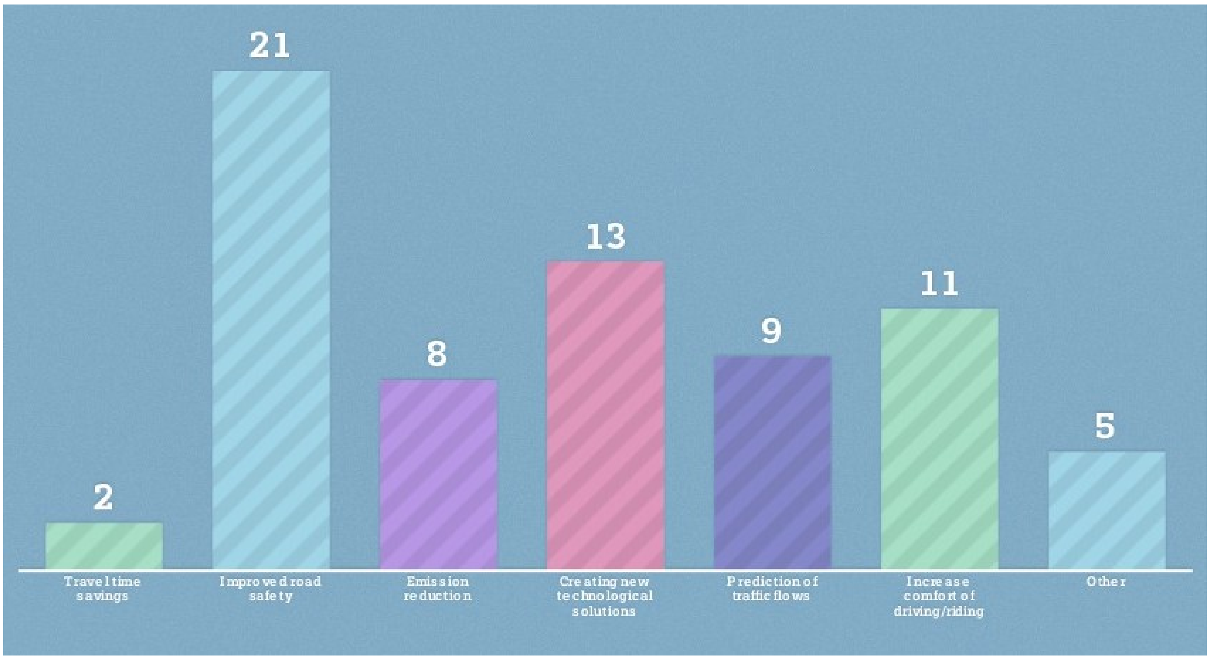

Figure 5 What are the most important benefits you expect automation to deliver? (Source: Mentimeter survey)

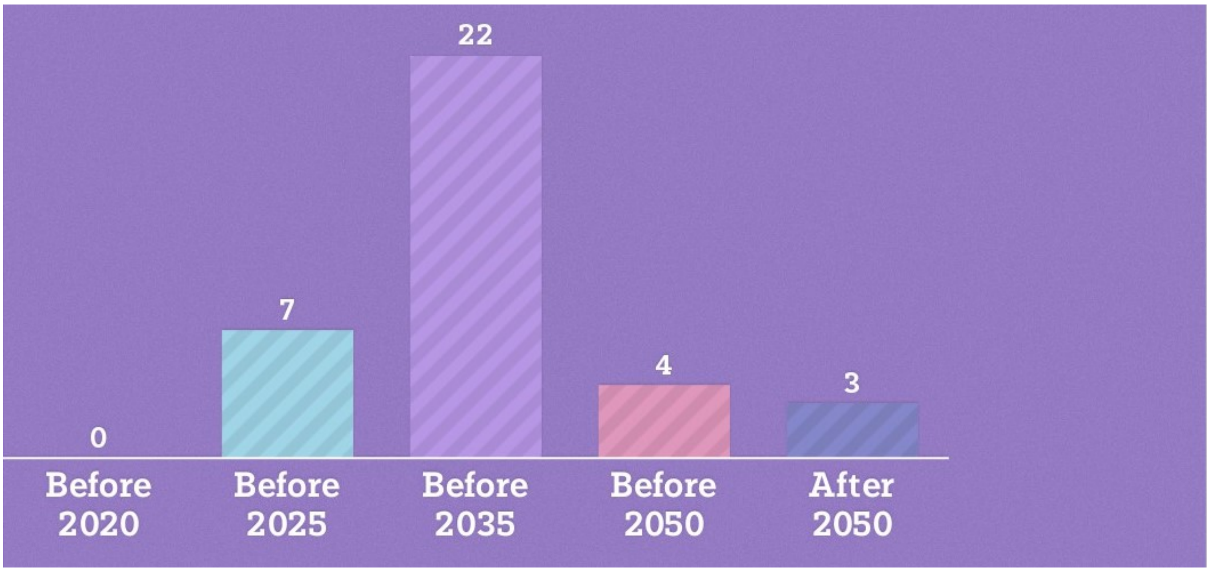

Figure 6 When do you expect automated vehicles will noticeably affect the roads of your city?

After the questions different presentations where held:

- Greenwich – the building of a trial
- University of California – innovation corridor Riverside (C-ITS testing)
- Czech Technical University – MAVEN survey Key findings included consensus on road safety as being the main benefit and general agreement that CAVs will be positive for society. In terms of traffic management, nearly half supported the notion of giving priority at traffic lights to a platoon of CAVs and many agreed that high capacity roads, public transport and lorries would benefit from platooning.

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– European Commission - On the road to Connected and Automated Mobility (CAM). The EC is working on CAM in three key areas. Technology to ensure Europe remains the market leader in terms of technology for CAV's. Safe automated mobility and future proof legal framework. Societal concerns - jobs & ethics. Ultimately, the EC's vision for CAVs is long term and it is currently focused on how to get there.

Small group discussions were held in the afternoon, regarding:

– Strategic planning for automated and connected vehicles,
– Traffic management in an increasingly connected and automated transport system
– Do cities and regions need a traffic technology/ITS strategy

Strategic planning for automated and connected vehicles

From the discussion, it became clear that cities across the EU have very different approaches on how to deal with CAVs in their strategic transport planning. Different approaches include the following:

– Some cities are developing comprehensive transport strategies that specifically consider the role of CAVs and their impacts on the mobility system. They are aware of the potential positive and negative impacts of the deployment and want to ensure that the deployment of CAVs aligns with existing mobility goals.
– Other cities are seeing CAVs more as a threat rather than an opportunity, which results in a situation where the issue is not tackled proactively.
– The role of CAVs in public transport is actively being investigated by some cities as it is seen in some cases as a "low-hanging fruit". Furthermore, the role of CAVs for school transport and social care is also being explored.
– As there are only a limited number of use cases available, it is important that cities learn by doing.
– Cities are developing more and more ITS, smart city and digital strategies, which can act as a foundation for CAV strategies and policies. Cities should focus more on "digital-readiness" rather than "automation-readiness".
– Some cities questioned the need to include CAVs in the transport strategies because CAVs are "just" technology and the focus should always be on humans. Furthermore, there is the concern that CAVs are still an unproven technology and cities should not overreact on hypothetical impacts.
– Cities need to think strategically about their role as data providers and managers.

Traffic management in an increasingly connected and automated transport system

Today cities see themselves as traffic programmers who are deeply involved in operating traffic systems on the traffic network. A possible new role, whether it is a supplement or complement to existing roles, is to set rules and constraints to those that provide mobility/operate (automated) vehicle fleets. While it offers new opportunities for traffic management, it was seen that new tools will be required. Traffic management and traffic control might exploit the higher compliance of AVs and be extended with tactical (direct) interventions in the vehicle behaviour. Interventions may include vehicle routing and traffic distribution on the system level and speed control measures on the vehicle level. What is considered acceptable in terms of interventions should be determined through a dialogue with OEMs and users. However, it was agreed that authority interventions are justifiable in case of conditions and events that affect traffic safety or system performance.

There was a fear among cities that transportation network companies will dominate the roads, with negative effects on modal split, a number of kilometres driven and eventually congestion. It was

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seen that rules and regulation should provide clear boundaries, but not kill innovation and competition. Incentivisation of favourable development/behaviour and pricing of unfavourable developments/behaviour was discussed and could be further explored, also in the broader context of managing travel demand with scarce space and capacity. Concrete examples are the definition of geofences to prescribe where AV functionality is/isn't allowed or to cap the total fleet size.

To understand what level of freedom vehicles might have (air traffic control was used as an example). Air traffic control is highly regulated and has zero freedom. A recurring question related to this subject was 'who owns the system?', and thereby has the power and authority to decide? Clearly, there are issues of equity, fairness and accessibility to all at play. Contrary to full authority control the perspective 'what if we do nothing?' was discussed. As it was seen, the challenges to regulate and operate a system as an authority are massive. It was agreed that a more suitable role for cities is to design and deliver a scheme for their situation, which then may be implemented and operated by others.

Data and information were agreed upon to become an important instrument to facilitate and influence AV development. Cities could provide open data portals, focus less on operation but more on planning and publishing data and information. Data and information could involve policy data as well. Managing considerable amounts of data requires new skills and expertise, as well as standards to ensure harmonisation. With such a role, the importance of data quality, accuracy and maintenance increases, which is in contrast with today's reality that many cities haven't digitalized their data and information yet, simply because there is no budget for it.

It was also discussed that CAV development should not be seen independently from other developments such as MaaS. Both developments are expected to converge, eventually, merge, and together will enable to efficiently guide the movement of people and goods in cities. In addition, the sharing economy is clearly challenging the old system. Who owns the vehicle will become an important factor for the eventual role of the traffic manager.

Do cities and regions need a traffic technology/ITS strategy?

Cities were clear that while there is widespread deployment of basic ITS equipment and capabilities, such as traffic counting, variable message signing and traffic control systems at junctions, that the capabilities are predominantly tactical and reflect the above. Larger cities, such as London have a significantly greater and more integrated ITS capability which enables corridor management and greater ability to proactively and reactively manage traffic around known events, such as large concerts and football matches, but unplanned events still pose issues for such ITS systems.

There was a discussion related to technology implementation decisions and how these are often led by previous investments which lead to incremental additions that work with existing systems. This led to a broad discussion about the flexibility and interoperability of ITS, with a varying response between cities. Some cities have been able to secure 'innovation' budgets and have procurement processes that enable testing and piloting of new systems and capabilities but most still struggle to procure the latest systems and technologies, driven by a combination of the prohibitive cost of upgrading underlying infrastructure and inflexible procurement policies. This creates a significant barrier to the adoption of new approaches, such as MAVEN, and is particularly acute for smaller cities with more limited resources. Austerity and budget pressures were also felt acutely by cities in terms of their ability to invest in ITS to the level they desired.

Views differed on the need for, or ability to, have wider city and regional led approaches to traffic management. Some authorities were moving in the direction of fully outsourcing traffic management to private contracts using outcome led procurements where the city/authority specifies the cities goals in terms of reduction in traffic jams, delays, journey time reliability and

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reduced emissions for example. Other cities were keen to maintain their in-house capability for managing traffic and acknowledged the need to keep using their existing systems to maximise their previous investments.

Cities were also vocal about their desire to utilise advancements in terms of in-vehicle and communications technologies but had concerns that citizens would rather follow their own existing knowledge when driving in the city, or follow their own navigation provider, limiting the ability of the city to influence driving decisions and behaviour.

There was broad agreement among cities that Connected Autonomous Vehicles and related enabling technologies such as V2I communications were both not well understood or yet forming part of any wider strategies being developed by cities as a way to improve societal outcomes. A few cities have identified the need for building this knowledge and have been able to secure research and government funding to collaborate on projects with academia and the private sector but these examples were few and far between. These cities also acknowledged that disseminating the findings of these projects to influence policy and strategy is not yet as comprehensively embedded as they would like within their respective wider organisations.

3.2 Field test survey

In order to meet one of the MAVEN research objectives, field test surveys were conducted during the MAVEN integration sprint 6 in Braunschweig on January 2019 and the MAVEN final demonstration event that took place during the ITS European Congress 2019 (June 3 - 6, 2019) in Helmond.

The objective of the integration sprint in Brauschweig was to verify the functionality of the cooperative speed advisory with DLR and Hyundai test vehicles on public roads. The objective of the demonstration event in Helmond was to show the cooperative interaction between the Hyundai AD test car and the Dynniq Traffic light controller as well as the automated reactions at vehicle and infrastructure side. Demonstrating platooning was not possible due to unavailability of the DLR vehicles in the Helmond demo test site.

In general, the surveys were focused on perceived trust and comfort when riding the automated vehicles implementing automated adaptation to infrastructure speed and, in the case of the Helmond demo, also to lane change advices. In Braunschweig, the survey was addressed to consortium members not involved in the technical development, who had the chance to be passengers of the car prototypes of DLR driving on public roads and real traffic conditions. In the Helmond demonstration, the survey was addressed to ITS congress delegates that could ride as passengers seated in the back of the Hyundai car along with an instructed safety driver and a presenter in the front. The demonstration on June 3 was open to the general public, so Helmond citizens were allowed to participate in the demonstration and complete the survey.

Before describing the results of the survey it is important to highlight some considerations that can explain some passenger reactions. The DLR car is purely an experimental platform used to test and validate technical developments and not primarily meant to address perfect user experience. The Hyundai AD test car, even if closer to a commercial platform than the DLR one, is still in a very early prototyping phase, and cannot be considered to have the level of maturity that can be expected from a vehicle on the market. As mentioned before, in the performed integration sprint and demonstration the main objective was to show primarily the cooperative interaction between an automated car and the road infrastructure as well as the automated implementation of infrastructure advices. Moreover, in the Helmond demonstration, the driven road section was not the one used for the testing throughout the whole project duration. Optimization of the vehicle automated behaviour in reaction to the infrastructure advices in that particular section was not

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possible in the short preparation time before the demo (1 week). Additional time would have allowed reaching the needed performance in terms of smooth and comfortable driving experience on the Hyundai car. Also, it must be said that some of the AD vehicle behaviours during the demonstration rides are a direct consequence of the policies provided by the infrastructure (sudden requests of speed increase or reduction, as well as advices to keep very low speeds). These are obviously very different from common human driving styles and might generally surprise unaware passengers.

The survey contained 12 questions with 8 multiple choice questions and 4 open questions. In total, 20 test drives participants completed the survey immediately after exiting the autonomous vehicle. Most of the survey participants (18) were as expected passengers, however, 2 vehicle operators completed the survey as well. There were 12 participants from the MAVEN affiliated companies (not only project partners, but also other colleagues from those companies), 5 participants from municipalities, 1 road authority representative and 2 other unspecified participants. For 60 % of the participants, it was the first live experience with autonomous driving.

When asked about their feelings during the test drive, most respondents indicated that the experience was positive to exciting, however, they noted that the lane change and the speed adjustment were not conducted smoothly. When specifically asked about any untypical behaviour during the test drive, the respondents reiterated their perception of less smooth lane changing, adding “unnatural” change of speed and slow driving speed. One of the passenger respondents, as well as one of the backup drivers, said that they observed “shaking” of the steering wheel, which, as explained by the Hyundai safety driver is normal for an AD prototype implementation. In general, it can be concluded that the participants were mostly concerned about abrupt lane change and unnatural accelerating and decelerating compared to human-operated car.

None of the respondents felt unsafe during the test as 85 % of them said they were “not at all” concerned about their safety. The remaining 15 % said they were “maybe partially” concerned because of lane and speed changing. One of the respondents who participated in Braunschweig test drives said that the automated vehicle going slow and sometimes breaking “without any understandable reason” that caused other non-automated vehicles to overtake it, sometimes in a potentially unsafe manner.

When asked a hypothetical question if they would be concerned about riding in an automated vehicle without any driver controls, 80 % of participants said they would be “slightly” to “moderately” concerned, 10 % said they would not be concerned at all and finally 10 % stated that they “would not sit in such a vehicle” (see Figure 7). It is interesting, yet maybe not that surprising, that the latter 10 % were the 2 vehicle operators who know the reliability level that can be reached by AD cars.

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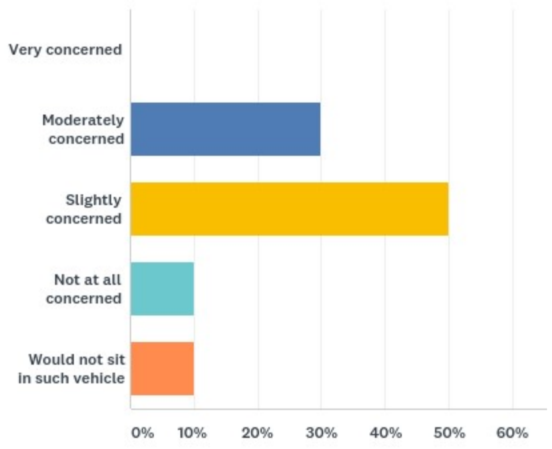

Figure 7 How concerned would you be about riding in a vehicle with no driver controls available in the real traffic? (Source: Filed test survey)

Only 12 respondents (60 %) answered the question related to keeping a safe distance by the autonomous vehicle. All but two were comfortable with the distance kept, while one said the distance was small, the other too large.

A similar situation was with the question of how the autonomous vehicle affected the behaviour of the nearby traditional vehicles that was answered by only 11 respondents (55 %). On the scale from 1 (Not at all / Very negative) to 5 (Very much / Very positive) the respondents we supposed to indicate if the autonomous vehicle affected nearby traditional vehicles and if it affected them in a rather positive way. The prevailing perception was that the other vehicles were affected (average score 3.1) in a positive way (average score 3.4), see Figure 8.

Presumably, the respondents who did not answer these two questions took part in the driving test on June 6, where no other vehicles were present.

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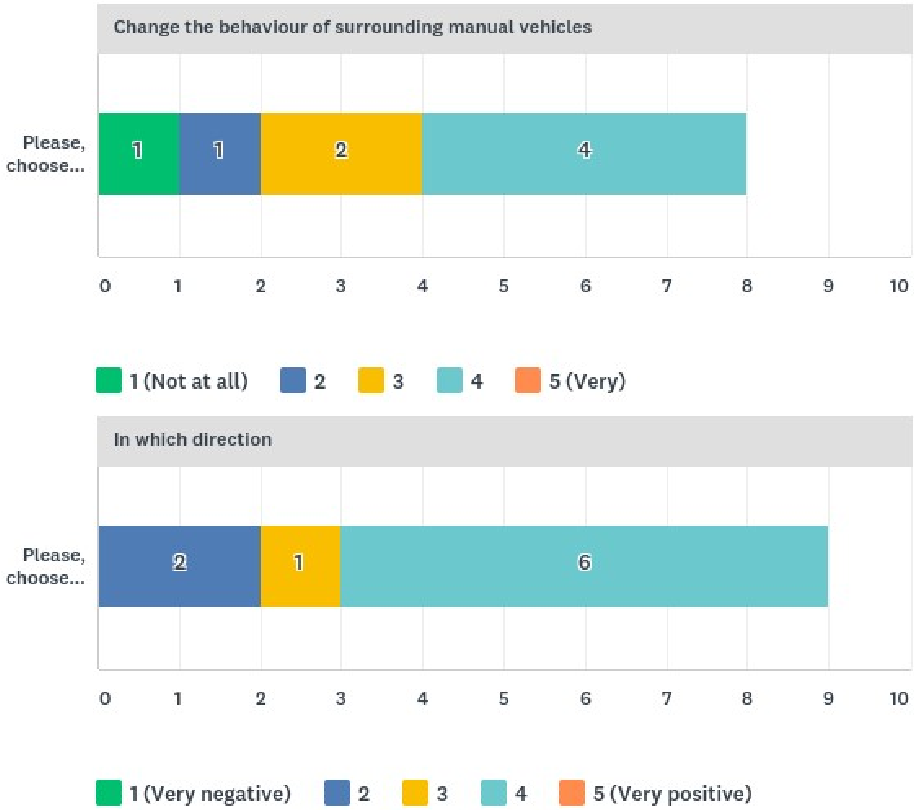

Figure 8 Please, check a number from 1 to 5 to quantify how the vehicle automation you saw change the behaviour of surrounding manual vehicles and in which direction? (Source: Filed test survey)

As for the overall perception of how valuable for the respondents was the participation in the demonstration, all respondents indicated that it was valuable bringing the average score to 4.5. out of 5.0, where 5 is "very valuable".

In their overall comments, the respondents underlined they were satisfied with their participation, however, that they would like to experience a platoon demonstration or interaction with other vehicles (June 6 participants) or even pedestrians. Also, there were expected comments on improving lane change and acceleration. As one of the respondents said: "…a lot has been done, but there is still a lot to do!".

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3.3 Online user survey

Introduction

In this chapter, we focus on the next means – an Internet survey. Selected individuals within the participating cities, as well as the general public, were surveyed using the tool Survey Monkey. Internet surveys, however, pose several problems to obtaining scientifically valid and accurate results. There are different approaches to minimize this effect (see for example https://help.surveygizmo.com/help/survey-bias). In order to increase the response rate, the respondents were also clearly informed about the benefits and possible improvements and effects resulting from the survey results.

Objectives adopted from D7.1 [10]

The deliverable D7.1 [10] identifies the main objectives of the user online survey:

"The internet survey addresses the acceptance and compliance of drivers and citizens of the particular MAVEN use cases and its results. Different target groups will be addressed, for example, the drivers of equipped vehicles and unequipped vehicles, as well as citizens of the pilot cities, guests, passengers. User surveys will be used to address this issue."

State-of-the-art analysis

Many surveys on the topic of autonomous vehicles have been done in the past years [38][39][40][41][42][43]. The public has generally expressed some concern regarding owning or using vehicles with this technology. The results varied considerably by country and interest levels were consistently lower when respondents were asked about allowing their children to ride in such vehicles.

Generally, the main topics addressed in the research were:

- Familiarity with and general opinion about autonomous vehicles
- Expected benefits of autonomous vehicles
- Concerns about using autonomous vehicles
- Concerns about the safety of autonomous vehicles in unexpected situations
- Concerns about cybersecurity issues
- Concerns about different possible implementations of self-driving vehicles
- Overall interest in owning and willingness to pay for autonomous-vehicle technology

The most frequently identified concerns/expected impacts are [44]:

- Safety and reliability of the system: safe functioning is often rated as people's top priority when judging the desirability of autonomous vehicles (e.g. [45][46])
- Security of the software: respondents typically raise the potential for people to hack into vehicle control systems as another serious concern (e.g.[47])
- Cost: there is an assumption that autonomous vehicles will increase the cost of vehicle ownership (e.g. [45][48])
- Liability: several surveys identify concerns around the legal issues associated with the use of the technology (e.g. [47][48])
- The majority of respondents have never previously heard of autonomous vehicles, have a positive initial opinion of the technology, and have high expectations about the benefits of the technology (e.g. [45][46])

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- The respondents also often express high levels of concern about vehicles without driver controls (e.g. [46])
- The majority of respondents are also unwilling to pay extra for the technology (e.g. [46])
- Females are more cautious about their expectations concerning benefits from using self-driving vehicles (e.g. [46] [48])

Methodology

In order to obtain really valid results, the questionnaire was designed based on the state-of-the-art review. A detailed analysis is provided in the following section. The literature review demonstrated that even though quite a lot has been done in this field, the MAVEN specific topics have not been covered. And this is exactly the objective of the online survey.

The process of survey design and analysis can be described in the following steps:

1.Preparatory phase

a.Literature review

b.Clustering of questions and identification of the main hypothesis groups

c.Identification of the MAVEN most related hypothesis groups

d.Definition of questions for particular hypothesis groups

e.Setting the priorities for particular questions (entire MAVEN team)

f.Creating the questionnaire (with questions with the highest priority only to keep the survey relatively short (see the discussion below about the length of the survey)

2.Survey execution

a.Identify the target groups (with the help of municipalities and groups of experts)

b.Distribute the survey

c.Monitor progress, response rate and (if needed) send reminders

d.Collection of the results

3.Survey processing

a.Data pre-processing (missing data analysis, identification of major errors in the collected data, etc.)

b.Data analysis

c.Reporting

Preparatory phase

Key aspects

The proper involvement of municipalities and/or professional organizations or groups can improve the awareness and thus increase the probability of an unbiased sample and as high as possible response rate. This allows us to share the survey via various methods: send out an email campaign, share it on municipality (or other) websites, post QR codes, etc. The combination of all these approaches was used.

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The entire survey procedure follows MAVEN guidance on ethics (deliverable D1.3 Ethics requirements and D1.4 Protection of personal data as well as General Data Protection Regulation (GDPR) (http://www.eugdpr.org/).

Hypothesis groups

The state-of-the-art analysis clearly showed that quite a lot of researches have been done in the field of user perception of autonomous driving. Within the MAVEN project and MAVEN survey, we do not want to cover all hypothesis groups. With respect to the other surveys that have been done in the past, the MAVEN position is the following:

1. Identify several questions from other surveys (mainly with respect to perception of possible impact) and use them to verify whether the respondents in other target groups and regions have the similar perception (*verification*).

2. Focus on the MAVEN related questions that are unique and has not been part of other surveys in the past (*uniqueness*).

With this in mind, the proposed questionnaire consists of several parts, aiming at different aspects of autonomous driving. The first part is socio-demographic and the aim is to get relevant data about the participants of the MAVEN survey. The following parts include questions related to different aspects of autonomous driving.

The questionnaire is divided into the following main topics:

1. Socio-demographic characteristics

2. Expected impacts / Effects of autonomous driving (e.g. expected impact on congestions, safety or others)

3. Integration into a city (e.g. sensitivity to sharing of public space, sensitivity to priorities of the different modes, reaction to MAVEN use cases)

4. The transition from the current state to a state with higher penetration of autonomous vehicles

5. Perception (e.g. concerns, potential issues)

The most relevant questions (i.e. questions with the highest priority) from all of these areas were included in the survey. Within the MAVEN survey, we did not want to repeat the previous studies.

For this reason, we focused on two main hypothesis groups:

- To identify fundamental questions from other surveys and verify them (*verification*).
- To prepare unique set of questions, important and relevant for the MAVEN project (*uniqueness*).

As most of the surveys about autonomous vehicles are related to perception and expected impacts, the main focus heads to sections 3. Integration into a city and 4. Transition.

Survey execution

Identification of target groups

The survey is ***targeting mainly on the general public***, i.e. future users of autonomous vehicles and participants of the traffic (drivers of conventional vehicles, VRU and others). Due to the nature of the survey distribution, this group also included experts, city authorities and in general people interested in the topic of autonomous driving. They are however not targeted primarily.

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Distribution of the survey

The survey was distributed to different participants in various countries (Czech Republic, Netherlands, UK, Germany and worldwide). The information and link to the survey were distributed using the following resources:

- MAVEN website and LinkedIn
- Greenwich website and city communication channel to inhabitants
- Helmond website and city communication channel to inhabitants
- POLIS network and distribution channels
- Distribution channels and website of the Operator ICT Prague (an organization dealing with smart city projects in the city of Prague)
- Members of Smart City Cluster Czech Republic
- Participants of the Workshop on Autonomous driving as part of SCSP 2018
- FIA, the European association of national motorist organisations, or alternatively the national driver's organisation directly. We have FIA contacts but not national level contacts.
- ECF, the European cyclist's federation
- EPA, European parking association
- EPF, European passenger federation
- Students of CTU, and
- Others.

Survey execution

The online survey was held from 1st of November till 31st December. The total number of the participants in the survey was 209.

The SW tool Survey monkey automatically stores the responses in a database available to the research team. Survey monkey also allows analysing the date from the survey.

The average time to complete the survey was 12 minutes, including the explanation of the MAVEN project and the key terms (e.g. autonomous vehicles, level of automation).

Selected results of the online questionnaire

This chapter includes two main subchapters. The first is shown all questions with their responses and includes the basic comments. The second subchapter shows the more detailed research analysis of particular responses and their comparison with other surveys or particular groups of respondents.

1.Socio-demographic characteristics

The first section of the survey is a socio-demographic characteristic and consists of 5 questions.

Q1 What is your nationality?

Respondents come from more than 30 countries. 33% come from the Czech Republic, 8% from the USA and the UK, 7% from Germany and 6% from the Netherlands. The rest of the nations are below 5%.

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Q2 Are you male or female?

70% of respondents are male and 30% are female as shown in Table 3.

Answer Choices	Responses
Male	69.90 %
Female	30.10 %

Table 3 Percentage of genders (male vs female)

Q3 How old are you?

The age structure is showed in Figure 9. 59% of respondents are between 25 and 44. 12% of respondents are older than 55 and 16% younger than 24.

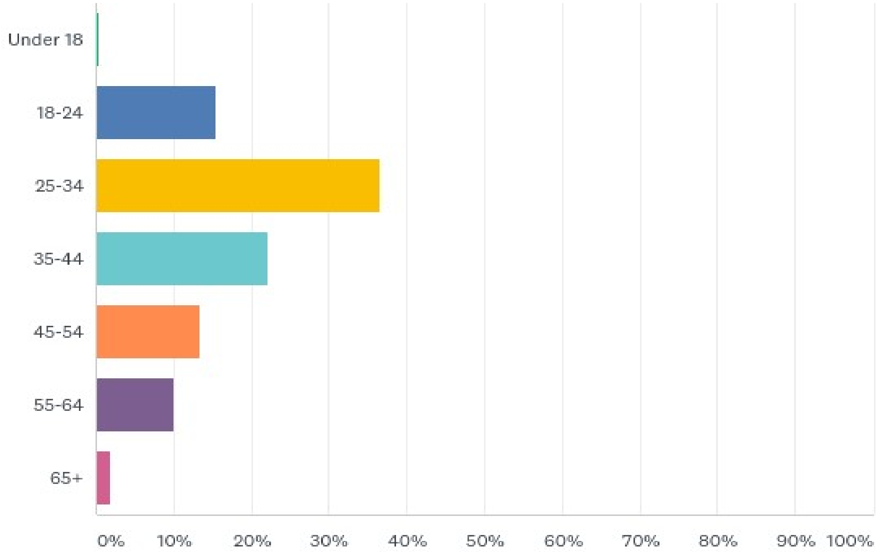

Figure 9 The age structure of respondents

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Q4 What is your working status?

The respondents have been a different working status as it can be seen from Table 4. The major groups coming from a public authority/municipality, university or research organization and a private sector. No seniors attended of this survey.

Answer Choices	Responses
Working for a public authority or municipality	19.90 %
Working for a university or a research organization	32.04 %
Working in a private sector	26.21 %
Self-employed or Entrepreneur	6.80 %
Unemployed	0.49%
Retired	0.00 %
Student	14.56 %

Table 4 The working status of respondents

Q5 What is your source of information related to automated vehicles?

The last socio question has been related where the respondents get information related to automated vehicles. The major group gets information from news and existing projects. This is done by the fact that many participants in the survey coming from a research area. The details responses are showed in Table 5.

Answer Choices	Responses
Information from news	80.29 %
Information from existing projects	59.62 %
Social Sites	36.06 %
Workshops	32.21 %
Conferences	49.52 %
Other	21.15%

Table 5 The source of information related to automated vehicles

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2.Expected impact

The second section is related to the expected effect of autonomous vehicles and consists of 6 questions.

Q6 Do you think that automated vehicles decrease the number of traffic accidents?

More than 80% of respondents have stated that they believe the number of accidents will decrease likely or very likely once automated vehicles are put into operation. In the age group 45-54, even 92% of respondents believe it will happen likely or very likely. The detailed responses are provided in Table 6.

Answer Choices	Responses
Very unlikely	3.54 %
Unlikely	4.55 %
Neither likely or unlikely	10.10 %
Likely	50.00 %
Very likely	31.82%

Table 6 Decrease automated vehicles the number of traffic accidents?

Q7 What are the most important benefits you expect automated vehicles to deliver?

The respondents could select more than one option. 75 % of respondents expect the improved of road safety which is fully in line with the previous question. The half of respondents also expect the better prediction of traffic flows and the increase of comfort. In the age group 45-54, only 15 % of respondents expect the travel time savings or 33% the increase of comfort of driving. Another interesting fact is that only a third of respondents expect the emission reduction. The detailed results are in Table 7.

Answer Choices	Responses
Travel time savings	35.82 %
Improved road safety	75.12 %
Emission reduction	36.32 %
Cheaper services, such as sending the kids around without paying a taxi driver	19.90 %
Prediction of traffic flows	52.24 %
Increase of comfort of driving/riding	51.74 %
Other (please specify)	14.43 %

Table 7 The most important benefits expected from automated vehicles

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Q8 What effect on traffic conditions (congestions) do you expect after introducing automated vehicles?

53 % of respondents expect to slightly improve the traffic conditions and 17 % expect of them the situation will be significantly improved. The only 17% of respondents expect that the situation will be significantly/slightly worsen. The detailed results are in Table 8.

Answer Choices	Responses
Significantly worsen	5.50 %
Slightly worsen	11.50 %
Remain the same	13.00 %
Slightly improve	53.00 %
Significantly improve	17.00 %

Table 8 The effect on traffic conditions

Q9 What effect on the travel time of the automated vehicles do you expect after introducing automated vehicles in cities?

Less than 5 % of respondents expect the travel time will significantly decrease and less than 2 % of respondents expect it will significantly increase. The majority of respondents expect that the travel time will either decrease or remain the same. The detailed results are in Table 9.

Answer Choices	Responses
Significantly decrease	4.52 %
Decrease	43.22 %
Remain the same	33.67 %
Increase	17.09 %
Significantly increase	1.51 %

Table 9 The effect on the travel time

Q10 What effect on the overall travel times (for all traffic) do you expect after introducing automated vehicles in cities?

The responses correlate with the previous question. Only 5 % of respondents again expect the travel time will significantly decrease and 2 % of respondents expect it will significantly increase. The majority of respondents expect that the travel time will either decrease or remain the same. The detailed results are in Table 10.

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Answer Choices	Responses
Significantly decrease	5.08 %
Decrease	45.18 %
Remain the same	31.98 %
Increase	15.74 %
Significantly increase	2.03 %

Table 10 The effect on the overall travel times (for all traffic)

Q11 What impact do you expect automated vehicles to have on your quality of life?

Half of the respondents expect a positive impact on their life and 27 % of them expect that there will be neither a negative nor positive impact. The detailed results are in Table 11.

Answer Choices	Responses
Very negative	1.50 %
Negative	7.50 %
Neutral	27.00 %
Positive	52.00 %
Very positive	12.00 %

Table 11 The expected impact on your quality of life

3.Integration into a city

The third section is related to the integration of autonomous vehicles into a city and consists of 8 questions.

Q12 If you would ride in an automated vehicle, how would you use the extra time instead of driving?

The respondents could have selected more than one option. Three-quarters of respondents would use the extra time for working on a laptop/tablet/smartphone. This could be done by the fact that the major group of respondents coming from a research area or public municipality. The detailed results are in Table 12.

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Answer Choices	Responses
Reading e.g. book	52.41 %
Watching a movie	22.46 %
Working on laptop/tablet/smartphone	74.33 %
Playing games on laptop/tablet/smartphone	17.65 %
Sleeping/Relaxing	55.61 %
Social networking	31.55 %
Interaction with others in the vehicle	51.87 %
Other (please specify)	11.23 %

Table 12: How would you use the extra time instead of driving?

Q13 How critical are the following issues related to mobility and infrastructure in your city?

The respondents should have marked how much are the issues below critical for them. The three most critical are parking, congestion and safe space for pedestrians. Nevertheless, all of them are similarly critical for them as can be seen from Figure 10.

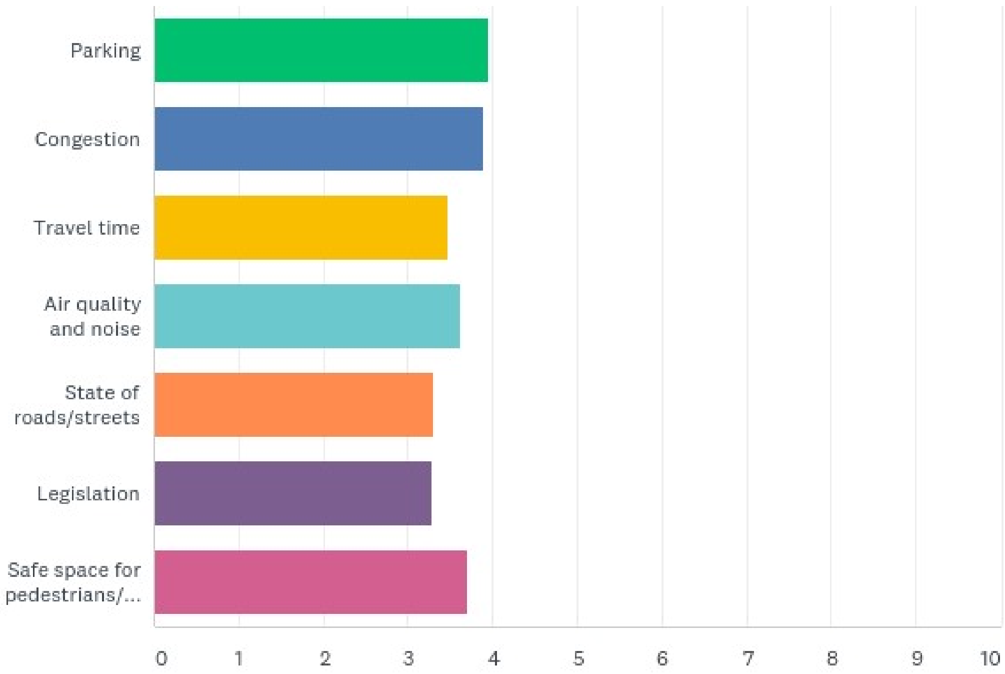

Figure 10 How critical are the following issues?

