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ABSTRACT:

Over the last years, significant resources have been devoted to developing new automation technologies for vehicles, whereas investment for road infrastructure, in general, has steadily dwindled. INFRAMIX is preparing the road infrastructure to enable the coexistence of conventional and automated vehicles. Its main target is to design, upgrade, adapt and test both physical and digital elements of the road infrastructure, ensuring an uninterrupted, predictable, safe and efficient traffic. For that purpose, new advanced microscopic traffic flow models, advanced simulation techniques and innovative control strategies will be employed. In order to provide a clear impact, INFRAMIX developments will be evaluated on user appreciation, transport efficiency and safety performance through three high-value traffic scenarios: (1) Dynamic lane assignment, (2) Roadworks zones, and (3) Bottlenecks. Tests of the three scenarios will be performed in real-life conditions, at the project test sites, and also through extended simulations, especially in high penetration cases. Special attention will be paid to assess the users' appreciation regarding the proposed information chain, the adequateness and understandability of visual and electronic signals, as well as the integrated control algorithms. Setting the respective research questions for the selected traffic scenarios, leading to new safety and performance criteria for mixed traffic, is an indispensable part of the evaluation methodology for such a complex and novel project. The evaluation methodology will be structured considering also the project objective of establishing an infrastructure classification scheme, which will set the basis for a timely deployment of an automation-appropriate infrastructure network.

Assessment of Road Infrastructure advances for Mixed Vehicle Traffic flows: the INFRAMIX approach

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1 INTRODUCTION

As more and more automated functionalities are incorporated in vehicles, the role of the road infrastructure in actively assisting them, has been vastly recognised. Although driveless vehicles have, in principle, been designed to operate independently using in-vehicle sensors, there are requirements that the road infrastructure should meet to enable their operation. (Zhang 2013), assigned infrastructure requirements to the different vehicle automation levels of NHTSA (National Highway Traffic Safety Administration 2018). Nowadays, road infrastructure is designed to accommodate for the circulation of conventional vehicles (human-driven vehicles). However, the role of the infrastructure is vital in managing the transition period when the penetration rate of Automated Vehicles (AVs) will gradually increase. In the near future, the infrastructure is called to enable and support the coexistence of conventional and AVs, accommodating for mixed traffic flows.

In this direction, the cooperative future, as it is envisioned by various researchers and automotive manufacturers, would not be possible without an active role of the infrastructure in the traffic flow management (Raposo et al. 2017), (Vantomme 2018). As a step further (Cheon 2003), made an infrastructure clustering in automation levels. In the first level, named "the infrastructure supported", the road infrastructure supports vehicle decision-making while in the highest level, named "the infrastructure controlled" characterizes an infrastructure that has the full traffic control in all driving situations. Preliminary infrastructure requirements have been also set for a Coordinated Automated Road Transport (C-ART) future, as it is envisioned by (Raposo et al. 2017). Furthermore, in (Vantomme 2018), a cooperative road transportation future is presented where the infrastructure has an indispensable role. (Shladover 2017), points out the potential support that the road infrastructure could provide towards automating road transport. Apparently, developments in road infrastructure are necessary in order to realize the vision of automated transportation. The incremental upgrades of the road infrastructure will enable the coexistence of vehicles with different automation functionalities and will minimize the incidents of misuse of the automated functions related to their operational design domain, as defined at (SAE Standards 2014).

Despite the recognition of its vital role, the road infrastructure development is not proportional to the rapid deployment of the new automated vehicle's technologies during the last decade. Consequently, the transportation research focuses mostly on the assessment of the novel automation functionalities (Barnard et al. 2015), (Innamaa & Kuisma 2018), rather than on the impact caused by road infrastructure upgrades.

