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A sophisticated intelligent urban road-transport network and cooperative systems infrastructure for highly automated vehicles

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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 EU-funded project MAVEN (Horizon 2020 Programme) has addressed some aspects of the relation and interaction between the (future) road transport network infrastructure and cooperative systems for highly-automated vehicles. The paper introduces a concept, an approach, and some scenarios that were developed by the project concerning this topic. Some preliminary results are presented as well, such as a survey of views on automated driving from the perspective of cities, and a high-level system architecture. Further research topics are discussed.

Keywords:

automated driving, cooperative systems, traffic management

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 [Lu (Ed), 2016]. The core technologies in the ITS domain are sensor technology, telecommunication, information processing and control technology. Different technologies can be combined in different ways to create stand-alone in-vehicle systems and cooperative systems (V2X). Deployment of infrastructure-based automated road transport systems is on the agenda of authorities in different regions and countries.

Several V2X use cases have been extensively researched in recent years. Especially Green Light Optimal Speed Advice (GLOSA) [Eckhoff, 2013] and cooperative signal priority for heavy goods vehicles [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 [Stevens, 2015]. Progress in this field has resulted in successful field trials and further work is now also focussing on legal, safety and organisational issues. 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.

Regarding safety, 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 and mitigates the problem by fusing data of multiple infrastructure sensors. A large potential can 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 [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.

As previously explained there is a high potential for cooperation between automated vehicles and the infrastructure. Therefore, 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 (assuming automation levels 3 and 4 [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) [Lu, et al, 2005] and C-ITS (Cooperative Intelligent Transport Systems) applications [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 is structured as follows: It provides an overview of a developed concept for enhancing intelligent urban road transport network and cooperative systems for highly automated vehicles. Furthermore, some developed scenarios for studying cooperative systems in future traffic management systems are discussed, and some key findings, potential impacts and further research are presented. Finally, a conclusion is drawn.

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 (see Figure 1).

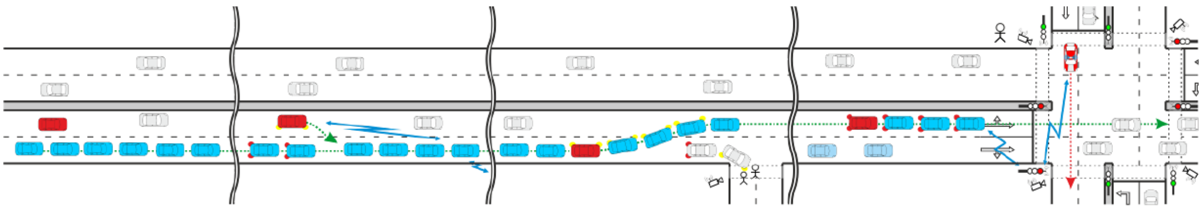

Figure 1 - An illustration of a vehicle entering/leaving a platoon, and traffic management with other roads users [MAVEN Consortium, 2016]

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 Figure 2, in which various aspects related to the core functionalities are illustrated.

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. In addition, user assessment will be included. 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.

Figure 2 - Concept for developing a sophisticated intelligent urban road-transport network and cooperative systems infrastructure for highly-automated vehicles [MAVEN Consortium, 2016]

Scenarios and potential benefits

Three aspects will 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 Figure 3 and Figures 4.