Q14 Do you agree that a platoon of five automated vehicles should get an extended green light to allow the full platoon to pass through the traffic signals?

Note: A vehicle platoon is a group of vehicles that travels near one another, nose-to-tail. A lead vehicle is followed by a number of other vehicles that closely match their speed and manoeuvres to

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the lead vehicle.

Half of the respondents have (strongly) agreed that the extended green light should be used. Almost 30 % of them have (strongly) disagreed and 20 % are neutral. This is one of the typical use cases where MAVEN is trying to find answers and this question shows that there is currently no general opinion about such a situation. The detailed results are in Table 13.

Answer Choices	Responses
Strongly disagree	12.90 %
Disagree	15.59 %
Neither agree nor disagree	20.43 %
Agree	45.16 %
Strongly agree	5.91 %

Table 13 Do you agree with the question below?

Q15 How would you react in the following situation?

Situation: You are driving manually on the left lane in a city while a platoon of 5 vehicles is driving on the right lane with the same speed. There are no other vehicles and the road is straight. You want to turn right on the next intersection in 200m, where a traffic light just became green, and need to change lane to the right. What will you do?

The question is asking about another MAVEN use case. Over 40 % of respondents have selected that the vehicle should break and change the lane behind the platoon. This is rather optimistic as it is the desired behaviour from the traffic management point of view. The detailed results are in Table 14.

Answer Choices	Responses
Accelerate and change lane in front of the platoon, even if this means to drive faster than allowed.	23.53 %
Break and change lane behind the platoon even if this means that you probably need to drive slowly and might not reach the upcoming traffic light at green.	43.85 %
Set the indicator and hope that the platoon opens a gap quickly.	28.34 %
Just drive to the right as the automated vehicles should be able to react.	4.28 %

Table 14 How would you react in the following situation?

Q16 What should be the minimum distance between vehicles (headway) platooning vehicles should follow in the automated mode?

This question is asking about the minimum distance between the platooning vehicles. 80 % of respondents have stated that the distance should be smaller than is allowed by law for non-platooning manual vehicles. 30 % of respondents have selected the choice that the distance should be smaller than 50% as allowed by law for non-platooning manual vehicles. The detailed results are in Table 15.

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Answer Choices	Responses
Same as allowed by law for non-platooning manual vehicles	20.54 %
0 to 25 % smaller distance as allowed by law for non-platooning manual vehicles	22.16 %
25 to 50% smaller distance as allowed by law for non-platooning manual vehicles	27.57 %
Distance smaller than 50% as allowed by law for non-platooning manual vehicles	29.73 %

Table 15 What should be the minimum distance?

Q17 What do you think would be an impact of platoons in urban areas?

Over 50 % of respondents expect less waiting time at the traffic lights. The interesting thing is that only 22 % of respondents expect fewer dangerous situations. On the other hand, 38 % expect that there will be more dangerous situations. The detailed results are in Table 16.

Interesting was also the more detailed answers in the other category. Many respondents expressed the opinion that "*It strongly depends on how (fast and accurate) the automated vehicles will react on non-automated vehicles*." It is also more elaborated in a way that "*Some manually driving vehicles may try to change lane and take the place between participants of the platoon (in some emergency situation or just as aggressive driving), so platoon should be ready to such situations. Maybe, less distance between participants of platoon could help to partially solve the problem, but how smaller distance would influence on safety?*"

Another respondent stated that: "*I think the impact would be neutral, as long as platoons are treated the same as the other vehicles on the road (i.e. not given special privileges, especially over other modes). Regulations have a way of encouraging or discouraging certain mode choices, so any "preferences" given to automated vehicles or platoons should never come at the cost of more sustainable modes (walking, cycling and public transport).*" Also, a group of respondents are worried about worsening of the situation for other participants, such as pedestrians crossing the street or public transport.

Answer Choices	Responses
Less waiting time at traffic lights as more vehicles can pass at green	55.38 %
More safety on roads	39.78 %
Less safety on roads	10.22 %
More free space as automated vehicles are driving closer together	46.24 %
More dangerous situations (e.g. due to interaction with non-automated vehicles)	37.63 %
Fewer dangerous situations	22.04 %
Other (please specify)	13.98 %

Table 16 What do you think would be an impact of platoons in urban areas

Q18 You are a passenger in an automated vehicle and you don't have an appointment at a specific time at your destination. Would you accept the vehicle taking a detour to reduce congestion? Note: This could lead to a better distribution of traffic in the network and thus reaching the overall optimum, but lead to an increase in travel time for you particularly.

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Only 18 % of respondents would not accept any delay and always want to be at their shortest travel time. Any delay is acceptable for 7 % of respondents. The major group (76 %) of respondents would accept a maximum of 5 % extra travel time including respondents for 10 % and 25 % of extra travel time. The detailed results are in Table 17.

Answer Choices	Responses
No, I always want my individually shortest travel time	17.84 %
Yes, maximum of 5% extra travel time	17.30 %
Yes, maximum of 10% extra travel time	38.38 %
Yes, maximum of 25% extra travel time	20.00 %
Yes, any delay is acceptable	6.49 %

Table 17 Would you accept the vehicle taking a detour to reduce congestion?

Q19 Where do you think, platooning could play a beneficial role in cities? Note: A vehicle platoon is a group of vehicles that travels in close proximity to one another, nose-to-tail. A lead vehicle is followed by a number of other vehicles that closely match their speed and manoeuvres to the lead vehicle.

76 % of respondents expect a beneficial role, especially in high capacity corridors. Benefits are expected at intersections, lorry routes and public transport routes by between 30 and 45 % respondents as shown in Table 18.

Answer Choices	Responses
Intersections	37.02 %
High capacity (multi-lane) corridors	75.69 %
Lorry routes	31.49 %
Public transport routes	44.75 %
Other (please specify)	3.87 %

Table 18 Where could platooning play a beneficial role in cities?

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4.Transition

The fourth section is related to a transition from the current vehicles to autonomous vehicles and consists of 7 questions.

Q20 For your business trip, you can order a standard taxi (with a driver) or an automated taxi (without a driver). Both with the same error rate. Which one will you select, if the automated taxi is 10% cheaper?

and

Q21 For your private trip, you can order a standard taxi (with a driver) or an automated taxi (without a driver). Both with the same error rate. Which one will you select, if the automated taxi is 10% cheaper?

Both of these questions address the issue, which vehicle respondents select if the automated taxi is 10 % cheaper. From the responses, it does not matter if the purpose of the trip is considered. In both cases, three-quarters of respondents would select a taxi without a driver as can be seen from Table 19.

Answer Choices	Business trip	Private trip
With a driver	23.76 %	21.11 %
Without a driver	76.24 %	78.89 %

Table 19 A standard taxi (with a driver) or an automated taxi (without a driver)?

Q22 In how many years do you expect 10 % of all vehicles in the cities to be automated?

Only 3 % of respondents expect it will happen in the next 5 years. 32 % of respondents expect a tenth of the automated vehicles in the cities within 10 to 15 years. The interesting fact is that 25 % of respondents expect it for more than 20 years. The detailed results are in Figure 11.

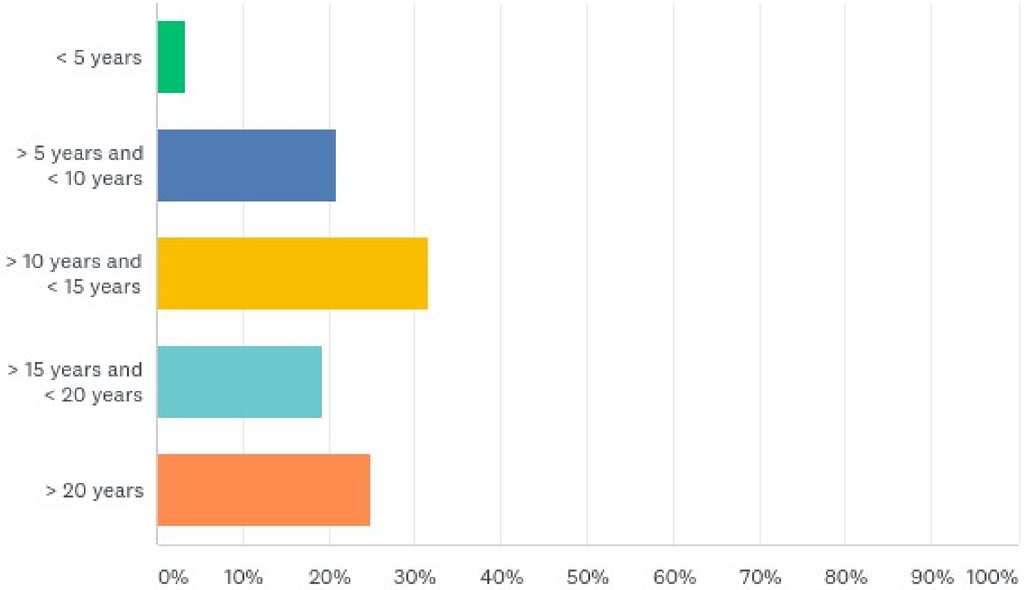

Figure 11 In how many years do you expect 10 % of all vehicles in the cities to be automated?

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Q23 Would you be prepared to pay more for automated features?

36 % of respondents would not accept to pay more for automated features. Only 6 % of respondents would accept to pay more than 5000€. This shows that customers will be able to pay a little bit more for automated vehicles, but 5000€ looks like a threshold. The detailed results are in Table 20.

Answer Choices	Responses
No - normal car without automated features	36.16 %
Yes - up to €2000 more for automated features	34.46 %
Yes - €2000 - €5000 more for automated features	23.16 %
Yes - €5000 - €10000 for automated features	5.65 %
Yes - €10000 plus for automated features	0.53 %

Table 20 Would you be prepared to pay more for automated features?

Q24 What do you see as the biggest obstacle to the introduction of automated vehicles?

Two biggest obstacles are cybersecurity/privacy concerns and the lack of a regulatory framework. Nevertheless, the results below (Table 21) show that all of the choices are potential obstacles as the difference between the biggest and lowest obstacles is only 18%.

Interesting here is also the almost 15% of respondents, who provided a detailed answer not fitting the predefined groups (other).

As those additional obstacles were stated among others:

"*People are not (mentally) ready to accept liability and responsibility concerns relating to car accidents with automated cars*."

"Interaction with humans (specifically pedestrians and cyclists:)"

"Interaction between automated vehicles and drivers of standard cars"

"Users' acceptance, users' trust, users' concerns about not having control over the vehicle."

"Responsibility for accidents and deciding in critical situations." or

"Too many government regulations".

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Answer Choices	Responses
Cost	44.20 %
Safety	37.02 %
Cybersecurity/privacy concerns	55.80 %
Capabilities of the technology	43.09 %
Consumer readiness to adopt	44.75 %
Lack of a regulatory framework	54.70 %
Other (please specify)	14.92 %

Table 21 What do you see as the biggest obstacle to the introduction of automated vehicles

Q25 Should automated vehicles be supported by the public government using lower taxes compared to non-automated vehicles?

More than 50 % of respondents have stated that there should be no tax support from a government side. On the other hand, only 7 % of respondents would apply no taxes for autonomous vehicles. The detailed results are in Table 22.

Answer Choices	Responses
No, the taxes should be the same	53.63 %
Yes, the taxes should be lower by max. 5 %	11.17 %
Yes, the taxes should be lower by 5% to 15 %	17.32 %
Yes, the taxes should be lower by 15 % to 40 %	10.61 %
Yes, there should not be any taxes for autonomous vehicles	7.26 %

Table 22 Should automated vehicles be supported by the public government using lower taxes?

5. Perception

The last section of the survey is related to the perception of autonomous vehicles and consists of 2 questions.

Q26 Who should be protected (prioritized) by the automated vehicle software in case of a dangerous situation?

More than half of respondents have stated that pedestrians or bicycles should be protected with the priority. Respondents could also choose the response “Other”, where many of them wrote that they simply do not know. The detailed results are in Table 23.

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Answer Choices	Responses
Passengers of the automated vehicle	26.52 %
Pedestrians/Bycicles	56.35 %
Other cars	1.10 %
Public property	0.00 %
Other (please specify)	16.02 %

Table 23 Who should be protected (prioritized) by automated vehicle software?

Clearly, this question raises some controversy. This can be seen also from the detailed responses in another category, for example:

"*I don't like the question in general as it can be solved on a geometrical level: In case of the emergency brake as hard as possible and evade to the observable free space with the largest extent (if applicable) --> that's enough*"

"*Depends on the situation. If it's car failure than no one outside should get hurt.*".

Nice elaboration of this dilemma is also here: "*I understand the dilemma of programming vehicle software, but the real question is not who to protect but to gain more safety in general with the introduction of automated driving. Regarding this, I think it's a big concern about how automated vehicles would react to disabled people of blind people willing to cross the road. Playing kids in a housing area or just someone who would like to catch a waiting bus on the other side of the street. These and other social values should lead to questions like do we really want to have robots in residential areas?*"

Q27 Would you be willing to accept liability if there was an accident while the car was driving automatically?

Only 7 % of respondents would be willing to accept liability. As the most likely option is that there will be some new type of car insurance will be liable. The detailed results are in Table 24.

The other category covers some answers of the type – I do not know, but also other interesting opinions:

"Passenger cannot be liable for the accident if he doesn't continuously drive the car himself. (He cannot be even obliged to turn off the auto-pilot and start to drive manually in case of danger). I think that the "concept of liability" itself (that for every particular case of an accident is someone "human" responsible) has to be redefined and accepted by the public."

Or

"All of the above except passenger".

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Answer Choices	Responses
Yes	6.63 %
No, the car manufacturers are liable	23.76 %
No, the auto-pilot software companies are liable	16.02 %
No, some new type of car insurance will be liable	43.65 %
Other (please specify)	9.94 %

Table 24 Would you be willing to accept liability?

Detailed analysis of particular questions

In this section, the goal is to research particular questions more closely. Generally, we want to compare total responses with other similar researches or apply some rules (e.g. total responses vs public authority, total responses vs age, total responses vs gender). Only the most interesting results are presented here.

R1 Compare the question Q6 (*Do you think that automated vehicles decrease the number of traffic accidents?) with* responses by public authority only.

The aim of the comparison is to find out if there is a difference between total response rate and the responses of public authority (question Q4 and working for a public authority or municipality) as the expectations could be different in case of people working for a public authority or municipality. As can be seen from Table 25, there is no significant difference.

Answer Choices	Total responses	Public authority
Very unlikely	3.54 %	0.00 %
Unlikely	4.55 %	7.69 %
Neither likely or unlikely	10.10 %	10.26 %
Likely	50.00 %	51.28 %
Very likely	31.82 %	30.77 %

Table 25 Total responses vs public authority

R2 Compare question Q7 (*What are the most important benefits you expect automated vehicles to deliver?*) with similar research [50].

We have compared our results from Q7 with the research from RAC [50]. In our survey, 75 % of respondents expect the improvement of road safety. Half of the respondents also expect a better prediction of traffic flows and an increase in comfort. In the age group 45-54, only 15 % of respondents expect the travel time savings or 33% the increase of comfort of driving. Another interesting fact is that only a third of respondents expect the emission reduction. The three least expected benefits of our respondents are emission reduction; travel time savings; and cheaper services, such as sending the kids around without paying a taxi driver.

The three most expected benefits of RCA`s respondents are enhanced freedom and independence for the young, ageing and those with mobility difficulties; travel time can be used more effectively / productively doing other activities; and fewer crashes. On the other hand, the three least expected

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benefits of RCA`s respondents are less traffic congestion; lower vehicle emissions; and less need for public parking in towns and cities.

The comparison shows that the expected impacts are quite different. For example, in our survey, the second biggest expected benefit is the better prediction of traffic flows. On the other hand, RAC`s respondents do not expect less traffic congestion.

R3 Compare question Q12 (*If you would ride in an automated vehicle, how would you use the extra time instead of driving?)* with the research [49].

This question has also been a part of a research done by the Ministry of Transport of the Czech Republic [49]. As can be seen from Table 26, the most significant difference is between the option – working on laptop/tablet (74 vs 31 %). This difference could be done by the fact that MAVEN questionnaire attended mainly by professionals who are more likely to spend their time working.

Answer Choices	MAVEN	MoT CR
Reading e.g. book	52.41 %	39.50 %
Watching a movie	22.46 %	36.90 %
Working on laptop/tablet/smartphone	74.33 %	31.10 %
Playing games on laptop/tablet/smartphone	17.65 %	23.80 %
Sleeping/Relaxing	55.61 %	35.30 %
Social networking	31.55 %	48.30 %

Table 26 How would you use the extra time instead of driving?

R4 Compare question Q14 (*Do you agree that a platoon of five automated vehicles should get an extended green light to allow the full platoon to pass through the traffic signals?)* with responses by public authority only.

As can be seen from Table 27, the most significant difference is between Strongly disagree choice. This can be caused by the fact that many respondents coming from research or public authority's area. These respondents also have a different source of knowledge as can be seen from the socio-demographic question (The source of information related to automated vehicles) where 60 % of respondents have knowledge from research projects and 50 % from conferences.

there is no significant difference between total and public authority responses.

Answer Choices	Total responses	Public authority
Strongly disagree	12.90 %	2.78 %
Disagree	15.59 %	22.22 %
Neither agree nor disagree	20.43 %	22.22 %
Agree	45.16 %	44.44 %
Strongly agree	5.91 %	8.33 %

Table 27 Total responses vs public authority

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R5 Compare question Q15 (*How would you react in the following situation? Situation: You are driving manually on the left lane in a city while a platoon of 5 vehicles is driving on the right lane with the same speed. There are no other vehicles and the road is straight. You want to turn right on the next intersection in 200m, where a traffic light just became green, and need to change lane to the right. What will you do?)* the total responses vs public authority.

As can be seen from Table 28, the public authority`s responses are the same in case of brake and change lane behind the platoon; and set the indicator. The difference is at the first and fourth choices. This difference can be explained by the fact that public authorities have a different level of knowledge about automated vehicles.

Answer Choices	Total responses	Public authority
Accelerate and change lane in front of the platoon, even if this means to drive faster than allowed.	23.53 %	11.11 %
Break and change lane behind the platoon even if this means that you probably need to drive slowly and might not reach the upcoming traffic light at green.	43.85 %	44.44 %
Set the indicator and hope that the platoon opens a gap quickly.	28.34 %	27.78 %
Just drive to the right as the automated vehicles should be able to react.	4.28 %	16.67 %

Table 28 Total responses vs public authority

R6 Compare question Q18 (*You are a passenger in an automated vehicle and you don't have an appointment at a specific time at your destination. Would you accept the vehicle taking a detour to reduce congestion?)* the total responses vs public authority.

As can be seen from Table 29, the public authorities would be generally willing to accept 10 % more extra travel time compare to individual shortest travel time. They would use this additional time mostly for working on laptop/smartphone/tablet. The difference between the total responses and public authority`s responses is negligible at choices 5 % and 25 %. The public authorities are also more tolerant of their individual travel time.

Answer Choices	Total responses	Public authority
No, I always want my individually shortest travel time	17.84 %	11.11 %
Yes, maximum of 5% extra travel time	17.30 %	19.44 %
Yes, maximum of 10% extra travel time	38.38 %	47.22 %
Yes, maximum of 25% extra travel time	20.00 %	19.44 %
Yes, any delay is acceptable	6.49 %	2.78 %

Table 29 Total responses vs public authority

R7 Compare question Q19 (*Where do you think, platooning could play a beneficial role in cities?)* the total responses vs public authority.

It can be seen from Table 30, the public authorities expect the major benefit at high capacity corridors. This is in line with the total responses. The main difference is that the public authorities

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expect a bigger benefit in public transport and lorry routes than in intersections.

Answer Choices	Total responses	Public authority
Intersections	37.02 %	19.44 %
High capacity (multi-lane) corridors	75.69 %	72.22 %
Lorry routes	31.49 %	38.89 %
Public transport routes	44.75 %	55.56 %
Other (please specify)	3.87 %	2.78 %

Table 30 Where could platooning play a beneficial role in cities?

R8 Compare question Q20 (*For your business trip, you can order a standard taxi (with a driver) or an automated taxi (without a driver). Both with the same error rate. Which one will you select, if the automated taxi is 10% cheaper?*) with question Q21 (*For your private trip, you can order a standard taxi (with a driver) or an automated taxi (without a driver). Both with the same error rate. Which one will you select, if the automated taxi is 10% cheaper?*) with the age group 55-64.

All age groups are reported similar results as the total responses (deviation max. 5 %). The only difference is the age group 55-64 which would consider more driving with a driver as can be seen in Table 31. The can be explained by the fact that the older generations have less trust in technology than the younger generations.

Answer Choices	Business trip (total responses)	Private trip (total responses)	Business trip (age 55-64)	Private trip (age 55-64)
With a driver	23.76 %	21.11 %	38.89 %	33.33 %
Without a driver	76.24 %	78.89 %	61.11 %	66.67 %

Table 31 - A standard taxi (with a driver) or an automated taxi (without a driver)?

R9 Compare question Q23 (*Would you be prepared to pay more for automated features?*) with the research in [47].

The respondents from the research in [47], on average, were willing to pay more for fully automated driving than for partial and highly automated driving. Figure 13 shows the distribution of responses, where 22% indicated that they were willing to pay nothing ($0) for fully automated driving. However, 240 respondents (4.9%) indicated they would be willing to pay more than $30,000 for fully automated driving.

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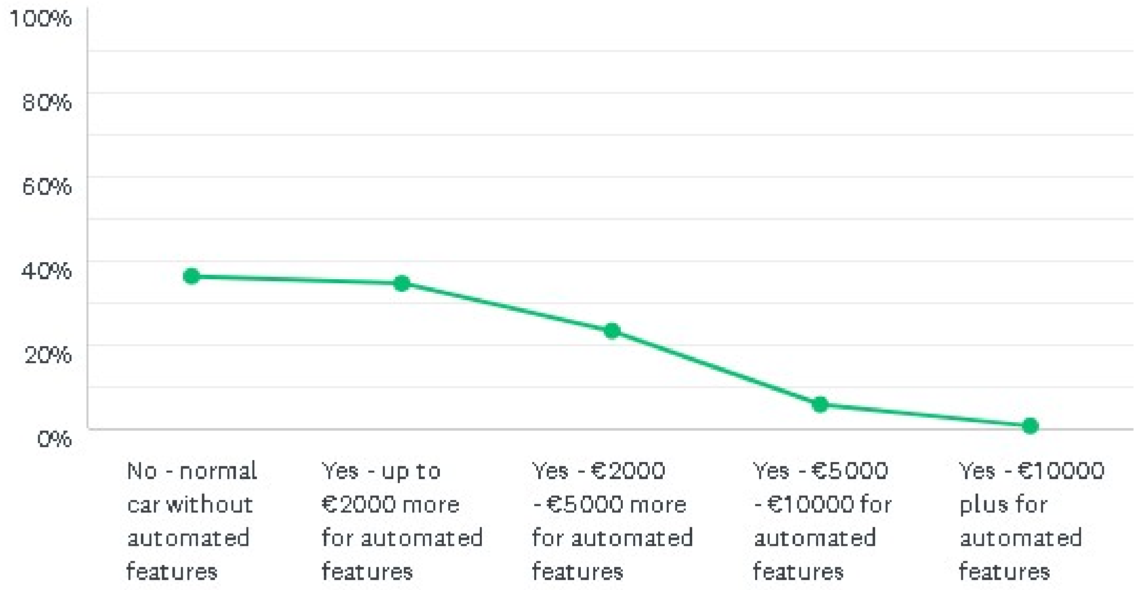

Figure 12 MAVEN results

In MAVEN, 36 % of respondents would not accept to pay more for automated features as it can be seen from Figure 12. Only 6 % of respondents would accept to pay more than 5 000€. This shows that customers will be able to pay a little bit more for automated vehicles, but 5 000€ looks like a threshold for most of people. On the other hand, 20 % of respondents from the second research stated that they would be willing to pay more than 7 000$.

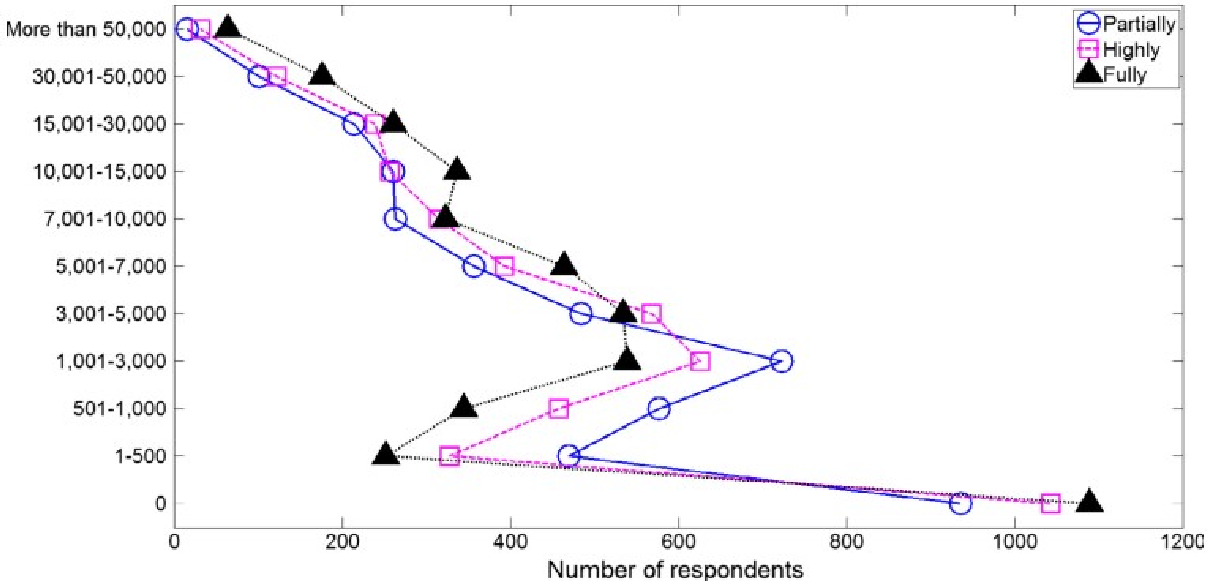

Figure 13 The results from [47]

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4 Results of Dominion simulations and Field tests

4.1 Use cases 1 through 6 (platooning)

Introduction

As described in D2.1 [1] several platooning use cases have been addressed in the MAVEN project. These are:

- UC1: Platoon initialisation
- UC2: Joining a platoon
- UC3: Travelling in a platoon
- UC4: Leaving a platoon
- UC5: Platoon break-up
- UC6: Platoon termination

The use cases are very much related to each other and cannot be investigated easily in a separated way, as there is always a platoon creation (platoon initialisation (UC1) or joining a platoon (UC2)), followed by travelling in a platoon (UC3) and finally platoon resolving (by leaving (UC4), break-up (UC5) or termination (UC6)). Because of this, all platooning use cases are handled together, in simulation as well as in field tests.

The following sub-chapters describe the method and results of the performed simulations and field tests.

Platooning in simulation

Platooning simulation has been performed in two different ways. On the one hand, broader effects of numerous platooning vehicles have been analysed using SUMO, on the other hand, sub-microscopic simulations of single vehicles have been performed to show how the automated driving software used in the field tests later on is exactly behaving. The two approaches and results of both are described in the following.

While the results of the microscopic traffic simulation in SUMO is described in Chapter 5, the following paragraphs describe the results for the sub-microscopic simulation using Dominion.

As shown in D6.4 [12] the platoon management use cases (UC1-6) have been simulated at DLR inside the Dominion simulation framework in several test events during the entire project. Dominion as a simulation platform is used at DLR's Institute of Transportation Systems (DLR-ITS) for all software integrations, as it offers high flexibility and scalability [51]. Dominion can be used on standard desktop PCs with Microsoft Windows™ and Linux derivates, but it is also used in all DLR-ITS' driving simulators and all test vehicles. The benefit is that the software is only developed once and can then be used in all available environments.

As a first step, the platoon logic library (see D3.1 [52] for details) has been implemented and connected to Dominion. This library has later on been also used in the DLR test vehicles, but it has also been provided to HMETC where it has been integrated into the AD software.

As a first scenario, a single straight lane has been implemented which is used by two automated vehicle instances. The complete vehicle automation software including a virtual sensor data fusion, digital map, trajectory planner (including the platoon logic), high-level vehicle controller and V2X

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communication is running at each of the entities on the same desktop PC. These modules are accompanied by the basic simulation software, including traffic simulation (here without any additional vehicle, but including simple vehicle dynamics for the automated vehicles), scenario control (providing the start positions), visualization and V2X emulation (forwarding all sent messages of one entity to the V2X message receiver of the other without any loss).

In the scenario, one vehicle is driving in front of the other. For the platoon logic, there are three important values for setting the initial distance between the vehicles: The default boundary for sending Platooning Cooperative Awareness Message (PCAM) (200 m; if the vehicles are coming closer than this distance, they start to send PCAMs), the default boundary for building platoons (100 m; if the vehicles are sending PCAMs and agree to form a platoon, it is starting to be formed when the vehicles are below this distance), and the default boundary for successful platoon forming (here: 5 m; this value is speed-dependent and is changed dynamically by the following vehicle depending on the situation). Therefore, the initial distance of the vehicles is set to 250 m, but the front vehicle gets a lower target speed than the follower. Different speed values up to 13.8 m/s have been tested.

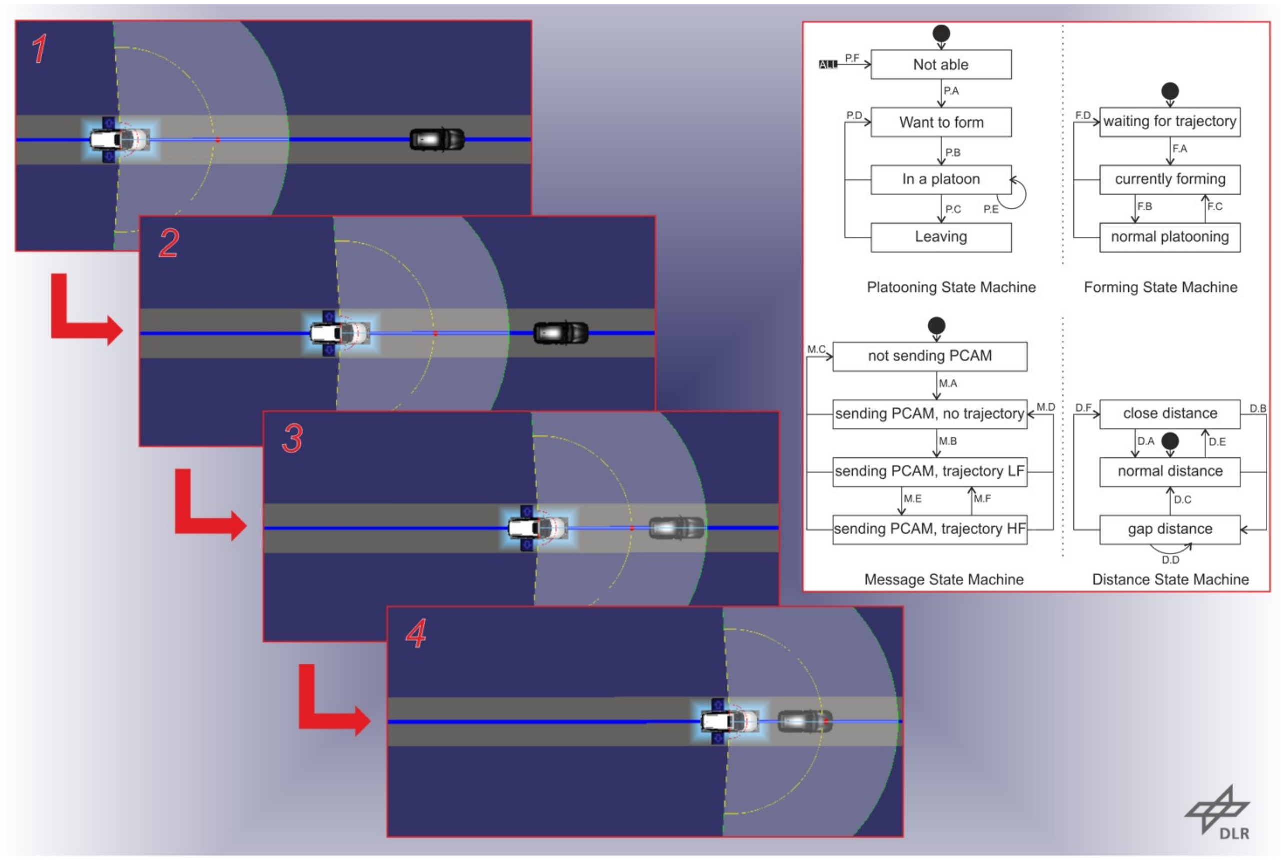

Figure 14 Platoon Logic state machines (top right) integrated into the DLR trajectory planner running on the Dominion framework. Here, platoon initialization is shown

As a result, it has been shown that the platoon logic was running as intended. All states of the four-state machines at each vehicle in the chronological order of actions are shown in Table 32, focusing on platoon initialisation and travelling. Details about the meaning of each of the states are defined in D3.1 [52].

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Action	Leader				Follower			
	Platoon SM	Forming SM	Message SM	Distance SM	Platoon SM	Forming SM	Message SM	Distance SM
1: Distance 250 m	Want to form	Waiting for trajectory	Not sending PCAM	Normal distance	Want to form	Waiting for trajectory	Not sending PCAM	Normal distance
2: Distance < 200 m			Sending PCAM, no trajectory				Sending PCAM, no trajectory	
3: Distance < 100 m			Sending PCAM, trajectory LF		In a platoon			
4: After reception of PCAM with trajectory at follower						Currently forming		Close distance
5: After receiving platoon info from follower	In a platoon							
6: Distance < 5 m						Normal platooning		

Table 32 All states of the four-state machines at each vehicle

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Whenever any relevant value of the platoon leader is changed manually (e.g. different route at an upcoming intersection, different speed acceptance) the platoon is instantly resolved.

In a second scenario, special focus has been put on platoon break-up (UC5). In this scenario, the two automated vehicles were already driving in a platoon from the very beginning, but on a road containing more than one lane. By using the Dominion traffic simulation, an additional vehicle is put on the adjacent lane, driving with the very same speed as the platoon. By using the scenario control of the simulation, the vehicle gets the advice to change lane to the lane of the platoon, by setting the indicator.

This behaviour is detected by the platooning follower vehicle, which is instantly opening a gap to allow the other vehicle to change lane. All details of the break-up, followed by further separation of the automated vehicles are shown in the following Table 33.