Assessment of the impact that the road infrastructure development would impose in a potential mixed traffic flow is an endeavor, which implies multiple challenges. Firstly, the precise definition of such a complex system, that characterizes the road infrastructure which includes the required functionalities to accommodate conventional and AVs simultaneously, does not exist. Moreover, the lack of real data and existing statistics from interaction of automated vehicles with road infrastructure, due to the minimum AVs currently in the streets, is an additional issue. Another challenge is the fact that important parameters of a mixed vehicle traffic flow, such as the expected penetration rate of the AVs through the years, are based on assumptions. Additionally, a structured and concise evaluation methodology analogous to the ones for the automated functions (e.g. FESTA, (FESTA 2016)) is still under investigation.

This is exactly the purpose of this paper, the presentation of an evaluation methodology suitable for a "hybrid" infrastructure where different types of vehicles are driving. This methodology is currently under discussion within the EU project INFRAMIX[1] and it is based on FESTA version 7 (FESTA 2016) originally developed for Field Operation Tests (FOTs), while addressing major transportation concerns which hassle the introduction of the AVs. The evaluation areas are the following: traffic safety, traffic efficiency, users' appreciation and technical feasibility.

The "hybrid" road infrastructure in INFRAMIX is primarily designed to take care of three critical traffic scenarios (in terms of importance with regard to traffic efficiency and safety), without loss of generality (Lytrivis et al. 2018). These scenarios will be the basis for the impact assessment and evaluation:

[1] https://www.inframix.eu/

- Dynamic lane assignment
- Roadworks zone / Construction site
- Bottlenecks

This work presents the hybrid infrastructure in the first section. The second section gives an overview of the traffic scenarios under investigation and the third one describes the evaluation methodology. The next section describes the future work, while the conclusions are drawn in the last part of this paper.

2 HYBRID ROAD INFRASTRUCTURE

While significant resources have been devoted to developing new automated vehicle's technologies, investments and resources for road infrastructure have been, in general, decreasing in the last decade. Little work has been done on the way the infrastructure could support and handle the introduction of automated driving systems on the roads, while maintaining, if not enhancing, traffic flow efficiency and safety. On top of that, one has to consider three additional important factors: a) road infrastructure's average lifecycle is well above (3-4 times higher) the average lifecycle of a vehicle, b) the high cost related to infrastructure's construction and maintenance and c) the limited space available for building new roads (esp. in urban environments).

All the above converge to the fact that there is a need for deploying innovative technologies also at the infrastructure side. So, apart from the obvious adaptations, which are necessary at the level of the physical road infrastructure in order to cater for automated driving, corresponding digital advances, such as the creation of High Definition (HD) maps and new electronic signals, are also a must. This leads to the need for the provision of a "hybrid" road infrastructure (both physical and digital) which will be ready to cope efficiently with the new safety challenges emerging from the introduction of AVs and especially within the transition period.

(Lytrivis et al. 2018), highlights the need to design new and adapt existing physical or digital infrastructure elements (e.g. segregation, traffic signs, electronic horizon etc.) in order to allow the current infrastructure to address the introduction of automation in a flexible, fast and cost-effective way, while being understood by all traffic participants, automated or not. In order to achieve that, the "hybrid" infrastructure concept merges the physical and digital infrastructure into one system. Physical infrastructure consists of the roads, road signs, road markings, gantries, etc. that form part of the physical world where vehicles operate. At the same time, digital infrastructure is defined as the static and dynamic digital representation of the physical world with which the vehicle will have to interact (OECD/ITF 2015). For instance, high definition maps, dynamic traffic information and advanced advice related to optimum routing are some of the state-of-art technologies which are included in the digital infrastructure part.

A preliminary concept is conceived by the INFRAMIX project regarding the "hybrid" road infrastructure with time horizon 2020. Figure 1, depicts this concept for a traffic scenario when a lane is assigned to AVs.

