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Traffic Management of the future and Autonomous Vehicles

Dr. Evangelia Portouli[1*], Dr. Angelos Amditis[2], Dr. Panagiotis Lytrivis[3], Dr. Johanna Tzanidaki[4], Frans van Waes[5], Johannes Liebermann[6]

1. Institute of Communication and Computer Systems, Greece, v.portouli@iccs.gr
2. Institute of Communication and Computer Systems, Greece
3. Institute of Communication and Computer Systems, Greece
4. TomTom Group, the Netherlands
5. Vialis IT&M, the Netherlands
6. AustriaTech GmbH, Austria

Abstract

Traffic Management should be prepared to accommodate the circulation of autonomous vehicles in real traffic. A survey conducted among the members of the TM2.0 ERTICO Platform studied in detail the communication and infrastructure needs for the most relevant traffic scenarios involving autonomous and manually-driven vehicles. The discussions revealed that an intelligent local Traffic Management Centre, keeping a registry of autonomous vehicles, their status and planned trajectory, would be beneficial. Updates to standards will be needed to convey the additional information. The physical infrastructure and signs need to be conceptualised, designed and implemented and redundant smart algorithms and data quality procedures have to be established.

Keywords:

Traffic Management, Road Automation, Connectivity

Introduction

Considering the interest by the research and industrial community on road automation [1-5], it is expected that vehicles at higher levels of automation will start entering the real traffic soon. In parallel, the latest developments in the area of mobile and wireless communications will lead to the circulation of numbers of "connected" vehicles, i.e. vehicles that may communicate in real time with the traffic infrastructure. Thus, in the future the traffic fleet will be a mixture of manually-driven and autonomous vehicles, at several levels of automation, while a lot of these vehicles will be connected.

Traffic Management and how it may answer the needs of mixed and fully automated environments is one of the topics being discussed within the TM2.0 ERTICO Platform [6]. The Platform originated in 2011 and was formally established on 17 June 2014 during the ITS Europe Congress in Helsinki. It now comprises more than 25 members from all ITS sectors, focusing on new solutions for advanced interactive Traffic Management, and aims to agree on common interfaces, principles and business models which can facilitate the exchange of data and information between the road vehicles and the Traffic Management Centres, improving the total value chain for consistent Traffic Management and mobility services as well as avoiding conflicting guidance information on the road and in the vehicles.

The work presented in this paper was conducted by members of the TM2.0 ERTICO Platform working under the TM 2.0 Task Force (TF) on "*TM 2.0 and Road Automation"*. The objective of this work was to study how the Traffic Managers (TM) of the future should be ready to regulate and monitor the circulation of a mixed fleet of manually-driven and autonomous vehicles, aiming to achieve optimum usage of the road network, optimum efficiency of the traffic flow and maximum safety for all traffic participants. On the one hand, the work focuses on understanding how TM should be ready to handle specific traffic scenarios involving vehicles at several levels of automation. On the other hand, this work studies how TM may use in an optimum way the amounts and variety of data coming from connected autonomous vehicles.

The work started with the selection of traffic scenarios for urban and highway environments, which would rather need some type of regulation or flow control of mixed fleets by the TM. Then, the needs for data communication in each scenario and the necessary process for information exchange between the vehicles and the TM were analysed. This has resulted in the identification of i) needs for extensions and updates of existing data communications protocols and b) needs for new road and traffic infrastructure. Data quality, safety and security issues have been also reviewed.

2. Most relevant traffic scenarios

Based on discussions among the members of the Task Force, the following scenarios, involving autonomous vehicles, have been identified as being the most relevant for Traffic Management. For each use case described below, the current situation and the future vision are described. Data requirements and communication procedures are outlined, based on the ETSI or TISA protocols [7,8]. An intelligent local Traffic Management Centre (TMC) is often referenced in the following descriptions of future scenarios. This entity is envisioned as being responsible for monitoring and regulating the traffic in a specific area of the traffic network.