Action	Leader				Follower			
	Platoon SM	Forming SM	Message SM	Distance SM	Platoon SM	Forming SM	Message SM	Distance SM
1: Initial situation	In a platoon	Waiting for trajectory	Sending PCAM, trajectory LF	Normal distance	In a platoon	Normal platooning	Sending PCAM, no trajectory	Close distance
2: Indicator detected by follower								Gap distance
3: Manual vehicle changed lane	Want to form				Want to form	Waiting for trajectory		Normal distance
4: Distance between platooning vehicles			Sending PCAM, no trajectory					

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> 100 m								
5: Distance > 200 m			Not sending PCAM				Not sending PCAM	

Table 33: Detail parameters of the break-up, followed by further separation of the automated vehicles

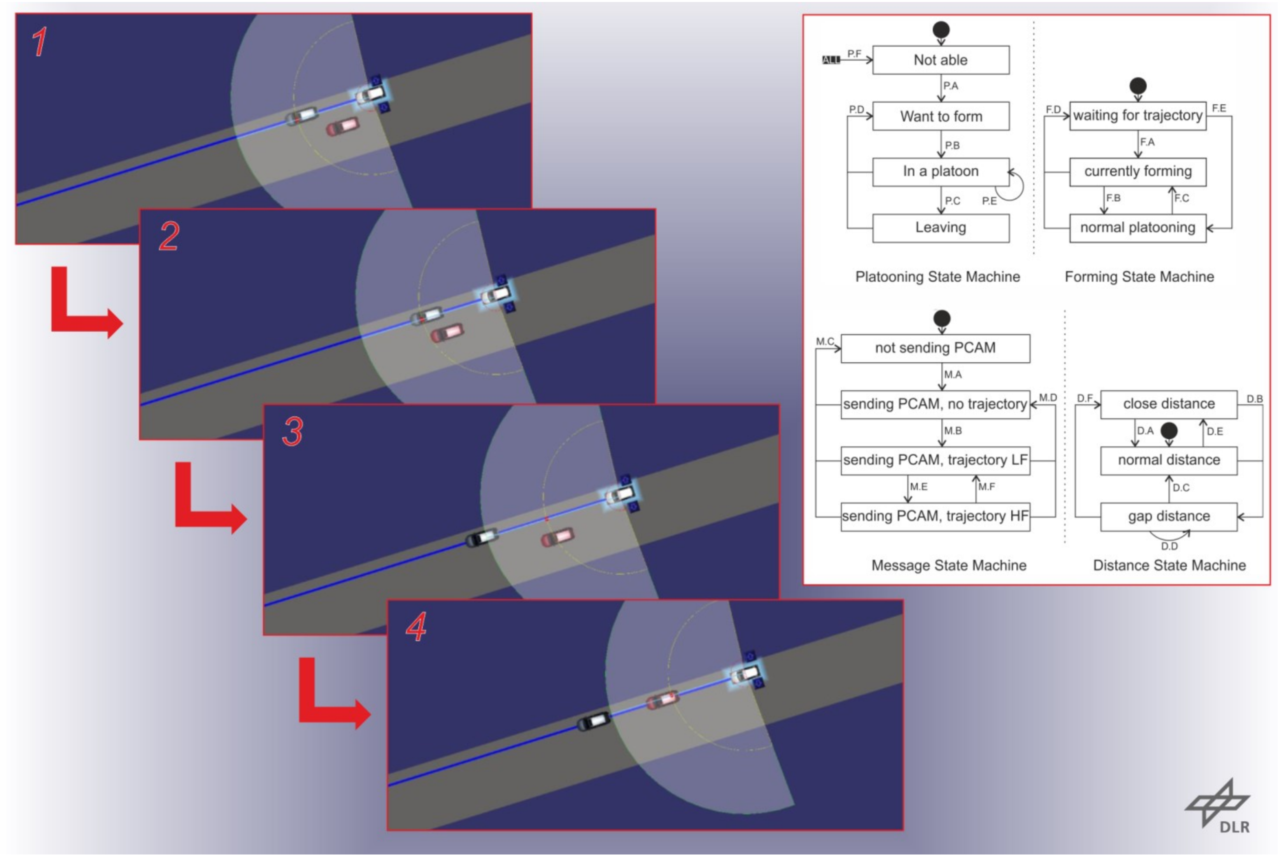

Figure 15 UC 5, platoon break-up, simulated in Dominion. The right side of the image shows the four-state machines implemented in the platoon logic, see D3.1 [52]

After the successful passing of the mentioned tests, the simulation activity was focusing on more complex road networks and on approaching the final road setup and complexity which will be found on the test track and public road field tests addressed later in the project.

For this purpose, a wider field of road topologies and a variety of traffic situations have been implemented. The road topologies included the test track layouts from Peine-Edesse and Griesheim as well as virtual topologies of the Braunschweig Tostmannplatz area where all final tests have been performed. Details are given in D6.4 [12].

Besides the complexity of the road and the variety of situations, all the above mentioned tests have been performed with two or three platooning vehicles. In addition, the tests have also been enriched with hardware-in-the-loop simulations. During those simulations, e.g. shown in Figure 16, two V2X-communication devices have been connected to the Dominion simulation platform. By

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doing this, the exchange of real messages could be tested in the simulation environment. As shown in the figure the simulations also took place virtually on the digital maps of the used test tracks and public roads, assuring to be as close to reality as possible. More details of the testing activities are described in Test event 13 in D6.4 [12] and in [53].

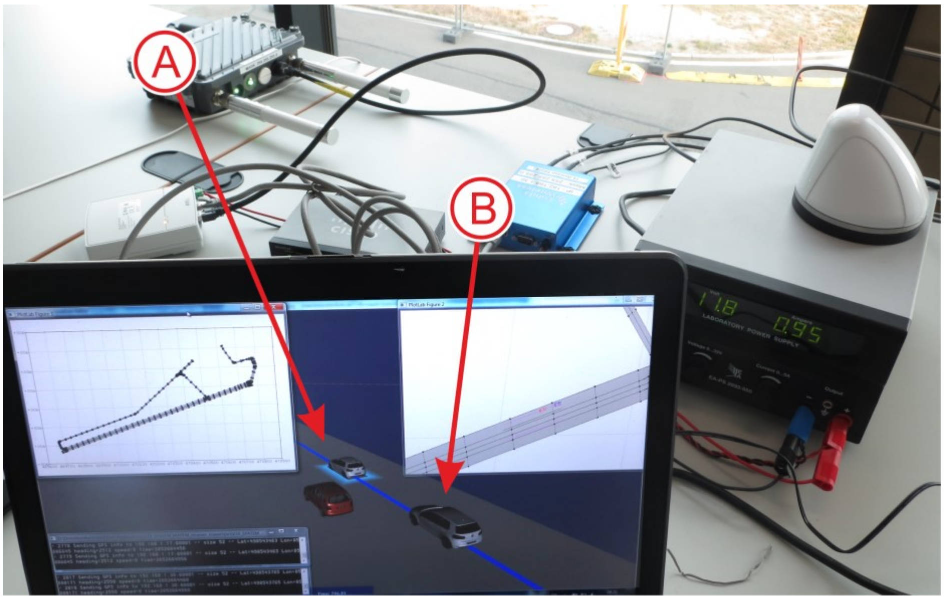

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Figure 16 Hardware-in-the-loop simulation with two Cohda-Boxes, allowing platooning on the virtual Griesheim test track with real V2X messages

Platooning in field tests

While simulation activity was ongoing through the whole project, platooning was also implemented in the real test vehicles. Several tests have been performed on the test tracks in Peine-Edesse and later on in Griesheim. Figure 17 shows one of the integration tests (test event 20) done in Griesheim, where the platoon logic software was executed in DLR and HMETC vehicles. Figure 18 shows the results of those tests. As shown, the test was focusing on the correct transmission and reception of V2X messages in line with the correct behaviour of the platoon logic.

During all the tests, it could be shown that object tracking is one of the most important aspects of the platoon logic. Reason for this is that the vehicles need to react at once whenever there is an obstacle in between the platooning vehicles, as this directly has to lead to a breaking up of the platoon. Technically, this is calculated in the following way: Each of the platooning vehicles knows its position and includes this information in the provided CAMs. The CAMs are received by the other platoon members and the positions are fused with other sensor data, in the tests with the LIDAR detected objects. In case the vehicles ahead and/or behind (dependent on the position within the platoon) are vehicles providing the same platoon information by CAM, the platoon is stable. Whenever there is a LIDAR detected object in between, which cannot be fused with any CAM, the platoon is breaking up at this position. Since a LIDAR detection is not free of errors, ghost objects are detected sometimes. In addition, also the fusion algorithm needs to be fault-tolerant as CAMs are in some conditions received at only 1Hz, and as the contained position is not very exact depending on the available position accuracy at both sending and receiving vehicles.

In our tests, the platoon was formed correctly, but in some situations, it has been broken up because of the mentioned limitations.

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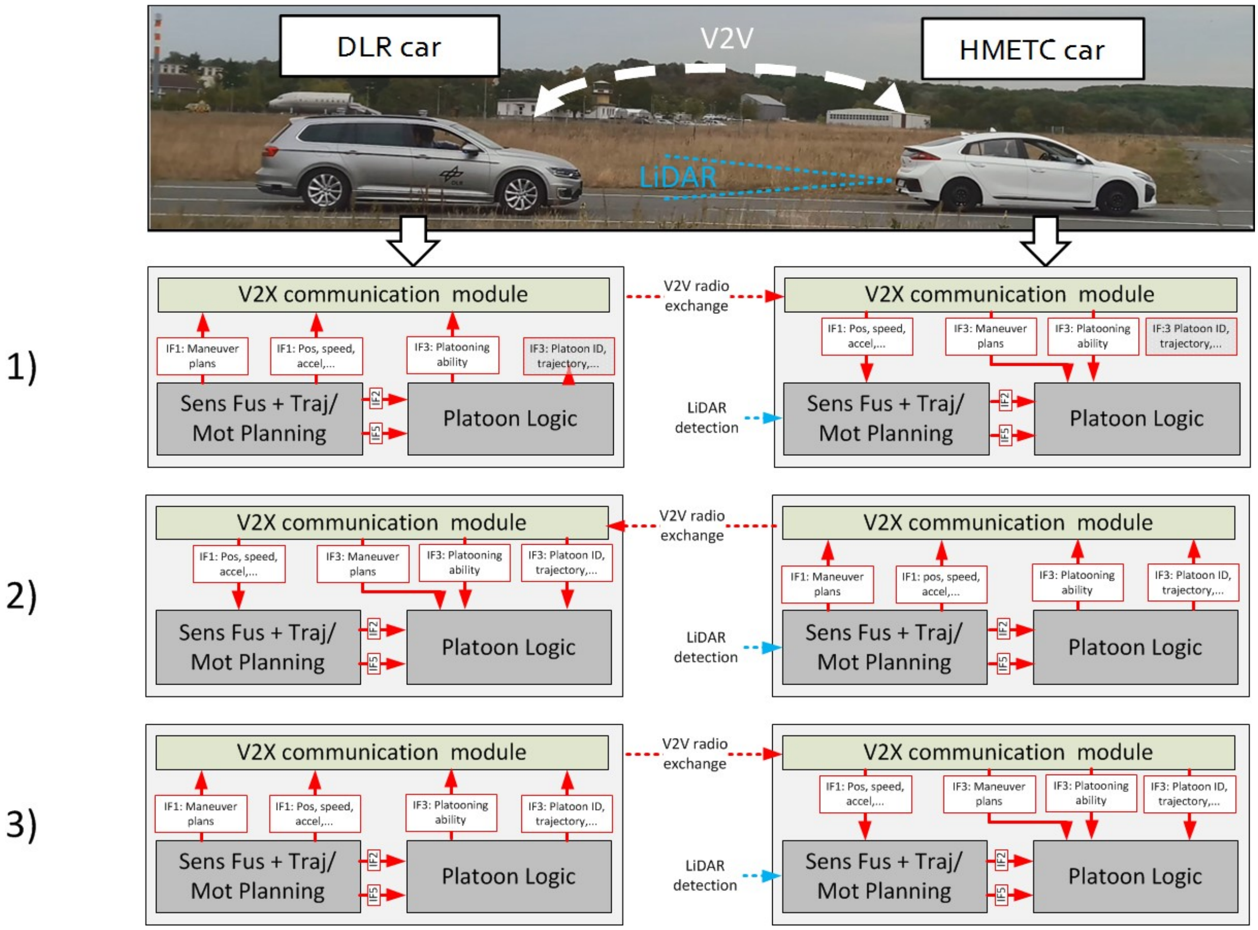

Figure 17 Schematic V2X interaction during platoon tests in Griesheim

	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 18 Summary of results for final platooning tests on the Griesheim test track

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Later on, the tests have been continued and the platoon behaviour has been combined with other use cases, esp. with UC7, where speed advice has been taken into account.

Here, the AGLOSA algorithm (described in D4.4 [4]) has been used to

- Allow the platoon to pass at green
- Avoid the splitting of the platoon by taking into account the number of vehicles in the approaching platoon.

Both parts have been tested on the Peine-Edesse test track (Figure 19) before performing them on the Tostmannplatz public roads.

Figure 19 Platooning combined with GLOSA advice

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The results of one test run on the Tostmannplatz are shown in Figure 20. The platoon is correctly formed in (A). After driving in the platoon, there was a short period in time where an object has been detected in between the following vehicle and the leader by the sensor fusion of the platoon leading vehicle (B), correctly leading to a break-up of the platoon. This object disappeared and the platoon was formed again before the platoon received SPAT advice and adapting its speed to them.

For safety reasons (mostly because of limited automated braking capabilities at the following car), the desired time headway during platooning was set to 2-2.5s during the trials. As normal driving time headway by DLR vehicle (Follower) has been set to 3s, driving in platoon results a shorter gap between MAVEN vehicles and gives enough margin to safety driver to intervene in case of any failure. Shorter gap between automated vehicle in platoon mode combined with GLOSA increase the traffic flow and decrease the emission and unnecessary deceleration and acceleration as well as travel time. Please note that the MAVEN platoon algorithm is allowing the setting of the proper distance for each car individually, as it remains to be the decision of the automation system which distance can be allowed.

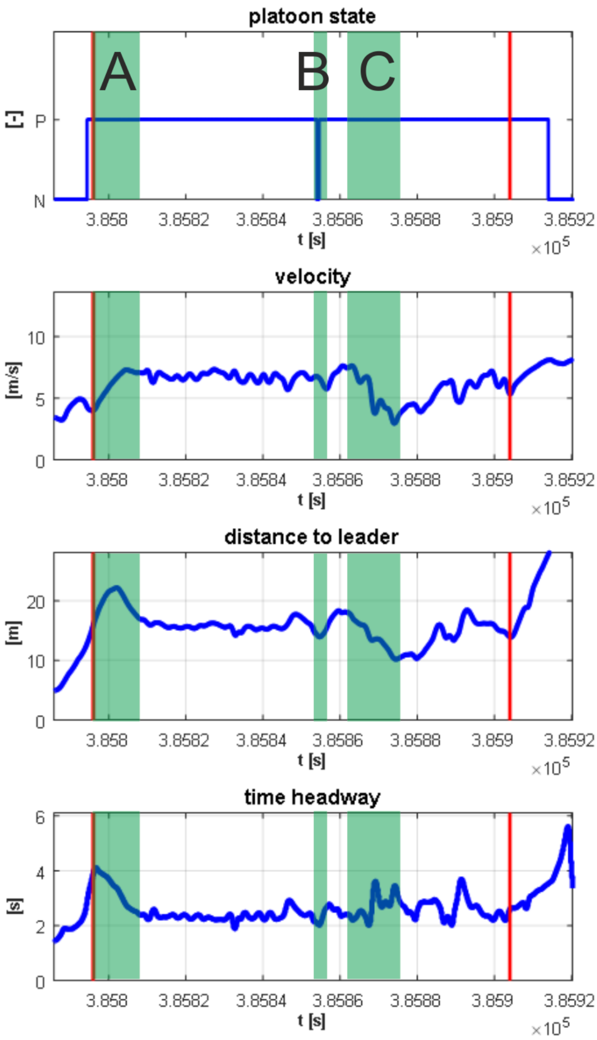

Figure 20 Platooning on Tostmannplatz with two vehicles. Red lines show enabling and disabling of automated driving. The green zones show the platoon forming (A), a very short platoon termination (B) and the GLOSA reaction (C) of the vehicle following the platoon

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Similar tests have been also performed by three vehicles in one platoon, as shown in Figure 21. During those tests, a non-automated vehicle was used as the last vehicle in the platoon showing the feasibility and scalability of the approach. In this vehicle, the full automation software was running as if it would be an automated vehicle, but a human driver has performed the final control.

The tests showed correct behaviour of the software, but as the third vehicle is driving manually no detailed analysis of the data of this vehicle has been done.

Figure 21 Logical platoon of three vehicles and the respective debugging HMI (left) as shown in the third platooning vehicle, the manually driven T5 bus.

Similar to the simulation activity, also the platoon brake-up by non-automated vehicles (UC5) has been in focus of the public road tests. On the Tostmannplatz intersection, there are two driving lanes in one direction, merging into one lane right after the intersection. This circumstance is used by the automated driving software, as any vehicle on the other lane is by default recognized as a vehicle with the intention to merge to the lane of the platoon. As shown in Figure 22, the following platoon vehicle is opening up a gap when a vehicle on the adjacent lane is detected. This allows smooth integration with normal traffic in urban areas.

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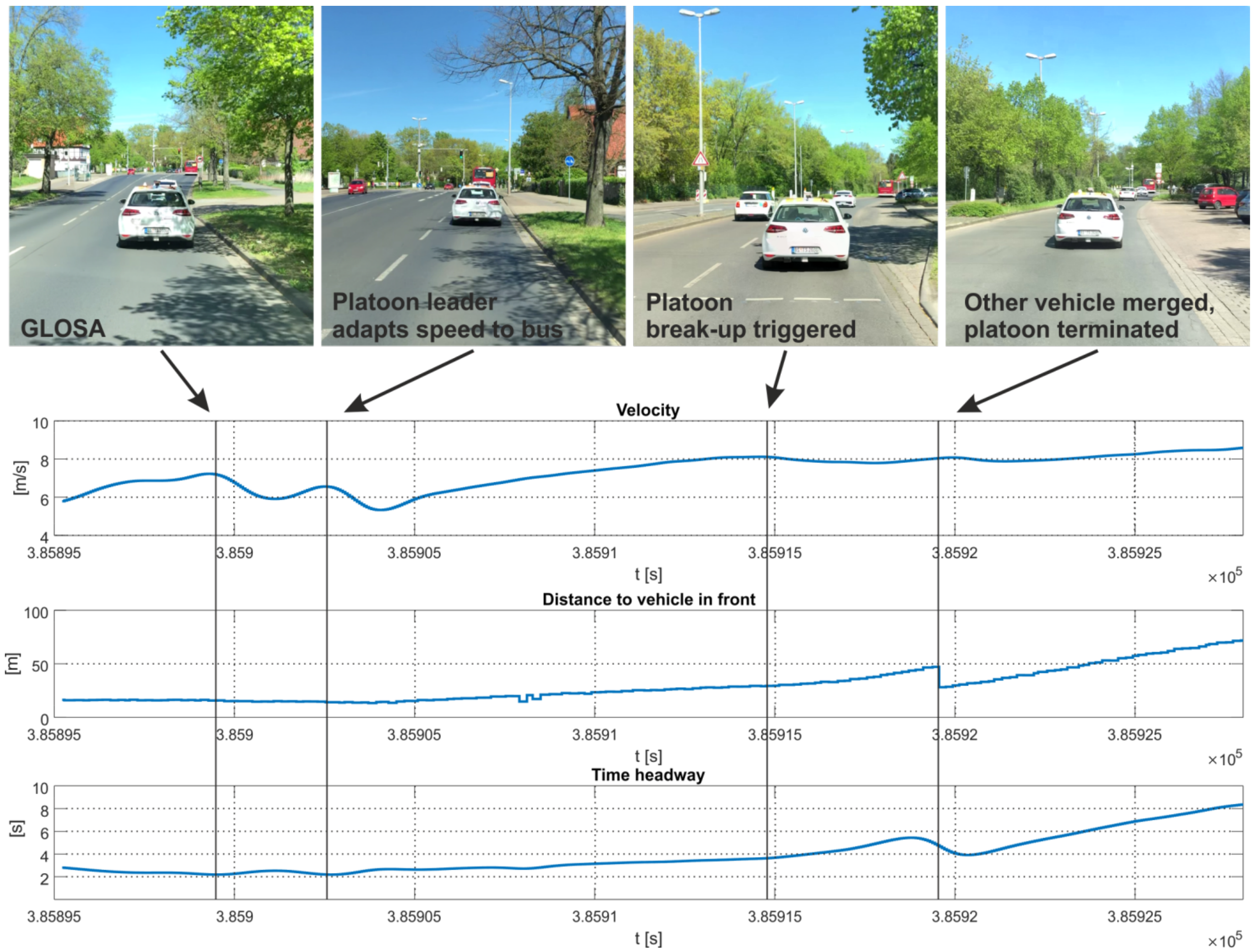

Figure 22 Platoon break up on Tostmannplatz

Platooning - Results of Dominion simulation and field tests

During the platoon tests, it could be shown that it is possible to use platooning in urban areas when following a dynamic and flexible approach. It is important to monitor the behaviour of other vehicles surrounding the automated vehicles in a platoon and to react to them in an accommodative way. As automated driving in urban areas still is a difficult task, vehicle automation algorithms are normally driving with large headways, to allow proper reaction and avoid collisions and dangerous situations. The platooning algorithm is able to compensate these negative effects by reducing the time headway, and may also be used to drive safe with headways lower than used in manual driving. In the MAVEN tests, the vehicles driving on public roads have been forced to drive in larger headways even when in a platoon, as the prototypic implementation did not allow smaller headways without risks.

As a result, no decrease in emissions or reductions in fuel consumption could be measured during the tests. In urban areas, where speed is limited, these factors are not foreseen to be very relevant for platooning, especially when taking into account the dynamic behaviour and reaction to any situation.

Nevertheless, at least in the simulation it could be shown that driving with low headways in a platoon is possible. The approach of urban platooning, in general, can unfold its full potential when combined with speed advice, as this allows a high number of vehicles to pass the green lights in a short time.

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As consequence, there is a reduction of the number of stops at traffic lights and related to this also a reduction of emissions and fuel consumption, in line with better use of the capacity of the existing infrastructure.

Of course, those KPIs (1-5) could not be measured directly in the Dominion simulations and field tests, as there have been only 2-3 platooning vehicles available. The detailed impact analysis is provided in Chapter 5.

4.2 Use case 7 (GLOSA)

Besides execution of this use case combination in a controlled test track environment, UC7 GLOSA has also been tested on public roads during integration sprint 6. The related test events have been performed on Braunschweig's Tostmannplatz test site (test events 21 and 26), and – in case of HMETC – also on the Helmond test site (test event 23) (for more details about the particular test events, p[lease, refer to D6.4 [12]).

For the events 21 and 26, the test scenario is like in the below figure, where the intersection has to be crossed in the south to north direction and the automated car has to adapt to the speeds advised by the traffic light controller for the two consecutive traffic lights controlling the two consecutive stop lines. The correct behaviour of this adaptation is shown in Figure 23 for two HMETC test runs.

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 the 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). In the first graph, the second stop line is not depicted as the log file is cut at the very end right before crossing it.

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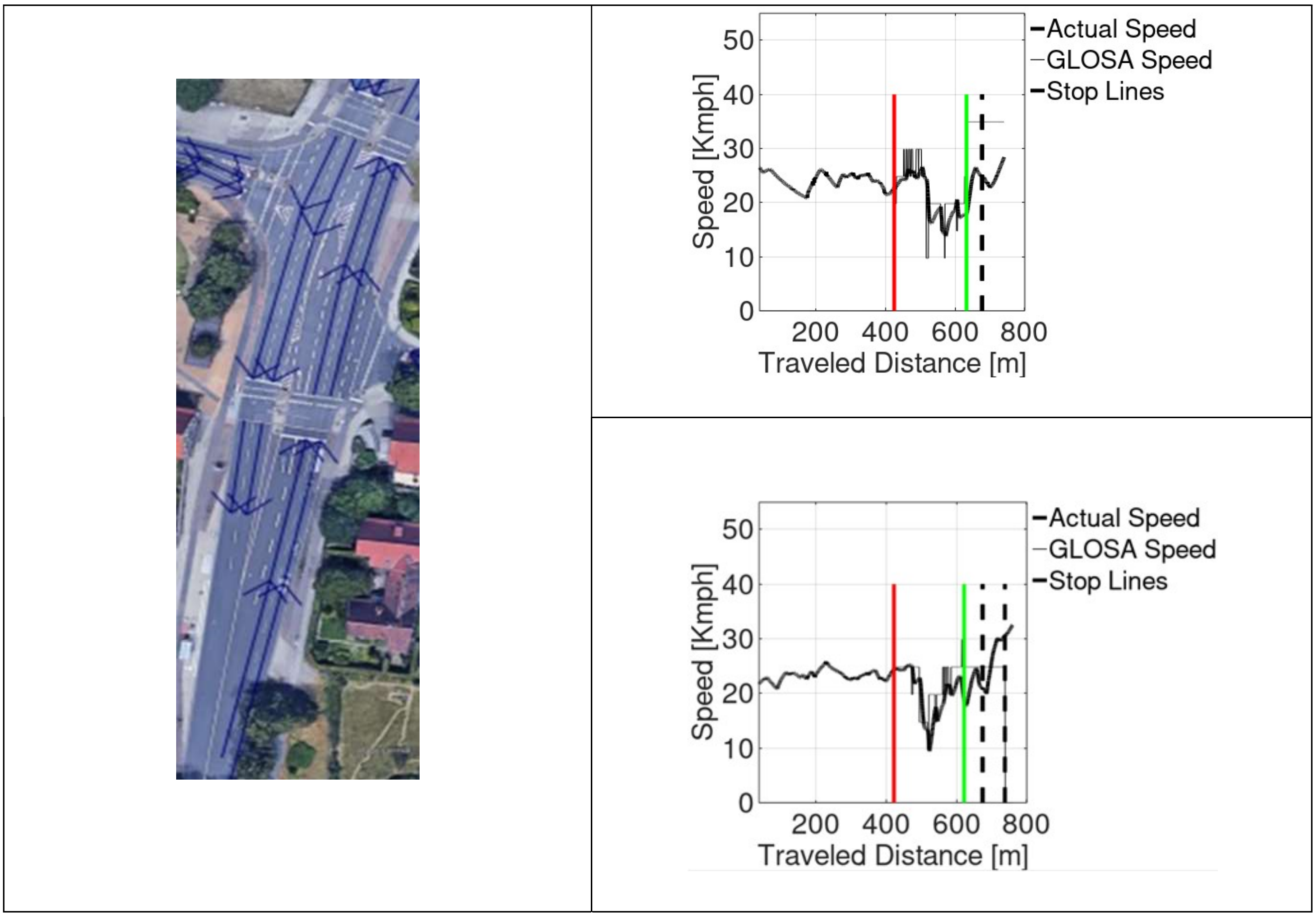

Figure 23 GLOSA speed adaptations performed by HMETC automated vehicle

The performance of the use case as observed by HMETC in terms of KPIs during the aforementioned events is described in the next table. Here, it is important to highlight that the application of the use case in real road conditions and for a limited time does not allow a scientifically rigorous evaluation. In particular provision of meaningful GLOSA advice from the DLR RSU in sync with the traffic light was allowed only in limited time windows of 3 hours/day and the test cars could not continuously drive in those slots because of possible fixes at the car or RSU implementations. Moreover, the speed of the test cars was kept below 30kph due to safety requirements at the DLR car when running the platooning algorithms on real road and traffic situations.

KPI ID	KPI description with units	Observed value	note
KPI 7	Minimum time to collision (s)	-	Not applicable to HMETC car, as this car has been devoted to act as the platoon leader in the performed tests.
KPI 8	Number of human interventions for safety (-)	0% of runs	In general, no driver interventions are necessary. Nevertheless, preventive take-over actions were performed when the safety driver

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			identified potential risky situations (other vehicles cutting in the driven lane, presence of VRUs too close to road profile). In order to ensure safety, the AD capability reactions of the test cars were never pushed to the limits as requested by internal company policies. Due to these preventive measures, the KPI could not be measured in 25% of the cases.

Table 34 The performance of the use case as observed by HMETC in terms of KPIs - GLOSA

Figure 24 illustrates similar runs performed by DLR. It is shown that the vehicle approaching the intersection is not receiving any speed advice in the first phase because the vehicle is far away from the intersection. While approaching, via V2X, the vehicle automation receives the "STOP velocity" and means that the vehicle reaches the intersection when the 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, new speed advice is sent from a traffic light and received by the DLR vehicle resulting in acceleration and the crossing of the intersection.

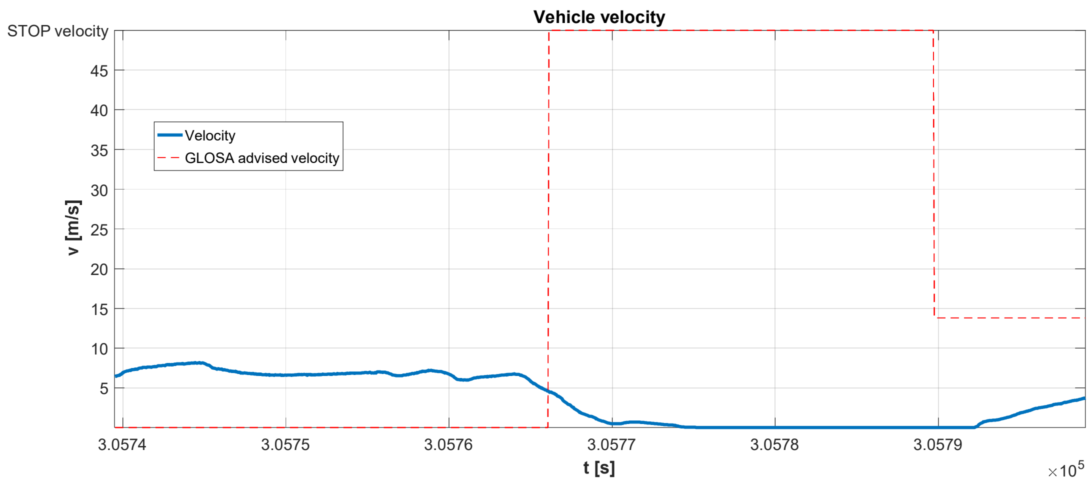

Figure 24 Tostmannplatz experiment 1, Driving with GLOSA advised velocity

Figure 25 illustrates another scenario in an urban area which shows how DLR vehicle automation reacts while receiving AGLOSA in mix traffic. 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 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 a 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 last 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 new advice is received.

The next table illustrates the performance of the use case as observed by DLR in terms of KPIs.

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KPI ID	KPI description with units	Observed value	note
KPI 7	Minimum time to collision (s)	~2s platoon mode ~3s no platoon mode	This value matches the vehicle automation safety.
KPI 8	Number of human interventions for safety (-)	0% of runs	In general, no driver interventions are necessary.

Table 35 The performance of the use case as observed by DLR in terms of KPIs - GLOSA

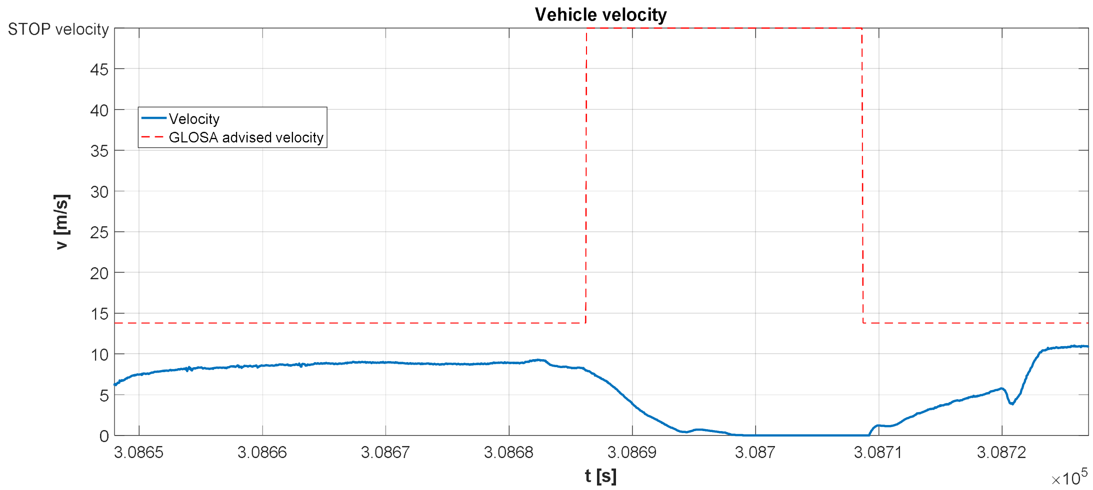
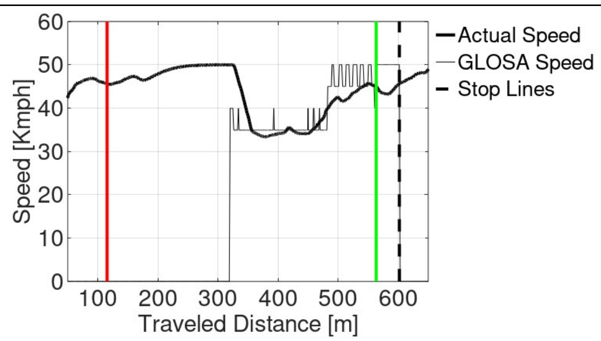


Figure 25 Tostmannplatz experiment 2, Driving with GLOSA advised velocity

For the events 23 (HMETC tests in the Helmond test site), the test scenario is also represented in the next figure. Here the intersection 701 has to be crossed in the east to west direction and vice-versa. Moreover, only one stop line has to be crossed. The same tests have been repeated at the adjacent intersection 806 in preparation to the MAVEN demo at the ITS Europe Congress, in much more controlled conditions (night-time tests with less presence of surrounding cars). The correct behaviour of the GLOSA adaptation is shown in Figure 26 for three runs at intersection 806.



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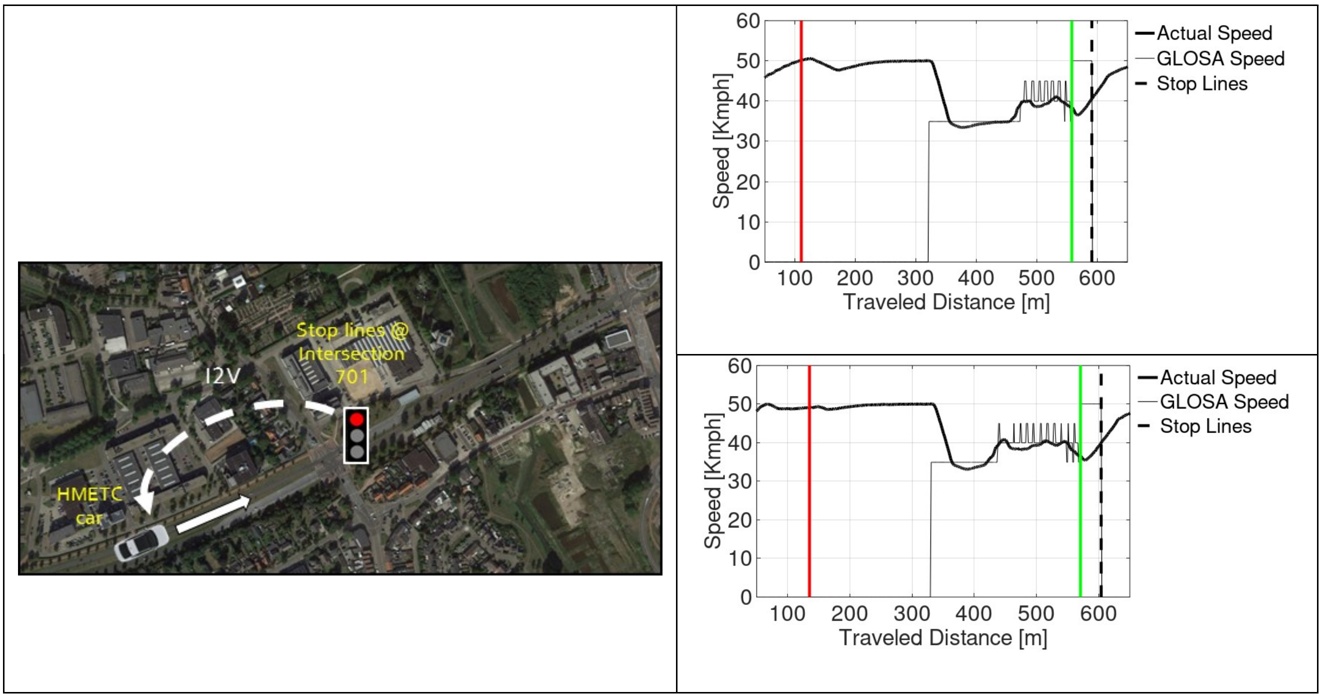

Figure 26 Speed advice test runs performed in Helmond by HMETC

The performance of the use case as observed by HMETC in terms of KPIs during the aforementioned event is described in the next table. Again, it is important to highlight that the application of the use case in real road conditions and for a limited time does not allow a scientifically rigorous evaluation. In particular provision of GLOSA advice from the RSU at the intersection 701 has been very sporadic in the time when the experiments have been conducted (either situation of green phase with speed advice to 50kph or red phase without speed advice were observed). The applicability of the GLOSA advice was tested in more controlled conditions during night tests at intersection 806 in preparation of the ITS EU congress demo. For this reason, the KPIs in the following refer to these last tests.

KPI ID	KPI description with units	Observed value	note
KPI 7	Minimum time to collision (s)	-	Not applicable to these tests
KPI 8	Number of human interventions for safety (-)	0% of runs	In general, no driver interventions are necessary. Nevertheless, preventive take-over actions were performed when the safety driver identified potential risky situations (other vehicles cutting in the driven lane, presence of VRUs too close to road profile) as dictated by RDW (the Dutch Authority for the provision of exemption for driving automated on dutch public roads). Moreover, the AD capability reactions of the test car were never pushed to the limits In order to ensure safety as requested by internal company policies. Due to these preventive measures, the KPI could not be measured in 5% of the cases. this

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			value is lower than at the Braunschweig Tostmannplatz due to the more protected road conditions at the Helmond intersections (e.g. larger lanes, guardrails preventing VRU access to the road, tests made during night time, etc.)