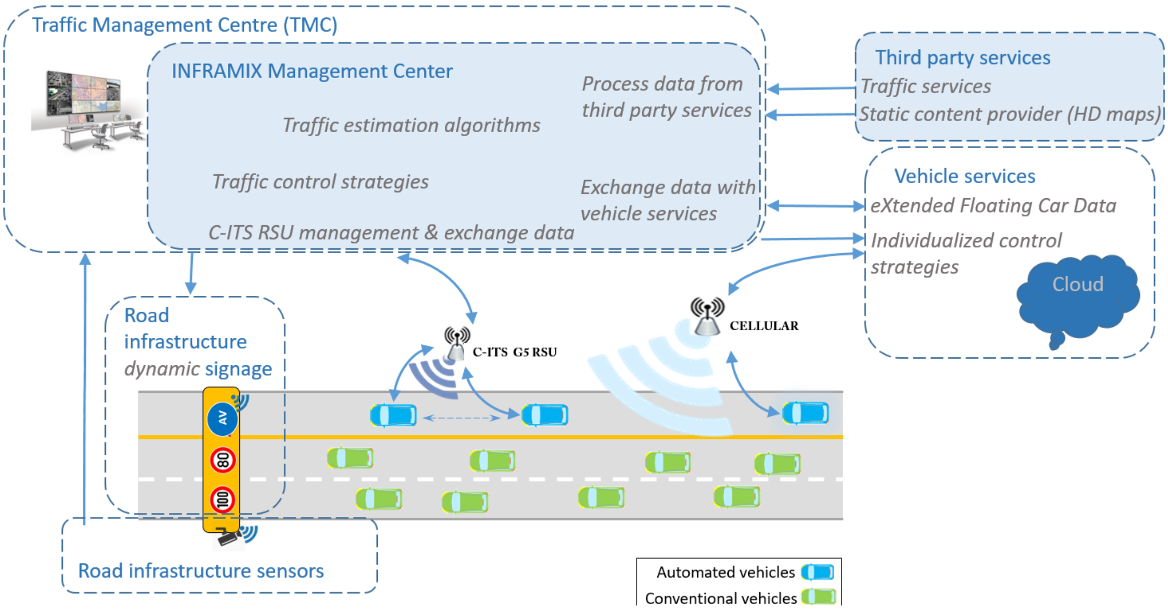

Figure 1. INFRAMIX high-level architecture (source: H2020 INFRAMIX project 2018[2]).

[2] Available at : https://www.inframix.eu/

In order to provide an overview of the challenges on the implementation and assessment of such a complex concept, a closer analysis of its consisted elements is necessary. The following paragraphs give an overview of the current status of each component (depicted in Figure 1) and the required upgrades in order to address the challenges assuming mixed traffic flows within INFRAMIX project.

Road infrastructure dynamic signage

As the road infrastructure nowadays is built to accommodate conventional vehicles (human driven vehicles), the visual signs provide mainly static information (e.g. speed limits). Modern highways include also dynamic signage (e.g. traffic jam information, weather conditions warnings etc.) through Variable Message Signs (VMS). Nevertheless, this is only to be recognized by human drivers. For mixed traffic flow new visual and electronic signals that communicate information, issue warnings or provide guidance to all highway users (conventional and automated vehicles) need to be implemented.

In the “hybrid” infrastructure concept, the use of the current road infrastructure communication elements is investigated to facilitate the infrastructure-to-vehicle (I2V) communication with the vehicles which are not connected with the traffic management center (e.g. conventional vehicles). Moreover, novel signaling content related to innovative traffic management, like the lane assignment to AVs (see Figure 1), needs to be investigated. This is a challenging part especially for the evaluation, as the human drivers’ appreciation of new content of signaling plays an important role in the acceptance of novel traffic management functionalities. Another challenge, related to the development of the physical infrastructure, is the automatic and the real-time communication between the road infrastructure elements and the traffic management center (TMC). Currently, even in modern highways, the changes in the dynamic signaling is made manually by the road operator located at the TMC. This causes a delay which might be a limiting factor for dynamic traffic control.

Related to the in-vehicle signaling and guidance of the AVs (or to the vehicles which just have on-board equipment that permits V2I and I2V communication), different alternatives will be investigated such as nomadic and cooperative systems. To enable such systems road infrastructure should not only be equipped with Road Side Units (RSUs) (e.g. for the ITS-G5 network) but also should handle the challenges of sending at the same time a specific message to all users through different networks (e.g. LTE-V and ITS G5 as shown in Figure 1).

