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Cooperative Systems for Future Automated Road Transport and Traffic Management in Urban Areas

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Abstract

Automated road transport in urban areas will be dependent on adequate connectivity and information exchange between highly automated driving systems in vehicles and the road infrastructure, based on a cooperative or connected ICT infrastructure. The paper especially addresses the challenges of cooperative systems for future road transport and traffic management in urban areas. For this appropriate management regimes for highly automated driving in urban areas will be developed focussing to guide vehicles at signalised intersections and corridors. Advanced Driver Assistance Systems will be enhanced by using cooperative communication. The paper serves as an overview of the status of the MAVEN (Managing Automated Vehicles Enhances Network) project. It introduces the concept, the architecture, and some scenarios that were developed by the project concerning this topic. The implementation of the Local Dynamic Map, which is at the heart of the architecture, will be used to discuss the signal negotiation scenario in more detail. Lastly, road authority views on the topic are also discussed.

Keywords: automated driving; cooperative systems; traffic management

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1. Introduction

Intelligent Transport Systems (ITS), based on ICT (Information and Communication Technologies), for road transport are rapidly developing since more than three decades, with the aim to improve safety, traffic efficiency, energy efficiency and comfort as described by Lu (Ed), (2016). Especially Green Light Optimal Speed Advice (GLOSA) as described by Eckhoff (2013) and cooperative signal priority for heavy goods vehicles as described by Koenders (2008) are promising applications that have a mutual synergy. However, they were all developed for a human driver as end-user. In parallel, research was carried out for automated driving. This focussed mostly on the platooning aspects like in Stevens (2015). Progress in this field has resulted in successful field trials and further work is now focussing on legal, safety and organisational issues as well. Both research topics have a large potential for increasing fuel economy and reducing pollutant emissions. GLOSA and cooperative priority prevent stopping for a red traffic light and platooning reduces aerodynamic drag due to close following distances.

However, the combination between automated driving and V2X communication is still underexposed. GLOSA for automated vehicles requires a different approach. Human drivers use their own perception to interpret the advice, while an automated vehicle will follow the advice precisely if safety permits. For cooperative priority, the considerations from the traffic management point of view change when vehicles arrive in large platoons. Ending the green phase in the middle of a platoon, will not just have consequences related to stopping some vehicles, but will also reduce the aerodynamic efficiency gains for the remainder of the trip.

The same applies to safety, cooperation between the infrastructure and vehicles by V2X communication has high potential. More sensors can be installed on both vehicles and infrastructure as cost effective sensors are currently under development. According to Ackerman (2016) this can bring the cost down from $80,000 for a spinning Light radar (Lidar) sensor to $500 or even $100 for alternative sensor technologies. Similar developments are ongoing for roadside sensors where sensors of existing test sites were very expensive, prices are expected to come down for mass production. However, this does not yet solve the problem of occlusion, which Loce (2017) described for pedestrian detection. This work mitigates the problem by fusing data of multiple infrastructure sensors. A large potential can, however, be realized by sharing sensor data from vehicular and roadside sensors, due to their different positions to observe traffic. This was demonstrated in several projects like Safespot as described by Vivo (2009). With automated vehicles, the potential should be even larger due to their extensive sensors on one hand and their higher needs for infrastructure sensor information on the other hand.

All these applications are dependent on adequate connectivity and information exchange between highly automated driving systems in vehicles and the road infrastructure and should be based on a cooperative or connected ICT infrastructure. The paper especially addresses the following challenges of cooperative systems for future road transport and traffic management in urban areas.

1) Develop appropriate management regimes for highly automated driving in urban areas. This is assuming automation levels 3 and 4 according to SAE (2014).
2) Monitor, support and orchestrate movements of road users to guide vehicles at signalised intersections and corridors.
3) Further enhance ADAS (Advanced Driver Assistance Systems) as described by Lu (2005) and C-ITS (Cooperative Intelligent Transport Systems) applications as described by the C-ITS Platform (2016), e.g. cooperative platoon organisation and signal plan negotiation to adaptive traffic light control algorithms.
4) Determine the expected roles of the city authorities, ICT-infrastructure (service) providers, OEMs, road operators and other actors for making the road transport systems safer, more reliable, and more robust.