Table 36 The performance of the use case as observed by HMETC in terms of KPIs - driving with GLOSA advised velocity

4.3 Use cases 8 (Lane change advisory)

DLR performed several tests of this use case on the test track (test event 16) and on the Tostmannplatz public roads (test event 22).

In test event 16, the combination of UC7 and UC8 was tested, as shown in Figure 27. In (A), one test vehicle is standing at the red traffic light on the right lane, constantly transmitting CAMs leading to the corresponding placement of the vehicle on the right lane of the AGLOSA algorithm running in the mobile traffic light. The FASCarE is also driving on the right lane, but still in a given distance. Besides sending out GLOSA advice, the AGLOSA algorithm detects that the FASCarE should better drive on the left lane, as the queue there is shorter. Therefore, a Lane Advice Message (LAM) is sent out addressed to the FASCarE. In (B) the FASCarE is already adapting to the GLOSA advice while also checking the left lane for other vehicles, before finally changing the lane (C). Thanks to the GLOSA advice, 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 standing vehicle.

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Figure 27 Combined UC7 and UC8 use case, showing lane advice coupled with GLOSA functionality on the test track

In test event 22, the lane change advisory scenario has been tested in a complex urban scenario at Tostmannplatz intersection. As it is shown in Figure 28, the DLR automated vehicle FASCarE drives autonomous from south to north. The red line in the figure represents the driven trajectory 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 in the desired lane, a lane change is effectuated.

Figure 29 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 (violet line), it receives the LAM message sent by the roadside unit installed at Tostmannplatz because the queue length is higher on the right lane. Therefore, the “tactical decision” module analyses the gaps and evaluates the required action to change the lane. As the lane change was possible at this run, the required action to merge to the selected gap is reducing velocity. The vehicle merges to the gap and increases its velocity again. Then the vehicle reaches the stop zone defined by GLOSA, shown with the red line in the figure, and therefore it reduces its velocity until reaching an unavoidable standstill behind the

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stop line. When the traffic light turns to green, shown with the green line, the vehicle accelerates and crosses the intersection.

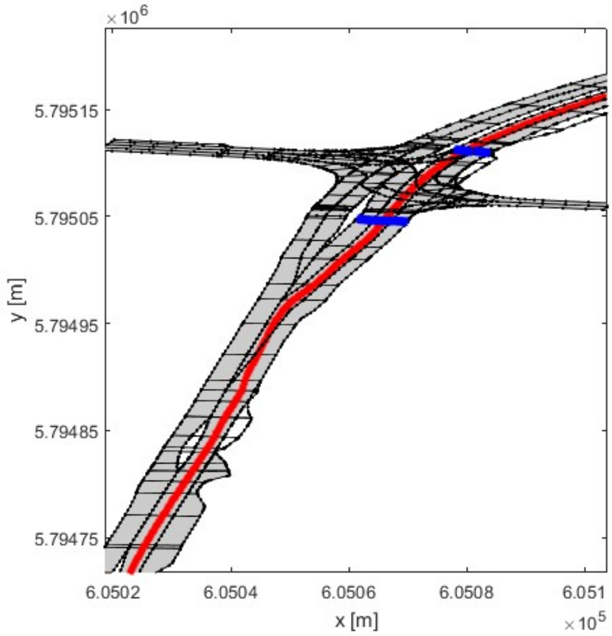

Figure 28 Lane changing scenario triggered by traffic light via LAM at Braunschweig Tostmannplatz

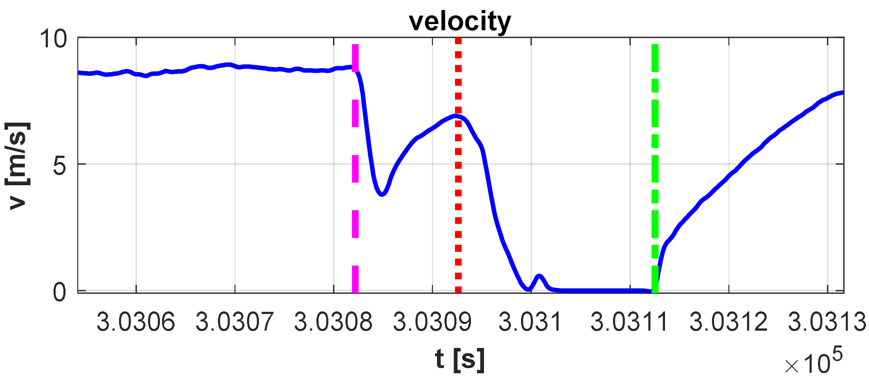

Figure 29 Velocity profile of lane changing scenario

For this use case, no driver intervention was needed and DLR vehicle automation successfully evaluates the gaps in the desired lane and performed the lane change. Analyzing time headway for lane change scenario must be done separately for each lane as they have different dynamics but the set value for DLR vehicle automation, as mentioned before, for no platooning use cases is ~3s.

Similar to DLR, Hyundai tested the UC8 Lane change adaptation first on test tracks and later on public roads during integration sprint 6 in the Helmond test site (Event 23). The test scenario is like in the below figure, where the intersection has to be crossed in the west to east direction and vice-versa. The vehicle is suggested to perform a lane change from the right to the left lane at 200m from the stop line. The functionality of the HMETC lane change advice adaptation logic at the Helmond test site can be also seen in the attached graph. The graph 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 approaching the intersection. In the top sub-graph, the point at which the lane change should be executed upon suggestion by the infrastructure is indicated. As

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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 sub-graph.

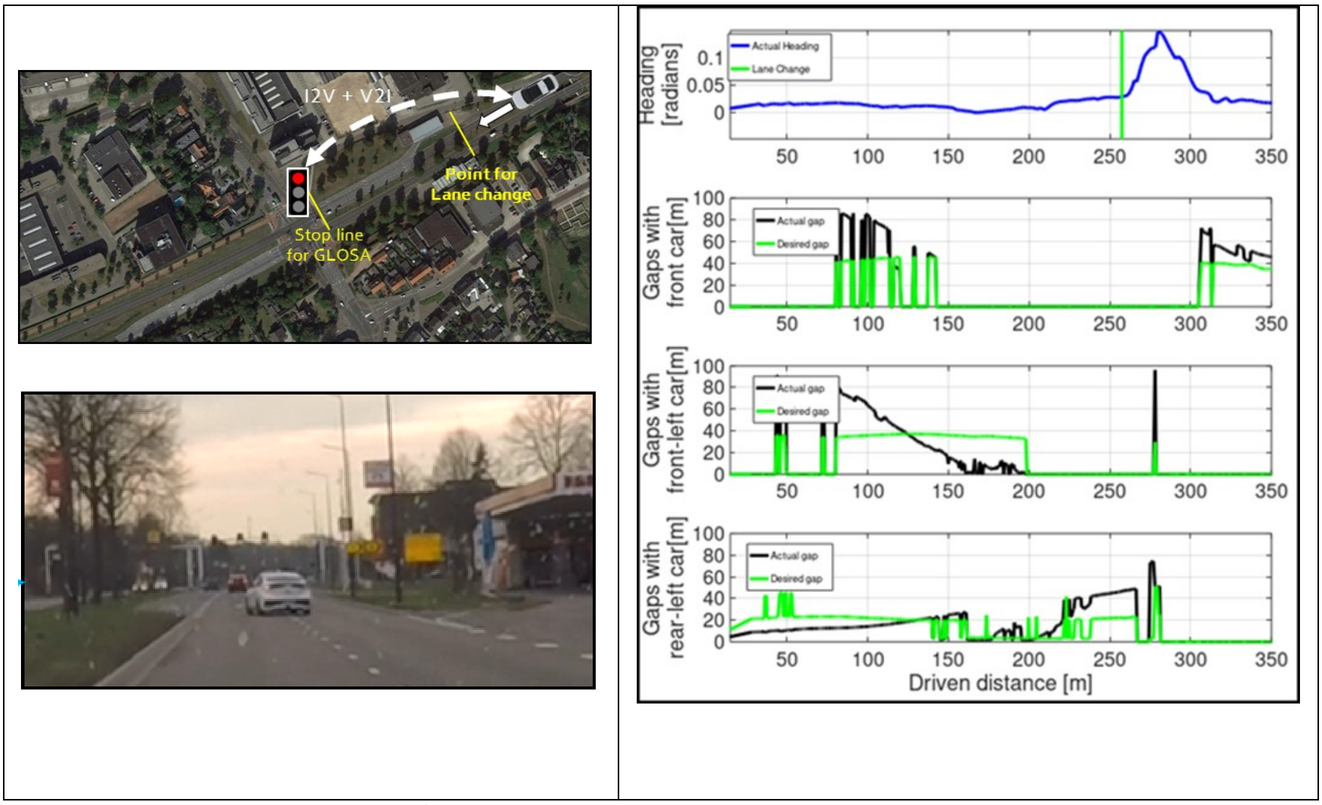

Figure 30 Lane change adaptation first on test tracks and later on public roads during integration sprint 6 in the Helmond test site.

The performance of the use case as observed by HMETC in terms of KPIs during the aforementioned event is described in the next table. In this case, the table represents results of the tests at the intersection 701 which were performed during the day time in order to stimulate and challenge the automated driving system with the presence of surrounding obstacle cars in real traffic. The lane change advice was always transmitted in combination with GLOSA advice (even if sporadic occurrences of GLOSA were observed as mentioned above). In order to have a given degree of repeatable test conditions, the lane change advice was provided always from the right to the left lane at a fixed distance of 200m from the stop line (the lane change advice algorithm in the RSU continuously emulated a queue of fixed length on the right lane).

KPI 8	Number of human interventions for safety (-)	0% of runs	In general, no driver interventions are necessary. Nevertheless, preventive take-over actions were performed when the safety driver identified potential risky situations (other vehicles cutting in the driven lane, presence of VRUs too close to road profile) as dictated by RDW (the Dutch Authority for the provision of exemption for driving automated on dutch public roads). Moreover, the AD capability

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			reactions of the test car were never pushed to the limits In order to ensure safety as requested by internal company policies. Due to these preventive measures, the KPI could not be measured in the 45% of the cases. This value is significantly higher than that observed at intersection 806 as these tests were conducted in the day time and in the presence of a non negligible number of surrounding cars.

Table 37 Results of the tests at the intersection 701 which were performed during the day time in order to stimulate and challenge the automated driving system with the presence of surrounding obstacle cars

4.4 Use case 9 (Emergency situations)

In contrast to the initial proposal to test use case 9 only in the Dominion simulation environment, it has been decided to only focus on Scenarios 1 (system failure of platoon participant) and 2 (vulnerable road user suddenly entering the road) of this use case, see D2.1 [1] and D6.4 [12] for details. Both aspects have been investigated on the test track during field tests by DLR, see test event 16 in D6.4 [12].

Therefore, UC9 is mostly focusing on the 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 the braking of the ViewCar2 and platoon termination, covering Scenario 2. As stated in D3.1 [7], the platooning is always stopped whenever there is any object between the vehicle and its predecessor. In the case of the test runs, this effect could be seen several times as false positives have been detected between the vehicles either by the platoon leader or by the vehicle following it.

In this case as the vehicles were driving in platoon, the time headway between them was set to ~2[s] and after detecting a ghost object, as false-positive between vehicle which results in a sudden change in time headway with vehicle in front which is not leader, DLR “Tactical decision” modules set the time headway to 3[s] to reduce the risk which resulted in high deceleration. As the false positive last only less than a second, the platoon logic switches back to platoon mode and “Tactical decision” modules set back the time headway to 2s.

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 receiving such information, the platoon is instantly terminated and the distance to the vehicle ahead is enlarged.

In both situations, no intervention from safety driver was needed.

4.5 Use cases 16 (detect non-cooperative road users)

Use case 16 has been tested by DLR first in simulation and later on the Tostmannplatz public roads. As DLR focused on detection of non-cooperative road users by using infrastructure

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equipment and communication, DLR's activity was bound to the Tostmannplatz where the hemispheric camera has been mounted. As the camera's field of view is only allowing detecting objects in southbound direction (see Figure 31), the FASCarE was driving in that direction during the runs. The camera was constantly monitoring the intersection and detecting the objects, as described in D6.4 [12]. The detected objects have been incorporated into collective perception messages (CPM) which have been broadcasted.

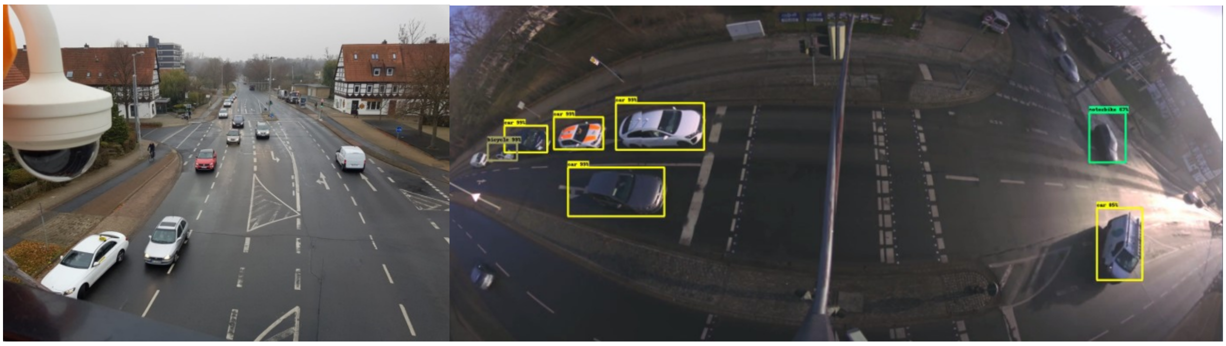

Figure 31 Hemispheric camera on Tostmannplatz (left) and detected objects of it used for CPM generation (right). Note that the right image is flipped.

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 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 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 behaviour 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 32 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 a consequence, the FASCarE is reducing speed (C) and stopping right behind the obstacle.

By reducing the speed before the obstacle comes into the field of view of the vehicle sensors, the time to collision (i.e. KPI 7) is generally increasing. This effect would be much larger in curvier areas, but as discussed all DLR activities had to take place in the Tostmannplatz area to make use of the mounted hemispheric camera.

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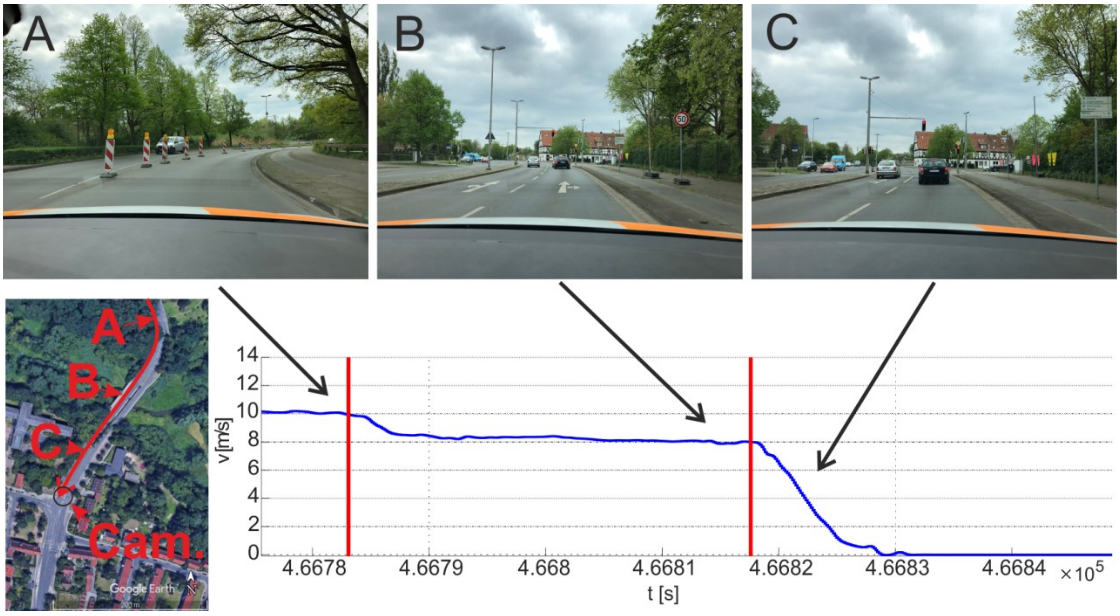

Figure 32 Soft and the hard reaction of the automated vehicle FASCarE

Hyundai performed this use case in a controlled test track environment, in order to check the repeatability of the obtained results while ensuring safety. Hyundai tested the UC16 Detection of non-cooperative road users via cooperative sensing using a moving dummy emulating a VRU in an intersection scenario as highlighted in the next figure (for more details please refer to Deliverable D5.2 [6]).

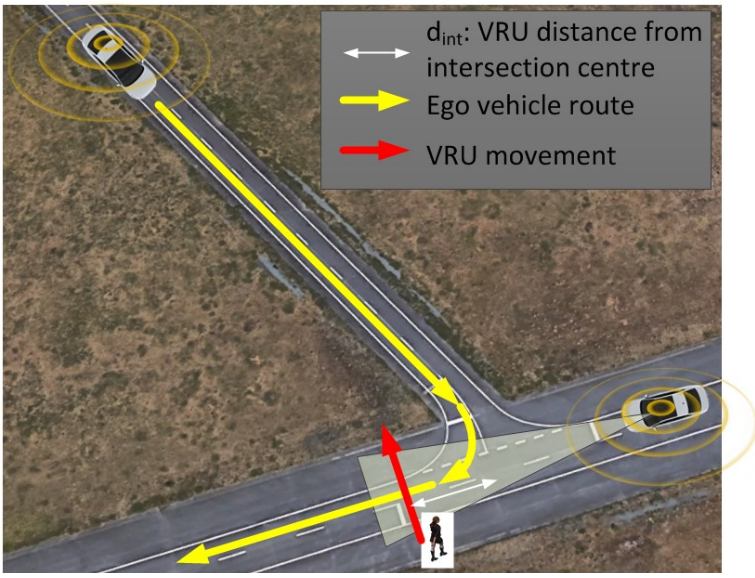

Figure 33 Cooperative perception

The results of the evaluations are shown in the next two graphs, representing the motion profile of the ego vehicle in terms of speed as a function of the distance covered. Both the speed computed by the motion planner and the actual speed applied by the vehicle controller are depicted. The results depict an experiment scenario where the VRU is very close to the turning point. With these

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settings, an ADAS approach based on onboard sensors only reaches its limits and cannot ensure safety (see D5.2 [6]).

On the left graph, the automated vehicle operates only based on inputs from onboard sensors and without cooperative sensing. As it can be seen, the vehicle starts to speed up to reach the goal speed of 50kmph and then it starts to slow down to reach the stop line at a relatively low speed allowing a comfortable turn to the right (10Kmph after covering 150m). After reaching the stop line and starting to turn, the speed ramps up again. In this case, the AD logic has not enough time correctly detect the VRU as a threat. This is due to the fact that the vehicle sensors are not all pointing to the position of the obstacle until right before the collision. Moreover, detections from individual sensors (in particular the corner radars) are hampered by the small dimensions of the VRU. The sensor fusion cannot obtain a robust and stable detection to be distinguished from many other false positives. As a result of the lack of a timely threat assessment, the ego vehicle is going to collide with the dummy and has to be manually braked (visible in the figure as an instantaneous speed fall to 0).

On the right graph, the results of the cooperative sensing applications are depicted.

As can be seen, the ego vehicle slows down to reach the stop line at a relatively low speed allowing a comfortable turn to the right (10Kmph after covering 150m). As the vehicle is aware via cooperative sensing of the VRU presence, when turning, it does not speed up. Instead, it further slows down as a result of taking the VRU presence into account. The ego vehicle then stops in front of the dummy and wait for it to move out of the driven lane (the speed goes to 0 approximately 163m after starting to drive). When the dummy is completely out of the lane, it is not considered as a threat any longer. As a consequence, the ego vehicle’s speeds ramp up to reach the goal speed of 50 kmph on the straight stretch.

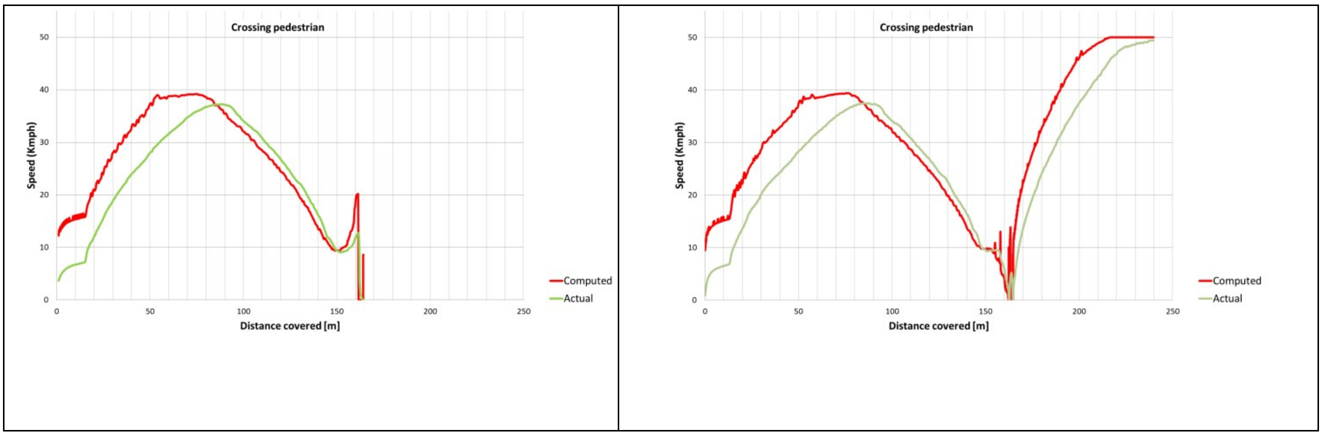

Figure 34 Results from cooperative perception

Several experiments of this kind showed the consistency of the investigated system functionality. To compare the performance of the cooperative sensing approach against the one based on onboard sensors only the KPI time to collision is modified and defined as:

$$TTC_{iv} = t_{d\_stop} - t_0$$

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t_0 is the time when the vehicle starts to move at the starting position and t_{d_stop} is the time when the vehicle is at the distance where it has to be braked manually in the tests not using the cooperative sensing. The reason for the modification of the KPI is there would be a collision without the MAVEN use case and the equipment would be damaged. The results of this use case in terms of the above mentioned KPI are summarized in the next table.

KPI ID	KPI description with units	Observed value	note
KPI 7	Minimum time to collision (s)	41s	The value indicated in the left column is relative to the application of the MAVEN cooperative sensing approach. When not using the MAVEN cooperative sensing, TTC_{iv}= 33s. The 8s gain obtained to the cooperative sensing approach is due to the fact that the VRU-aware vehicle slows down and stops before reaching the point where the vehicle had to be manually braked in the test runs without cooperative sensing

Table 38 Results of the tests with respect to the minimum time to collision

Regarding the KPI 8 “number of human interventions”, when applying the cooperative sensing no such interventions were needed because the car was smoothly slowed down before automatically reaching a safe stop before the VRU dummy. Nevertheless, and as highlighted at the beginning of this section, these tests were conducted in a controlled environment to ensure safety. When driving automated on real roads this KPI was intentionally not taken into account. In fact, the HMETC testing team has to respect a safety policy to take manual control of the vehicle back whenever a VRU was close enough to the driven areas such to imply possible risky situations. In the Netherlands, the same policy was imposed by RDW, the national authority for vehicle homologation and admission from which HMETC obtained the exemption to drive automated in the Helmond test site.

4.6 Verification of requirements - Test protocols

The functionality of the system prototypes was also verified using a procedure described in D7.1 [10] and D6.4 [12]. For particular use cases, a series of system requirements were defined. Each requirement got assigned one or more test cases. And for each event, the relevant test cases were executed. The results, i.e. particular Test protocols, are provided in Appendix A.

At some cases during the execution in planned events, some of the components were not fully working or fully integrated. This is, for example, the case in Test Protocol 17 and 18. The failed Test case (in this case test case T5_17: CAM extensions population and reception of info for platoon formation) as well as those that could not be executed because of the failed test (for example T5_18: CAM extensions population and reception of info for platoon control) were however successfully tested in the following test events (in this case Test Protocol 20 and Test Protocol 25).

In order to close the loop and show where (at which events) particular requirements were tested, an overview table is provided in Appendix B. Here not only the link to events is provided, but also the fact whether the testing was successful or not. At some (typically) earlier events, some functionality was not implemented yet or was not successful. Each particular event had a different

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focus. Some were conducted on a simulation platform only, also the location of the vehicles used to differ. For this reason, it is possible that an earlier event proved certain requirement (for example in simulation), while a later one (e.g. first field tests) was not successful. The table, however, demonstrates, that each requirement was successfully tested at least once. In case of a failure, there was always a later successful event in the same environment.

We can thus conclude, that all the test cases were tested successfully and thus the requirements on the system prototypes were all met.

4.7 Dominion simulation and fields tests - Summary

The simulation in Dominion SW as well as the field test experiments demonstrated mainly meeting of the technical and functional requirements and expectations on the prototypes. While the verification procedure (Test Protocols) proved that all individual requirements were met (i.e. the vehicle exchanges messages with the infrastructure etc.), the events and the reported behavior provided clear demonstration of the entire use cases (i.e. a vehicle approaching intersection informs the controller about its position, the controller updates its control strategy and sends the vehicle a message, based on which the vehicle adopts speed or changes lanes. Using this approach, it was demonstrated that the entire use cases work while we keep the traceability to the original requirements.

To summarize, we can state that all presented Use Cases were really properly implemented and that they fulfil the expectations. The results show the feasibility of the whole process. In the future, it shall be followed by the industry.

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5 Impact evaluation using traffic microscopic simulation

5.1 Introduction

In order to demonstrate the impact of particular MAVEN use cases (individually as well as jointly), a stochastic traffic microsimulation model was used with implemented MAVEN use cases enabled by simulated C-ITS – CAV communication. The verification was performed according to the Impact Assessment Plan which is a deliverable D7.1 [10] of MAVEN project.

Another interesting aspect is the evaluation of combinations of use cases. However, not all use cases can be combined or function in the same network. This is shown in Table 39.

Use case	1-6	7	8	10	11	12	13	14	15
1-6 - Platooning		S	S	S	I	I	S	I	
7 – Speed change advisory	S		S	X	R	I	S	R	
8 – Lane change advisory	S	S		I	R	I	S	S	
10 – Priority management	I	X	I		R	I	X	X	
11 – Queue length estimation	I	I	I	I		I	I	I	
12 – Local level routing	I	I	I	I	R		I	I	
13 – Network coordination/ green wave	S	S	S	X	S	I		X	
14 – Signal optimization	S	S	S	X	R	I	X		
15 - Negotiation	S	R	S	S	R	I	X	R	

Table 39: Relationship between use cases: Required (R), Synergy (S), Independent (I) or eXcluding (X)

Most use cases have been tested separately in D4.4 [4] when possible. Only UC1-6 was not tested and at a workshop road authorities indicated the importance of isolating the effects of platooning and therefore this was added to the list of scenario's to be tested here. Priority management is also a special use case because it interferes with UC7, the speed advice, by making the signal plan unpredictable. It works directly against the stabilization efforts of the signal optimization in UC14, which is a requirement for UC7. Green wave and priority also cannot be combined as the green wave would have to be interrupted for any priority request. Therefore, it was tested together with queue length estimation and negotiation while all other UCs were switched off. The scenario with a prioritized platoon had UC1-6 enabled for that specific platoon. Routing targeted a larger network with alternative routes available, it requires queue modelling as an information source, but otherwise functions independently of other use cases. Therefore, only the combination of those two UCs were simulated.

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Looking at the isolated intersection setup, a much bigger combination of use cases can be switched on. UC7, speed advice, requires UC11 and UC14 to function properly, but a synergy is expected with UC8. Therefore a large combination of UCs could be simulated together. The same holds for the corridor network where the mutually exclusive UC14 was replaced by the green wave UC13.

The safety use cases (9 and 16) are excluded from this table because they cannot be simulated in SUMO. Both are independent of the traffic efficiency use cases and can perfectly function in parallel. Lastly, it should be noted that UC15 is negotiation and the combination of UC7, UC11 and UC14 or UC10 with UC12. Therefore, the column of UC15 is greyed out as the use case is automatically achieved by turning on a combination of others. The total overview of simulations in this chapter is then as presented in table Table 40.

Simulation	Network	UC combination
Platooning of CAV	Helmond single	UC1-6 (simpla)
Lane Change advisory	Helmond single	UC1-6, UC8 (not isolated in D4.4)
Priority Management	Helmond corridor	UC1-6, UC10, UC11, UC15
Queue length estimation	Helmond single	UC1-6, UC11 (extra assessment after D4.4)
Local-level routing	Prague network	UC11, UC12
Actuated signal optimization algorithms	Braunschweig single	UC1-6, UC7, UC11, UC14 and UC15
Adaptive signal optimization algorithms	Helmond single	UC1-6, UC7, UC11, UC14 and UC15
Network coordination	Helmond corridor	UC1-6, UC7, UC8, UC11, UC13
Combined use cases	Helmond single	UC1-6, UC7, UC8, UC11, UC14 and UC15

Table 40: Overview of simulations performed

5.2 Simulation setup

Simulations of the described MAVEN use cases were performed in 3 simulation scenarios. These are real-life networks from the cities of units performing simulations: Helmond, Prague and Braunschweig.

In order to ensure the validity of the results, each of the performed simulations was thoughtfully planned, analyzed and calibrated in order to minimize the discrepancies from the real-world behaviour of vehicles in a baseline simulation. The baseline scenario was calibrated using real-world data collected in particular networks. Each simulated scenario with tested UC was performed 10 times for each parameter setting, and the results were averaged to ensure a statistically

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significant outcome. The equation to compute the exact number of required simulation runs is provided for example in [54]. This is important to ensure that achieved results are not overwhelmed by stochastic discrepancies.

It is important to note, that Use Cases 1-6 and 15, which are platooning of the CAV vehicles and Negotiation between CAV and C-ITS is implemented in all of the simulations. Therefore, their indirect impact on the simulations is tested in each of the simulated scenarios.

Braunschweig

The Braunschweig simulation network covers the intersection Tostmannplatz (see Figure 35). It consists of four approaches of which numbers 1 and 2 are in the main direction of the traffic flow. Approach 4 leads to a Volkswagen factory, so there is notable traffic demand going from and to the factory whenever the shifts of workers change. The network data was taken from OpenStreetMap[1] and converted into the SUMO file format automatically with the SUMO tool NETCONVERT. However, the network needed to be patched manually because of its non-common geometry (note, for example, the displacement of approaches 2 and 4). These patches mostly consist of geometrical corrections and the correction of turning directions at the intersection. The final version of the network that was used for the simulation studies is depicted in Figure 35.

Figure 35 Tostmannplatz with consecutively numbered approaches and corresponding SUMO network

In order to create diverse results, two different types of traffic demand were taken into account, displayed in Table 41 and Table 42. The evening demand has a high traffic flow in the main flow direction (from the south and from the north) and a high demand from the western approach, indicating a shift change in the Volkswagen factory that creates a high amount of outgoing traffic. In the morning, the demand level in the main flow direction is slightly lower, but there is a larger number of vehicles driving from south to West. This corresponds to the commute of workers to the Volkswagen factory in the morning. The overall traffic demand and turn ratios were taken from observations and counts at the intersection. For both demands, a low, a high and an intermediate

[1] https://www.openstreetmap.org

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level of demand were considered during the simulations, corresponding to demand factors of 0.5, 0.75 and 1.0 applied to the numbers displayed in the aforementioned tables.

From/to	**1**	**2**	**3**	**4**
1	-	10	500	100
2	10	-	10	10
3	500	10	-	100
4	500	10	50	-

Table 41 Evening demand

From/to	**1**	**2**	**3**	**4**
1	-	10	500	500
2	10	-	10	10
3	200	10	-	360
4	25	5	25	-

Table 42 Morning demand

Apart from the demand, also the traffic light control algorithm, the availability of platooning for automated and connected vehicles and the penetration rate of said vehicles were variable. As algorithms for the traffic controller, two options are available: The Bellis2 algorithm, which simply is an actuated traffic control based on time gaps that are currently used at the Tostmannplatz, and the AGLOSA algorithm that was created by the DLR and is an actuated traffic control algorithm based on bi-directional V2X communication. AGLOSA sorts all detected vehicles' arrivals at the intersection and calculates an optimal sequence of phases that minimizes the delay time of these vehicles. The algorithm is also capable of creating speed advice to delay vehicles' arrivals which should allow them to pass the intersection without stopping. The parametrization of the connected automated vehicles was taken from Dynniq's simulation.

Helmond

To implement the algorithms necessary for testing the full range of planned UC, a corridor with multiple intersections in Helmond was built up using SUMO, shown in Figure 36. Seven intersections: intersection 701, 702, 704, 101, 102, 103 and 104 are distributed on this stretch of corridor, with the same main direction, east-west through directions 2 and direction 8 for each aforementioned intersection. Respectively, signal group 2 of each intersection is east-west bound and signal group 8 is west-east bound.

[2] Bellis is the operator of the Braunschweig traffic lights and streetlights (see http://www.bellis.de/)

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Figure 36 Case study of Helmond, with at the top a detailed view of intersection 701 and an overview of the green wave corridor at the bottom

The configuration of the two signal groups, SG 2 and SG 8 of intersection 701 are almost identical. They contain the same number of lanes (two lanes each), have the same saturation flow (1800 vehicle/hour), the same number of signal heads and they both appear in the same stages/ stage assignment. The simulated traffic is detected in SUMO, then the detected vehicle information is sent back to ImFlow to calculate and optimize the signal timing plan. After making the decision of which plan to choose, ImFlow sends back the chosen plan to SUMO to continue the simulation. The detection type of SG 2 and SG 8 are both set to adaptive unconditional in ImFlow configurator. Therefore, stabilized GLOSA can be provided to these two signal groups. More detailed configuration of the simulation in Helmond network was provided in deliverable D4.4 [4] Cooperative adaptive traffic light with automated vehicles [1].

It should be noted that all seven intersections are always switched on to create realistic arrival patterns. The measurements for impact assessment, however, are only taken at either intersection 701 or at the corridor of 101-104 (for green wave and priority)

Prague

The city of Prague has been actively working on implementations of intelligent transport systems and in supporting innovative traffic control strategies. These activities cover among others collecting data from different sensors, movement of mobile phones, or for example floating car data, applying different control algorithms such as adaptive control system MOTION, priorities for public transport, tunnel control systems or highway management system on the Prague city ring. The city of Prague has been also a partner in different research projects, mainly of the Technological agency of the Czech Republic.

For the project MAVEN, a selected area of Prague - Žižkov was used for the simulation network. This area is very important as it has a direct impact on the overall traffic situation in Prague. It is

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well suitable since it offers various alternate routes as depicted in Figure 37, which is a requirement for validation of a use case dedicated to local level routing.

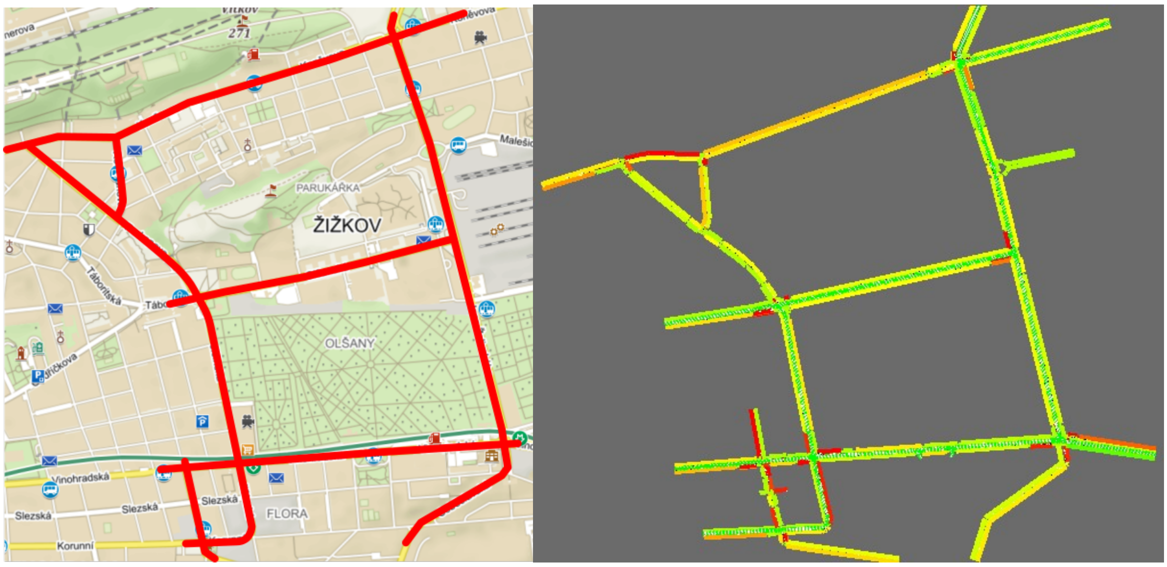

Figure 37 UC12 test polygon at Praha Žižkov (left) and a snapshot of the Eclipse SUMO simulation (right) showing actual link travel delays for the highest (i.e. circa 3600 vph) flow rate settings.