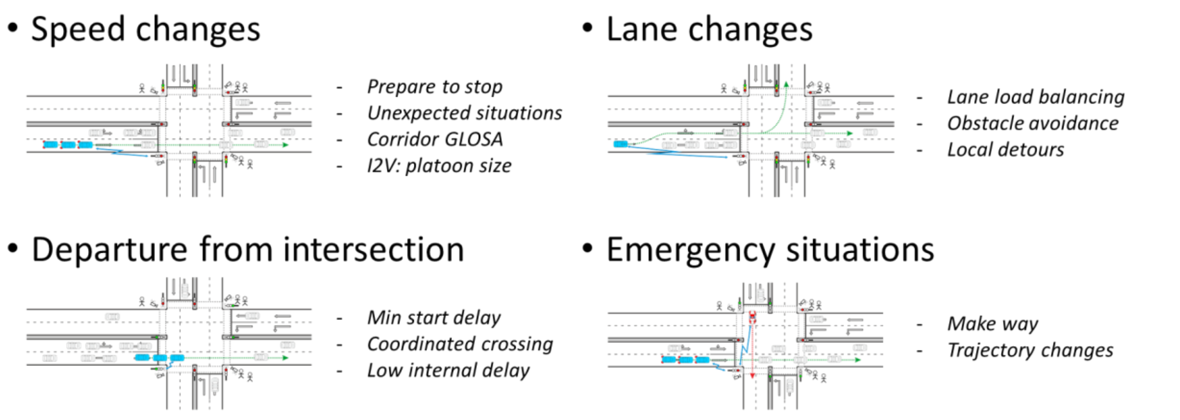

Figure 3 - Scenarios for platoon progression and the progression of individual automated vehicles [MAVEN Consortium, 2016]

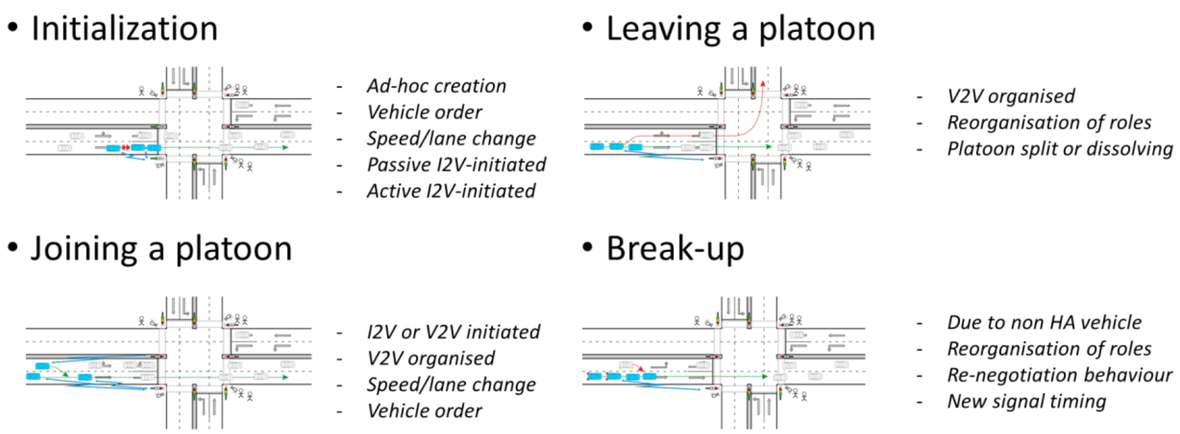

Figure 4 - Scenarios for platoon organisation [MAVEN Consortium, 2016]

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.

Perspective of cities

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 1.

Table 2 - 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?	Traffic management will not be needed any more as automated vehicles will do this as a system
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.

System decomposition and architectures

A high-level hardware oriented system decomposition is presented in Figure 5.

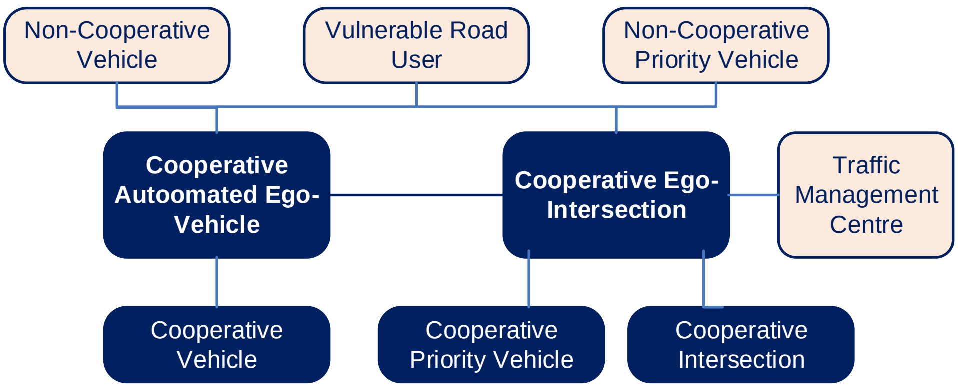

Figure 5 - High-level system decomposition (Adapted after [Blokpoel, et al. 2017])