The paper serves as an overview of the status of the MAVEN (Managing Automated Vehicles Enhances Network) project, which aims to progress beyond the state of the art on the aforementioned challenges for automated driving. Therefore, it starts by introducing the objectives, concept and approach of the project. This is followed by a description of the scenarios that were developed by the project. The first results are presented as well, this includes the architecture, the implementation of the Local Dynamic Map (LDM), which is at the heart of the architecture, and its application to the signal negotiation scenario. Lastly, a survey of views on automated driving from the perspective of cities is presented before closing with conclusions and further research.

2. An overview of the proposed main objective, concept and approach

The main goal is to provide solutions for managing automated vehicles in an urban environment (with signalised intersections and mixed traffic), for which algorithms for organising the flow of infrastructure-assisted automated vehicles, and structuring the negotiation processes between vehicles and the infrastructure will be developed. Platooning is an evident example of a technology in this domain as can be seen in Fig. 1.

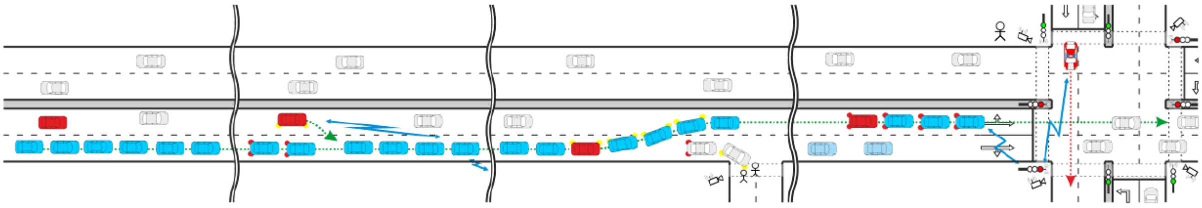

Fig. 1 An illustration of a vehicle entering/leaving a platoon, and traffic management with other roads users, taken from MAVEN Consortium (2016)

The basic concept is to develop a sophisticated intelligent urban road-transport network and cooperative-systems infrastructure for highly-automated vehicles, with the aim to substantially increase traffic efficiency, improve utilisation of infrastructure capacity, and reduce emissions. For this see Fig. 2, in which various aspects related to the core functionalities are illustrated.

Fig. 2 Concept for developing a sophisticated intelligent urban road-transport network and cooperative systems infrastructure for highly automated vehicles, taken from MAVEN Consortium (2016)

To achieve the objective, and in line with the concept, a prototype system both for field tests and for extensive modelling for impact assessment will also be built. Furthermore, MAVEN will contribute to the development of enabling technologies, such as telecommunication standards and high-precision maps. A roadmap for the introduction of road transport automation will be developed, to support road authorities in understanding potential future changes in their role and in the tasks of traffic management. A White Paper on "management of automated vehicles in a smart city environment" will position the results in the broader perspective of transport in smart cities, and embed these with the principles and technologies for smart cities, as well as service delivery.

3. Scenarios and potential benefits

The scenarios were developed to enable three aspects to be investigated: 1) vehicle automation (e.g. trajectory and manoeuvre planning), 2) infrastructure automation (e.g. adaptive traffic light control optimisation), and 3) integration of vehicle and infrastructure automation. Various scenarios (so-called MAVEN use cases) are made. These are described in Fig. 3 and Fig. 4.