Considering a wireless bi-directional communication with the AVs, ITS specific wireless messages extensions are required. Therefore, the enhancement of existing messages like MAP, CAM, DENM and other C-ITS messages expected to be proposed (ETSI TS 103 301 2016), (ETSI EN 302 637-3 2014), (ETSI EN 302 637-2 2014). This is another challenge for evaluation similar to the one for the novel visual signs on the physical elements. In this situation, the assessment in matters of both users’ appreciation and technical feasibility (in the sense of implications to the AV operation) is necessary regarding the new wireless messages extensions. The evaluation outcome would be critical for the standardization of the wireless messages (e.g. in relevant standardization bodies such as (ETSI/ISO-CEN/SAE).

Road infrastructure sensors

Road infrastructure sensors are currently used to acquire traffic data (such as radar, ultrasound sensors and LIDAR) or record traffic incidents (camera). Despite the installation and maintenance costs, the data from infrastructure sensors are valuable for their reliability. However, in the future, a huge amount of data obtained from connected vehicles is expected. The connected vehicle will be able to send (and receive) real-time information to (and from) a local or central monitoring (and control) center. Connected vehicles may communicate their position, speed and other relevant information, i.e. they can act as mobile sensors. This allows for a sensible reduction (and, potentially, elimination) of the necessary number of spot sensors, which would lead to sensible reduction of the purchase, installation and maintenance cost for traffic monitoring; while, at the same time, improving the traffic estimation quality.

Traffic Management Center (TMC)

Nowadays, TMCs monitor traffic and provide information to vehicles, mostly related to safety. In order to incrementally move to a future where the driving manoeuvres will be controlled and the traffic mobility will be fully cooperative (Vantomme 2018), novel traffic control strategies should be involved in the TMCs activities (Iordanidou G. et al. 2017). In Section 3, several traffic scenarios and use cases, provide the potential traffic control functionalities which will be investigated within the INFRAMIX concept.

The efficiency of the traffic management is highly depended on traffic flow estimation methods for mixed traffic, comprising conventional and connected vehicles at any (even low) penetration rates. The penetration rate of connected vehicles is a dynamic and difficult to predict factor. However, it influences the traffic estimation. This is because the estimation tools will receive information provided by connected vehicles and will fuse them with measurements stemming from a minimum number (necessary for flow observability) of spot sensor measurements; in order to deliver in real-time reliable estimates of traffic density and traffic flow by segment and even by lane, as well as travel times and incident detection.

Vehicle and Third party services

Two of the basic aspects in this area are the High Definition (HD) maps and the accurate localization (lane level accuracy), where different companies offer different solutions, at a limited scale though. More advanced concepts of the digital infrastructure integrate aspects of low latency communication and cloud computing; however, these are at an early stage (Lytrivis et al. 2018).

The exchange of data between an enhanced TMC as described above and traffic party services (e.g. HD map providers) will be the basis for the extraction of the in-vehicle electronic horizon and will help both automated and conventional vehicles to perform challenging maneuvers with increased safety and comfort. Currently, the electronic horizon is static and based on the digital map of the road. Learning fleet data quickly, based on a combination of data from vehicles and the infrastructure, electronic horizon could contain dynamic information about traffic flow (e.g. speed and density of vehicles, if possible in certain situations even separately for trucks and private cars) as a basis for individualized speed and lane recommendations. Such recommendations, considering traffic control strategies, will enable smoother and safer operation in dense mixed traffic, allowing for a reduction of both traffic jams and dangerous maneuvers.

After the description of the "hybrid" infrastructure concept and its components, section 3 describes the traffic scenarios, which were selected to define a set of functionalities/services of the "hybrid" infrastructure and demonstrate their impact to mixed traffic flow.