Cooperative Vehicle and Cooperative Intersection are the main actors. Actors that interact with the system are non-cooperative vehicles and Vulnerable Road Users (VRU). Cooperative automated vehicle architecture and cooperative intersection system decomposition are presented in Figure 6 and Figure 7 respectively.

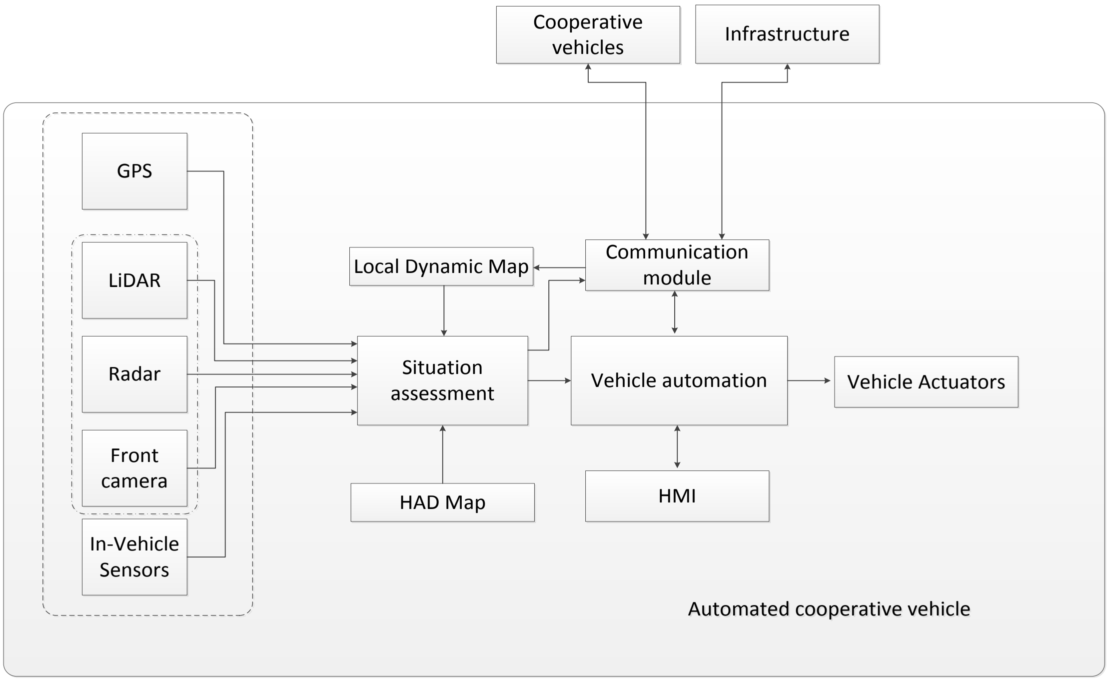

Figure 6 - Automated cooperative vehicle architecture [MAVEN Consortium; Blokpoel, et al. 2017]