2.1 Traffic light signal and timing transmission

Human drivers see the traffic light status and its changes. In the future, the traffic light status can be digitally communicated to autonomous vehicles. As a minimum, this communication should convey the traffic light status. Still, if a digital communication channel is available, additional information can be transmitted, namely the time until the change in the traffic light status (time to red or time to green) and the intersection topology, that is the geographical representation of the road network in the vicinity of the traffic light. The information may be communicated to a connected autonomous vehicle either directly or via a service provider. Based on such additional information about the signal timing and intersection topology, the autonomous vehicles may employ more intelligent algorithms and the

service providers may offer more intelligent services, for example by calculating an optimal speed for smooth stop, if the light will change to red, or for a safe and comfortable crossing if there is enough time.
The local TMC could maintain a registry of autonomous vehicles in its area of control, for example by receiving Cooperative Awareness Messages (CAMs) including the level of vehicle's automation. The local TMC could communicate the traffic signal status and timing and the intersection topology, to all connected vehicles in its area of control, via a Signal Phase & Timing (SPaT) and a Map Data (MAP) message [8], and to service providers, via a Transport Protocol Experts Group (TPEG) message [9]. The service providers could communicate the information to their members. Autonomous vehicles should send an acknowledgement of receiving such communication.

2.2 Information about Road works ahead

Human drivers are informed about upcoming road works via numerous means, for example road signs, Variable Message Sign (VMS) announcements, navigation device alerts, head up display alerts, or via specific information services, either stand-alone or in cooperation with their navigation system. In the future information about road works can be digitally communicated to autonomous vehicles.
The local TMC could maintain a registry of autonomous vehicles in its area of control, for example by receiving CAM messages including the level of vehicle's automation. The local TMC could communicate the road works location and the resulting traffic obstructions, for example the closed lanes, to all the connected vehicles approaching the roadworks, via an In-Vehicle Information (IVI) message or a Decentralized Environmental Notification Message (DENM), and to service providers. Service providers could send the information to their member vehicles' navigation system via internet connection. An acknowledgement of reception by the autonomous vehicles of such communication will be beneficial for the TMC.

2.3 Policeman present at an intersection

Human drivers see the policeman's commands. According to the Traffic Law, the policeman's commands have priority over all other rules. In the future, the policeman's commands can be digitally transmitted to autonomous vehicles.
All vehicles could transmit their level of automation and their planned trajectory to the local TMC, possibly via a CAM. The policeman could carry a smartphone with an appropriate application, which would communicate the given commands to the local TMC. The local TMC could communicate the policeman's command to the autonomous vehicles, possibly via an IVI message, and to service providers, via a TPEG message. In the latter case, the service providers could communicate the command to their member vehicles.
Autonomous vehicles should send an acknowledgement of having received such communication.

2.4 Priority request by emergency vehicles

Human drivers hear the siren and see the flashing lights of emergency vehicles, like ambulances, police cars, fire brigade vehicles. In the future, the priority can be digitally requested by autonomous vehicles.

The local TMC could maintain a registry of autonomous vehicles in its area of control, for example by receiving CAM messages including the level of vehicle's automation. The emergency vehicle could communicate its priority status (flashing light on or off) to the local TMC, possibly via a CAM message. Additionally, the emergency vehicle could communicate its planned route, for example preferred lane or next turn. The local TMC could communicate the right to drive for each lane to all vehicles in its area of surveillance, via an IVI message, and to service providers, via a TPEG message, thus emptying the appropriate lane for the emergency vehicle. Autonomous vehicles should send to the local TMC an acknowledgement of having received such communication.

2.5 Dynamically assign lanes to specific vehicles

Human drivers are informed about lane restrictions via traffic signs, road signage, VMS or in-vehicle announcements. In the future dynamic lane restrictions can be digitally communicated to autonomous vehicles.

The local TMC could maintain a registry of autonomous vehicles in its area of control, for example by receiving CAM messages including the level of vehicle's automation. The local TMC could communicate restrictions per lane and time to all vehicles in its area of surveillance, possibly via DENM, SPAT/MAP or IVI message, and to service providers, via TPEG message. Autonomous vehicles should send to the local TMC an acknowledgement of having received such communication.

2.6 Extended Probe Vehicle Data collection and analysis

Probe Vehicle Data (PVD) is collected from connected vehicles via Cloud services and the sapling time is in the order of minutes. Critical data, namely data related to safety and imminent manoeuvres, are transmitted via CAMs, as agreed within the Amsterdam Group [10]. In the future, bigger amounts of vehicle data will be available due to the expected increase of connected autonomous vehicles in real traffic.