5.3 KPIs

Following sections will consist of discussion of particular Use Case simulation results and their benefits for traffic conditions. Each section will be divided into two parts containing literature review on a given topic and achieved results.

All of the Use Cases are evaluated in light of the KPIs stated in MAVEN, deliverable D7.1 [10] and sometimes additionally by queue length on intersections and an impact indicator. A measure of effect introduced in MAVEN D4.4 [1] indicating the performance of the traffic network is an impact. It can be defined using the following formula:

$$impact = \frac{\sum_{i=0}^{i=I} delay_i + 8\, stops_i}{I} \quad (1)$$

The formula sums over all traffic participants to calculate the average overall impact. An overview of performance indicators and their expected impact on traffic are presented in Table 43. Additionally, KPI 3 and 4 (produced emissions and fuel consumption) are linearly correlated and hence the tests are not duplicated.

KPI ID	KPI description with units	Expected impact
KPI 1	Number of stops at traffic lights (-)	Reduction
KPI 2	Control delay time (s)	Reduction
KPI 3	Produced emissions (g)	Decrease

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KPI 4	Fuel consumption (l)	Reduction
-	Queue length (m)	Decrease
-	Impact (-)	Decrease

Table 43 Overview of key performance indicators used in traffic simulations

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5.4 Platooning of CAV

A promising possibility to enhance future traffic efficiency is the formation of platoons by automated vehicles. For simplicity, in the traffic simulation model, we regard a platoon as a group of automated vehicles following each other with a reduced time headway and possibly employing additional control schemes to maintain a coherent state within the group. Because the jurisdictional details for such an operation are still to be clarified, it is highly relevant to study the expectable effects on city traffic flow. On the other hand, once the regulations are known and applied, the simulation results could be different. MAVEN focusses these studies on (signalized) junctions, where the greatest effect may be expected from a compactification of traversing traffic flows.

The influence of vehicle platooning is a topic of high interest in scientific research. However, most of its benefits are elaborated in reference to the highway conditions [56][57]. In the MAVEN project, we focused on the influence and potential benefits of platoon forming in the urban area.

The simulations of platooning were performed on two networks being Helmond and Braunschweig. Detailed investigation of the benefits of introducing platooning in isolation of the other use cases was not initially part of this evaluation. Its functionally was implemented in simulation and elaborated, based on feedback received from road authorities at a workshop. Platooning in MAVEN project is realised by utilization of the *Simpla* plug-in in the SUMO microsimulation model. The detailed functionality of *Simpla* is described in section 3.1 of MAVEN deliverable 4.4 [1].

Queue lengths

The study performed by Lioris et al. [58] provides a detailed view of the modelled benefits of platooning in urban environments with the use of discrete event simulation. In specific, it focuses on intersections as critical elements in urban infrastructure. This approach is very similar to MAVEN. However, the presented results are based only on the scenario of the 100% penetration of automated vehicles. The study forecasts significant improvements of intersection throughputs with the application of platooning. Experimental results in [58] suggest, that for platoons of Cooperative Adapted Cruise Control (CACC) vehicles, a technically achievable capacity increase of the urban road infrastructure is as high as an unprecedented 200 to 300 per cent using connected vehicle technology. Moreover, authors discuss that the benefits of platooning are the same as for simple adaptive cruise control for penetration smaller than 50% of traffic flow.

The indirect indicator of intersection throughput can be queue lengths at intersection inlets. This indicator tells us about the saturation rate of traffic light green light phases. If the throughput of the intersection is oversaturated, the vehicles tend to accumulate in front of the traffic lights which forms longer queues. The decrease of these queues indicates better flow/throughput ratio which allows assuming better traffic conditions as argued in [58]. Figure 38 depicts the results for average measured queue lengths during a 24-hour simulation in Helmond Network. The results for the increased ratio of CAV vehicles (x-axis) show a significant decrease in queue length (y-axis). An especially large reduction can be seen with the first introduction of 20% ratio of CAV penetration which results in 1,5 [m] shorter average queue (22,44%). With a 100% penetration rate of CAV in traffic flow, the resulting queue length is shortened by 39% which seems to be in line with Lioris results [58].

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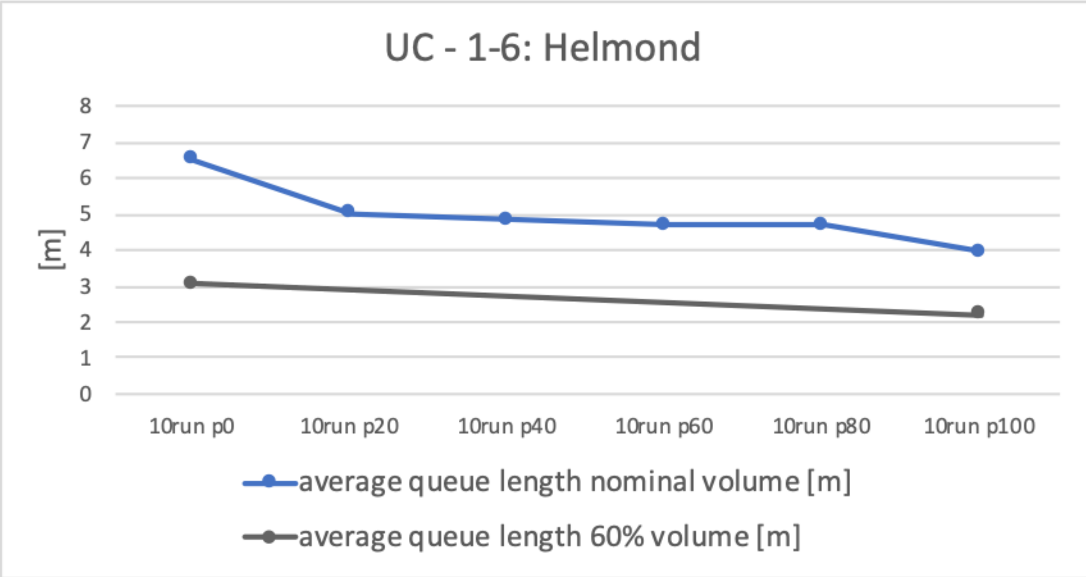

Figure 38 Average queue length measured in Helmond network with different CAV penetration rates.

CO_2 emissions

The reduction of pollutants emissions was stated as one of the biggest benefits of the MAVEN project features. This effect is often anticipated from cooperative vehicles, but it is not examined very well. Due to the implicit difficulties in performing accurate simulations, existing studies focus mainly on CAV in highway conditions [59] or emission reduction of platooned heavy-duty vehicles on highways [60][61]. While investigating the CO_2 emissions in relation to platooning, there are a number of factors that should be taken into consideration. Firstly, a strong relation of emissions with the fluency of the driving (number of stops, acceleration, deceleration etc.) and secondly aerodynamics. While in urban conditions the latter is not of a big impact, the fluency remains the main factor influencing the emissions. Platooning directly influences the fluency of driving. On one hand, it allows more coordinated trajectories and manoeuvres of the cooperating vehicles, but on the other hand, it increases the number of joining and leaving the platoon events. While the first factor decreases pollutions, the latter tends to increase the number of short term speed fluctuation among the vehicles. This effect can be seen in the results of performed simulation in MAVEN. Initially, the introduction of CAV vehicles with platooning capabilities leads to a decrease in pollutions over the investigated network.

The introduction of 20% of CAV capable of platooning alone, leads to a decrease of CO_2 emissions of 2,6% Helmond network. The decreasing trend of emissions continues for 40% of penetration rate (decrease of about 3,4%) but it turns positive on for penetrations from 60%. After that a positive impact continues and the overall decrease of CO_2 emissions reaches over 8,1% for automated vehicles only. Interestingly, this number for the nominal value of Helmond traffic (about 4500 veh/day) corresponds roughly to the results of full penetration for decreased travel demand (60% of this value).

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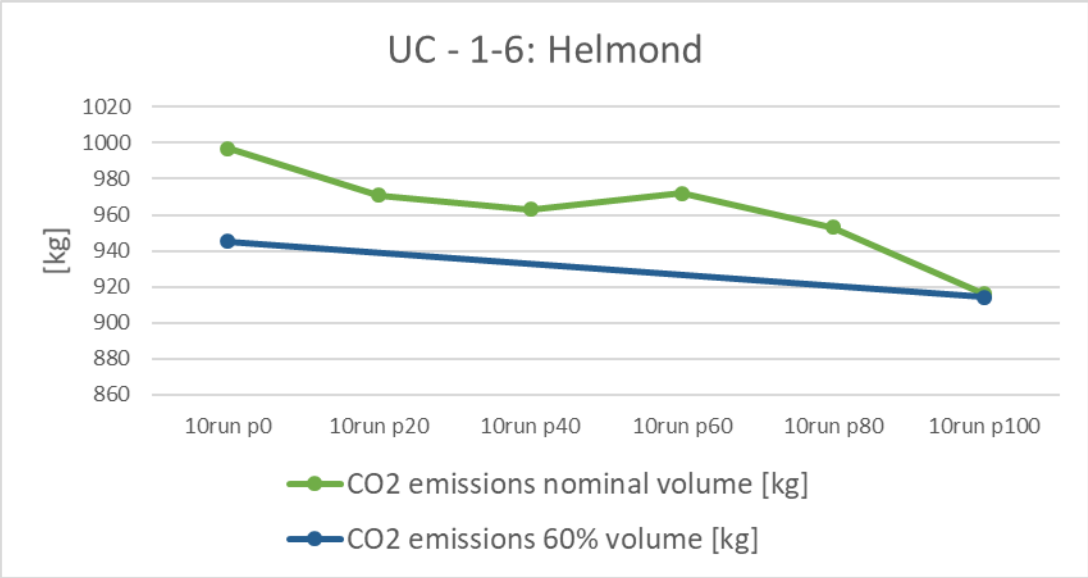

Figure 39 Helmond simulation - CO_2 emissions with a different penetration rate of CAV vehicles.

Impact

Results of platooning on impact, are presented in Figure 40, where lower the impact, better the effect of platooning on initial traffic conditions. There are two important results to be identified here. For one, in the nominal traffic volume scenario, the impact of platooning is almost linearly decreasing when increasing the penetration rate of automated vehicles. By 20% penetration, there is a decrease of about 17,7 %, with automated vehicles only, the decrease reaches over 42 %. This is in a line with the expectations where platooning with shorter intravehicular headways allows for more fluent traffic and increases road and intersection capacities. For lower traffic volume the effect is less pronounced because the intersection is far from its maximum capacity.

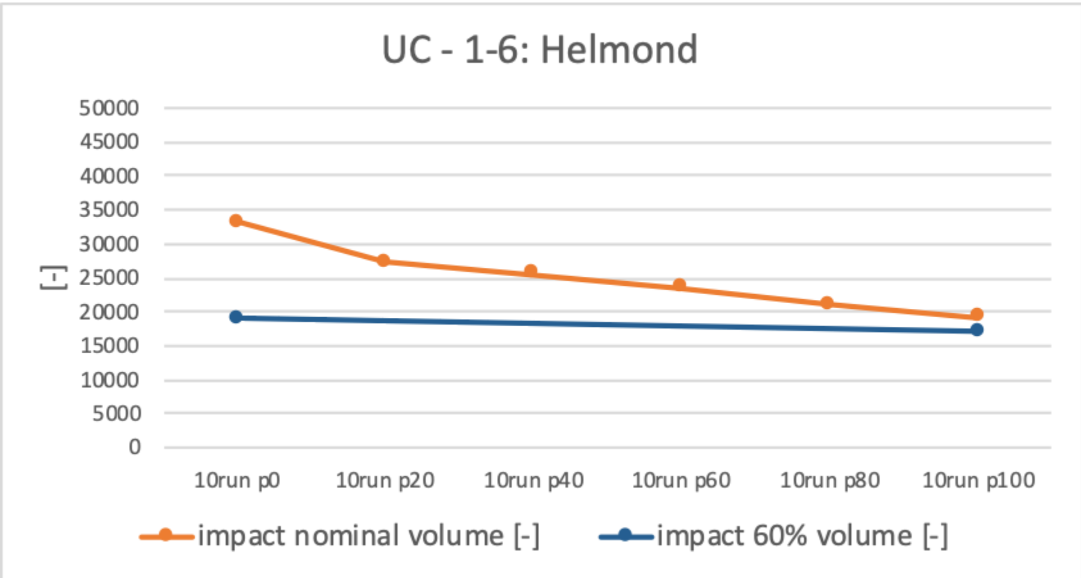

Figure 40 Helmond simulation – impact measure with a different penetration rate of CAV vehicles.

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Simulation of platooning in SUMO – Summary

The microscopic traffic simulation results of platooning show, that the highest expected improvements in almost all aspects (i.e. impact, emissions and queue lengths) happens at the penetration levels of 20%. For example, the queue length in Helmond decrease by about 20% for this penetration rate, while in case of automated vehicles only (penetration level of 100%) is the decrease about 39% in queue length. This is an important conclusion looking at the transition phase (i.e. mixed traffic): significant effects can be expected at an early stage.

For the full penetration of automated vehicles, the impact on CO2 emissions reaches over 8 %, which is a significant improvement.

5.5 Lane Change Advisory

This feature of automated vehicles allows the exchange of information between the approaching vehicle and the C-ITS infrastructure on the intersection in order to inform the vehicle about the queue lengths on different lanes of the intersection approach. By mutual exchange between vehicle and infrastructure, precise queue length can be estimated, and thus vehicles can be redirected to less congested lanes of the approach. Existing literature assigns to this utility numerous benefits such as reduction of delay time [69][70], improved merging and average speed on highways [71] to name few. In the same thought, first estimations forecast possible reduction of road capacity due to the increased number of required accelerations needed to fulfil all of the speed advice [70]. In MAVEN lane change advisory Use Case was tested together with activated queue length estimation in order to assure bilateral information exchange V2I and thus test the optimal conditions of functioning in urban conditions. Without UC11, queue length information, it would simply not be possible to give lane advice. This use case was tested in Helmond network. For this Use Case, the simulated scenarios consisted of baseline scenario (0% CAV in traffic flow), 40% penetration and 100% penetration. Additionally, UC1-6, the simpla platooning was also turned on for all CAVs.

Queue length

The most direct effect of UC 8 is probably the reduction of queue lengths at intersections. This effect is not only the most direct but also the highest. Below we present a decrease in lengths of the average queue in performed simulations.

	p0 v100%	p40 v100%	p100 v100%	p0 v60%	p100 v60%
Average queue length [m]	6,49	4,81	3,18	3,06	1,97
Percentage change		-25,9%	-51,1%	0%	-35,7%

Table 44 Overview of emissions reduction by AGLOSA

The queue length reduction is significantly higher than the 39% for just UC1-6, showing the effectiveness of this UC on queue lengths. During simulations with only UC1-6 enabled qualitative assessment showed that platoons would often stay together on one lane, basically only having the leader choosing the shortest queue and the rest of the platoon picking the same lane. Especially with long platoons, this can cause significant imbalances that are resolved by this use case.

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Number of stops

The intuitive prediction was a decrease of a number of stops due to the more fluent assignment of the approaching lanes by vehicles informed by the length of queues on given approach lanes. However, similarly to AGLOSA feature, we did not see any significant changes in the average number of stops when the penetration rate of CAV was increased in traffic flow. As visible in Figure 41, the number of stops fluctuated through different penetration rates from 0,56 to 0,67 average stops by vehicle in one simulation run.

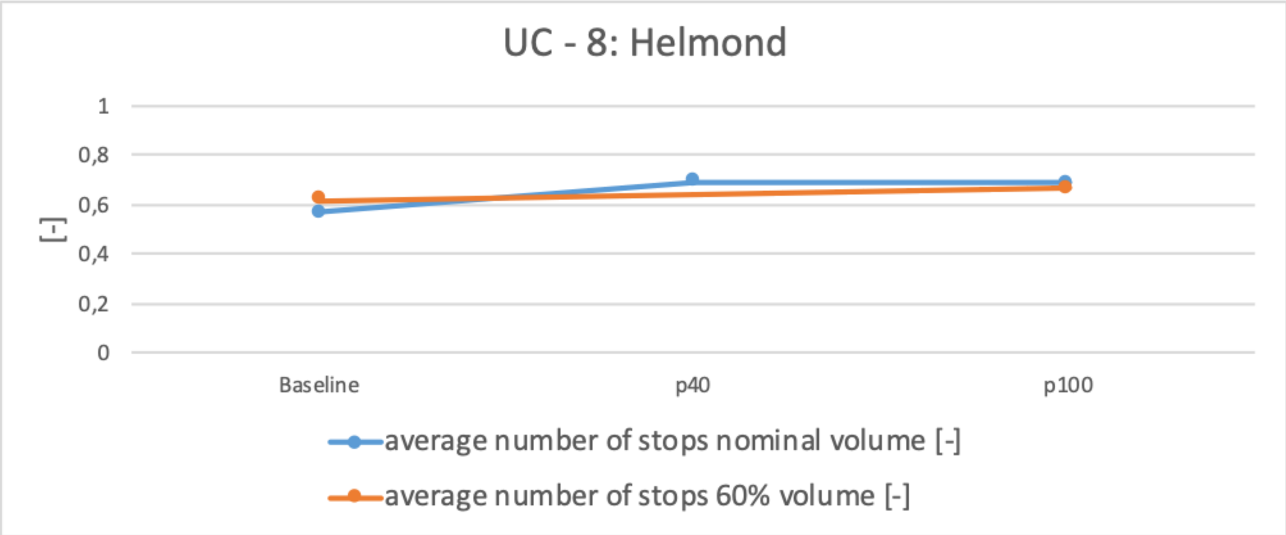

Figure 41 Helmond simulation – the average number of stops by vehicle with activated lane change advisory system with a different penetration rate of CAV vehicles.

Here additional interesting founding was, that the magnitude of the traffic flow does not seem to have an effect on an average number of stops.

Delay

Another anticipated benefit of the introduction of lane change advisory system is a reduction of the delays. Due to the redirection of approaching vehicles to the less occupied lanes, their travel through the intersection should be more fluent in general, and time spent stopped waiting on the green phase of signalisation should be shortened. The results of the performed simulation do confirm this expected effect. As presented in Figure 42, the delay was consequently reduced with a higher penetration rate of CAV vehicles.

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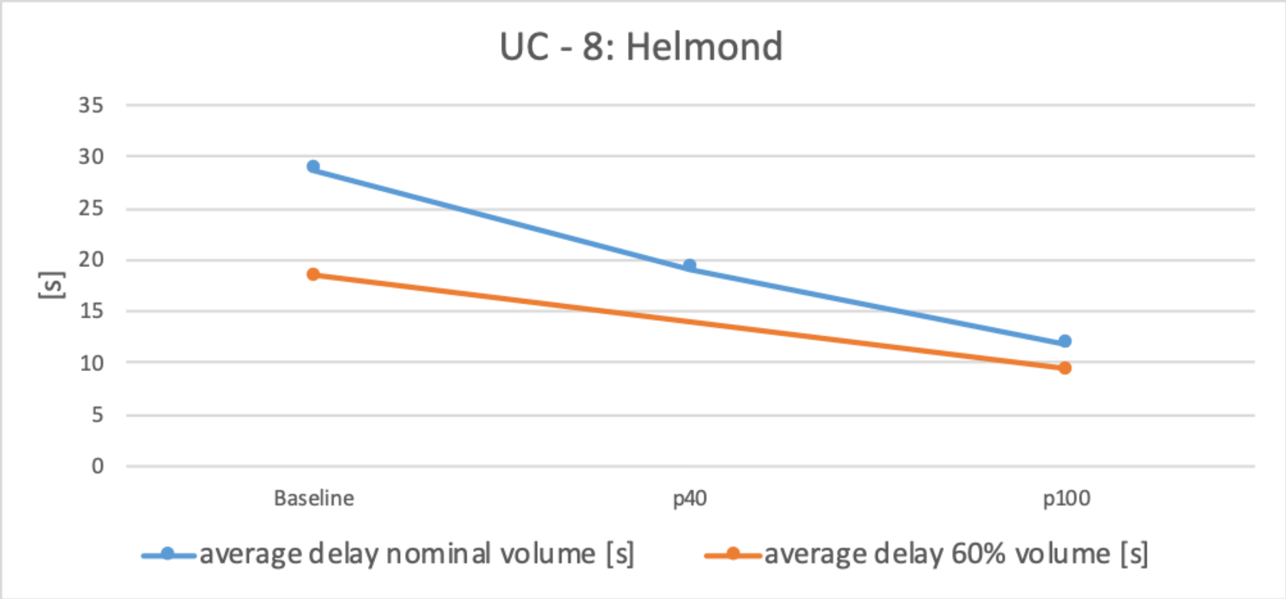

Figure 42 Helmond simulation – the average delays by vehicle with activated lane change advisory system with a different penetration rate of CAV vehicles.

A detailed look into depicted results reveals that reduction of delay is equal to 9,6s and 17,4s (33,4% and 60,5%) for a 40% penetration rate and 100% penetration rate respectively. This is assumedly due to the advised lane change. Since the reduction in queue lengths was significant, we can presume that the distribution of the vehicles among lanes was much more even. This causes fewer cases of the vehicles not crossing the intersection on the first closest green phase on signalisation. Vehicles start at a green light and cross intersection more fluently on each phase change. This allowed great saving in vehicles delays.

CO_2 emissions

Contrary to the expectations and predictions in available studies worldwide (e.g. [71][72]), it was demonstrated that lane change advisory by itself has a negative effect on emissions, i.e. leads to a slight increase in emissions (about 4,2 % for full penetration of automated vehicles).

There are two effects that could play a role here. One is the reduced fuel efficiency due to breaking up of the platoons close to the intersection for distributing the platoon over the lanes. The second is more significant but also more complex. The traffic control algorithm of UC14 was calibrated with the same settings for each simulation run. Having more compact platoons passing the intersection means the average green phase duration gets shorter. If the phases get shorter, there are fewer vehicles who can just pass without stopping by accident (i.e. not following any form of guidance). At the same time, the delay time is going down because the vehicles that were already stopped for the next phase have to wait less time. This is exactly what we see happening in the other KPIs. Therefore, this effect could be countered by calibrating the traffic light controller to give more importance to stops and bridging the gap between the end of a platoon and a single arriving vehicle further upstream. For a fair comparison, the configuration of the algorithm was not altered, but delay time could be exchanged for stops, lowering the CO_2 emissions.

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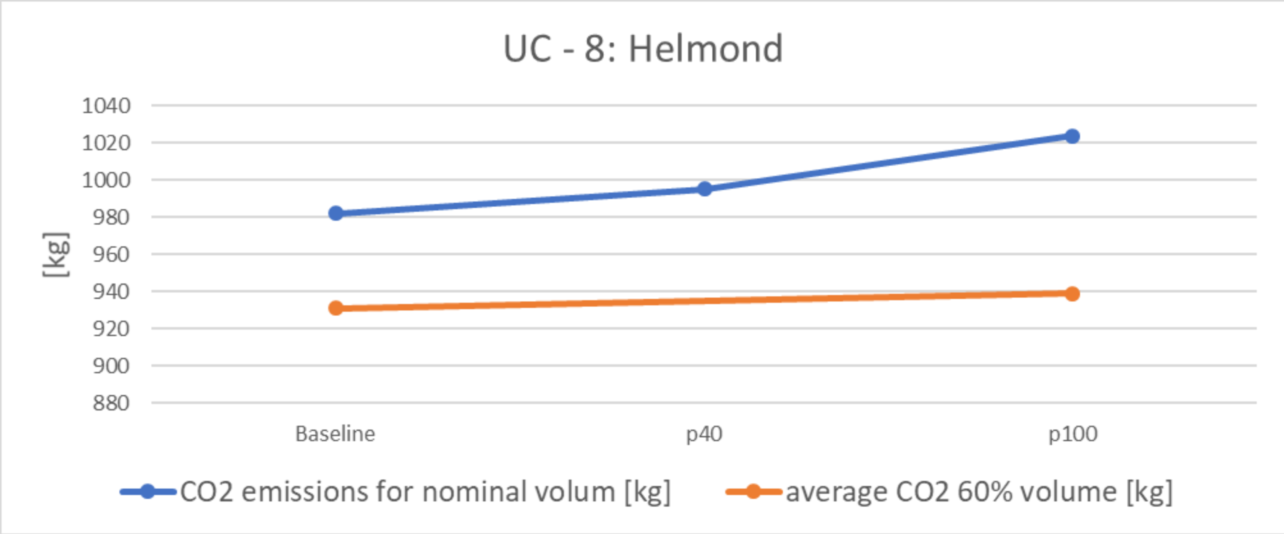

Figure 43 Helmond simulation – the emissions by km of the network with activated lane change advisory system with a different penetration rate of CAV vehicles.

Simulation of Lane change advisory – Summary

The simulation of the Lane change advisory showed a very large improvement on the total delay, but an increase of the average number of stops and increase in emissions (these two parameters typically depend on each other). Recalibrating the traffic control parameters for balancing between stops and delay in the presence of platoons and lane advice could be an interesting case for future research. The effects are especially present for higher traffic volumes and depend strongly on the penetration lane. In the case of 100% penetration rate of automated vehicles, there is a decrease of almost 60% on delay.

5.6 Priority Management

Priority management is another investigated feature of MAVEN project. It covers priority for public transport (PT) and platooning vehicles on arrival at the intersection. It is a simple feature, however, its demonstrated that its combination with other Use Cases is causing the disruption of the traffic flow and decreased the performance of the optimization algorithms. It is vital to understand, that each of the priorities given to the vehicle, causes extension, cut-off or reordering of green light phases, which makes an accurate prediction of signal phases impossible. The latter is a crucial condition for the effective functioning of speed advise system, green wave management and signalisation optimization. Scientists agree that such solution is not only beneficial for increasing the sustainability of future cities through popularizing of PT [73] but also has direct benefits of reduction of air pollution and reduction of travel times for the platooning vehicles' routes [74][75]. In the MAVEN Project, we investigated different strategies on prioritizing PT transport with different weights assigned to the PT vehicles.

The route of priority vehicles starts at the south of intersection 103, then turns right towards 104 and then left to leave the network in a northbound direction. Therefore, the entire corridor from 101-104 is used for acquiring evaluation measurements. Tested configurations have priority weight w=0 (baseline), w=5 and w=50 in accord with the finding of section 9 in [1]. Additionally, a scheduling strategy is applied by first collecting 6 shuttles in a platoon when the weight is set to 50.

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Number of stops

A number of stops in the network are one of the parameters that are expected to be influenced by implementing PT priority. However, in the I deal case, this effect is not to big on overall traffic as to not disturb the functioning of the green phase length predictability. Results of the simulations depicted in Figure 44. The average number of stops seems to be not affected by priority management with weight 0 and weight 5.

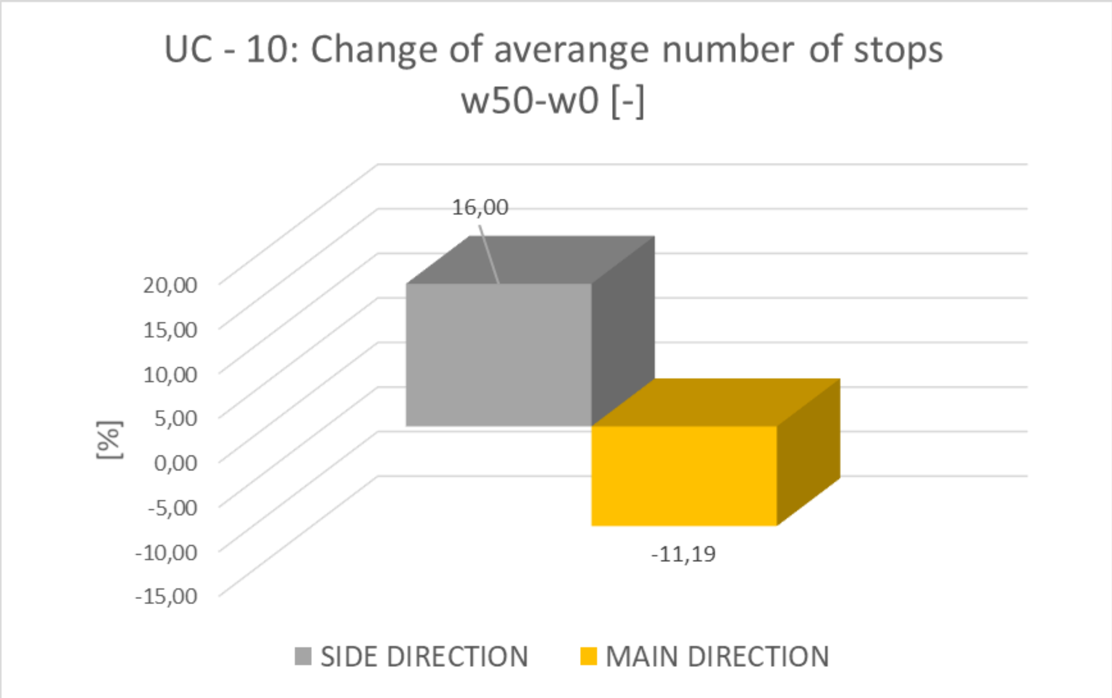

Figure 44 Helmond simulation – the change of an average number of stops by vehicle, depicted for each of the intersections in the network. Change is depicted between weights from w=0 and w=50.

Delay

The delays of the vehicles were expected to be the parameter which could be influenced in the most severe way by the introduction of public transport priority. The expected effect of priority is a slight increase in the delays along the main direction and decrease of the delays on the side approaches to the intersections. This scenario was fulfilled in MAVEN simulations. Intersection tested in simulations achieved decreased delays with the application of PT prioritization of weight 5, but only insignificantly in the range 0,17 second per vehicle on average, and increased delays on side directions of 0,20 seconds. This seems counter-intuitive that there is a small increase in delay for prioritized vehicles. However, this is because the shuttles have a lower speed than regular cars and disrupt the traffic more if they are not grouped. So the shuttles themselves don't have an increased delay, but the other traffic does and hence the increased delay.

In Figure 45, the results with grouped shuttles and a higher priority weight are shown. In this case, the results are as expected. Thanks to the grouping, the other traffic is much less disturbed and the higher priority level doesn't have a too high impact on the traffic in the main direction.

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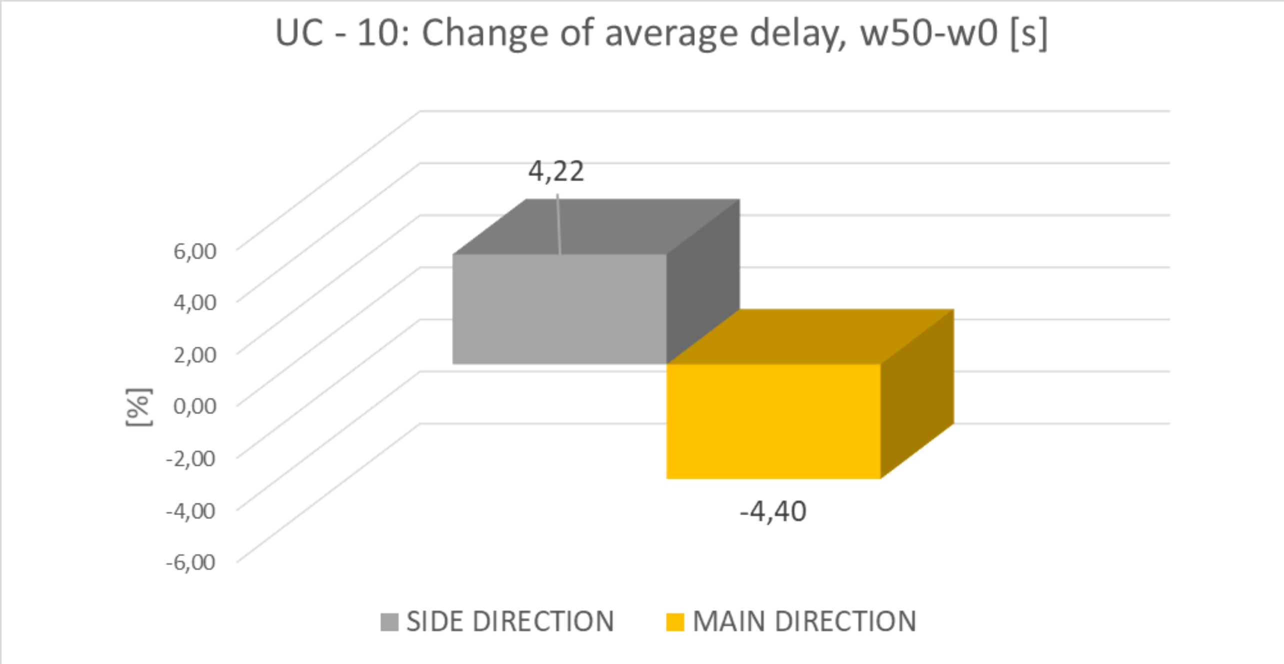

Figure 45 Helmond simulation – the average delay by vehicle with activated platoon priority management and with a different weight of platooning vehicles priority.

CO_2 emissions

Emissions of the pollutions are of high concern when considering platoon prioritization. As explained in the introduction to this chapter, the prioritization of platooning vehicles implies disturbances in the signalisation plan on intersections. This was of high concern in the MAVEN project and thus was thoughtfully analysed in simulations. The results indicate that there is a small decrease in the CO_2 emissions at priority w=5 nor w=50 (see Figure 46).

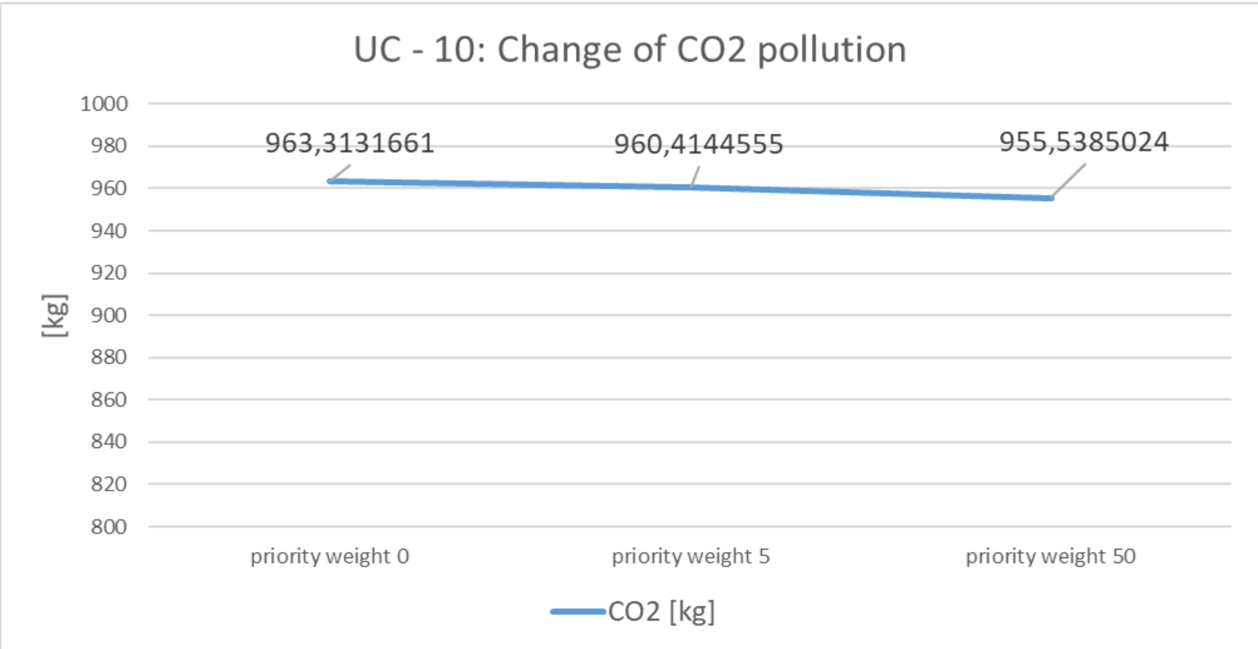

Figure 46 Helmond simulation – the emissions by km of the network with activated platoons priority management with a different weight of platooning vehicles priority

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Simulation of Priority management – Summary

The priority management is a feature that has a clear positive effect on the side direction of traffic thanks to grouping the shuttles into a platoon before entering the network. The overall effect is rather positive as we can see for example on the slight improvement of CO_2 emissions in the entire network. In this case, the priority was not given on the main direction and therefore, in combination with the existing control algorithms, it leads to a significant worsening of the situation on the main directions. The grouping of priority shuttles proved effective to cause less disturbance to other traffic, which justifies giving a higher priority to reshaped platoons as compensation for this grouping. Overall, it is a policy that can be used by traffic managers in order to influence the acceptance and comfort of a mixed fleet of automated shuttles and manually driven vehicles.