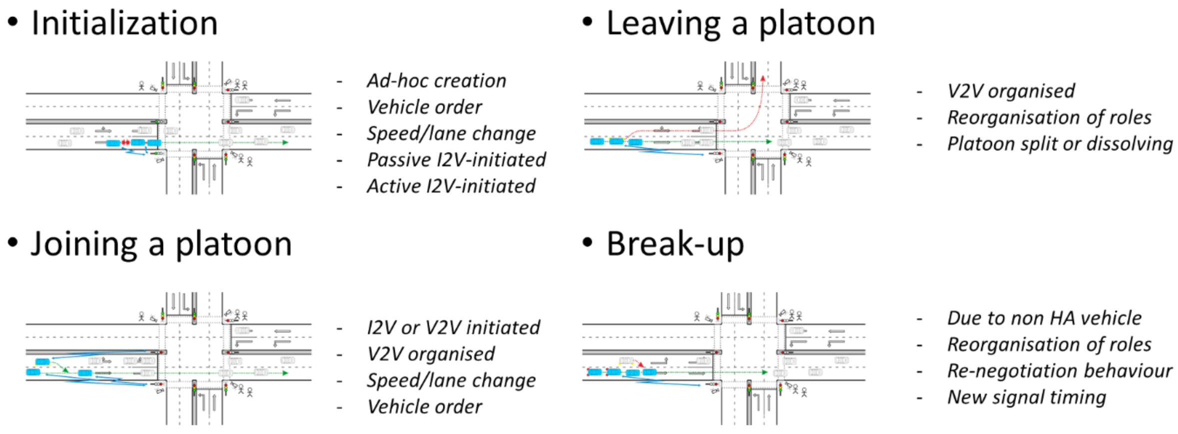

Fig. 3 Scenarios for platoon organisation, taken from MAVEN Consortium (2016)

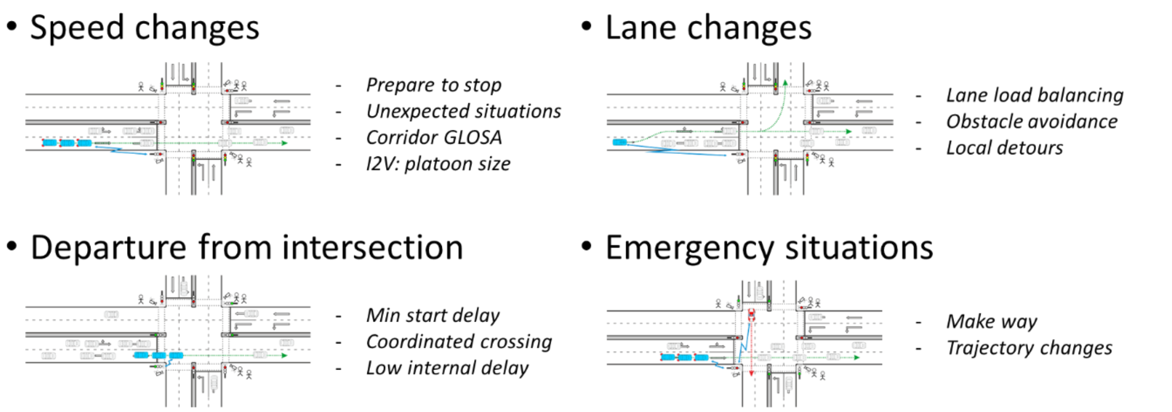

Fig. 4 Scenarios for platoon progression and the progression of individual automated vehicles, taken from MAVEN Consortium (2016)

To implement these scenarios, several extensions to the standardized message sets from SAE J2735 were developed. These include a new message the LAM (Lane Advice Message), which provides instruction where and when to change lanes. Extensions were made to the CAM (Cooperative Awareness Message) that indicate platooning state, intended turn direction, speed and lane advice compliance. These are all essential for the GLOSA negotiation scenario, which will be described in more detail in a separate section together with the LDM application. Map and SPaT (Signal Phase and Timing) messages were profiled, i.e. the interpretation of fields and selection of optional fields, in detail to support the scenarios. Lastly, the Collective Perception Message (CPM) was designed for the scenario to detect non-cooperative road users and based on efforts from previous projects, like the Sensory Observation Message (SOM) as described in Blokpoel (2016).