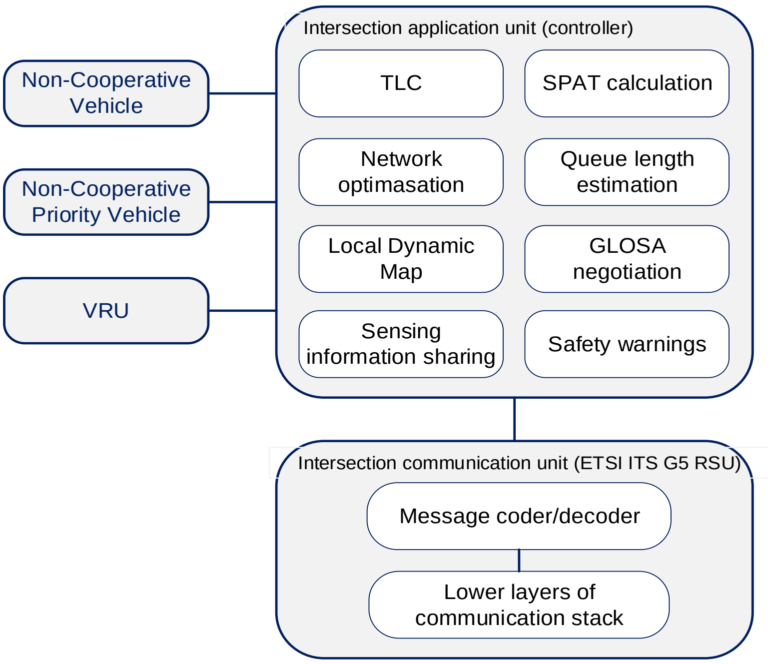

Figure 7 - Hardware oriented cooperative intersection system decomposition [MAVEN Consortium; Blokpoel, et al. 2017]

An interoperable architecture between simulation and pilots for cooperative and automated driving has been developed [Blokpoel, et al. 2017] (see Figure 8). A step further from real-world hardware architecture to a simulation architecture has been established by keeping maximal compatibility and re-use of real-world systems, while enabling retrieving sensor information from the simulation environment and changing states of traffic lights and vehicles according to the actuator outputs.

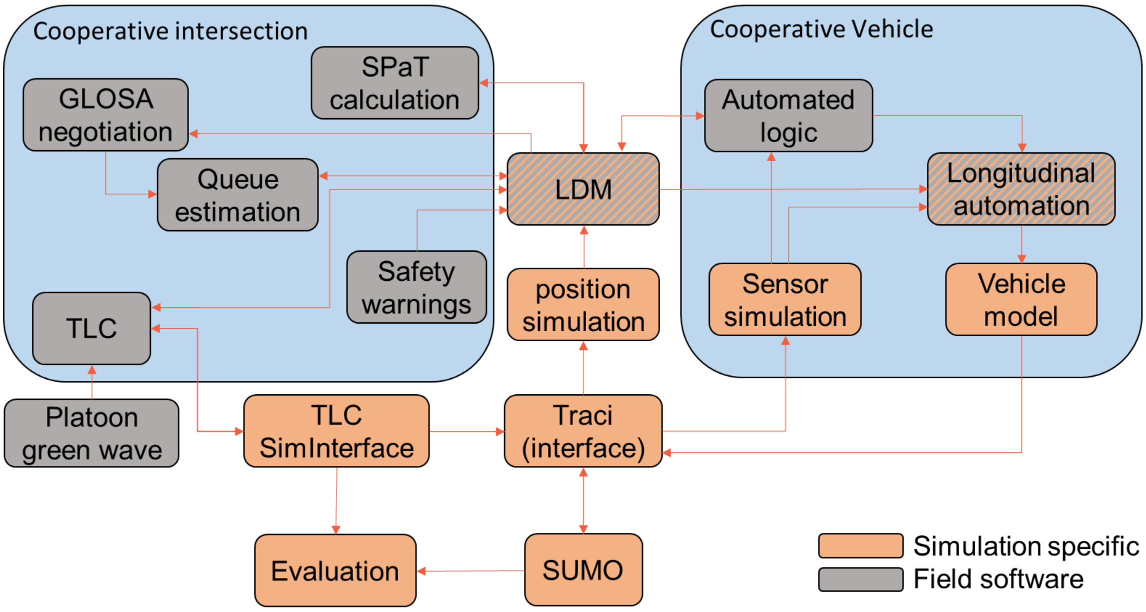

Figure 8 - High level simulation architecture [Blokpoel, et al. 2017]

Further research

Main further research topics include:

1) Generic concept, use cases, requirements and specifications – providing a detailed system design, including use case descriptions, requirements and specifications.
2) Vehicle automation – focusing on the vehicle-perspective and is responsible for the design and development of vehicle trajectory and manoeuvre planning algorithms.
3) Infrastructure automation – focusing on the roadside-perspective and is responsible for the design and development of optimisation algorithms for cooperative adaptive traffic light control.
4) Enabling technologies – responsible for the development of enabling technologies, e.g. V2X communication protocols and message sets that support automation algorithms, as well as usage of Highly Automated Driving (HAD) maps and realisation of complementary ADAS functions.
5) Integration, implementation and test – responsible for the integration of relevant results following an incremental manner resulting in a prototype (vehicles and infrastructure).

