Cooperative ITS Challenges: AUTOCITS Pilot in Lisbon

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***Abstract*—Cooperative, connected and automated Intelligent Transportation System (ITS) aims to improve road traffic safety, comfort, security, and traffic management by sharing data/information among vehicles, infrastructure and road users. Cooperative ITS (C-ITS) also targets the reduction of environmental impact by the road transportation systems. Regarding self-driving vehicles, C-ITS plays a complementary role for enhancing on-board vehicle sensory data and thus making autonomous vehicles more robust and safe. In this paper we present the C-ITS platform, the test-cases and scenarios to be performed during the Lisbon Pilot of the AUTOCITS project. We also provide a description of the C-ITS Day-1 services, as simulated and also real-world events, that will be deployed and evaluated during the test-cases. Conventional, instrumented and autonomous vehicles will take part on the Lisbon Pilot, all equipped with on-board connected vehicular technologies. Two scenarios will be considered, motorway and urban-node scenarios, having distinct vehicles and test-cases, but all sharing the same C-ITS technology framework.**

***Index Terms*—C-ITS, connected vehicles, autonomous driving.**

I. Introduction

In the directive of the European Union [1], intelligent transportation system (ITS) is defined as 'systems in which information and communication technologies are applied in the field of road transport, including infrastructure, vehicles and users, and in traffic management and mobility management, as well as for interfaces with other modes of transport'. However, based on the recent advances on vehicular technologies for ITS, referred as V2X technologies, and the rapid progress witnessed in the technologies around automated systems for vehicles, currently the term C-ITS, which stands for cooperative ITS, has been used most often than ITS. The combination of C-ITS and autonomous vehicle (AV) technologies gives rise to the so called connected autonomous vehicles (CAVs) [2], [3]. Both technologies, AV and C-ITS, are two pivotal factors to improve safety and efficiency of mobility systems in the near-future.

(a) (b)

Fig. 1. Some connected autonomous vehicles to be tested in the Lisbon Pilot. Shuttle vehicles, as in (a), will be used in urban-node scenario, while instrumented and autonomous vehicles, like the one in (b), will be deployed in motorway scenarios.

The generation of AVs we see today belongs to the levels 3 or 4 (with respect to the SAE's levels of automation in vehicles). The key system of an AV is its perception system, which is in charge of all tasks related to Object and Event Detection and Response (OEDR). Therefore, a perception system is responsible for sensing, understanding and reasoning about vehicles surrounding [4]. Besides the software modules, data from in-vehicle sensors (*e.g.*, Vision, RADAR and LIDAR) also plays a key role in a perception system for autonomous driving. Within a C-ITS environment, CAVs would leverage and complement on-board sensor data by using information from vehicular communication systems (*i.e.*, V2X): information from other connected vehicles, from infrastructure and road users (and *vice-versa*) [5].

Although much has been said about autonomous driving and C-ITS, it is necessary to test and assess such technologies in real-world conditions [6]. In Europe, a dedicated website was recently created to disseminate the projects and initiates addressing C-ITS and AVs, which is available

Part of this work is funded by the project AUTOCITS - Regulation Study for Interoperability in the Adoption of Autonomous Driving in European Urban Nodes - Action number 2015-EUTM-0243-S, co-financed by the European Union Innovation and Networks Executive Agency - Connecting Europe Facility (INEA-CEF).

here: https://connectedautomateddriving.eu/. In this context, the AUTOCITS[1] project [7] aims at integration of the C-ITS infrastructure and deployment of CAVs in Madrid, Paris and Lisbon [8]. The outcomes of the AUTOCITS project are expected to contribute to large-scale deployment of CAVs in Europe, and to update legal framework at National and European levels concerning autonomous driving systems. This paper, in particular, focuses on the role of C-ITS services and autonomous driving in the Lisbon Pilot. Figure 1 shows some of the CAVs to be used in the Lisbon Pilot.

The structure of this work is as follows, a description of the employed C-ITS services and communication equipment is provided in Section II, while the test-cases and scenarios are described in Section III. Finally, section IV brings concluding remarks and points out future work.

II. C-ITS FRAMEWORK AND EQUIPMENTS

A C-ITS infrastructure is basically composed of a traffic management center (TMC): centralizing data/information received from vehicles and infrastructure; roadside units (RSUs): stationary wireless access devices enabling the communication between roadside infrastructure and vehicles; and onboard units (OBUs): mobile wireless devices mounted in-vehicle sides and supporting information transmission of OBU–OBU (V2V) and OBU–RSU (V2I/I2V) [9], [10], [11].