Apart from the direct V2X scenarios presented in Fig 3 and Fig 4, several infrastructure scenarios with an indirect effect on the vehicles were developed. These are intersection priority management, queue length estimation, local level routing, network coordination (e.g. green wave) and signal optimization. More details about the MAVEN scenarios can be found in Pribyl (2017).

Besides potentially high positive impacts on environment, energy efficiency and safety, the development of a sophisticated intelligent urban road-transport network and cooperative-systems infrastructure for highly automated vehicles will benefit automotive industry, ICT infrastructure (service) providers, authorities, academia, and end users (drivers and road users). The details are presented in Table 1.

Table 1 - Benefits of the development of a sophisticated intelligent urban road-transport network and cooperative-systems infrastructure for highly automated vehicles

Actors	Benefits and relevance
Automotive industry	The cooperative automation is expected to ensure safety by releasing the role of drivers: in decision and execution of manoeuvres and in safety-critical road network zones such as intersections; collaborative detection capabilities of infrastructure and vehicles will allow the implementation of advanced safety functions for VRUs and drivers protection while avoiding the necessity of expensive sensor technologies. Cooperative platoon organisation combined with traffic light signal timing negotiations will increase the efficiency in road usage, which leads to reduction of driving time, as well as fuel consumption and emissions.
Infrastructure service providers	MAVEN addresses some challenges of cooperative systems for future road transport and traffic management in urban areas. Infrastructure service providers will play an important role for future deployment of automated driving. Technological solutions will be developed based on the needs of local authorities and end users (e.g. reliability, safety, security, robustness, efficiency, cost-effectiveness). Results from MAVEN will benefit future infrastructure services
(City) Authorities	Cities see a huge potential of automated vehicles to support sustainable mobility systems for all citizens and efficient use of public space. This will only work when vehicles are connected with each other, communicate with other road users, and integrated in the traffic management systems of cities. MAVEN is an important step for cities, as it will give good insight in the impacts and requirements in this transition towards integrated, safe and sustainable automated vehicles.
Academia	Future traffic management needs to deal with the imminent challenge posed by the autonomous vehicles; the entire approach, algorithms and methods used in traffic management will have to change. Academia, in cooperation with industrial partners and municipalities will enable theoretical research results be tested and applied in real life conditions. MAVEN will create new knowledge and opportunities for innovation in various fields, e.g. electrical engineering, computer science and traffic engineering.
End users	All road users will benefit from a safe and efficient transport system, with a substantial reduction of accidents (risk) and traffic jams. Drivers, in addition to safety and traffic efficiency benefits, will experience more comfort, and improved fuel efficiency. The envisaged sophisticated intelligent urban road-transport network and cooperative-systems infrastructure for highly automated vehicles will enable these advancements. Traffic at conflict points will be synchronised, and the traffic flow will be more homogenous.

4. Architecture

The main actors involved in the architecture are the cooperative automated vehicle and cooperative intersection. Outside the boundaries of the architecture, several actors interact with the system. These are non-cooperative vehicles and Vulnerable Road Users (VRU) as actors that only interact in traditional ways with the system, e.g. respecting the traffic lights and safe interactions with other traffic participants. Priority vehicles request priority in a traditional way from a functional perspective (using check-in and check-out points), and can use both new cooperative technology or other traditional methods as communication channel. Lastly, the Traffic Management Centre (TMC) is an external actor that may change policy parameters in the intersections and coordinates green waves over multiple intersections. Human intervention from the road authority or traffic management software can trigger this.

