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Managing Automated Vehicles Enhances Network

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Abstract

The MAVEN project (Managing Automated Vehicles Enhances Network) aims to provide solutions for managing level-4 automated vehicles (HAV) at (urban) signalised intersections. It will develop algorithms for infrastructure-assisted guidance of HAVs using negotiation processes between vehicles and the infrastructure. HAVs receive advice and/or requests from the road infrastructure to adjust their trajectory and manoeuvring policies, while infrastructure dynamically adapts traffic light timing at single or multiple intersections. This bi-level optimisation is expected to contribute to maximising the economic benefit of traffic flow while reducing energy consumption and environmental impact as well as ensuring traffic safety. This paper provide further details on the system concept and use cases, its innovation and relevance, and results from a stakeholder consultation workshop with road authorities.

Keywords:

AUTOMATED DRIVING, TRAFFIC MANAGEMENT, SYSTEM CONCEPT, USE CASES, STAKEHOLDER CONSULTATION

Introduction

Highly automated and fully automated vehicles, connected with an intelligent environment, could significantly contribute to meeting the EU objective of reconciling growing mobility needs with more efficient transport operations, lower environmental impacts and increased road safety. The coming years will see an increase in the automation of driving tasks and the introduction of highly automated vehicles, with the role of the human driver diminishing. At the same time, the deployment of Cooperative ITS technology (C-ITS), will not only be a key enabler for distributed coordination of highly automated vehicles, but combined with intelligent traffic management and control applications will also enable road infrastructure to monitor, support and orchestrate vehicle movements [2, 3].

To date, in most C-ITS applications, communication capabilities have predominantly been used in a unidirectional manner, enabling dedicated features at the receiving end. For example, vehicles receiving Cooperative Awareness Messages for collision avoidance applications or vehicles receiving Signal Phase and Timing data for trajectory planning applications. Actual cooperation between two communicating entities - based on two or more applications operating bilaterally - has been rare. What if two vehicles about to use the same scarce infrastructure resource were to negotiate their respective trajectories simultaneously, or if a traffic light and a vehicle would negotiate their signal timing and trajectory respectively? Moreover, the rapid progress currently being made in network and satellite technologies - in network latency and geospatial accuracy - is making it increasingly feasible for highly automated vehicles to interact reliably with pervasive infrastructure systems. Intelligent infrastructure can provide these vehicles with a wider awareness of road capacity, signals and other road users in the context of their planned journey [4].

Though vehicle technologies related to self-driving, fully or highly automated vehicles receive most of the attention of the general public, the foundation of the MAVEN project is that infrastructure applications will continue to play a vital role in the management of the traffic network. Similar to today’s operation of traffic networks, traffic management and traffic control systems will have a coordinating, orchestrating and sometimes dictating influence on traffic flow and dynamics in support of societal and collective objectives. However, with the increasing autonomy and self-organizing capabilities of vehicles, the need for weighty involvement of infrastructure applications shifts to infrastructure-initiated scenarios which are further implemented by vehicles [5, 6]. For example, infrastructure applications may organise the formation of dynamic platoons, set targets for such platoons, but leave the details of its progress to the platoon as a self-organising unit. In MAVEN and as opposed to road trains, dynamic platoons exist on the fly and have a collective intelligence that is able to negotiate internally and externally and then make a collective decision. As such platoon leader is a position and not a management role meaning the platoon leader is the vehicle in front but is not necessarily in charge. In the remainder of this document ‘platoon’ refers to a dynamic platoon as defined here.

MAVEN objectives, contributions and expected impact

To bring the potential of cooperative automated driving at signalized intersections and corridors into reality, the MAVEN project explores the paradigm of a hierarchical self-organizing system: multi-level, top-down guidance of self-organising dynamic platoons of cooperative automated vehicles. With this approach, MAVEN fosters road transport automation at different interfacing levels as depicted in Figure 1. This figure also suggests the focus of the MAVEN project. While it covers topics from the Cooperative Vehicle and Traffic Management Centre (TMC) perspective, it focuses mainly on the management of automated vehicles, i.e. on the Cooperative Intersection (CI) level.