The C-ITS framework defined for the AUTOCITS Lisbon Pilot will be managed by a TMC, which will make use of ITS-G5 (5.9 GHz) and 3G cellular communications, and will be responsible for the management of all the information exchange between the connected equipments. The RSUs will be interconnected by TCP-IP network to the TMC platform, and will broadcast messages needed to support V2I/I2V applications. Each RSU to be used in the Lisbon Pilot, shown in Fig. 2, will be composed by a radio module, together with a processing board and two antennas, GPS antenna and radio antenna respectively, with an influence range between 500 and 1500 m depending on the landscape, the horizontal/vertical alignment and the existence of dwellings in their vicinity. The ITS-G5 stations, configured as RSUs, will be mounted inside the road side equipment cabinets along the highway (see Fig. 2 (c)). These cabinets have already power and TCP/IP communications, being only necessary to install the radio and GPS antenna outside, near to the cabinet.

The ITS-G5 stations configured as OBUs, shown in Fig. 2 (a), will be installed on-board the test vehicles. Each vehicle will be equipped with one 5.9 GHz antenna placed on the roof as well as an external GPS antenna in order to synchronize communications and to provide GPS data. The OBU is powered by the vehicle battery through the 12V DC lighter plug. This system has a human machine interface (HMI), being this the App that runs in a tablet, connected to the OBU through a USB cable.

The messages sent by RSUs were defined by ETSI TC ITS which is produced by European Telecommunications

[1] http://www.autocits.eu/

(a) (b) (c)

Fig. 2. OBUs (onboard the vehicles) and RSUs (installed in the infrastructure) to be used in the AUTOCITS Lisbon-Pilot.

TABLE I
SUMMARY OF C-ITS TEST-CASES ON MOTORWAY.

Scenario	C-ITS Test Event	Event Type
Dedicated Lane	Low road adhesion due to ice on the road	Simulated
	Stationary vehicle due to break down	Realistic
	Rock falls detected on the road surface	Simulated
	Big objects detected on the road	Simulated
Shared Lane	Low visibility due to heavy rain	Simulated
	Awareness about strong winds	Simulated
	Soft hail	Simulated
No Restriction	Traffic jam volume increasing	Simulated
	Slow driving maintenance vehicle	Realistic

Standards Institute Technical Committee Intelligent Transport System (for example see [12]), and belong to the Decentralized Environmental Notification (DEN) basic service that supports road hazard warning. These messages serve the propose of spreading information about spontaneous events that can happen on the road, like a car breakdown, or ice on the road.

The types of vehicle technologies that will be involved in the Pilot, all equipped with OBUs, are: autonomous Shuttles, autonomous vehicles (level 3-4), instrumented cars (for sensor data collection), and traffic control vehicles (TCV). The AVs will be subjected to a series of event-messages, categorized as ‘Simulated’ and ‘Realistic’. Simulated messages are generated at the TMC according to virtual events, while realistic messages will be triggered by a real-world event, for example a TCV on the roadside. A summary of the test-case scenarios planned to be carried out in the Pilot is presented in Table I. The following section will further detail the setup for the test-cases and scenarios.

III. C-ITS SCENARIOS AND TEST CASES

In motorway conditions, and considering the base scenario illustrated in Fig. 3, the following definitions and conventions will be adopted.

• *Destination area:* is where the vehicle (connected) will repeatedly receive warning message(s) for the respective event;

• *Pre-event action:* is where the vehicle may need to slow down and/or change lane (if applicable) to maintain safe conditions while traveling;

• *Event:* zone where the vehicle must maintain safe conditions for a given distance, this can be a single point obstacle, and it can be stationary or moving on the motorway;

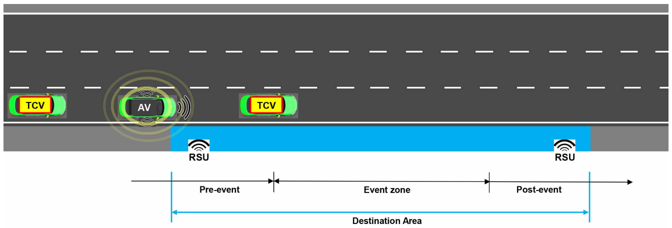

Fig. 3. Illustration of the base/reference scenario for the use-cases in motorway conditions, showing the destination area and the event-actions zones.