Details about the hardware architecture of the cooperative automated vehicle and the cooperative intersection can be found in Blokpoel (2017). Fig. 4 shows how both systems are combined in one architecture for simulation using SUMO, Krajzewicz (2012). It is important to keep the simulation as accurate as possible, but also interoperable with the real-world systems for ease of use. However, simulation has another requirement, the simulation speed, which important for impact assessment. Fast simulation allows for more extensive evaluation of scenario's and in general traffic engineers expect at least 10x real time speed for a network with 5 complex intersections on a contemporary desktop pc. For this reason, it will not be feasible to simulate each vehicle with several separate processes as in a real vehicle. This would result in over a thousand individual processes communicating with each other and running in parallel. Additionally, the messages for communication are ASN.1 UPER encoded. This means values can start and end halfway a byte. Encoding and decoding are therefore quite computationally intensive.

Fig. 5 shows the simulation architecture, based on selecting required components from the hardware architecture and adding new ones specifically required for simulation.

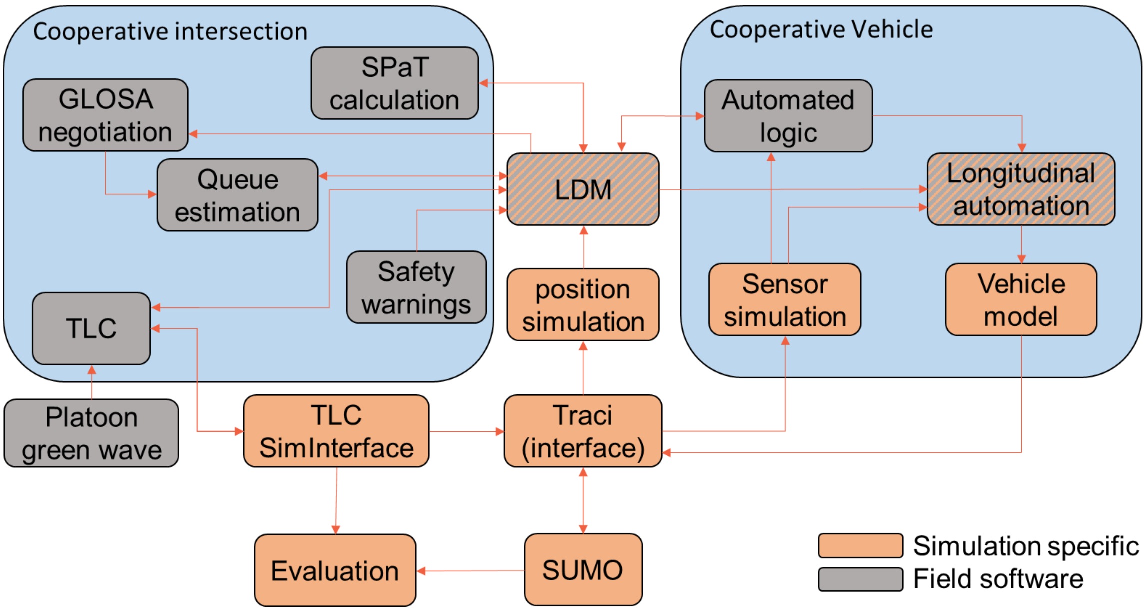

Fig. 5 High level simulation architecture

Components that are identical to the real-world implementation are grey, simulation specific components orange and adapted elements are grey/orange striped. Important for the striped element is that the interfaces to the grey elements should stay the same. Both the vehicle and the intersection have a shared LDM now. This is because the communication units have been removed, saving a lot of computational time for encoding and decoding messages. Systems connected to this LDM will not notice a difference, the same data is still present in the same format.

The simulation architecture contains several new components shared between the vehicle and the intersection. Most importantly, SUMO, but in theory another simulation package could be used as well. The interface towards SUMO is called Traci and can be used to retrieve data about anything happening in the simulation, e.g. vehicle speed, position, route, detector status, vehicle ID on detector, etc. The interface can also be used to change data in the simulation, e.g. signal head status, vehicle speed, vehicle route, etc. Positioning simulation replaces the actual positioning sensor of the vehicle. As Traci offers a 100% accurate position, it is not realistic to use this for simulations. The results of this simulated position are used to replace the data from regular CAM messages received by the LDM. A separate TLC interface for simulation is moved out of the cooperative intersection to emphasize that for simulation several additional functionalities had to be added. Signal heads, infrastructure sensors and traditional priority have been integrated with this interface as the actual hardware is not present and it has to connect to Traci for this. Evaluation is a new component required for impact assessment, TLC and SUMO logging is used for this. Lastly, the platoon green wave component from the TMC connects directly with the TLC using the same interface as in the real world (just like the LDM and queue estimation components).