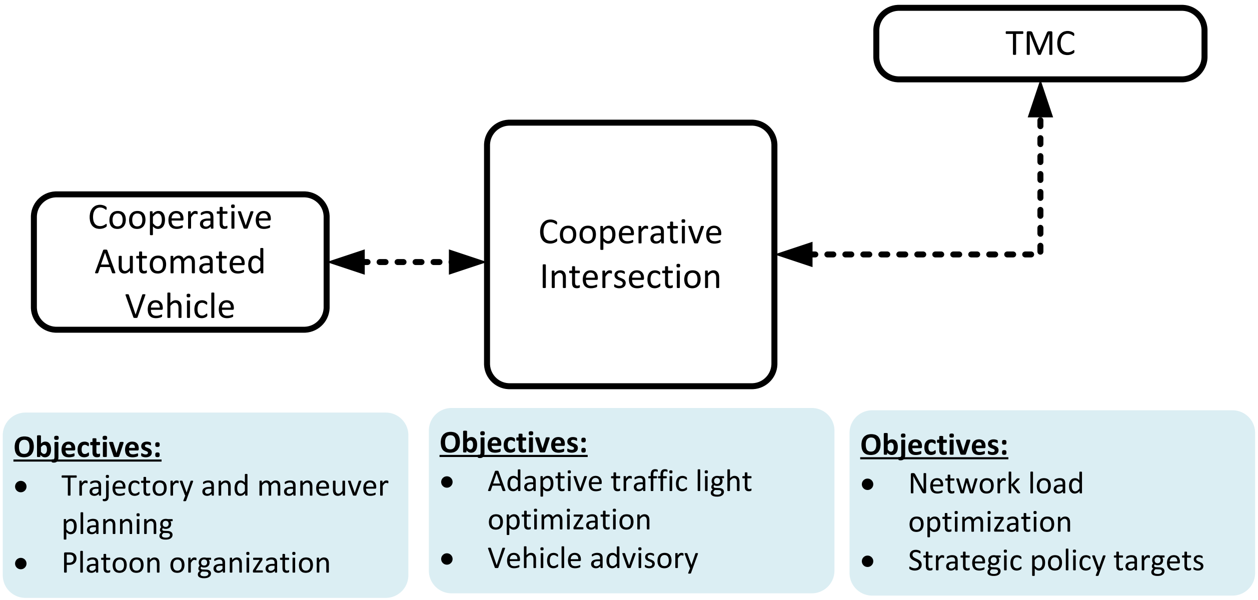

Figure 1 - MAVEN hierarchical self-organizing road transport concept

The originality of MAVEN is to develop and exploit cooperative automated driving applications at the crossing of (1) infrastructure versus vehicle systems' authority; (2) global versus local and societal versus individual users' objectives, and (3) traffic light optimization versus vehicle trajectory and manoeuvre optimization. This contributes to maximising the economic benefit of traffic flow while reducing energy consumption and environmental impact as well as ensuring traffic safety. Beyond the level of intersections and corridors, MAVEN will cyclically adapt routing strategies for automated vehicle clusters to local conditions and control strategies and vice versa. On the vehicle level this may imply for example automated lane change manoeuvres and automated detours. To complement this system, MAVEN will develop optimised ADAS technologies that exploit the benefits from integration with traffic management and infrastructure, and allow further simplification of the vehicle interface in order to reduce human error. The objectives of the MAVEN project are the following:

- Develop a generic multi-level system for the guidance of highly automated vehicles, applied to dynamic platoons at signalized intersections and signalized corridors. The system supports decentralized management functions at both vehicle and infrastructure level, with vehicles and traffic systems operating as interacting agents. At vehicle level, examples of such functions are infrastructure-assisted organization of dynamic platoons and platoon progression. From the road infrastructure perspective, adaptive traffic light control solutions based on cooperative vehicular data are considered. These functions will be based on transport policy goals, constraints and targets set in a top-down manner and weighted against local conditions and individual road users' preferences.
- Contribute to the development of C-ITS communication standards, in particular message sets for vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) interactions to support vehicle platooning and negotiation and scheduling algorithms. Additionally, MAVEN aims at exploiting

the increased accuracy and robustness of satellite navigation systems as well as high quality maps by harvesting lane-dependent state information and providing traffic light optimisation and guidance to vehicles with lane level precision.