• *Post-event action:* is where the vehicle should return to its initial (and regular) traffic condition.

In the motorway/highway scenario, the test-cases considered in the Lisbon Pilot will be evaluated based on three conditions: dedicated lane, shared lane and road without restrictions. The test-cases are described in the sequel.

A. Dedicated lane: the leftmost lane

In this case, dedicated lanes will be segregated from normal traffic by means of vertical signs, variable-message signs (VMS's) and traffic control vehicles (TCVs), as well law enforcement agents from local authority. Before each test, the AVs will be driven manually to the beginning of the dedicated lane and then switched to automatic/autonomous mode. Four test-cases (three simulated and one realistic events) are proposed, as described in the following sub-sections.

1) Low road adhesion due to ice on the road: Low road adhesion due to ice on the road will be a simulated event, where the TMC generates the respective message for a predefine location. Just after receiving the DEN message for the simulated event "ice on the road", the AV should start to reduce its speed. As soon as the AV reaches the end of the Event zone (*i.e.*, the Post-event zone) it will accelerate again to the previous speed. At the end of the test the vehicle must be switched to manual driving. Figure 4 (a) illustrates this test-case.

2) Stationary vehicle due to break down: The "stationary vehicle due to break down" will be a test-case using a real-world obstacle (a realistic event generated by a connected TCV). In a predefined location, a connected vehicle will act as a break down stop on the roadside (as shown in Fig. 4 (b)) with the adequate signaling and will broadcast the DEN message with the respective cause code event. The TCV in the front will start slowing down in the Pre-event zone, while the AV is already in autonomous mode. The DEN message for the event of the stationary vehicle will be received by the AV and it should start to reduce its speed and then make the lane-change correctly (at this point there is a TCV holding the traffic back: as indicated in Fig. 4 (b)). After the AV passes the obstacle, it will accelerate again to the nominal speed and return to the original lane. At this point the test is considered finished and the AV should be switched to manual driving.

3) Rock falls detected on the road surface: Rock falls detected on the road surface will be a simulated event. A connected vehicle broadcasting the DEN message for the event that is taking place will be driving ahead of the autonomous vehicle and, while passing the event location, will generate the respective message for the predefined location, continuing to send this message until the test ends. A TCV will start slowing down the traffic behind the AV. As the traffic control vehicle approaches the beginning of the dedicated lane, the autonomous vehicle will start in self-driving mode. After the DEN message for this simulated event is received, the AV should start to reduce its speed and change lane (at this point there is a TCV holding the traffic back). When the AV reaches the end of the reference of this event, will accelerate again to the previous speed and then the vehicle must be switched to manual driving, ending the test (see Fig. 4 (c)).

4) Big objects detected on the road: Big objects detected on the road will be a simulated event, as shown in Fig. 4 (d). In this case, the detected obstacles are big objects (obstacle on the road). A connected vehicle will be driving ahead of the autonomous vehicle and, when passing the event location, will be generated the respective message for that event location, continuing to send this message until the test ends. The connected vehicle will be used with the objective of broadcasting the DEN message for the event that is taking place. A traffic controlling vehicle will start slowing down traffic before the beginning of the dedicated lane. The connected vehicle will drive to the event location and start sending the message for the event of big objects on the road while continuing to move on the road. For realism purposes, this vehicle can also slow down at the event perimeter. As the traffic control vehicle approaches the beginning of the dedicated lane, the autonomous vehicle will start in autonomous driving from the beginning of the dedicated lane and will accelerate to a predefined speed limit (for example, 100 Km/h). The DEN message for the simulated event of big objects on the road will be received. The action expected from the autonomous vehicle is that it should start to reduce its speed and change lane (at this point there is a vehicle holding the traffic back for safety reasons). When the autonomous vehicle reaches the end of the reference of this event, it will accelerate again to the previous speed. After that the test will be finished and the vehicle must be switched to manual driving.

B. Shared lane

The shared lane case does not have barriers (*i.e.*, the TCV-based corridor) to segregate the autonomous vehicles from the traffic, as illustrated in Fig. 5. The real traffic can use any of the lanes in any circumstance but, the autonomous vehicles must only use the left-most lane. This so called shared lane case will be sufficient for reducing speed actions required for the events chosen. For this case, three tests are proposed.