Probe vehicle data could be transmitted to the local TMC. The local TMC could send a Probe Data Message (PDM) to the vehicles, including the request to send their stored data. The vehicles could transmit the requested information to the local TMC via a PVD message, which should also include their level of automation. Vehicles connected to a Probe Data service could transmit their data to the service provider, including possibly additional information about safety and traffic density related aspects.

2.7 Unsignalised intersections support by Traffic Management

In unsignalised intersections human drivers typically interact among themselves so as to coordinate their passing the intersection. Such interactions may be based on flashing of headlights and even drivers' gestures or head movements. Human drivers also anticipate others' intent using other cues, like vehicle approach speed, speed and lateral position variation. These interactions are necessary for

the smooth coordination in traffic [11]. Autonomous vehicles currently lack such interaction capabilities and this leads to their driving behaviour being unpredictable by other traffic participants.
The local TMC could maintain a registry of autonomous vehicles in its area of control, for example by receiving CAM messages including the level of vehicle's automation. Vehicles approaching the intersection could communicate to the local TMC their planned trajectory, possibly via a CAM. An intelligent module in the local TMC could check the trajectories plans of the approaching vehicles and should assign priorities to them. The local TMC could communicate the priority to each vehicle, via an IVI message, or to service providers, via a TPEG message. Autonomous vehicles could send to the local TMC an acknowledgement of having received such communication.

2.8 Shockwave damping

In case of a shockwave, TM tries to reduce the inflow of vehicles in the traffic jam and to dissolve the jam as quickly as possible. Currently, information about the jam and speed advice are communicated to human drivers via VMS, in-vehicle services via navigation devices, or via specific information services, either stand-alone or in cooperation with their navigation system. In the future information about the location of the jam and speed advice can be digitally communicated to autonomous vehicles.
The local TMC could maintain a registry of autonomous vehicles in its area of control, for example by receiving CAM messages including the level of vehicle's automation. The local TMC could communicate the location of the jam and the speed suggestion to each vehicle, via an IVI message, and to service providers, via a TPEG message.

3. Key findings

3.1 Communication needs

It is expected that the TM of the future will have to communicate and regulate the circulation of mixed fleets of human-driven and autonomous vehicles, some of which will also be connected. This communication may be based on multiple technologies, including cellular communication, Wi-Fi, ITS-G5 and Bluetooth technologies. Redundant communication technologies should be considered, especially for safety-critical scenarios. The concept of hybrid communication is currently being discussed within the C-ITS platform [12] and within the Amsterdam Group [10].
According to the data requirements of the scenarios studied in this work, extensions or complementary definitions in standards will be needed to communicate the necessary information between the local TMC, the vehicles and service providers. The CAM should include information about the level of automation of the vehicle. This topic is under discussion in ETSI and it is expected to be included in the next release of the CAM specification.
It would be useful if vehicles approaching unsignalised intersections and emergency vehicles could communicate their planned path to the local TMC. The data needed for this should be studied and standardised, but it could include the vehicle position, speed and acceleration per time point for a certain time horizon. The time horizon and the granularity of information should be studied too. It should be studied, if such information may be encapsulated in a CAM message.

An updated IVI message specification will be required so that the local TMC may communicate the right to drive for each lane to all vehicles in its area of surveillance.

Several of the studied scenarios, like the emergency vehicle priority request and the unsignalised intersection control, require a high accurate geolocation reference.

Finally, autonomous vehicles should send confirmation to the local TMC of having received the information sent. This will be very beneficial for the TMC, especially for scenarios in which the digital message may be the only communication channel towards autonomous vehicles. A procedure and protocol so that the autonomous vehicles can confirm the reception of information is needed. Such an acknowledgment can be sent via a CAM, which should be appropriately specified. Liability implications deriving from such acknowledgements should be considered. As regards TPEG protocol, TM 2.0 is already cooperating with TISA to assess how such an acknowledgement may be possible.

In general as regards the TISA protocols, the communicated data can be transformed into a TPEG message, which will be sent to service providers, who will forward it to their members vehicles. A modification that will be needed in the TISA protocol is to include the confidence level of the incoming information, so that a reliable decision can be taken.

3.2 Needs for infrastructure

As regards needs for new infrastructure, the intelligent local TMC which is referenced in all the scenarios discussed, may be implemented as a roadside ITS station or at a traffic light controller or even as a unit in the cloud. This local TMC should be aware and should keep a registry of autonomous vehicles in its area of control. The registry of autonomous vehicles could possibly be integrated within a local dynamic map. Among others, this local TMC will be responsible to communicate information to the autonomous vehicles and to the service providers and to verify its reception by the autonomous vehicles.