When looking at the cooperative vehicle, many sensors have to be replaced by sensor simulation, which acquires data from Traci. The simulation software mostly simulates one-dimensional movement; lateral lane positions and lane changes are simulated using discrete sub-lanes. The decision whether to change lanes is evaluated based on vehicle positions on the other lane. This means the automation functionality also has to focus on the longitudinal dimension, while modelling the lateral speed of a lane change to determine the sub-lane correctly. Lastly, the automation functionality has no actuators to interact with, so a vehicle model is required to translate the outputs of the real-world automation into speed, lane and route information for Traci.

Looking at the cooperative intersection the functionality is the same as on the street, the simulation specific functionality is all in the TLC SimInterface. An important requirement is that this interface should be in charge of the timing and the controller should be able to run with variable clock speed so the simulation can run as fast as the computations allow.

5. LDM implementation and application to signal negotiation

As shown in the architecture, the LDM plays a central role in both the vehicle and infrastructure systems. For automated driving new opportunities arise, which should be supported by the data structure. This means new functionality has to be added compared to an LDM meant for cooperative applications only, which is presented in Koenders (2014). An overview of new functionality added for automated driving is given in Table 2.

Table 2 New functionality in LDM for automated driving

Data element	Applicable scenario
Number of occupants	Intersection priority management. Can be used to prioritize High Occupancy Vehicles (HOVs).
Distance to following vehicle	Queue estimation. This information can improve queue model accuracy, leading to more optimal solutions for GLOSA negotiation and signal timing.
Distance to preceding vehicle	Queue estimation. This information can improve queue model accuracy, leading to more optimal solutions for GLOSA negotiation and signal timing.
Platooning state	Signal optimization and intersection priority management. Platoons can be prioritized, especially for not breaking them. Information about the increased departure efficiency helps the signal optimization determine the optimal green duration.
Desired speed	Queue estimation and GLOSA negotiation. If the desired speed of a vehicle is lower than the legal speed limit, the arrival time at the intersection is not estimated correctly. This information corrects this problem and leads to more optimal signal timing.
Current lane	Lane advice. When there are multiple lanes for a certain turn direction at an intersection, the infrastructure can supply a lane advice when it is known in which lane all vehicles are.
Route information (including turn direction at next intersection)	Queue estimation, signal optimization and GLOSA negotiation. This scenario is further detailed in Fig. 6.