1) Low visibility due to Heavy Rain: In this event, the cause of low visibility is heavy rain (low visibility). This will be a simulated event and the TMC will generate the respective message for the predefine location, as shown in Fig. 5 (a).

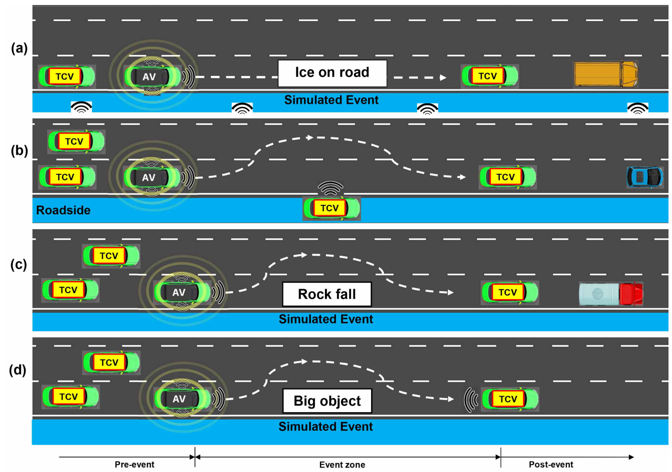

Fig. 4. Dedicated lane case, where TCVs are used to control the traffic and to create a dedicated/separated moving corridor. The Day-1 based test cases are: (a) low road adhesion due to ice on the road (simulated); (b) stationary vehicle due to break down (real-world event); (c) rock falls detected on the road (simulated event); (d) big object on road (simulated event).

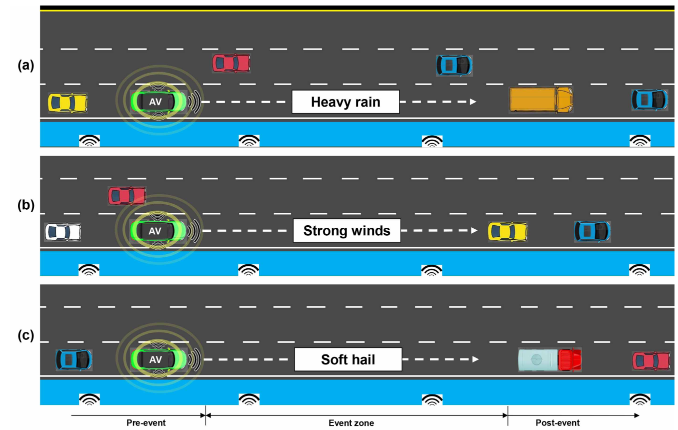

Fig. 5. Shared lane case, where TCVs are not used to control the traffic and "conventional" vehicles are allowed in all lanes. AVs should always maintain the route on the leftmost lane.

2) Awareness about Strong Winds: In this test-case, illustrated in Fig. 5 (b), the type of extreme weather condition is strong wind (strong lateral winds destabilize driving). This will be a simulated event and the TMC will generate the respective message for the predefine location.

3) Soft Hail: In this case, the type of precipitation is soft hail (low visibility). This will be a simulated event and the TMC will generate the respective message for the predefine location (Fig. 5 (c)).

For each of the above mentioned services, the connected TMC will generate the respective message for a predefine location. The AV will switch to autonomous mode in the beginning of the shared lane, while located in the pre-event zone. Based on the received and interpreted DEN messages by the AV, related to one of the events described above, the AV should start to reduce its speed once located in the event area. As soon as the vehicle reaches the end of the event-zone, the AV will accelerate again to the previous speed. Subsequently, as the AV passes the Post-event zone, the test will finish and the vehicle must be switched to manual driving.

C. No restrictions

The "road without restrictions" situation means that no physical barriers or any other means of constraints exist and autonomous vehicles are mixed with current traffic, changing lane or reducing speed whenever it's necessary. In this case two test events, one simulated and another realistic, are proposed as follows.