5.7 Queue Length Estimation

The purpose of this use case is to investigate the effects of incorporating information from automated vehicles into a queue length estimation algorithm. Traditional queue length estimation algorithm use information from standard sensors as inductive loops or Bluetooth/RFID systems to detect vehicles passing a certain point at an approach to an intersection. From this information, an estimate of the queue length at the given approach is computed and later used by a control algorithm to predict vehicle waiting times on the approach.

In an ideal case, speed, position and route information about each vehicle would be available, providing almost exact position of the queue tail at every moment of measurement. However, traditional sensors are unable to provide this information and the control algorithms have to rely on estimates of queue lengths and turning rates. In this use case, we use automated vehicles as a source of floating car data (FCD). FCD is used to correct the original model estimating the position of the queue tail by analysis of automated vehicle position, its trajectory and travel time.

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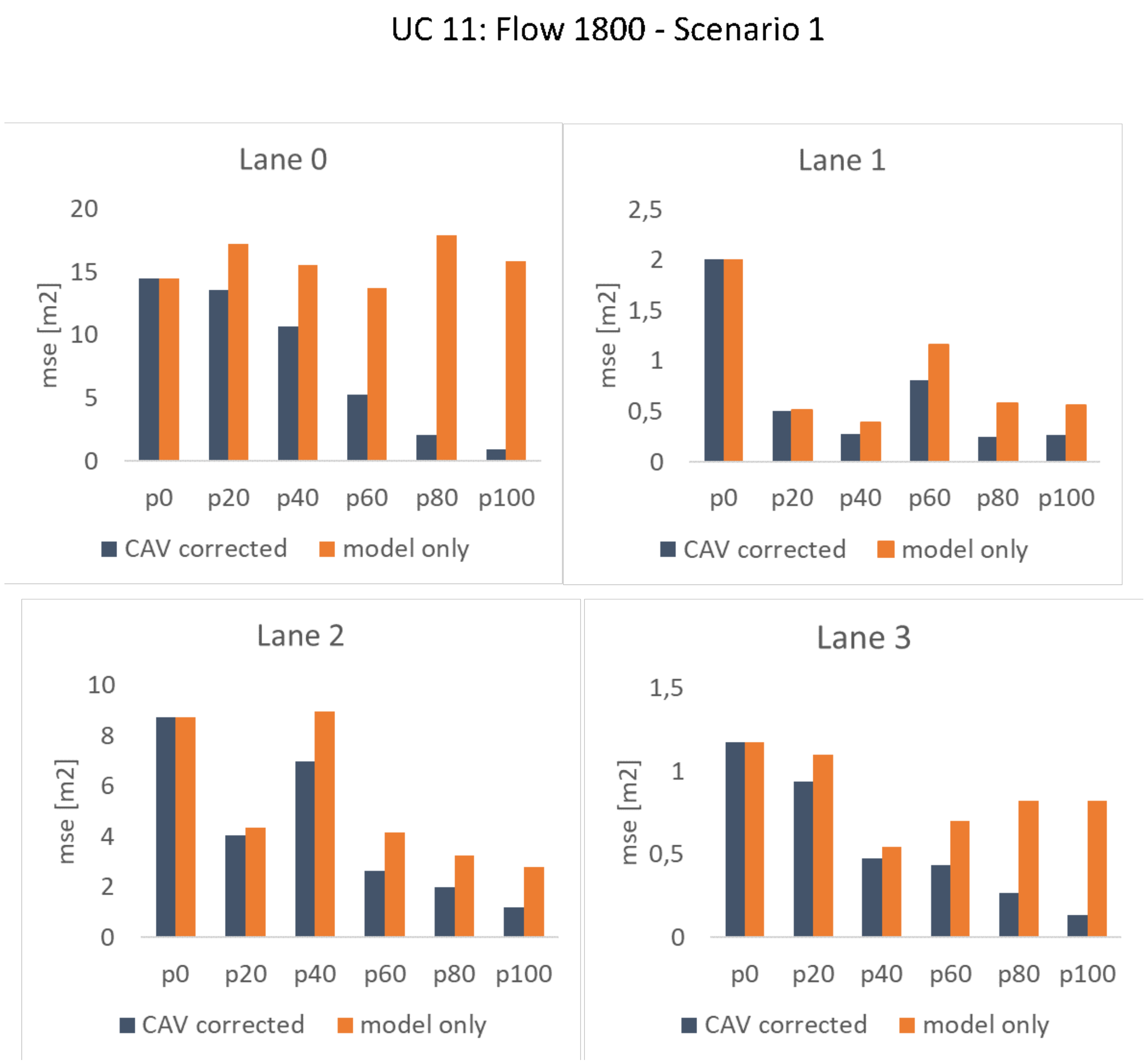

Figure 47 Helmond simulation of four-lane approach for different automated vehicle penetrations (0, 20, 40, 60, 80, and 100% of passenger vehicles) and medium traffic flow.

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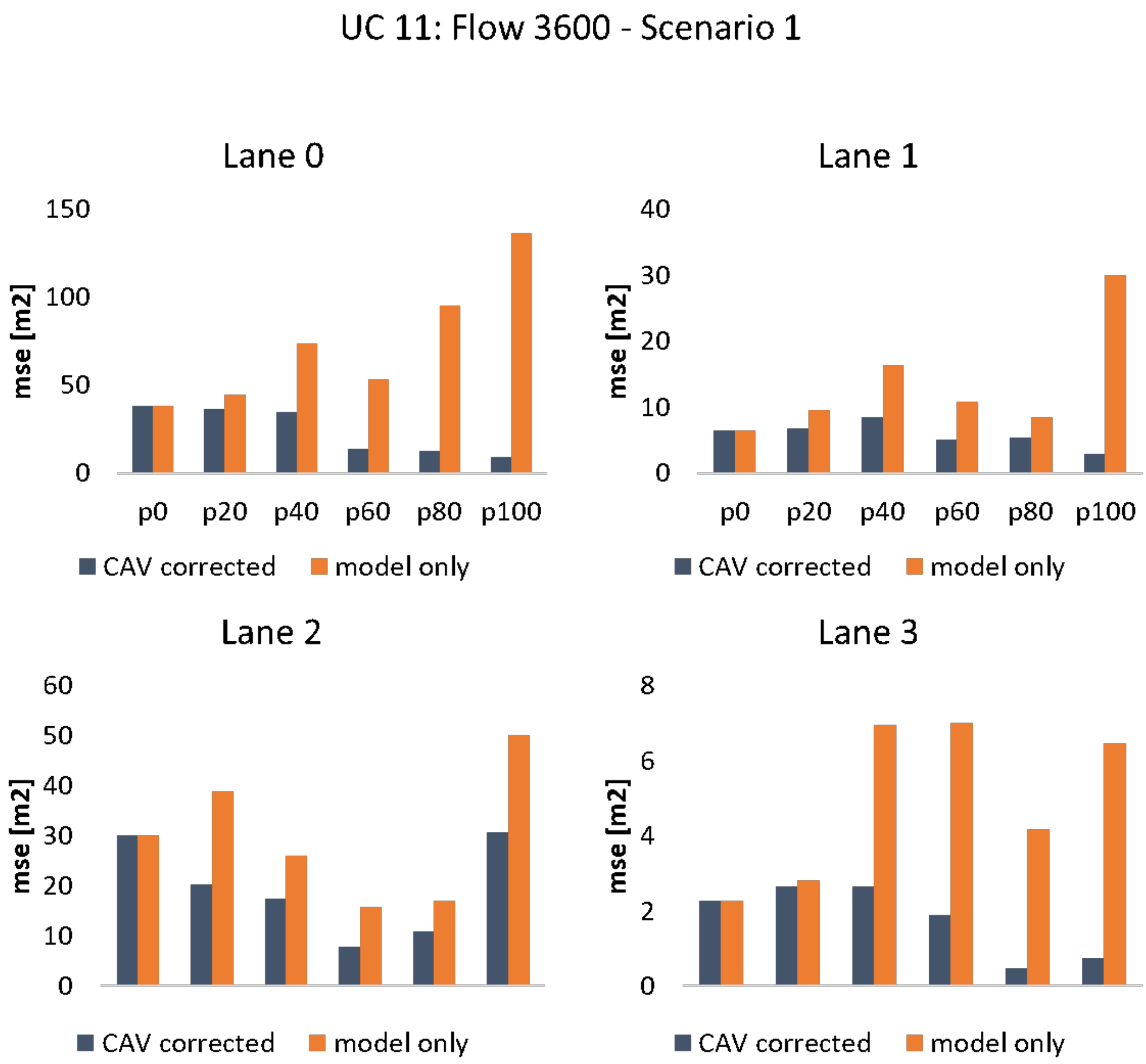

Figure 48 Helmond simulation of four-lane approach for different automated vehicle penetrations (0, 20, 40, 60, 80, and 100% of passenger vehicles) and traffic flow close to saturation.

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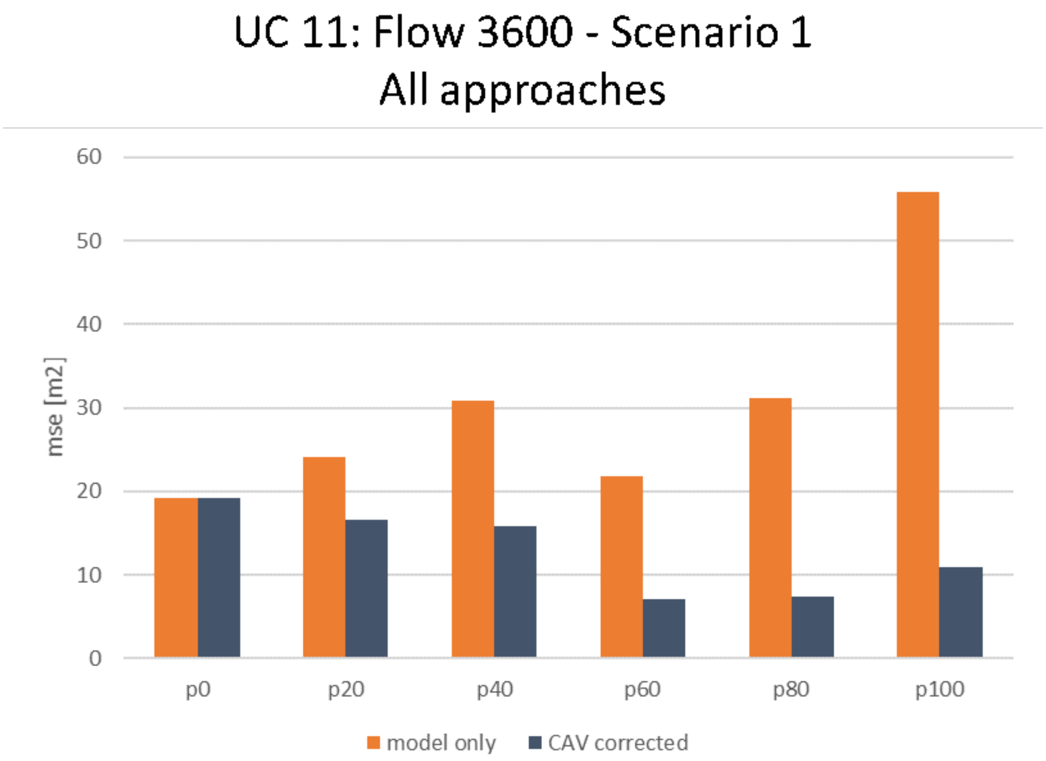

Figure 49 Combined MSE of all approaches Helmond at the simulation of four-lane approach for different automated vehicle penetrations and traffic flow close to saturation.

Model corrections from FCD data

As expected and as can be seen in figure Figure 47 and Figure 48, queue estimation error (in our case measured by MSE between “true” and modelled queue) decreases with growing penetration of automated vehicles in the traffic. We can also see that even the error of the traditional queue length estimation model is to some extent affected by the penetration rate of automated vehicles. One possible explanation is that the traffic flow properties (which are assumed identical for all AV penetrations by the model) depend to some extent on the penetration rate of automated vehicles – in our simulated scenarios, automated vehicles tend to maintain smaller gaps to leader vehicles, and are allowed to change speed with slightly higher acceleration and deceleration values. Additionally, the forming of platoons causes vehicles to arrive more in bursts in the queue instead of arriving according to traditional Poisson distribution.

An interesting phenomenon can be observed also in Figure 49 for the case when all passenger vehicles are automated. In this case, we can see that the queue length model does not perform well, and the MSE of model differences to real queue measured by the simulator rises significantly. This is probably caused by platooning of automated vehicles – while all vehicles in a platoon behave identically and they share an identical route, the traditional model works without knowing this information, treats the platoon as a group of individual vehicles and may actually distribute the platooned vehicles to different outgoing lanes. This error is corrected later when the platoon leaves the intersection.

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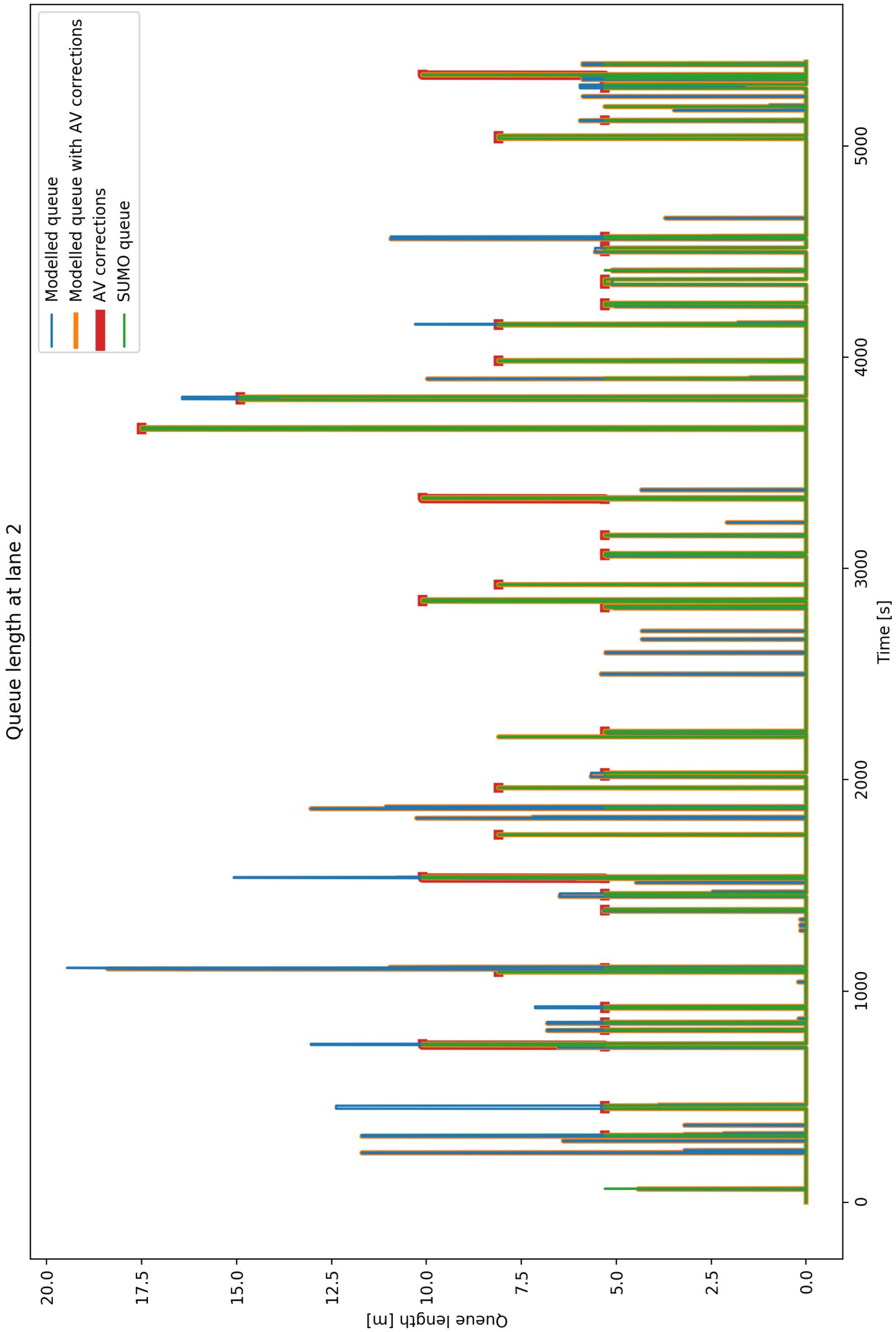

Figure 50 Example of queue model correction by automated vehicles

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Detailed corrections from FCD data

Figure 50 shows 90 minutes of queue length modelling and automated vehicle corrections on the measurement-by-measurement basis. We can see that in cases when an automated vehicle stops in the queue, the queue model is assimilated to the position of the stopped automated vehicle(s). We assume that AVs “see” not only the leader vehicle, if present, but also the follower if there is any. Therefore, an automated vehicle is able to provide slightly more precise queue length estimate also in cases when a non-automated vehicle starts queuing right after them – for cases of this situation are visible in Figure 50, denoted by a vertical red line.

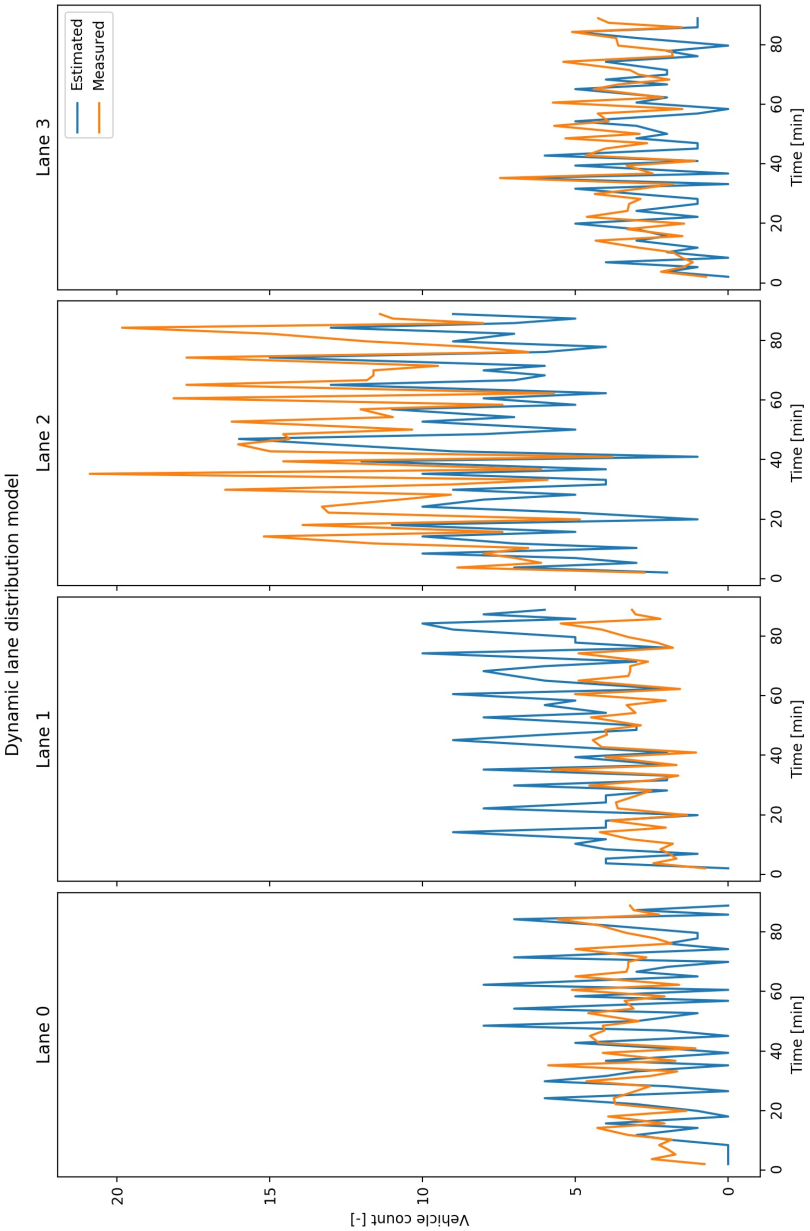

Figure 51 Estimation vs measurement of traffic on stop-bar detectors for two input and four output lanes. The lane-change model in this case slightly overestimates arrivals to lane 1 at the cost of underestimating arrivals to lane 2.

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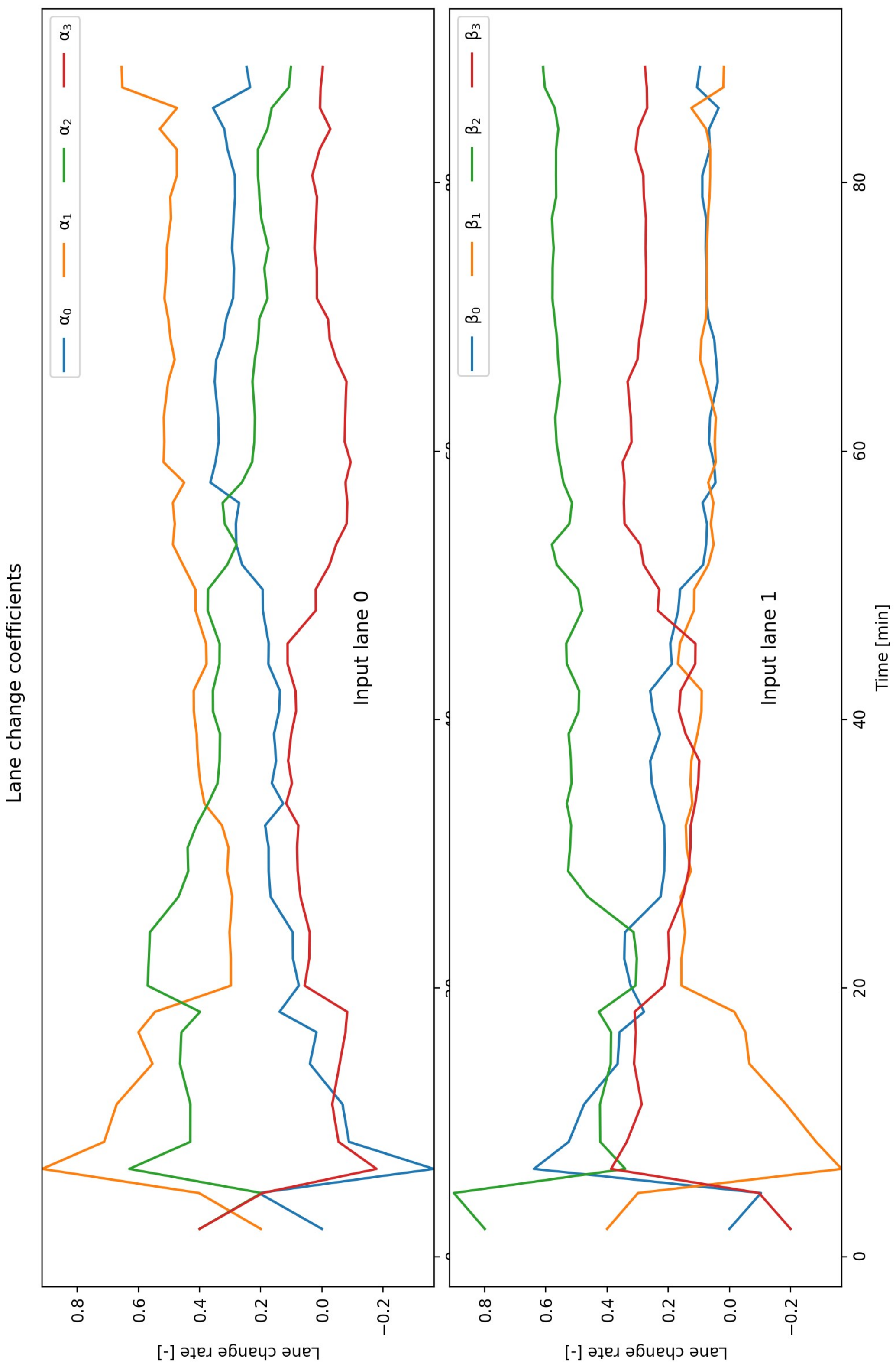

Figure 52 Estimation of lane change coefficients for two input and four output lanes

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Lane arrival modelling

One of the project goals was to make the queue length model work with lane precision. This is not possible without estimating the unknown number of vehicles that enter every lane at a signalized intersection. Figure 52 demonstrates the output of such an estimator that is based on an autoregressive model. For two input and four output lanes, this model estimates six-lane change probabilities out of total eight. The remaining two coefficients, one for every lane, are computed so that the sum of lane change probabilities for every input is equal to 1.

Figure 52 also demonstrates one of the deficiencies of models that are derived assuming normally distributed data: the value range for real coefficients is allowed only in the range [0,1], but the support for normally distributed coefficients is infinite. Currently, this is solved by clamping the model output to [0,1] interval.

Queue Length Estimation – Summary

An exact estimation of queue length on signalized intersections is essential for successful implementation of algorithms such as green wave or signal optimization. The results demonstrate the potential of improving the queue length estimation by taking into consideration information from automated vehicles.

For AV penetration 20%, the SUMO simulations on Helmond network indicate almost a 50% decrease in the queue length estimation means square error when compared to the queue length model based on pure detector readings, while for 100%, almost 90% of the original error was eliminated. The remaining inaccuracy is due to a certain amount of non-automated vehicles in other classes such as trucks or buses. Possibly even more important is that without this use case the introduction of automated vehicles will decrease the performance of traditional queue estimation, which can be countered with this MAVEN solution.

5.8 Local Level Routing

A local level routing system is a type of route guidance system. The traditional routing algorithms are based on the anticipated travel time based solely on current travel speeds on each section. This algorithm is used as a reference value and is denoted HTT (Headway Travel Time) in the evaluation. The proposed algorithm denoted LLR is described in details in D4.4 [4]. The LLR system enables vehicles (with a destination outside the area modelled by the system) to find the optimal route considering nearby more accurate predictions and faraway stored information, avoiding route advice to an unnecessary local optimum. It also utilizes information about signal phases from traffic controllers. In addition, the system can work with simultaneous entrance points where vehicles would start receiving real-time information, accounting for other vehicles that have passed any entrance point. Vehicles can share their intended route to improve the accuracy of the traffic predictions but it is not necessarily a requirement. These predictions are based on modelling vehicles microscopically within the road and statistically (but maintaining the number of vehicles) between junctions throughout the planning horizon.

The simulations were performed on the Prague traffic network for low traffic volumes of 6700 vehicles/simulation as well as high traffic volume of 22300 veh/simulation. Unless stated otherwise, the presented results are based on the high traffic volume as it better shows the performance of the algorithm.

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The penetration rate also denotes the rate of vehicles that use the HTT or LLR routing algorithms. For this reason, we observe also an improvement for the HTT in case of increasing the penetration rates.

Mean time spent waiting

The first parameter to be investigated is the meant time spent waiting, which is a variance of the delay indicator. The indicator “waiting time” is defined as “average time spent standing (involuntarily)“. It, however, does not take into account vehicles slowing down towards a queue, just those really stopped at an intersection. On the other hand, the delay in other Use Cases is defined as total difference between travel time of the vehicle when travelling in free flow conditions, compared with actual travel time Actual travel time includes surrounding traffic conditions and vehicle speed changes involving slowing of the vehicles due to the (A)GLOSA recommendations, speed change due to joining and leaving a platoon, vehicle rerouting, or priority given to platoons. In simulations, the reference travel time for computation of the delays was measured as travel time of a given vehicle without other vehicles in the network and no MAVEN features applied in the infrastructure. This relation is important to understand why in this particular Use Case Waiting time is used rather than delay KPI.

We can see that the LLR algorithm outperforms the HTT algorithm already for 10 % penetration of automated vehicles by 16,9% and is constantly better for all different penetration rates. The LLR algorithm also improves the mean waiting time by about 33 % in case all vehicles receive complete information.

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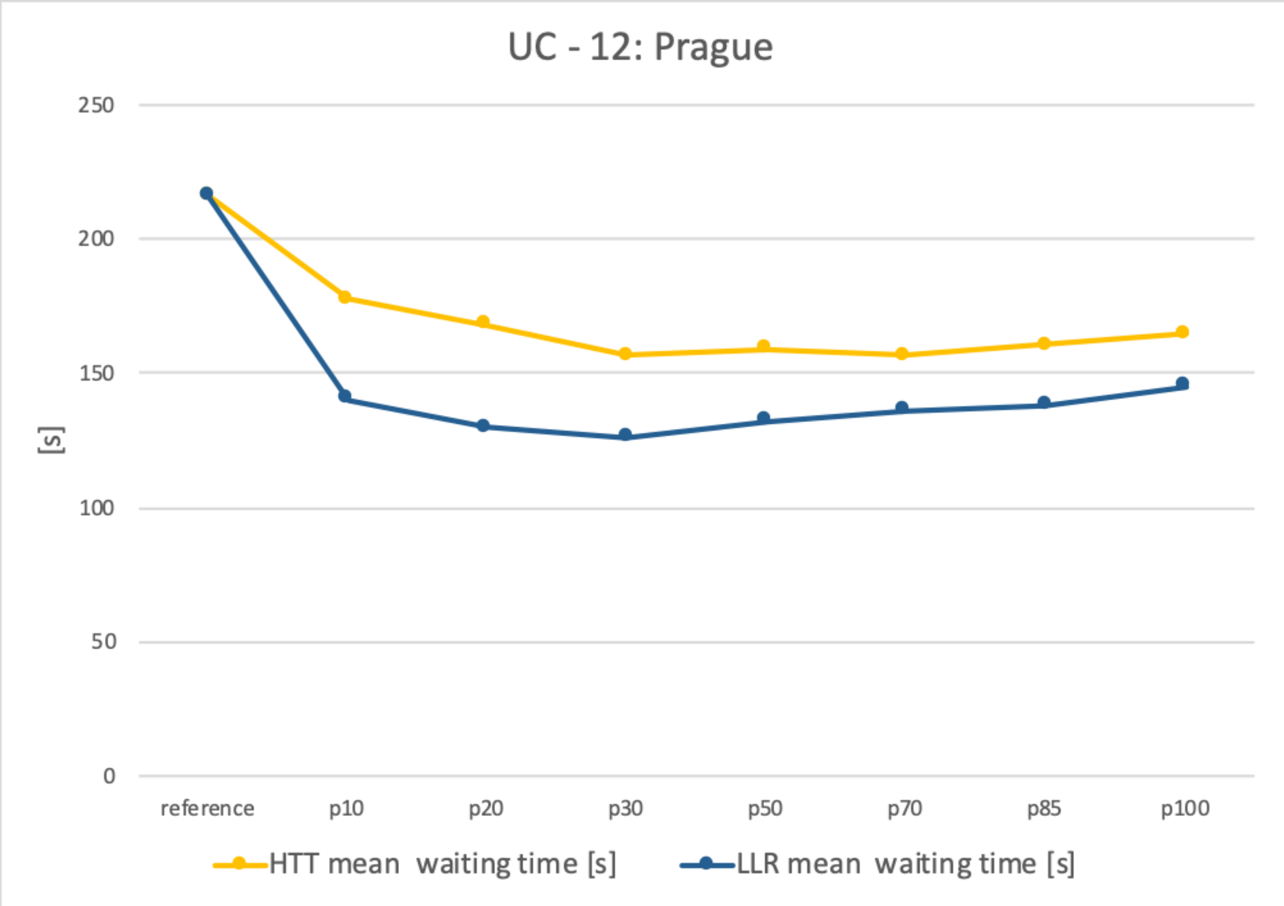

Figure 53 Prague simulation –mean waiting time for LLR as well as HTT algorithms

CO_2 emissions

A similar trend was demonstrated also for the CO_2 emissions. Here, at the 10% penetration rate of vehicles able to receive LLR information, there is an improved performance of the LLR algorithm by about 7,5%. This better performance is almost constant between about 8% and 10% for all penetration rates, in case all vehicles do use the LLR algorithm, the overall savings in CO_2 emissions reach almost 19%.

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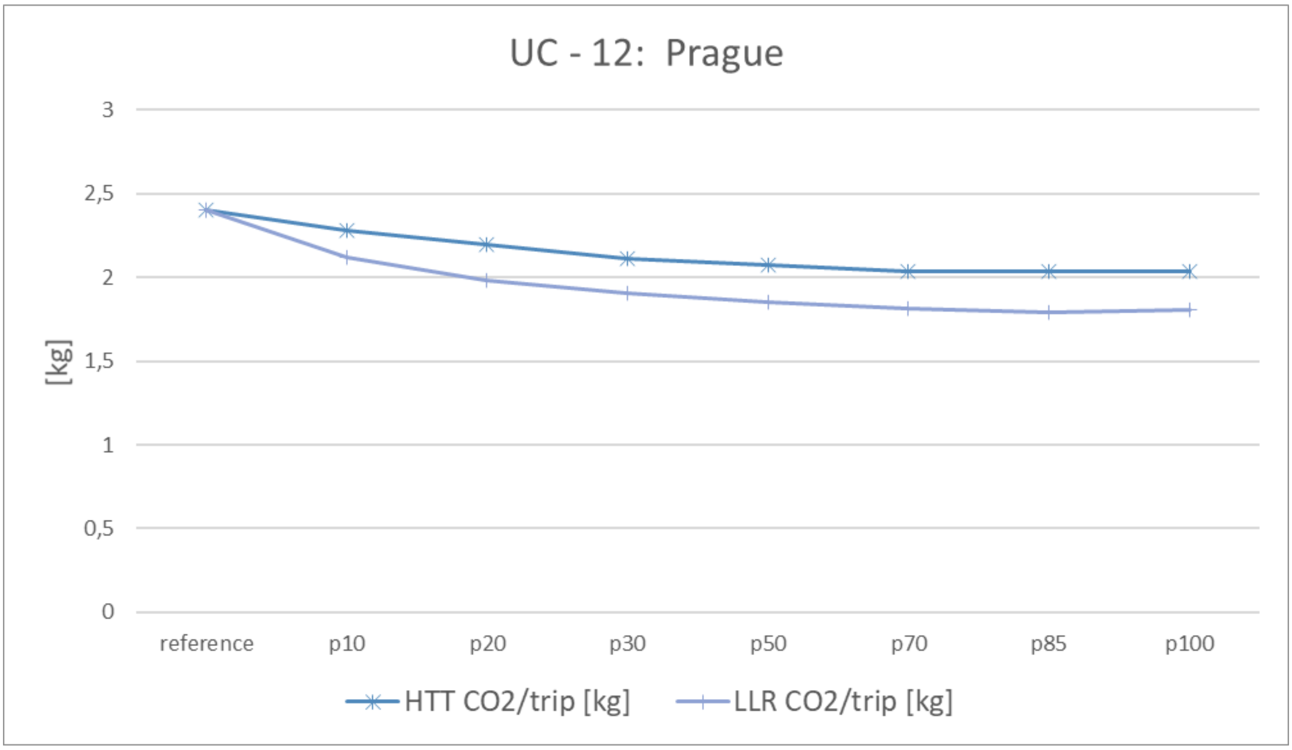

Figure 54 Prague simulation –mean CO_2 emissions for LLR as well as HTT algorithms

The following table provides the results for different indicators for both, the high as well as low traffic volume. In this case, we provide a comparison (improvements) for the 100% penetration rate of CAV in traffic to the base case scenario without automated vehicles:

	Low-intensity traffic	High-intensity traffic
LLR trip duration reduction	9,4%	24,6%
LLR mean waiting time reduction	7,4%	32,9%
LLR mean CO_2 emissions reduction	8,8%	18,8%
LLR mean fuel consumption reduction	7,8%	10,6%

Table 45 Overview of impacts on traffic with LLR functionality

Simulation of Local level routing algorithm – Summary

The local level routing algorithm was compared to a situation with routing using travel times in the network only, which is the current state of the art. The proposed algorithms clearly outperform the traditional HTT algorithm in all investigated indicators.

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5.9 Actuated signal optimization algorithms

Signal optimization is a feature that brings the benefits for traffic management and is specifically designed to support GLOSA for automated vehicles. Existing adaptive traffic light control algorithms, can adapt more efficiently and accurately thanks to enhanced information source – CAV of UC 11 and the GLOSA algorithm itself also uses the enhanced queue information. Also here, these use cases were tested together with the use case 7 – GLOSA. The combination of UC7 and UC11 automatically implies that negotiation (UC15) is going on as well. Applied signal control algorithm has the potential to bring benefits even without the utilization of CAV information. In order to depict these benefits, we introduce to the graphs in this section not only data from simulations with different CAV penetration rate but also a baseline scenario data reflecting the current control algorithms.