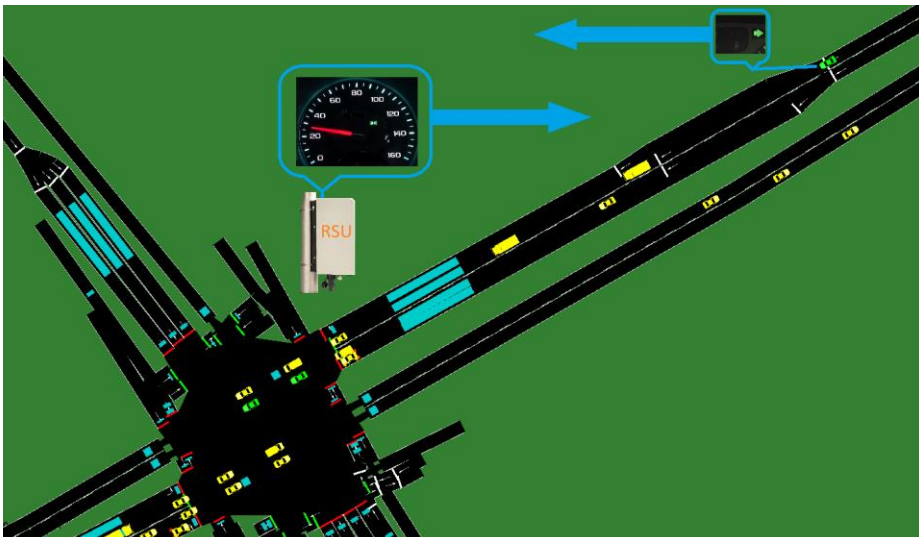

Fig. 6 GLOSA negotiation information exchange

The scenario for signal negotiation is illustrated in Fig. 6. Originally, the signal controller was assuming the vehicle are going straight at the intersection based on low historic turning ratios for the right and left-turn. If a vehicle turns right, this would only be detected once it reaches one of the detectors close to the stop line. Therefore, the cyclists in parallel to the green signal groups for motorized traffic will remain green until a vehicle for the right turn is detected, since bicycles are not detected upstream and their demand cannot be predicted.

However, in this case an automated vehicle with MAVEN-extended CAM transmissions is arriving. It indicates its intended right turn manoeuvre at the intersection. This information is stored in the LDM and the queue estimation component uses it to update the arrival vector in the queue model. These results are again stored in the LDM and the signal optimization uses it to conclude it is best to switch the right turn signal to green. Since the cyclists have a mandatory amber and clearance time, this cannot be executed instantly. Therefore, the time to green prediction that is written in the LDM shows 10 seconds. With this, the GLOSA component calculates that a speed of 30 km/h would be optimal for the approaching vehicle to arrive when the light turns green and avoid stopping. The communication software reads this from the LDM and encapsulates the information in an updated SPaT message, which is broadcasted back to the vehicles.

6. Stakeholder views on automated driving

A survey focusing on the perspective of cities was carried out at a workshop on 15 November 2016. The key findings are presented in Table 3.

Table 3 Summary of the key findings concerning the perspective of cities

No.	Question	Opinion of the majority
1)	What is the most important factor for automated vehicles in normal traffic?	Traffic safety
2)	Which vehicle class has the most potential for automation?	Public transport
3)	What are the most critical issues in your city related to mobility and infrastructure?	Parking, congestion, safety
4)	Looking at traffic management, to what level do you agree with the following statements?	Operational traffic management will not be needed any more as automated vehicles will do this as a system, the role will shift towards a more strategic level. Setting policies and ensuring accessibility for all modes will be the main activities.
5)	What views, questions or concerns do you have regarding the (changing) role and responsibilities of a traffic manager?	The role of the traffic manager will shift from an operational level to a strategic level.
6)	What do you think the impact of automated vehicles in the urban environment will be in relation to?	Mainly to traffic safety. In addition, non-automated vehicle drivers and VRUs will feel tempted to try to "disrupt" automated vehicles. There are also concerns on socio-economic impact, like driver jobs lost upon higher penetration of automated public transport applications.

7. Conclusion

The paper has given an overview of the status of the MAVEN project. The first result was a set of scenarios that were developed by the project, specifically designed to allow investigation of vehicle automation, roadside automation and the interaction between them. The architecture of the project was designed to enable implementation of those scenarios. A specific simulation architecture was developed to allow fast, but accurate simulations for impact assessment in the project. The LDM was identified as a key element in the architecture. The extensions with respect to the state-of-the-art were discussed and its effectiveness was demonstrated by describing its application to the GLOSA negotiation scenario. Lastly, a survey of views on automated driving from the perspective of cities was presented to place the findings in a broader perspective.

With these results, the project can continue confidently into its implementation and evaluation phase. The feedback from stakeholders resulted in a focus on creating policy settings related to automated driving. This should facilitate the envisaged shift from operational to strategic traffic management.

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