1) Traffic jam volume increasing: it will be a simulated event. A connected vehicle will be driving ahead of the AV and, when passing the event location, will generate the respective message for a predefine location, continuing to send this message until the test ends. For realism purposes, this vehicle can also slow down at the event perimeter. The AV will switch to autonomous mode in the beginning of the motorway section, while keeping a safe distance from a connected vehicle ahead. As soon as the 'traffic jam' message for the simulated event is received and processed, the AV should start to reduce its speed and maintain this behavior until it reaches the traffic jam zone, enabling its systems to react with more time in case of changing lane or even a complete stop. After the TMC sends the termination message (no more traffic jam), the autonomous vehicle will recover its previous (nominal) speed and, finally, after the test is concluded the vehicle must return to manual driving mode.

2) Slow driving maintenance vehicle: it will be performed using a real-world obstacle on the road in a certain location. A maintenance vehicle will travel slowly at the roadside, broadcasting the respective DEN message to alert other approaching vehicles with the same heading from the risk associated to this potential dangerous situation. The test begins when the AV approaches the pre-event area and, at this point, the AV has to be in autonomous mode. From a certain distance from the 'slow driving maintenance vehicle', and assuming the DEN message for this event has been received and processed, then the AV should start to reduce its speed and execute the lane-change. After passing the maintenance vehicle, the AV has to accelerate to reach its previous speed and also return to the original lane. After all manoeuvres have been completed, the test will be finished and the AV should be switched to manual driving mode.

D. Autonomous Shuttles

In Lisbon Pilot, two autonomous shuttles will be used for the scenario designated as urban-node. These shuttles are based on a technology, called MOVE, developed by IPN[2]. Essentially, MOVE is a driverless electric vehicle, designed to be easily used for small trips at low speed, with the aim to be a horizontal lift able to connect buildings of private or semi-private spaces.

[2]https://www.ipn.pt/

The autonomous shuttles will circulate on a dedicated road situated in Lisbon urban zone, transporting people along a pre-defined route. No other kind of vehicles will have access to the road dedicated to Shuttles. In the same way as for autonomous vehicles, the behavior of the autonomous Shuttled within a C-ITS environment will be tested based on two types of actions: 'reducing speed' and 'changing lane'. The test-cases will be performed according to the following C-ITS services (one realistic and two simulated): 'Stationary vehicle due to a stopped public transport'; 'Low road adhesion due to ice on the road'; 'Low visibility due to heavy rain'.

Stationary vehicle due to a stopped public transport will be a non-simulated test-case proposed for the urban-node scenario. For this case, one Shuttle (operating as a public transportation vehicle) will stop at a predefined location and will broadcast the appropriated message associated to this event. Then, another connected autonomous Shuttle driving in the same direction, and approaching the stopped Shuttle, will reduce its speed and, if necessary, will stop completely. The behavior of the second Shuttle will depend on the received C-ITS messages and also on its LIDAR-based perception system.

The services 'Low road adhesion due to ice on the road' and 'Low visibility due to heavy rain', both will be simulated events generated by the TMC and broadcast through the local RSUs, will generate a similar behavior by the autonomous Shuttles. For these test-cases, and based on the correct interpretation of the received messages, the autonomous Shuttle are expected to reduce its speed when entering the destination zone.

IV. Remarks and Future Work

This paper describes the C-ITS framework, the RSU and OBU technologies, and the test-cases to be deployed in the AUTOCITS Lisbon Pilot under distinct scenarios. Several test-cases, based on C-ITS Day-1 services and connected autonomous vehicles (CAVs), are particularly detailed in this work. Considering motorway and urban-node (in Lisbon urban zone) scenarios, the proposed test-cases are designed to evaluate the role of cooperative ITS infrastructure and CAVs under realistic situations. Finally, and considering a more comprehensive scope of the AUTOCITS project, we hope that this work can also contribute to the deployment of C-ITS and self-driving technologies in Europe and abroad. As future work, and as part of the AUTOCITS's goals, we will elaborate a methodology and protocols for assessment of the Pilots; moreover, and based on the experience and field data from the Pilots, we will prepare documentation and reports as a means to contribute to further deployments of CAVs in Europe.

Acknowledgements

This work has been partially supported by "AUTOCITS - Regulation Study for Interoperability in the Adoption of Autonomous Driving in European Urban Nodes" - Action number 2015-EU-TM-0243-S, co-financed by the European Union Innovation and Networks Executive Agency - Connecting Europe Facility (INEA-CEF), and also co-supported by MATIS - "Materiais e Tecnologias Industriais Sustentáveis" - reference CENTRO-01-0145-FEDER-000014.

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