Average delay

The first and most anticipated benefit of signal optimization through cooperation with CAV is the reduction of average delay over all network. This expectation seems to be met by results achieved in Helmond network depicted in Figure 55 below. The vertical grey line depicts also the baseline scenario without the MAVEN signal optimization algorithm. You can see, that even for a 0% penetration lane (i.e. network without automated vehicles), there is already an improvement in delay of about 6,4%. Compared to this baseline value, the algorithm with a 100% penetration rate of CAVs can improve the delay by over 43%.

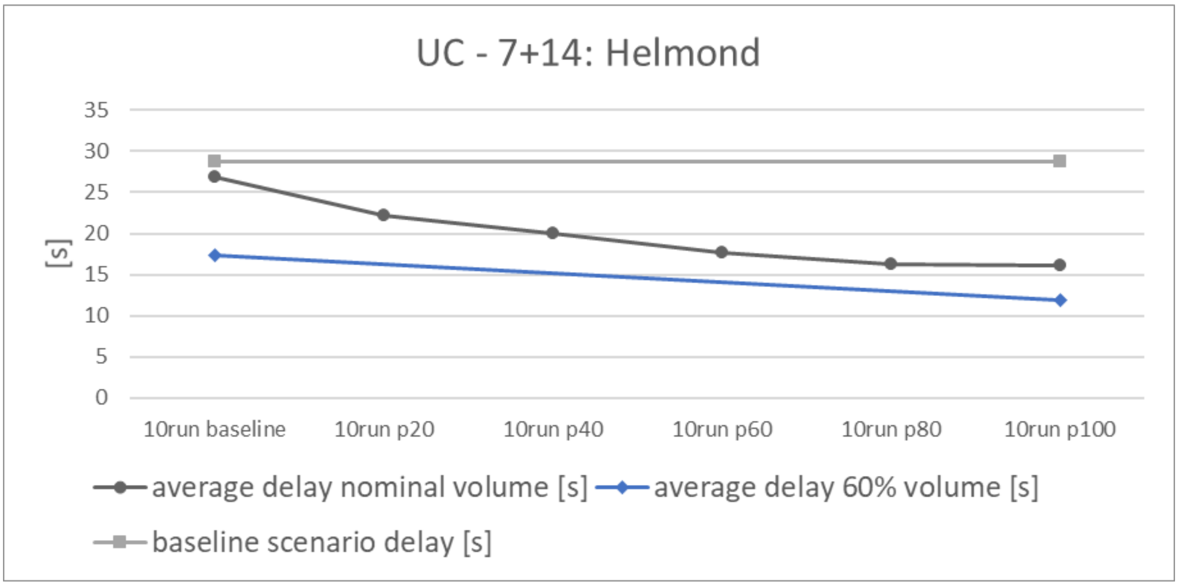

Figure 55 Helmond simulation – the average length of the queues in the network with activated network coordination at a different

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Impact

It is very important to note, that signal optimization will not deteriorate traffic conditions for pedestrians and cyclists. The average impact factor calculated for Use Case 14 – Signal optimization shows that vulnerable users, in fact, do benefit from this feature as well. Already at a CAV penetration of 20%, over 13% of improvement on the impact indicator is realized as presented in Figure 56. Overall for 100% of automated vehicles, the impact is improved by about 35%.

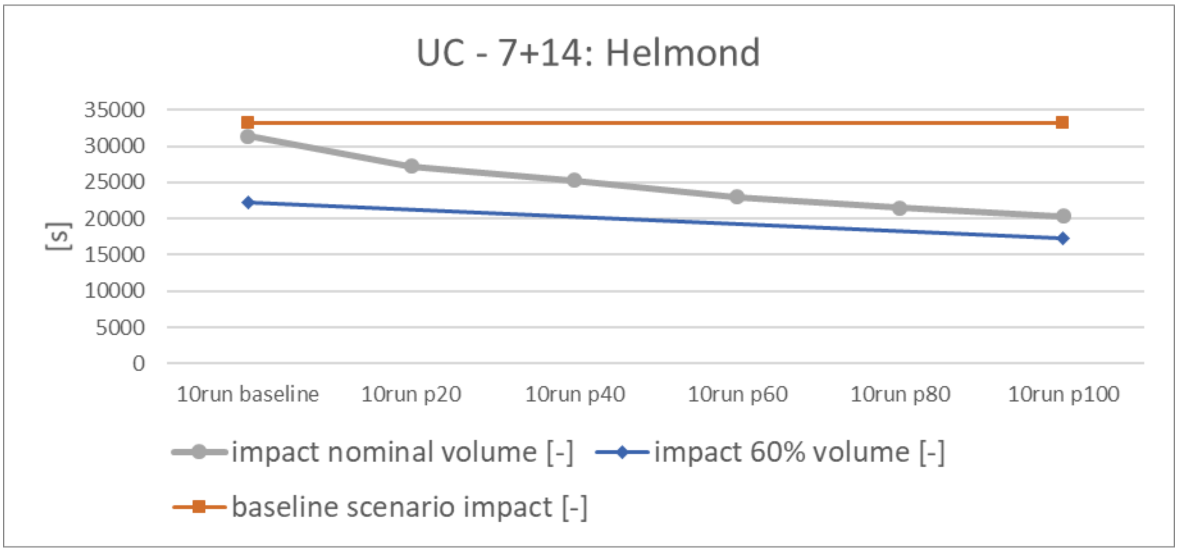

Figure 56 Helmond simulation – the average length of the queues in the network with activated network coordination

CO_2 emissions

The study performed by Eckhoff [65] reported a potential for emissions reduction with the use of speed advisory systems of 2% to 12% pollution reduction. These results, of course, depend on CAV penetration rate and traffic density. On the other hand, Lebre et al. [68] achieved emission reduction in the range of 3 to 10%.

In our experiment, the achieved reduction of CO_2 emissions for the full penetration of automated vehicles was about 5%. Detailed results are visible in Table 46 and Figure 57.

	p0	p20	p40	p60	p80	p100
CO_2 emissions [g/km]	142,93	141,97	142,01	140,81	138,47	135,71
percentage change		-0,7%	-0,6%	-1,5%	-3,1%	-5,1%

Table 46 Overview of emissions reduction by AGLOSA

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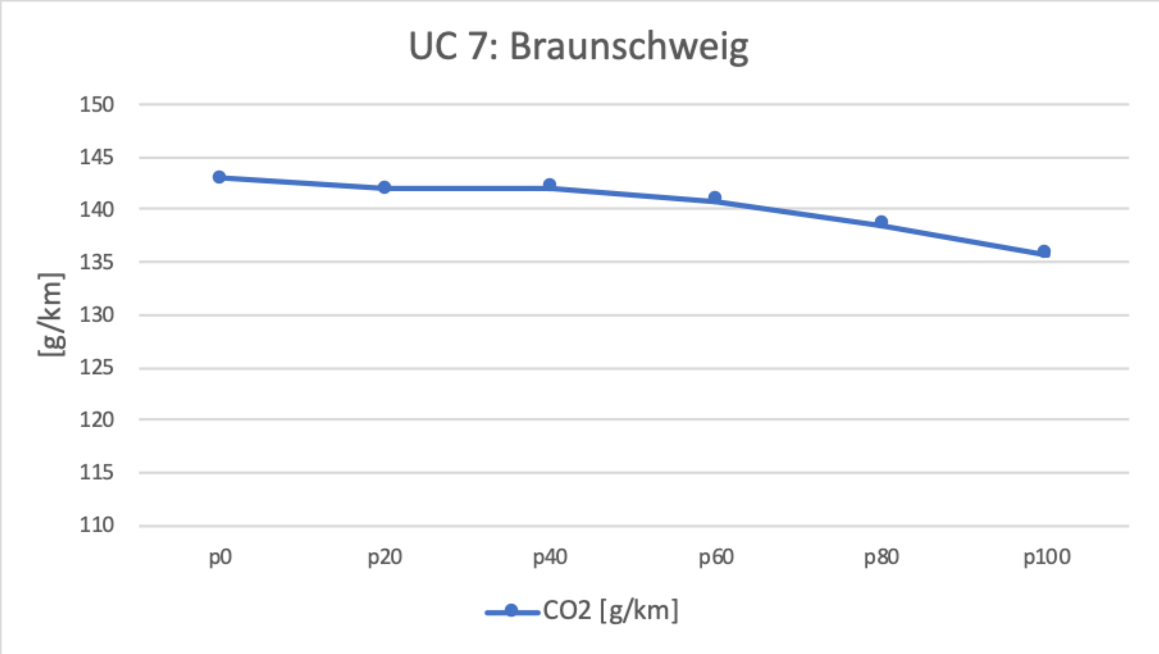

Figure 57 Braunschweig simulation – the emissions caused by active AGLOSA with a different penetration rate of CAV vehicles.

In Helmond scenario, there is a clear improvement of about 11,5% in the CO_2 emissions for the low travel demand (60%). The situation for the nominal demand is more complicated. By increasing the penetration rate, the emissions actually slightly increase (maximum of about 1,1% increase of CO_2 emission for 40% penetration). After that, there is first a slow improvement and rather a big step when reaching complete penetration of CAVs. The overall improvement reaches over 12% of CO_2 emissions. Non-equipped vehicles overtaking CAVs following speed advice is the underlying cause of the sub-optimal performance at lower penetration rates. It is also interesting to see that applying UC14 without any CAVs in the network already reduces the total CO_2 emissions from 997 kg to 982kg.

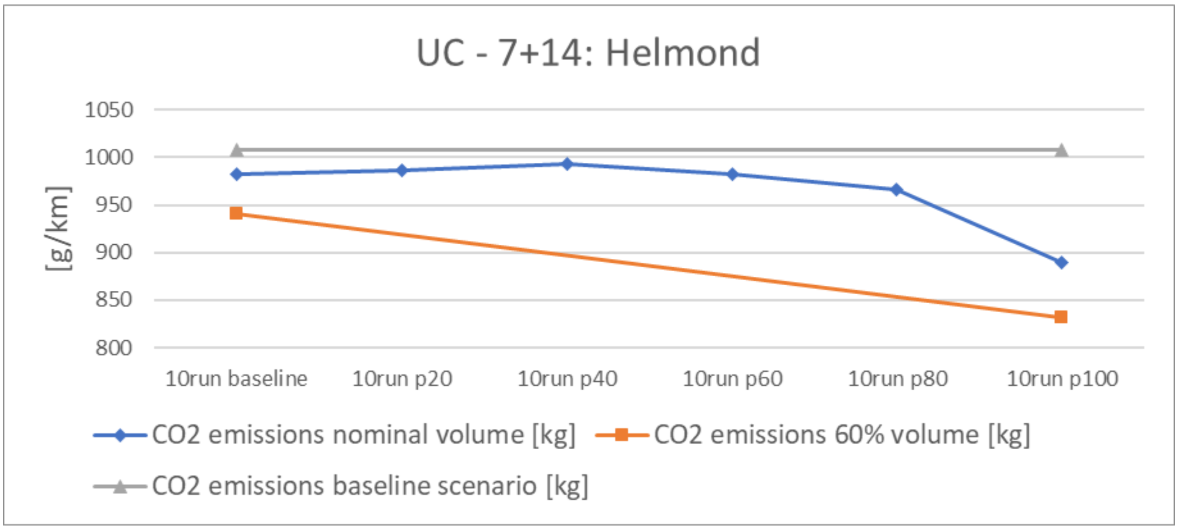

Figure 58 Helmond simulation - CO_2 emissions

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Joint simulation of Signal Optimization Algorithms and GLOSA – Summary

This combination clearly improved the measured indicators. This is true for low demand as well as the nominal traffic volume. For example, the indicator impact is improved by 35% for the full penetration while the trend is rather linear. Moreover, minor improvement in each analysed KPI is visible from implemented algorithm alone without CAV.

5.10 Network coordination

The Green wave (also known as network coordination) is a well-known phenomenon described for example in D4.4 [4]. The literature describes this Use Case as coordination of signal phases on intersections in such a manner, as to provide coordinated waves of green lights on the intersections that are positioned on a main traffic flow trajectory over the network. This action shall result in more fluent traffic in the signal groups that are saturated in the most severe manner at each intersection. Predicted impacts of this Use Case are reduced overall delays in-network, decreased number of stops and improved fuel efficiency-lower CO_2 emissions. The average length of the queue shall also be reduced. It is important to note that this Use Case was tested together with UC 7 – optimum speed advisory system for CAV vehicles, a dedicated simulation of UC13 was already done in D4.4. Overview of all resulting KPIs is presented in the table below.

	Average delay [s]	Average number of stops [-]	Impact [-]	Average queue length [m]	CO_2 emissions [kg]
10run p0	40,8	0,9	48008,9	13.2	949.7
10run p20	36,2	0,8	42506,1	12,7	948,9
10run p40	32,0	0,7	37205,4	10,4	931,1
10run p60	24,5	0,5	28174,5	6,5	898,1
10run p80	21,8	0,4	24960,1	5,6	883,7
10run p100	17,9	0,3	20499,6	3,4	847,8

Table 47 Overview of benefits of UC 13+7+11

Queue length

First, we present the MAVEN simulation results of Helmond network concerning queue length at intersections. As expected, coordination of the network signal controllers brought a significant reduction of average queue lengths. Two significant levels of penetration that deserve highlight are 60% penetration (reduction of queue length by almost 51%) and 100% penetration (reduction of queue length by 74,4%).

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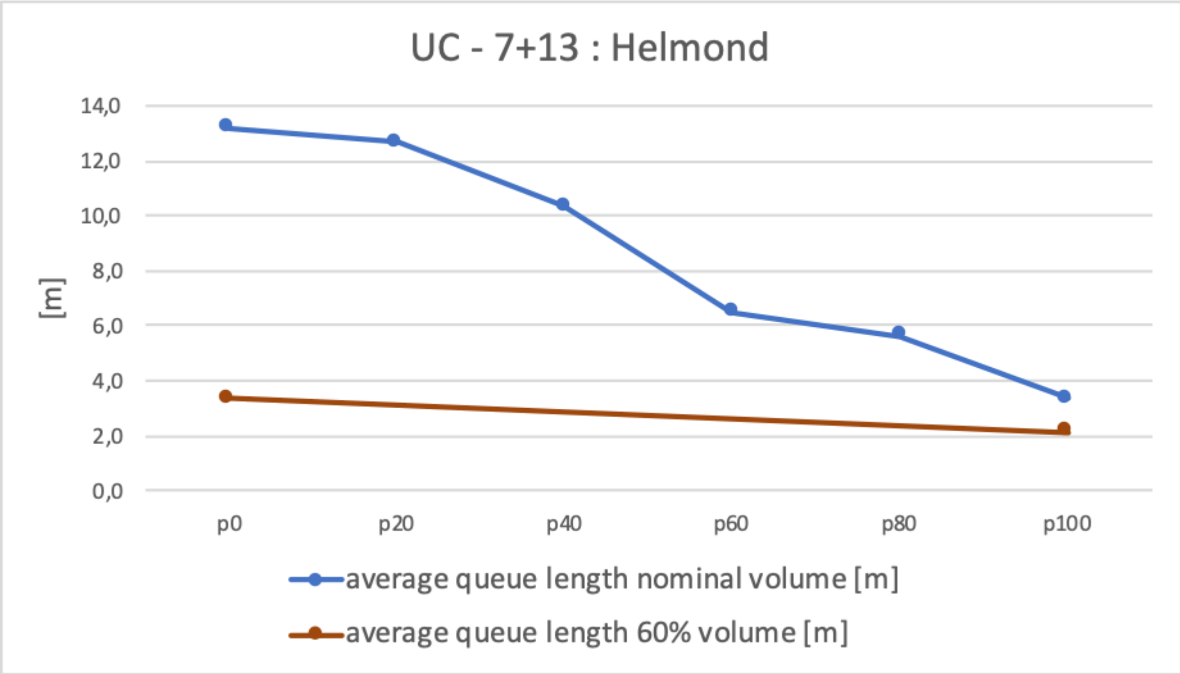

Figure 59 Helmond simulation – the average length of the queues in the network with activated network coordination at a different level of CAV penetration

Number of stops

Together with a reduction of average queue lengths, a number of stops is also expected to decrease. This is a direct impact of improved fluency of the traffic flow (Figure 60). Looking at the stops for the main corridor in isolation, the number of stops decreases from 0.69 to 0.01, demonstrating the near-perfect performance of the green wave.

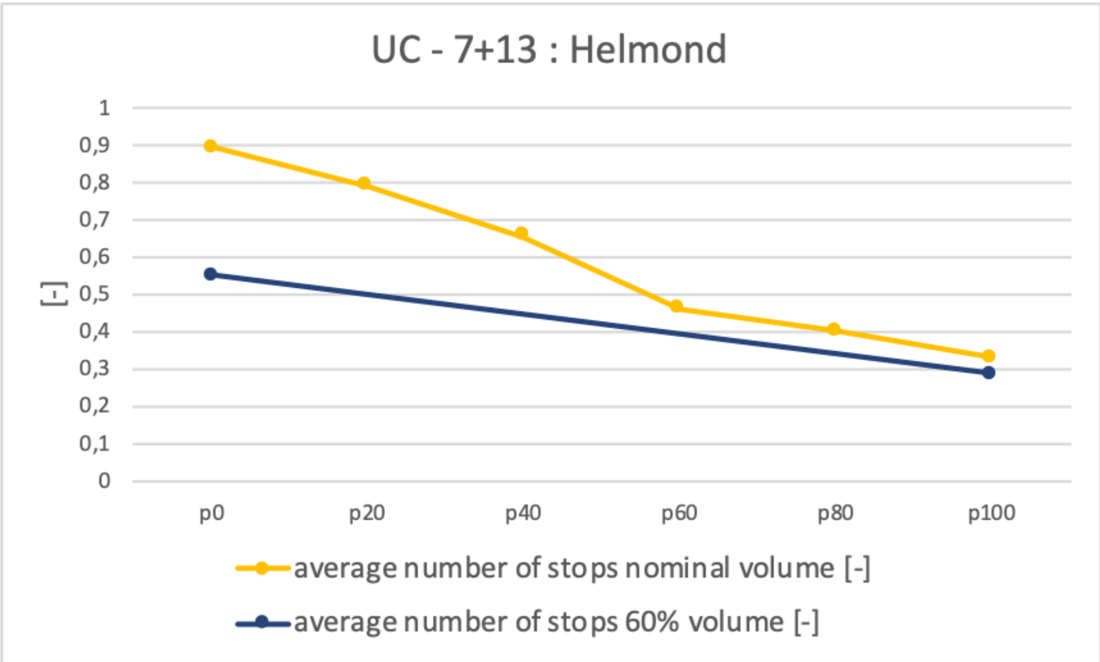

Figure 60 Helmond simulation – the average length of the queues in the network with activated network coordination at a different

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Throughput simulation

The throughput is the *KPI 5* of MAVEN determined in D7.1. This is most relevant in corridors and therefore a special series of simulations were done with this network, comparing the capacity with and without the MAVEN use cases. The most challenging area of the network when it comes to capacity is the road van 101 to 102 because these intersections required the strongest steering by the green wave system.

In the baseline it could be observed that the lack of speed guidance by GLOSA caused most vehicles to stop (61%) at intersection 102, causing a shockwave all the way back to the 101, ultimately lowering the capacity of its green phase. Therefore, 35 vehicles could pass through during 30 seconds of green time. This means the capacity was 2100 veh/h/lane.

With the full set of use cases (UC1-6, UC7, UC8, UC11 and UC13) turned on, the shockwave effect was eliminated and replaced by vehicles following lower speed advice from UC7. This reduces capacity compared to a free flow state with constant green at intersection 102, but still clearly outperformed the shockwave without UC7. Additionally, UC1-6 with a lower car-following distance also increased the capacity. UC8 ensured optimal usage of both lanes, although human drivers in the baseline were also distributing themselves well. Lastly, UC11 ensured the effectiveness of both UC7 and UC8. This resulted in a capacity of 47 vehicles per green phase of 30 seconds, leading to a capacity of 2820 veh/h/lane.

Joint simulation of Network coordination and GLOSA – Summary

While the simulation of AGLOSA functionality only had a limited impact on the measured KPIs in Braunschweig, the joint simulation of GLOSA and signal optimization based on adaptive control was already significantly better. When combined with UC13, network coordination, the performance is even more promising, because the performance is more robust at lower penetration rates. Especially for the penetration level of automated vehicles equal to 60%, there is a significant improvement in the average number of stops of about 48,4%, the impact indicator of 41,3% or average queue lengths of about 50,7%. For the penetration level of automated vehicles equal to 100%, there is an expected reduction of emissions of about 10%. Specific simulations isolated the capacity and revealed an increase of 34% thanks to the combined MAVEN use cases.

5.11 Combined use cases

In order to demonstrate the joint impact of the particular MAVEN Use cases, the following section examines the effectiveness and impact on traffic flow of all Use Cases that can be combined on the signal intersection network of Helmond, i.e. the platooning (UC1-6), GLOSA (UC7), Lane change advisory (UC8), Queue modelling (UC11), signal optimization (UC14) and negotiation (UC15). Here only the nominal traffic volume is evaluated.

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Average delay

The average delay indicator is provided in Figure 61. Here a clear decreasing trend is visible for the combined use cases. Already for 20% penetration rate of autonomous vehicles, there is a decrease of about 23%. For a penetration rate of 100%, there is a decrease of over 52 %.

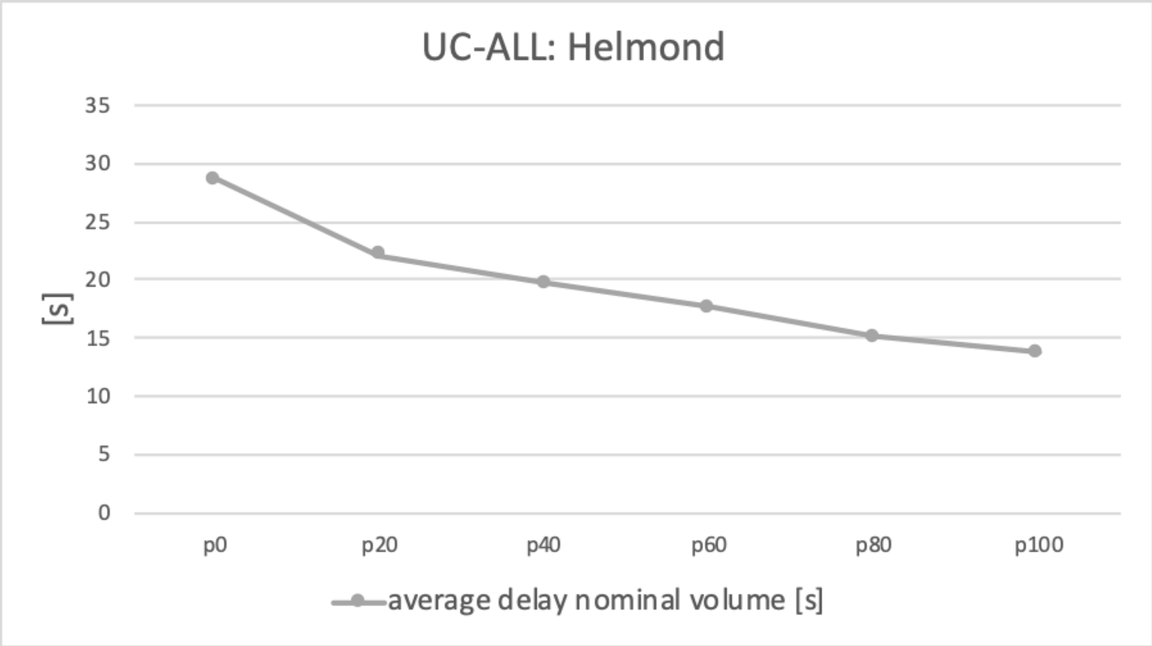

Figure 61 Helmond simulation - Average delay for all use cases

Average queue length

Similarly, to the delay indicator, the combined use cases have a positive effect on average queue lengths. There is a rather large initial decrease of over 21% for a penetration rate of 20%. Further increase in penetration has an only a small positive effect. However, in the case of the fully automated traffic stream, the queue lengths decrease by about 46%, which is a very significant improvement.

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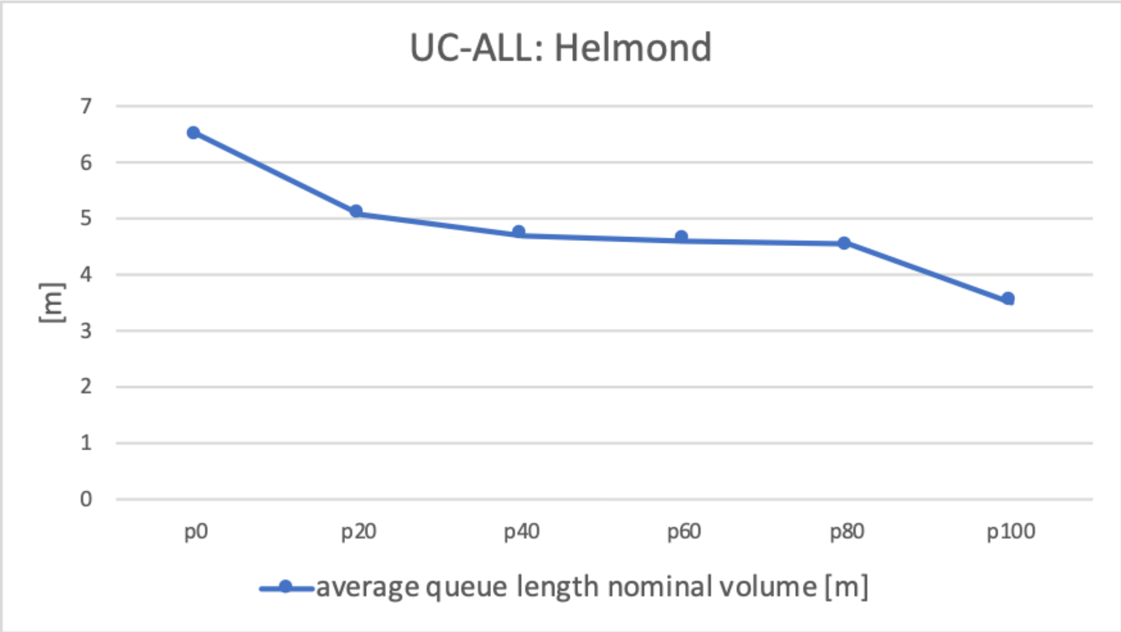

Figure 62 Helmond simulation - Average queue length for all use cases

Impact

The influence of the combined use cases on the indicator impact closely follows the results for the delay (as the impact is a combination of delay and number of stops). After a larger improvement for the penetration level of 20%, the trend is more or less linear.

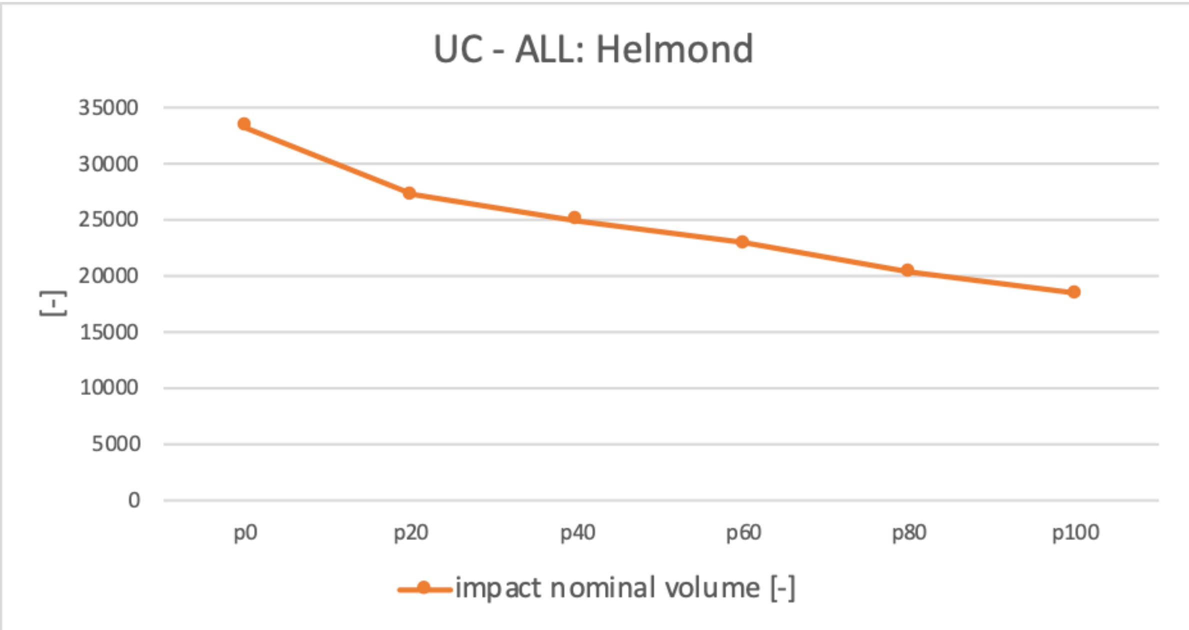

Figure 63 Helmond simulation – Impact for all use cases

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The average number of stops

A similar situation is visible for the indicator of the average number of stops. Here the combined use cases actually worsen the situation about 13% for 20% penetration rate and slightly less, about 4%, for automated vehicles only. These 4% are still a lot better than the 19% increase for UC8. However, some of the effects of the traffic optimization being able to minimize for delay better with UC8 still carry over in this simulation.

It is however interesting that for both last indicators (CO_2 emissions and an average number of stops) there is an improvement by increasing the penetration rate of autonomous vehicles from 80% to full penetration.

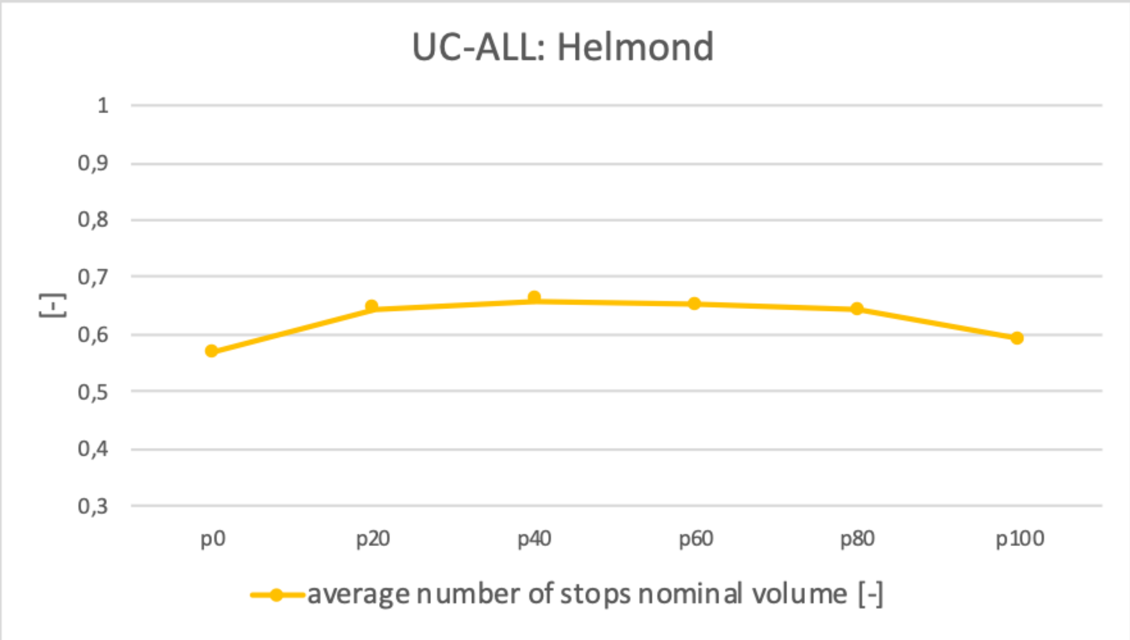

Figure 64 Helmond simulation - Average number of stops for all use cases

Average CO_2 emissions

Rather negative impact of the combined use cases is on the emissions. The same effect we observed in the stops, also carries over in the CO_2 emissions when lane advice is added to the other use cases.

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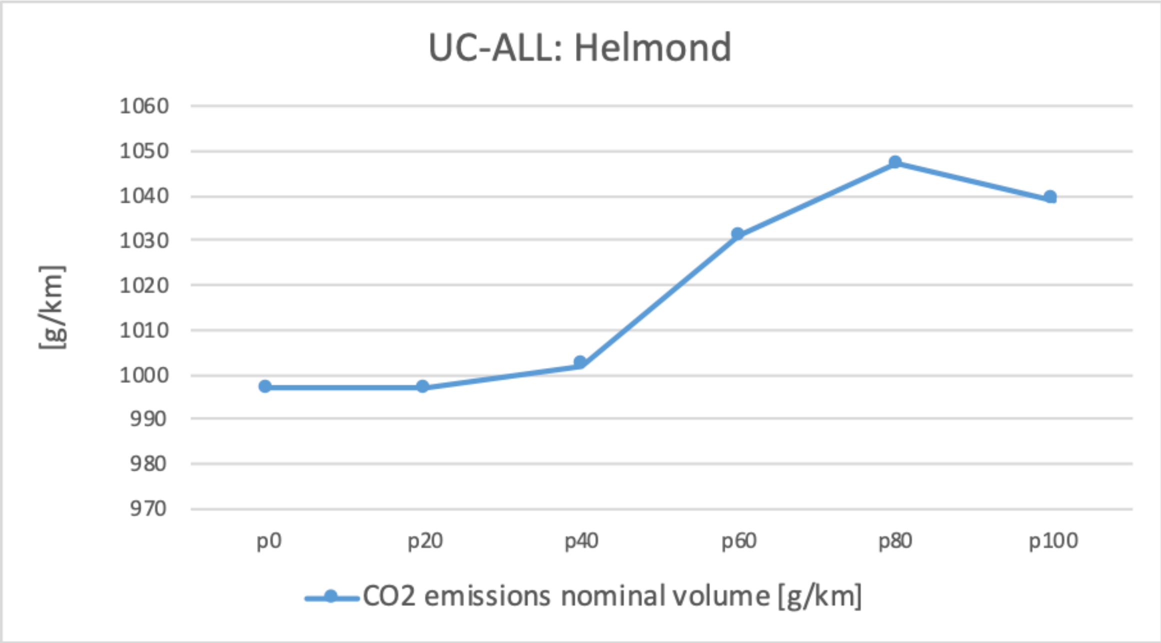

Figure 65 Helmond simulation - CO_2 emissions

Joint simulation of combined use cases – Summary

The combination of all use cases has a very positive effect on the average delay, queue length, and impact. On the other hand, it has a negative impact on the number of stops and CO_2 emissions.

This indicates that it might be advisable to apply the different use cases carefully for each traffic and network situation and also with respect to the expected impact on traffic. Minimizing the delay does not necessarily lead to most harmonized traffic flow.

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6 Conclusions

The deliverable D7.2 (this document) provides an overview of MAVEN results. It covers different dimensions of the impact assessment as stated in D7.1 [10].

The **field tests** proved that the technology in the vehicle works together with the infrastructure and the solution is technically feasible. This was demonstrated also during particular events and is reported in the attached test protocols. At the same time, the emulation and simulation in Dominion software proved the functionality, for example with respect to the cooperative perception or safety indicators.

This deliverable also discussed selected results of a detailed **user survey** aiming at understanding the expected impacts and transition of automated vehicles. In the survey, there is, in general, no significant difference in the perception of public authority representatives compared to all respondents. This can be caused by the fact, that mainly city representatives interested in the topic of automated vehicles were included. In this respect, they are not so different from researchers or industry representatives.

Not surprisingly, age proved to be an important factor with respect to willingness to use automated vehicles. Older respondents are less likely to use automated taxis. In general, it can be concluded that the general public is rather optimistic with respect to automated vehicles. Over 80% of the respondents believe that CAVs will decrease the number of traffic accidents. Similarly, about 70% of the respondents expect improvements in traffic congestions.

As for the willingness to pay, most customers would pay a bit extra, up to 5000€ for a car with automated features.

There was also good news for traffic management, over 82% of respondents declared that they would accept some detour when driving if it helps the overall traffic situation. Which opens up new opportunities for the routing use case of MAVEN.

The **literature review** however clearly indicated that autonomous vehicles will have either positive or negative effect on the environment, depending on the policies. For example, opening cars as a mode of transport to new user groups (seniors, children etc.) together with improvements to the traffic flow parameters can increase the traffic volume on roads. Policy makers shall focus on the integration of the CAVs into a broader policy concept including car or ride-sharing, electromobility or others.