Additionally, for signalised intersections, a specific interface of the traffic light controller to the local TMC should be put in place. Such an effort is already underway in the Netherlands and Austria. In several cases, traffic lights are already connected, so a web service giving access to a remote TM operator could be implemented. A smartphone application may be used by a policeman to transmit his/her commands to the local TMC. Physical segregation of restricted lanes may be necessary, together with new traffic signs and new road markings, similar to those used for bus lanes.

Correct dimensioning of the processing and communication network will be needed for extended probe vehicle data collection and analysis. As regards G5 such an effort has already started. For example, in crowded areas the signal strength is reduced to minimise disturbances. As regards LTE, an idea is to assign priorities in data transfer. For example, probe data exchange from autonomous vehicles could be prioritised against data download for entertainment. This prioritisation should be most probably the responsibility of the network operator. A flag in the data exchange, similarly to the one used for prioritisation of emergency calls, could be employed.

As regards unsignalised intersections, smart algorithms in the local TMC could calculate and propose appropriate speeds to all approaching vehicles. This smart module could additionally consider the strategies of the road authority. In such a case, priorities could be assigned with the general objective to reduce energy consumption and emissions or to increase efficiency. Assigning priorities in such a way can be much smarter than the historical right priority.

In cases of traffic jams, smart algorithms in the local TMC could calculate and propose an appropriate speed to each vehicle, so that the shockwave is diluted. Such smart algorithms may be much more efficient than single human drivers in estimating the optimum speeds, since the human drivers do not have a general overview of the situation. Such a strategy will be much more effective, if the speed suggestion by the TMC is compulsory for the autonomous vehicle.

3.3 Data management, systems redundancy, data privacy and integrity aspects

As regards data, locally generated data should stay locally and only information of relevance to higher level of TM should be passed to a higher level. This layered way of handling data and information should be further studied in the future. Taking into account that the same data may originate from different sources, systems or accounts, rules and procedures on how to compare inconsistent data and take decisions are needed. Data from different sources should be related in time or location. Detailed and reliable information about intersections topology and about lanes should be available. Dynamic data about roadworks should be available to the TM of the future in digital format, including position, length and lane that is obstructed. It should be noted that today the majority of roadworks information is not of high quality level with regards to the accuracy of start and end locations and the exact start and end times. Public authorities should ensure that accurate data are available. In several of the studies scenarios, a high accurate geolocation reference is required.

Additionally, redundancy of systems and processes should be ensured. Redundant intelligence should exist on the vehicles themselves, in case of failure in the local TMC. For example, in the case of unsignalised intersection support, in case the local TMC is not operating properly, the autonomous vehicles should be able to safely cross the intersection in collaboration with the surrounding vehicles. Similarly, in case of priority request by an emergency vehicle, (Car-to-Car) C2C communication may be employed in case the roadside local TMC is not operating. This is especially intriguing in case of the policeman regulating the traffic, as in such a scenario the autonomous vehicles should themselves be able to perceive the policeman’s commands. Redundancy of the communication network itself is also advisable. Another crucial issue for safety and quality of service is that the local TMCs should be inter-connected, so that there are no boundaries for the vehicles.

Finally, privacy is another aspect that requires attention. EU law describes that data transmitted and archived cannot be traced back to an individual. Data have to safeguarded from hacking and archive or abuse without the data owner’s consent. It is very important to have tamper-proof connected autonomous vehicles and connected infrastructure nodes to avoid cyberattacks and in turn any possible degradation of the offered TM services. Especially in the future where the motion of autonomous vehicles will be heavily affected by the TM instructions, one should safeguard security and safety of all road participants and avoid misuse or faking of C-ITS messages from hackers or even terrorists. As regards, reception of messages by the autonomous vehicle, one significant yet open issue is the way that the reception of an authentic message ensures the trustworthiness of its sender. Data integrity, typically guaranteed by security controls such as hash functions and digital signatures could cause fatal consequences if breached in case of autonomous vehicles.

4. Conclusion

As a conclusion, road infrastructure and TM may play a significant role in order to facilitate the gradual introduction of autonomous vehicles on real roads. Specifically, the TM should be well prepared in advance to smoothly handle the transition period, when human drivers and autonomous vehicles will share the road network.

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