- Develop and integrate ADAS techniques to prevent and/or mitigate dangerous situations taking into account Vulnerable Road Users (VRUs, e.g. pedestrians and/or cyclists). A mix of on-board vehicle sensors, infrastructure sensors and V2X communication will enable detection of VRUs. In safety critical situations, information about VRUs presence will affect vehicle manoeuvre algorithms and infrastructure management policies.
- Develop, test, demonstrate and evaluate the MAVEN system for signalized intersections and signalized corridors, including local level routing strategies, traffic light optimization and trajectory planning, by means of a real-world prototype vehicle and traffic simulation studies. Additionally, compare this MAVEN system to alternative approaches, such as bottom-up self-organization, and demonstrate that the MAVEN system is capable of improving network performance, energy use and safety, while increasing drivers' satisfaction.
- Produce a roadmap for the introduction of MAVEN-type systems. Identify steps to be taken by policy-makers, road-authorities, standards-development organisations and other stakeholders on the route to a high penetration of highly or fully automated vehicles.

The expected benefits of MAVEN include:

- Improved efficiency, safety and traffic flow and reduction of emissions
- Robustness and performance of sensor and data analysis systems
- Development costs, competitiveness and breakthrough technological solutions

[work ongoing: final version will elaborate expected benefits from different stakeholder perspectives]

Stakeholder consultation

The stated aim of this first MAVEN stakeholder consultation workshop 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 a first occasion to learn about and to share views on automation and urban transport. Hence, the discussion largely remained at a rather general level, covering the potential advantages and disbenefits of automated vehicles in the urban environment. Nonetheless, some requirements and recommendations emerged from the discussion that have bearing on the use cases, the demonstrations and impact assessment.

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 the 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 and land use
- 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
- Scalability of MAVEN system needs to be addressed, ie, 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 concern that alerting other road users to the presence of automated platoons could lead to 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 less 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 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
  - Automation has to be implemented incrementally for public acceptance reasons.

Aforementioned findings from the workshop have been incorporated in the use case descriptions and requirements collection step.

MAVEN use cases

MAVEN's vision is illustrated in the use case in Figure : Your fully automated vehicle turns onto an urban signalized corridor. While gaining speed your vehicle starts to overtake a platoon of six vehicles coming from an upstream intersection (A). When your vehicle and the platoon enter the communication range of the next intersection controller, your vehicle is instructed to join the platoon. As the last two vehicles of the platoon will leave the corridor at the next intersection, the platoon leader initiates a merging scenario. Your vehicle slightly decreases speed while the fifth vehicle in the platoon increases its headway to allow your vehicle to merge (B). Immediately after completing the merge your vehicle turns to following mode. The platoon leader registers the new platoon formation at the intersection controller, which in turn reiterates the start and duration of the green phase and returns updated platoon progression instructions. A few seconds later and due to a right of way situation involving pedestrians, traffic flow on the right lane will be low. Therefore, the intersection controller instructs the platoon leader to move to the left lane (C). The platoon leader cascades the instruction and initiates the lane change manoeuvre. The last two vehicles continue driving on the right lane, leave the platoon and return to individual mode. Shortly before reaching the intersection your vehicle slows down and stops (D). The intersection controller has given priority to an emergency vehicle coming from the left, now safely passing the green light. Right at the onset of green the platoon departs from the intersection with minimum start delay, heading for the next intersection.