In order to evaluate the transition, for example, the influence of different penetration rates of CAVs on the performance, **microscopic traffic simulations** were performed. Here the particular use cases, as well as their combination, was addressed.

The results of the simulation are rather promising. For example, just introducing *platooning* by itself decreases the CO_2 emissions by over 8% for the full penetration of CAVs. The evaluations focused on four types of existing networks: with actuated control, adaptive control, green wave strategy and larger networks with opportunities for strategic routing. For all of these situations, MAVEN has demonstrated to have a solution with a large benefit compared to the state-of-the-art.

The AGLOSA solution in Braunschweig was designed to replace the existing actuated traffic control. It showed a clear improvement in CO_2 emissions of up to 5%, but a point of attention is the trade-off between delay time and stops in the side road on one hand and GLOSA performance in the main direction on the other. Traffic managers should be aware of this when applying this service.

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The combination of *GLOSA and network coordination* (UC7 and UC13) was very successful and can be directly applied to networks following a green wave strategy. The synergy between these use cases is better than expected, resulting in a reduction of impact indicator of up to 41,3%, average queue lengths up to 50,7% and emissions up to 10%.

The *signal optimization combined with GLOSA, queue modelling and negotiation* (UC7, UC11, UC14 and UC15) is the MAVEN solution for single intersections controlled by adaptive controllers. It clearly improved all measured KPIs. The impact is improved by up to 35% and CO_2 emissions were reduced by up to 12%.

The lane advice use case, however, did not perform as expected for the single intersection. Normally, the controller has a bias for preventing stops due to platoon dispersion. However, when platooning and lane advice are combined, this effect does not occur and the algorithm automatically follows its setpoint to give high priority to reducing the delay. Both when the lane advice use case was simulated in isolation and especially when combined with all other use cases applicable to a single intersection (7,8,11,14 and 15) this resulted in a very large reduction of delay time. Due to the balance shift from stops to delay, the CO_2 emissions increased. Therefore, traffic managers should take into account that recalibration of the policy parameters is probably required when using all MAVEN use cases.

For larger networks with routing options, the Local level routing algorithm (UC12) outperforms the existing HTT algorithms in for example indicator mean waiting time already for the 20 % penetration rate by 23,7% and is constantly better for all different penetration rates. The LLR algorithm also improves the mean waiting time by about 34,2% for the 20% penetration rate.

The results are also promising with respect to the transition phase. It was demonstrated that already for lower penetration rates (even 20% penetration of CAVs), there are significant improvements in traffic performance. For example, the platooning leads to a decrease of CO_2 emissions of 2,6% or the impact indicator by 17,7% in the Helmond network. The only exception was GLOSA, that can have some trouble with overtaking by non-equipped vehicles. The potential for improvements in traffic performance is clearly there. It was demonstrated that a proper integration of CAVs into city traffic management can for example help with respect to the environmental goals (Climate Action of the European Commission) and reduce CO_2 emissions by up to 12 % (a combination of AGLOSA and network coordination).

At the same time, the different algorithms can aim at contradictory objective functions, for example, the number of stops versus delay. The traffic managers should choose the traffic management objectives first and based on that select the most suitable tools (use cases).

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8 Appendixes

8.1 Appendix A – Test protocols

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	MAVEN - Managing Automated Vehicles Enhances Network	
	Test Protocol	

Event identification

Event Name:	Basic AGLOSA Scenario, basic longitudinal-only UC1/3/6	**Event ID:**	**1**
Event location:	DLR Braunschweig	Date:	05.09.2017

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

	Name	*Organization*	*Role*
Participants	Julian Schindler	DLR Braunschweig	test manager
	Reza Dariani	DLR Braunschweig	witness

Introduction and prerequisites

Event objectives	Show GLOSA behaviour and basic longitudinal platooning behaviour in simulation, related to UC 1 / 3 / 6 / 7
HW and SW configurations	Dominion simulation environment, vehicle automation (esp. Maneuver planner, virtual V2X receiver), Dominion-included Scenario control and driving simulation software

Test results

	Number	*Proposed measure*
Fail	0	
Pass	16	
Inconclusive	1	
Not executed	**1**	MAVEN extensions have not been implemented at this time, req. is not suitable.

Conclusions	All the planned tests are successful, no need for corrective actions.

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Test Protocol

Event identification

Event Name:	V2V platoon messages and V2I negotiation messages (CAM extensions)	**Event ID:**	**3**
Event location:	Hyundai Motor Europe Technical Center	Date:	XI.17

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

	Name	*Organization*	*Role*
Participants	M. Rondinone	Hyundai Motor Europe Techical Center	test manager
	T. Walter	Hyundai Motor Europe Techical Center	witness

Introduction and prerequisites

Event objectives	The MAVEN communicating stations (vehicles and RSUs in this case) correctly code (at transmitter side) and decode (at receiver side) V2X messages for V2V platoon messages and V2I negotiation. These messages are backward compatible CAM extensions as defined in the MAVEN deliverable D5.1. Transmitting and receiving stations share the same ASN1 definitions for the tested messages. When they are turned on, they automatically start transmitting test messages. Receiving stations receive the tested messages and log their content. The received content is correctly decoded and its correctness is verified in dedicated analysis tool (e.g. whireshark)
HW and SW configurations	Cohda MK5 communication modules. MAVEN V2X test application, Cohda SDK, wireshark. Cohda SW for simulation of vehicle positions (see MAVEN deliverable D6.3)

Test results

	Number	*Proposed measure*
Fail	0	
Pass	2	
Inconclusive	0	
Not executed	0	

Conclusions	All the planned tests are successful, no need for corrective actions

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	MAVEN - Managing Automated Vehicles Enhances Network	

Test Protocol

Event identification

Event Name:	Infrastructure LDM	**Event ID:**	**2**
Event location:	Simulation - Helmond&Prague	Date:	30.11.2018

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

	Name	*Organization*	*Role*
Participants	Aleksander Czechowski	Dynniq	Developer/tester
	Jan Přikryl	CTU	user of LDM interface
	Robbin Blokpoel	Dynniq	Evaluator

Introduction and prerequisites

Event objectives	Technical verification of the LDM interface and the queue injection functionality of ImFlow
HW and SW configurations	Laptop with ImFlow running connected to SUMO simulation.

Test results

	Number	*Proposed measure*
Fail	0	
Pass	2	
Inconclusive	0	
Not executed	**0**	

Conclusions	All tests have have been carried out successfully

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MAVEN	**MAVEN - Managing Automated Vehicles Enhances Network**	European Commission
	Test Protocol	

Event identification

Event Name:	Installation of camera and	**Event ID:**	**4**
Event location:	Tostmannplatz Braunsch	Date:	Dec. 17
	Major	*Minor*	*Internal*
Event significance	☐	X	☐
	Name	*Organization*	*Role*
Participants	Julian Schindler	DLR Braunschweig	Test manager
	Daniel Wesemeyer	DLR Berlin	witness
	Andreas Leich	DLR Berlin	witness

Introduction and prerequisites

Event objectives	Installation of camera and hardware
HW and SW configurations	Installation of Roadside-Unit, traffic light controller, and hemispherical camer

Test results

	Number	*Proposed measure*
Fail	0	
Pass	1	
Inconclusive	0	
Not executed	**0**	

Conclusions	All hardware except the hemispherical camera have been mounted in Dec. 2017. Due to cabel channel problems requiring digging activities on Tostmannplatz, the camera could be mounted in November 2018.

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	MAVEN - Managing Automated Vehicles Enhances Network	European Commission
	Test Protocol	

Event identification

Event Name:	Installation of hardware	Event ID:	5
Event location:	Simulation-Helmond	Date:	14-12-2017

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

	Name	*Organization*	*Role*
Participants	Aleksander Czechowski	Dynniq	tester
	Robbin Blokpoel	Dynniq	evaluator

Introduction and prerequisites

Event objectives	Verification of RSU and TLC hardware
HW and SW configurations	RSU and TLC with default software, laptop with SSH client and web browser for accessing interfaces

Test results

	Number	*Proposed measure*
Fail	0	
Pass	0	*note that the tests were not in D2.2
Inconclusive	0	
Not executed	0	

Conclusions	All tests passed, the queueing model in the local controller was operational and the RSU had a functioning geonet daemon to transmit MAVEN messages in the future. Camera installation was successfully completed at 18-10-2018, this was delayed due to equipment and service staff availability issues.

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Test Protocol

Event identification

Event Name:	V2X cooperative sensing messages (CPM)	**Event ID:**	**6**
Event location:	Hyundai Motor Europe Technical Center	Date:	XII.17

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

	Name	*Organization*	*Role*
Participants	M. Rondinone	Hyundai Motor Europe Techical Center	test manager
	T. Walter	Hyundai Motor Europe Techical Center	witness

Introduction and prerequisites

Event objectives	The MAVEN communicating stations (vehicles and RSUs in this case) correctly code (at transmitter side) and decode (at receiver side) V2X messages for cooperative sensing. These messages are ETSI compatible CPMs as defined in the MAVEN deliverable D5.1. Transmitting and receiving stations share the same ASN1 definitions for the tested messages. When they are turned on, they automatically start transmitting test messages. Receiving stations receive the tested messages and log their content. The received content is correctly decoded and its correctness is verified in dedicated analysis tool (e.g. whireshark)
HW and SW configurations	Cohda MK5 communication modules. MAVEN V2X test application, Cohda SDK, wireshark. Cohda SW for simulation of vehicle positions (see MAVEN deliverable 6.3)

Test results

	Number	*Proposed measure*
Fail	0	
Pass	1	
Inconclusive	0	
Not executed	0	

Conclusions	All the planned tests are successful, no need for corrective actions

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Test Protocol

Event identification

Event Name:	UC1/3/6/7/8 in simulation	**Event ID:**	**7**
Event location:	DLR Braunschweig	Date:	08.03.2018

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

	Name	*Organization*	*Role*
Participants	Julian Schindler	DLR Braunschweig	Test manager
	Reza Dariani	DLR Braunschweig	witness

Introduction and prerequisites

Event objectives	Show lateral and longitudinal platooning behaviour in simulation
HW and SW configurations	Dominion simulation, Platoon logic integration in simulation

Test results

	Number	*Proposed measure*
Fail	0	
Pass	15	
Inconclusive	3	Requirements do not fully apply as this is a simulation event
Not executed	0	

Conclusions	All the planned tests are successful, except for those requiring real world hardware which is not present in this simulation. Nevertheless, the basic principles, software interfaces and structures are already created in line with the later hardware specifications. No need for corrective actions.

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Test Protocol

Event identification

Event Name:	Longitudinally automated UC1/3/6/7 with emulation on test track	**Event ID:**	**8**
Event location:	DLR grounds, Braunschw	Date:	30.03.2018

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

	Name	*Organization*	*Role*
Participants	Julian Schindler	DLR Braunschweig	Test manager
	Reza Dariani	DLR Braunschweig	witness
	Daniel Wesemeyer	DLR Berlin	witness

Introduction and prerequisites

Event objectives	Basic longitudinally automated platooning and speed advice shown in real vehicle. Partner vehicles for platooning are emulated
HW and SW configurations	DLR vehicle FASCarE, Cohda MK5, Dominion framework, Vehicle automated driving software. Infrastructure: Mobile traffic light, AGLOSA on industrial PC, Linkbird for communication

Test results

	Number	*Proposed measure*
Fail	0	
Pass	24	
Inconclusive	0	
Not executed	**0**	

Conclusions	All the planned tests are successful, no need for corrective actions

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Test Protocol

Event identification

Event Name:	I2V negotiation	**Event ID:**	**9**
Event location:	Dinniq	Date:	II.18

	Major	Minor	Internal
Event significance	X	☐	☐

	Name	Organization	Role
Participants	Robbin Blokpoel	Dynniq	test manager

Introduction and prerequisites

Event objectives	Show that MAVEN I2V messages coded as described in the MAVEN deliverable D5.1 can be transmitted and received successfully
HW and SW configurations	Dynniq RSU and independent ASN.1 decoder (at http://asn1-playground.oss.com/). Helmond simulation network of intersection 701.

Test results

	Number	Proposed measure
Fail	0	
Pass	2	
Inconclusive	0	
Not executed	0	

Conclusions	All the planned tests are successful, no need for corrective actions

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European Commission

Test Protocol

Event identification

Event Name:	Adjusted ImFlow in TLC	**Event ID:**	**10**
Event location:	Simulation-Helmond	Date:	28.02.2018
	Major	*Minor*	*Internal*
Event significance	☐	X	☐
	Name	*Organization*	*Role*
Participants	Xiaoyun Zhang	Dynniq	tester
	Robbin Blokpoel	Dynniq	evaluator

Introduction and prerequisites

Event objectives	Technical verification of plan stabilization and priority requests.
HW and SW configurations	ImFlow running on a laptop connected to a SUMO simulator on the same laptop.

Test results

	Number	*Proposed measure*
Fail	0	
Pass	3	
Inconclusive	0	
Not executed	**0**	

Conclusions	All tests have have been carried out successfully

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Test Protocol

Event identification

Event Name:	Green wave integration	**Event ID:**	**11**
Event location:	SUMO, DLR Berlin	Date:	28.02.2018

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

	Name	*Organization*	*Role*
Participants	Daniel Wesemeyer	DLR Berlin	test manager
	Julian Schindler	DLR Braunschweig	witness

Introduction and prerequisites

Event objectives	Green wave coordination works with GLOSA
HW and SW configurations	SUMO simulation

Test results

	Number	*Proposed measure*
Fail	0	
Pass	4	
Inconclusive	0	
Not executed	**0**	

Conclusions	All the planned tests are successful, no need for corrective actions

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	MAVEN - Managing Automated Vehicles Enhances Network	European Commission

Test Protocol

Event identification

Event Name:	UC7 longitudinally and laterally automated with emulated infra messages or mobile traffic light on test track	**Event ID:**	**12**
Event location:	Edemissen Air Field	Date:	01.05.2018

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

	Name	*Organization*	*Role*
Participants	Reza Dariani	DLR	Test manager
	Julian Schindler	DLR	Test manager

Introduction and prerequisites

Event objectives	Show the MAVEN vehicle functionality of driving longitudinally and laterally automated and adapt its velocity based on the information received from emulated infrastructure and mobile traffic light.
HW and SW configurations	Dominion simulation environment, vehicle automation, Cohda box and mobile traffic light

Test results

	Number	*Proposed measure*
Fail	0	
Pass	34	
Inconclusive	0	
Not executed	**1**	Detection of indicator light has not been implemented at this time.

Conclusions	The main tests are succesfull, no need for corrective actions.

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	MAVEN - Managing Automated Vehicles Enhances Network	
	Test Protocol	

Event identification

Event Name:	UC1-8 in simulation	**Event ID:**	**13**
Event location:		Date:	June 2018

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

	Name	*Organization*	*Role*
Participants	Reza Dariani	DLR	Test Manager
	Julian Schindler	DLR	Test Manager

Introduction and prerequisites

Event objectives	Simulate platooning management uce cases (1-6) and speed change advisory and lane change advisory in simulation.
HW and SW configurations	Dominion

Test results

	Number	*Proposed measure*
Fail	0	
Pass	21	
Inconclusive	1	In simulation there is no need to acces vehicle CAN data, but similar interfaces are available in simulation environment to keep the system compatible in simulation and vehicle
Not executed	1	Indicator light detection is not implemented at this level, but other road user intention can be predecited.

Conclusions	The main tests are succesfull, no need for corrective actions.

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Test Protocol

Event identification

Event Name:	TLC - Vehicle interteraction tests	**Event ID:**	**14**
Event location:	Helmond	Date:	22.08.2018
	Major	*Minor*	*Internal*
Event significance	X	☐	☐

	Name	*Organization*	*Role*
Participants	Robbin Blokpoel	Dynniq	Evaluator
	Xiaoyun Zhang	Dynniq	Vehicle operator
	Aleksander Czechowski	Dynniq	RSU/TLC operator
	Frank van den Bosch	Helmond	Observer
	Martien van den Broek	Helmond	Observer

Introduction and prerequisites

Event objectives	Verification of full information flow from vehicle to RSU to traffic control algorithm. Check how the traffic control algorithm responds to having turn direction and speed information from the vehicle.
HW and SW configurations	Dynniq OBU in vehicle with application that takes a manual input for turn direction. RSU with support for MAVEN extended CAM and control algorithm with interface to inject this information.

Test results

	Number	*Proposed measure*
Fail	0	
Pass	10	
Inconclusive	0	
Not executed	**14**	These are for February 2019 when the CAV is present

Conclusions	The test was successful!

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MAVEN	**MAVEN - Managing Automated Vehicles Enhances Network**	European Commission
	Test Protocol	

Event identification

Event Name:	UC7/8/15 on test track	**Event ID:**	**15**
Event location:	Griesheim Test Track	Date:	23/08/2018
	Major	*Minor*	*Internal*
Event significance	X	☐	☐
	Name	*Organization*	*Role*
Participants	Michele Rondinone	HMETC	Test manager
	Dominik Matheis	HMETC	Test manager
	Thomas Walter	HMETC	Test manager

Introduction and prerequisites

Event objectives	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 realroad 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
HW and SW configurations	Vehicle equipped with HW as described in D6.1 automation SW based on ROS emulating V2X receptions logged from real world road infratsructure (see D6.4), Cohda MK5 OBU for V2X communication

Test results

	Number	*Proposed measure*
Fail	0	
Pass	31	
Inconclusive	0	
Not executed	**0**	

Conclusions	The main tests are succesfull, no need for corrective actions

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Test Protocol

Event identification

Event Name:	UC1/3/6/8/9 on Testtrack	**Event ID:**	**16**
Event location:	Edemissen Air Field	Date:	IX.18
	Major	*Minor*	*Internal*
Event significance	X	☐	☐
	Name	*Organization*	*Role*
Participants	Reza Dariani	DLR	Test manager
	Julian Schindler	DLR	Test manager

Introduction and prerequisites

Event objectives	Platooning, lane advice and emergency handling working on test track
HW and SW configurations	Dominion simulation environment, vehicle automation, Cohda box and mobile traffic light

Test results

	Number	Proposed measure
Fail	0	
Pass	34	
Inconclusive	0	
Not executed	**1**	Routing not needed during test

Conclusions	The main tests are succesfull, no need for corrective actions

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Test Protocol

Event identification

Event Name:	Platoon Logic integration HMETC car	**Event ID:**	**17**
Event location:	Griesheim	Date:	IX.18

	Major	Minor	Internal
Event significance	X	☐	☐

	Name	Organization	Role
Participants	Julian Schindler	DLR	Test manager
	Reza Dariani	DLR	Test manager
	M. Rondinone	HMETC	Test resource
	T. Walter	HMETC	Test resource

Introduction and prerequisites

Event objectives	To integrate designed platoon logic by DLR in HMETC vehicle and test its functionality
HW and SW configurations	Vehicle equipped with HW as described in D6.1 automation SW based on ROS, Cohda MK5 OBU for V2X communication

Test results

	Number	Proposed measure
Fail	1	failure investigation in simulation environment after the tests and repetition in later sprint
Pass	17	
Inconclusive	0	
Not executed	**3**	tests not executed because dependant from the failed one . The missing test cases will be performed in the next integration sprint

Conclusions	DLR designed platoon logic was succesfully integrated in the HMETC vehicle. Nevertheless, the failure of one single test case prevented the colnclusion ot 3 furhter tests. These tests will be repeated in the next integration sprint.

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Test Protocol

Event identification

Event Name:	UC1/3/6 with two cars (DLR and HMETC) on test track	**Event ID:**	**18**
Event location:	Griesheim	Date:	IX.18

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

	Name	*Organization*	*Role*
Participants	Julian Schindler	DLR	Test manager
	Reza Dariani	DLR	Test manager
	M.Rondinone	HMETC	witness
	T.Walter	HMETC	witness
	D. Matheis	HMETC	witness

Introduction and prerequisites

Event objectives	By using two automated vehicles from DLR and one from HMETC initialise a platoon, travel in platoon and terminate a platoon in the Griesheim test track. Main focus on Platoon logic, communication between vehicles and cooperative trajectory planning and environment perception
HW and SW configurations	Vehicles equipped with HW as described in D6.1 automation SW based on ROS (HMETC) and Dominion (DLR), Cohda MK5 OBU for V2X communication

Test results

	Number	*Proposed measure*
Fail	1	failure investigation in simulation environment after the tests and repetition in later sprint
Pass	28	
Inconclusive	0	
Not executed	**5**	

Conclusions	The failure of one test case in the platoon logic integration prevented the execution of 5 tests cases. These tests will be repeated at later integration sprints

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	Test Protocol	

Event identification

Event Name:	UC 13 Green Wave	**Event ID:**	**19**
Event location:	Helmond simulation	Date:	07.12.2018
	Major	*Minor*	*Internal*
Event significance	☐	☐	☐
	Name	*Organization*	*Role*
Participants	Xiaoyun Zhang	Dynniq	Simulation expert
	Robbin Blokpoel	Dynniq	Reviewer

Introduction and prerequisites

Event objectives	Test the capability of the adaptive control algorithm to deal with external green wave input
HW and SW configurations	Real ImFlow control software as it runs in the field coupled to SUMO simulation environment.

Test results

	Number	Proposed measure
Fail	0	
Pass	1	
Inconclusive	0	
Not executed	0	

Conclusions	Tests passed successfully, although a more optimal solution was identified during the research.

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Test Protocol

Event identification

Event Name:	UC1-/3/6 with three cars (DLR and HMETC) on test track	**Event ID:**	**20**
Event location:	Grießheim	Date:	I.19
	Major	*Minor*	*Internal*
Event significance	X	☐	☐
	Name	*Organization*	*Role*
Participants	Reza Dariani	DLR	Test Manager
	Julian Schindler	DLR	Test Manager
	Michele Rondinone	HMETC	witness
	Thomas Walter	HMETC	witness

Introduction and prerequisites

Event objectives	By using two automated vehicles from DLR and one from HMETC initialise a platoon, travel in platoon and terminate a platoon in the Griesheim test track. Main focus on Platoon logic, communication between vehicles and cooperative trajectory planning and environment perception
HW and SW configurations	Vehicles equipped with HW as described in D6.1 automation SW based on ROS (HMETC) and Dominion (DLR), Cohda MK5 OBU for V2X communication

Test results

	Number	*Proposed measure*
Fail	0	
Pass	33	
Inconclusive	0	
Not executed	**2**	For this event no mobile or emulated RSU was used, therefore all RSU related test cases were not tested. At this stage obstacle intention prediction is used instead of indicator light

Conclusions	The three MAVEN vehicle succesfully built , drove and terminate a platoon.

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Test Protocol

Event identification

Event Name:	UC 7 with DLR and HMETC cars on public roads	**Event ID:**	**21**
Event location:	Braunschweig	Date:	I.19

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

	Name	*Organization*	*Role*
Participants	Reza Dariani	DLR	Test manager
	Julian Schindler	DLR	Test manager
	Jan Lauermann	DLR	Test resource

Introduction and prerequisites

Event objectives	Verify, for the first time on real roads and urban traffic, the MAVEN use case 7 for infrastructure-assisted automated driving using the DLR automated vehicle.
HW and SW configurations	HW: DLR automated vehicle, Codha box, RSU SW: Dominion

Test results

	Number	*Proposed measure*
Fail	0	
Pass	42	
Inconclusive	0	
Not executed	0	

Conclusions	All test cases were successful. No need for corrective actions.

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	Test Protocol	

Event identification

Event Name:	UC8 on public roads	**Event ID:**	**22**
Event location:	Tostmannplatz	Date:	II.19
	Major	*Minor*	*Internal*
Event significance	□	☐	☐

	Name	*Organization*	*Role*
Participants	Reza Dariani	DLR	Test Manager
	Julian Schindler	DLR	Test Manager
	Jan Lauermann	DLR	Test resource
	Michele Rondinone	HMETC	witness
	Thomas Walter	HMETC	witness

Introduction and prerequisites

Event objectives	Drive longitudinaly and laterally autonomated in Braunschweig and cross Tostmannplatz intersection. After receiving LAM messages from infrastructure, the MAVEN vehicle changes the lane.
HW and SW configurations	Dominion, Cohda

Test results

	Number	*Proposed measure*
Fail	0	
Pass	34	
Inconclusive	0	
Not executed	**1**	Indicator light detection was not needed.

Conclusions	All the test are succesfull, no repetition is required.

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Test Protocol

Event identification

Event Name:	UC7/8/10/14/15 validation on public roads	**Event ID:**	**23**
Event location:	Helmond, N270	Date:	Feb. 19

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

	Name	*Organization*	*Role*
Participants	D. Matheis	HMETC	Test resource
	M. Rondinone	HMETC	Test manager
	T.Walter	HMETC	Test resource
	R. Blokpoel	Dynniq	witness

Introduction and prerequisites

Event objectives	Verify, for the first time on real roads and urban traffic, the MAVEN use cases for infrastructure-assisted automated driving using the HMETC 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
HW and SW configurations	Vehicle equipped with HW as described in D6.1 automation SW based on ROS Cohda MK5 OBU for V2X communication. Dynniq Traffic light controller and RSU

Test results

	Number	*Proposed measure*
Fail	0	
Pass	43	
Inconclusive	0	
Not executed	**0**	

Conclusions	All test cases were successful. No need for corrective actions.

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Test Protocol

Event identification

Event Name:	UC 11 Queue estimation + UC 12 route advice	**Event ID:**	**24**
Event location:	Traffic simulation	Date:	15.03.2019

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

	Name	*Organization*	*Role*
Participants	Jan Prikryl	CTU	Tester
	Andre Maia Pereira	CTU	Tester

Introduction and prerequisites

Event objectives	To demonstrate the implementation of the queue length estimation algorithm and the local level routing algorithm and evaluation in SUMO
HW and SW configurations	PC with Prague network and Helmond simulation environment with implemented LLR and QLE algorithms.

Test results

	Number	*Proposed measure*
Fail	0	
Pass	4	
Inconclusive	0	
Not executed	**0**	

Conclusions	Both algorithm, LLR and QLE have been tested succesfully. No need for corrective action.

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	Test Protocol	

Event identification

Event Name:	UC1-7 & 16 on public roads	**Event ID:**	**25**
Event location:	Tostmannplatz	Date:	IV.19

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

	Name	*Organization*	*Role*
Participants	Reza Dariani	DLR	Test manager
	Julian Schindler	DLR	Test manager
	Jan Lauermann	DLR	Test resource
	M. Rondinone	HMETC	witness
	D. Matheis	HMETC	witness
	T.Walter	HMETC	witness

Introduction and prerequisites

Event objectives	show the platoon management use-cases in urban environment with DLR and HMETC MAVEN vehicle as well as detect and react to other road useres esp. Non-cooperative road users.
HW and SW configurations	Vehicle equipped with HW as described in D6.1 automation SW based on ROS (HMETC) and Dominion (DLR), Cohda MK5 OBU for V2X communication. DLR RSU, traffic light controller and emispheric camera

Test results

	Number	*Proposed measure*
Fail	0	
Pass	60	
Inconclusive	0	
Not executed	**5**	These tests are not relevant for this event as they were tested elsewhere.

Conclusions	All tests are succesfull.

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8.2 Appendix B – Requirement testing overview

The test methods are: (A) analysis, (D) demonstration and (T) test

Requirement	Verification method	Events in which the requirement was not fulfilled	Events in which the requirement was fulfilled
3.1.1: Global digital map available	T		1, 2, 7, 8, 12, 13, 16, 18, 20, 21, 22, 25
3.1.2: Global digital map accessible	T		1, 2, 7, 8, 12, 13, 16, 18, 20, 21, 22, 25
3.1.3: Use global digital map for routing	T	16	1, 2, 7, 8, 12, 13, 18, 20, 21, 22, 25
3.1.4: Topological high accurate map available	T		1, 2, 7, 8, 12, 13, 15, 16, 17, 18, 20, 21, 22, 23, 25
3.1.5: Topological high accurate map accessible	T		1, 2, 7, 8, 12, 13, 15, 16, 17, 18, 20, 21, 22, 23, 25
3.1.6: Update topological high accurate map with vehicle sensor data	T		1, 2, 7, 8, 12, 13, 16, 18, 20, 21, 22, 25
3.1.7: Link topological high accurate map ID's to global digital map ID's	T		1, 2, 7, 8, 12, 13, 16, 18, 20, 21, 22, 25
3.1.8: Environment model	T	7, 13	1, 2, 8, 12, 15, 16, 17, 18, 20, 21, 22, 23, 25
3.2.1: High precision positioning data	T	7	1, 2, 8, 12, 13, 15, 16, 17, 18, 20, 21, 22, 23, 25

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3.2.2: Obstacle detection and classification	T		1, 2, 7, 8, 12, 13, 15, 16, 17, 18, 20, 21, 22, 23, 26
3.2.3: Obstacle position and heading	T		1, 2, 7, 8, 12, 13, 15, 16, 17, 18, 20, 21, 22, 23, 27
3.2.4: Obstacle velocity and acceleration	T		1, 2, 7, 8, 12, 13, 15, 16, 17, 18, 20, 21, 22, 23, 28
3.2.5: Indicator lights detection	T	12, 13, 20, 22	25
3.3.1: Platoon brake-up due to merging	T		13, 25
3.4.1: Access to the vehicle CAN data	T		8, 12, 15, 16, 17, 18, 20, 21, 22, 23, 25
3.5.10: System override	T		8, 12, 15, 16, 18, 20, 21, 22, 23, 25
3.5.3: Actuator reference value	T		1, 2, 7, 8, 12, 13, 15, 16, 18, 20, 21, 22, 23, 25
3.5.4: LDM: state of traffic lights	T		1, 2, 7, 8, 12, 13, 15, 16, 20, 21, 22, 23, 25
3.5.4: Path matches reference trajectory	T		1, 2, 7, 8, 12, 13, 15, 16, 18, 20, 21, 22, 23, 25
3.5.5: LDM: probabilities	T		1, 2, 7, 8, 12, 13, 15, 16, 18, 20, 21, 22, 23, 25
3.5.6: LDM: data fusion	T		1, 2, 7, 8, 12, 13, 15, 16, 18, 20, 21, 22, 23,

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			25
3.6.1: Trajectory prediction of dynamic objects	T		1, 2, 7, 8, 12, 13, 15, 16, 18, 20, 21, 22, 23, 25
3.6.10: Calculation of info needed for negotiation	T		1, 2, 7, 8, 12, 13, 14, 17, 21, 22, 23, 25
3.6.2: Minimum Risk Maneuver	T	18	1, 2, 7, 8, 12, 13, 16, 20, 21, 22, 25
3.6.3: Communication about planned trajectories	T	1, 7, 18	2, 3, 8, 12, 13, 16, 20, 22, 23, 25
3.6.4: Communication about platoon administration	T	1, 7, 18	2, 3, 8, 12, 13, 16, 20, 22, 23, 25
3.6.5: Communication about actions	T	1, 7, 18	2, 3, 8, 12, 13, 16, 20, 22, 23, 25
3.6.6: Platoon leader as coordinator	T	18	2, 7, 8, 13, 16, 20, 22, 25
3.6.7: Platoon leader as negotiator	T	18	2, 7, 8, 13, 16, 20, 22, 25
3.6.8: Platoon leader as decision maker	T	18	2, 7, 8, 13, 16, 20, 22, 25
3.6.9: Calculation of info needed for negotiation	T	18	1, 2, 7, 8, 13, 14, 15, 16, 18, 22, 23
3.7.1: V2X communication and behaviour	T	1	2, 6, 7, 8, 9, 12, 13, 14, 15, 16, 17, 18, 20, 21, 22, 23, 25
3.8.1: V2X CAM message	T	7	1, 2, 3, 8, 12, 13, 14, 15, 16, 17, 18, 20, 21, 22, 23, 25

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3.8.2: Planned route of the ego vehicle	T		1, 2, 7, 8, 12, 13, 15, 16, 18, 20, 21, 22, 23, 25
3.9.1: Trajectory planning based on obstacles	T	18	1, 2, 7, 8, 12, 13, 15, 16, 20, 21, 22, 23, 25
3.9.2: Trajectory planning based on tasks and roles	T	18	1, 2, 7, 8, 12, 13, 15, 16, 20, 21, 22, 23, 25
4,9,2: Routing communications	T/A		24
4.1.1: Common unit	D		10
4.1.2: Stakeholders for policies	D		10
4.1.3: Improving a policy parameter	D		10
4.1.4: Clear policy resolution	T		10
4.2.1: Using external queue measurements	T		14, 24
4.2.10: Communication with other TLC	T		10, 11
4.2.11: GLOSA	T		8, 10
4.2.12: GLOSA	T		8, 10
4.2.13: GLOSA negotiation	T		2, 8, 14
4.2.2: Using external queue measurements	D		2, 4, 14
4.2.3: Using spillback detection	T		24
4.2.4: Using spillback detection	D		24
4.2.5: Incorporating partial conflicts	T		25

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4.2.6: Green wave Negotiation	T		19
4.2.7: Negotiation	T		11, 16
4.2.8: Negotiation - conflicts	T		11
4.2.9: Negotiation - conflicts	T		11
4.3.1: Detecting waiting vehicles	T		24
4.3.2: Detecting obstructing vehicles	T		24
4.3.3: Calculating partial conflicts	T		24
4.4.1: Detecting spillback	T		24
4.5.1: Dynamic Green wave	T		11, 19
4.5.2: Green wave - criteria	T		11, 19
4.5.3: Green wave - policies	T		11, 19
4.5.4: Green wave - recalculation	T		11, 19
4.6.1: Queue estimates - Lane level accuracy	T		24
4.6.2: Queue estimates - GPS inaccuracy	T		24
4.6.3: Queue estimates - penetration rate	T		24
4.6.4: Queue estimates - C-ITS	T		24
4.6.5: Queue estimates - automated vehicles	T		22, 24
4.7.1: GLOSA - optimal speed	T		10, 11

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4.7.2: special road users - recognition	T		10
4.8.1: Synchronization	T		10
4.9.1: Routing data	A		24
5.1.1: Access to positioning data	T		8, 12, 14, 15, 16, 17, 18, 20, 22, 23, 25
5.1.10: Message transmission triggering - event-based	T		12, 14, 15, 22, 23
5.1.11: Message transmission triggering - periodic	T		12, 14, 15, 16, 17, 18, 20, 22, 23, 25
5.1.12: Message coding & decoding - standards	T		3, 9, 12, 14, 15, 16, 17, 18, 20, 22, 23, 25
5.1.13: Message coding & decoding - MAVEN standards	T		3, 6, 9, 12, 14, 15, 16, 17, 18, 20, 22, 23, 25
5.1.14: Messages for vehicle dynamics information	T		12, 14, 15, 16, 17, 18, 20, 22, 23, 25
5.1.15: Messages for hazard warning	T	Not applicable as all hazard are locally evaluated and detected by reception and processing of CPM messages	
5.1.16: Messages for platoon formation	T	17, 18	16, 20, 25
5.1.17: Messages for platoon control	T	17, 18	16, 20, 25
5.1.18: Messages for platoon management	T	17, 18	16, 20, 25
5.1.19: Messages for cooperative sensing	T		25

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5.1.2: Access to map database	T		12, 14, 15, 16, 17, 18, 20, 21, 23, 25
5.1.20: Messages for negotiations	T	14	12, 15, 16, 17, 18, 20, 22, 23, 25
5.1.21: Messages for cooperative sensing	T		25
5.1.22: Messages for traffic light phasing and road topology	T		12, 14, 15, 23, 25
5.1.23: Messages for road info	T	Not applicable as not needed by the identified maven use cases	
5.1.24: Messages for speed advisory	T	14	12, 15, 21, 23, 25
5.1.25: Messages for lane advisory	T	14	12, 15, 22, 23, 25
5.1.3: Access to traffic light information	T		21, 23, 25
5.1.4: Access to traffic management center information	T	Not applicable as not needed by the identified maven use cases	
5.1.5: Access to vehicle dynamic information	T	14	8, 12, 15, 16, 17, 18, 20, 21, 22, 23, 25
5.1.6: Access to information from on-board sensors	T		25
5.1.7: LDM database management	T	14	16, 17, 18, 20, 23, 25
5.1.8: Fusion of LDM with databases of entries detected by on-board sensors	T	14	16, 17, 18, 20, 23, 25
5.1.9: Message transmission	T		12, 14, 15, 22, 23

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triggering			
5.2.1: Maps availability for relevant testing locations	T		13, 15, 17, 18, 20, 22, 23, 25
5.2.2: Maps availability with different granularity	T		15
5.2.3: Management of maps with different granularity	T		15
5.3.1: Risky situation detection with own sensing capabilities	T		25
5.3.2: Risky situation detection with cooperative sensing capabilities	T		25
5.3.3: ADAS reactions on own system controllers	T		25
5.3.4: ADAS reactions to influence other systems' controllers	T	Not applicable because of more detailed scope of T5.2 with respect to ideas described in D2.1	

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