6) Assessment and demonstration - responsible for the evaluation of the impacts through field and simulation studies; field demonstrations and a user satisfaction study are included.

The interactions of these topics are presented in Figure 9.

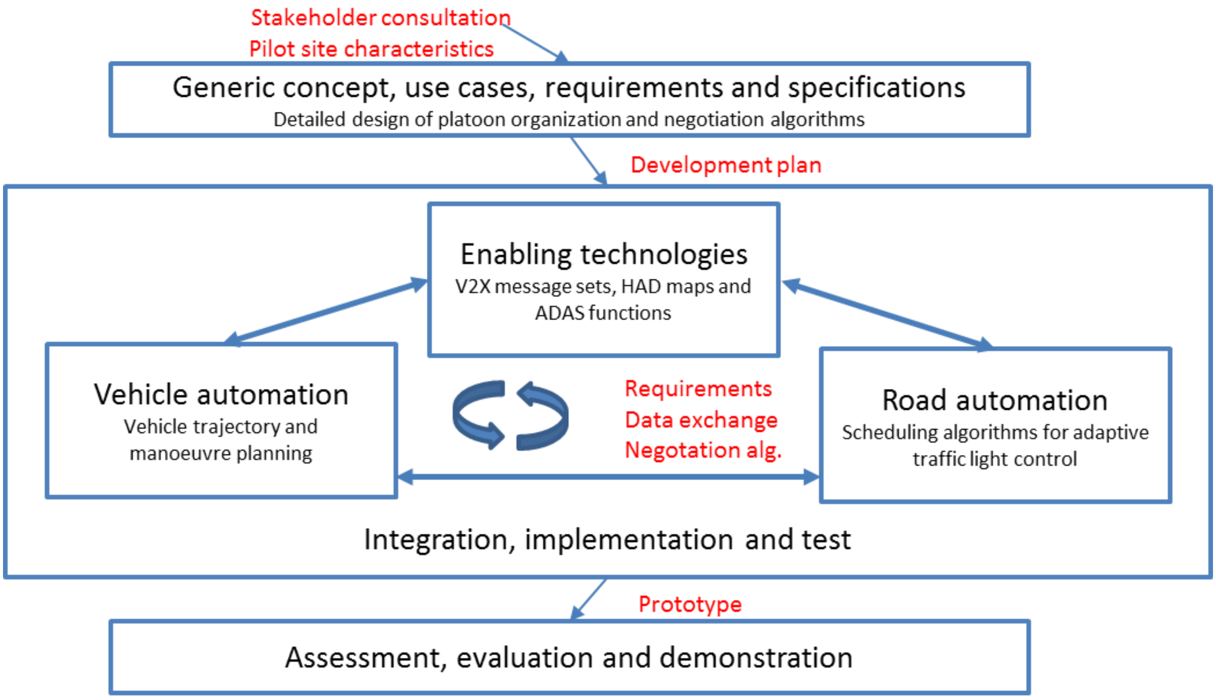

Figure 9 - Research topics and interactions [MAVEN Consortium, 2016]

Conclusion

Automated road transport has a huge potential to improve traffic safety, traffic efficiency, energy efficiency and comfort. Automated driving in urban areas (with mixed traffic situation) needs adequate connectivity and information exchange between highly-automated driving systems in vehicles and the road infrastructure, based on a cooperative and/or connected ICT infrastructure. The proposed MAVEN concept is holds the promise to provide a valuable contribution for the realisation of this infrastructure, and the results will benefit OEMs, ICT infrastructure service providers, city authorities and end users.

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