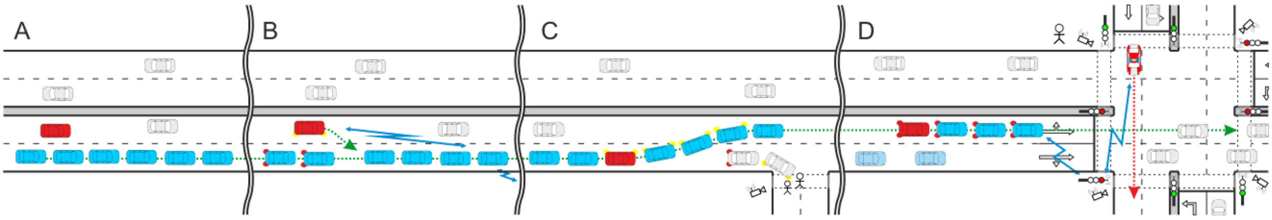

Figure 2 - MAVEN global perspective

The MAVEN project distinguishes sixteen use cases of which six are grouped under ‘platoon management’ and five are grouped under ‘signal optimisation’. In summary the objectives of these use cases (UC) are as follows:

- UC1: Platoon initialisation: One or more HAVs are triggered/recommended by the infrastructure to form a platoon directly or indirectly with other cooperative vehicles.
- UC2: Joining a platoon: After triggering, a single non-platooning HAV or a platooning HAV from another platoon joins an existing platoon.
- UC3: Travelling in a platoon: The HAV drives (follows/leads) in platoon until one of the following situations happen: leaving platoon (UC4), breaking-up (UC5), platoon termination (UC6) or any emergency situation (UC9).
- UC4: Leaving a platoon: A platooning HAV is triggered by the infrastructure or by the platoon leader to leave the platoon, or decides internally to leave the platoon, e.g. due to driver commands, route changes or technical needs.
- UC5: Platoon break-up: Platooning HAVs will react to a non-cooperative/non-automated vehicle by splitting up the platoon and allowing the lane change.
- UC6: Platoon termination: Platooning HAVs will react to this request and drive individually.

- UC7: Speed change advisory (GLOSA): To calculate a speed advice based on signal phase and timing information and to enable a vehicle or platoon to pass a signalised intersection in the most efficient manner.
- UC8: Lane change advisory: To distributed vehicles over the available lanes to make optimal use of the road capacity.
- UC9: Emergency situations: To mitigate the risks of unexpected events and to ensure traffic safety.
- UC10: Priority management: The objective of this use case is to balance the priorities according to the policies set by the road operator.
- UC11: Queue length estimation: With this improved queue length estimation a better control strategy should be possible and more accurate speed advice for GLOSA.
- UC12: Local level routing: The objective is to give vehicles an advice on a small horizon of <5 minutes which route to take.
- UC13: Network coordination – green wave: The objective of this use case is to create a dynamic green wave for HAVs in close cooperation with GLOSA speed advice with less impact on other traffic than traditional green wave systems have.
- UC14: Signal optimisation: Improve controller performance (reduced average delay and stops for all traffic) by using the new data and functionality of other use cases.
- UC15: Negotiation: Performing a bidirectional exchange of information for negotiations using communications from infrastructure and vehicles and back.
- UC16: Detect non-cooperative road users: Detection and characterization of complementing non-cooperative road users (vulnerable road users, non-cooperative vehicles) for their inclusion in relevant use cases.

A more detailed description and illustrations of the use case interactions (called scenario’s) and resulting system requirements is given in [7].

Conclusions

The MAVEN project (Managing Automated Vehicles Enhances Network) focusses on automated driving in urban areas and role of infrastructure, and aims to develop algorithms for infrastructure-assisted guidance of HAVs. This paper provided details on the system concept and use cases, its innovation and relevance, and results from a stakeholder consultation workshop with road authorities. Future work includes building a prototype system that will be used both for field tests and for extensive modelling for impact assessment. In addition, the project will contribute to the development of enabling technologies, such as telecommunication standards and high-precision maps. Finally, 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 MAVEN 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.

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