3 TRAFFIC SCENARIOS

The traffic scenarios under investigation are described in this section. These scenarios were carefully selected based on the following criteria:

- the expected impact on traffic flow;
- the expected impact on traffic safety;
- the importance of the challenges faced, in the sense that if not handled in a proper and timely way, they will negatively influence the introduction of AVs on the roads;
- the ability to generalize on the results (applicable in other scenarios and environments e.g. urban).

Below a high-level description of each scenario takes place, including main aspects under investigation per scenario as well as hints on the anticipated impact that will be associated with it. It should be noted that these descriptions, as well as the figures, are not detailed but indicative of the work to be performed.

Scenario 1 – Dynamic lane assignments

The study of this scenario intends to give us insights on how to manage at lane level mixed vehicle traffic flows on normal highway segments, that is without any tunnels, lane drops, entry or exit lanes. The purpose here is to check if a dedicated lane to AVs, either permanent or dynamic, could support AVs introduction in everyday traffic, and which are the related implications in order not to influence in a negative way current traffic.

During this process, parameters such as the penetration rate of AVs and the prevailing traffic conditions will be considered. In addition, speed limits per lane or road segment will be dynamically adapted taking into account also potential adverse weather conditions. An instance of this scenario is highlighted in Figure 2.

The goal is to provide proper indicators for activation and deactivation of lanes assigned to AVs, customized speed and lane recommendations for all vehicles on this segment based on prevailing traffic conditions and also visual and electronic ways for informing all vehicles and drivers involved. It should be noted that in this scenario the usage of physical segregation elements, such as road studs and/or solid yellow lane markings or others, for indicating a lane dedicated to automated traffic (similar to existing bus lanes) will also be investigated. Questions such as "At which penetration level of automated vehicles a dedicated lane for them will be beneficial in terms of traffic efficiency and safety?" and "What kind of physical elements will be used, according to the existing (or emerging) traffic regulations, to make the dedicated lane obvious to all traffic participants?" will be studied.

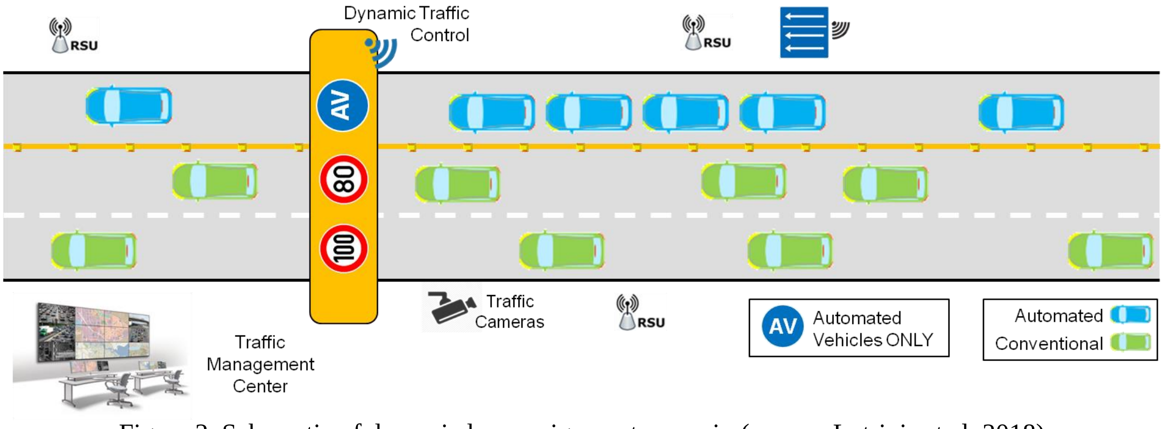

Figure 2. Schematic of dynamic lane assignment scenario (source: Lytrivis et al. 2018)

The assignment of a dedicated lane to automated traffic is expected to reduce the safety concerns around the penetration of the AVs to conventional traffic. Moreover, one of the targets of this scenario is to understand how to balance mixed traffic in order to maintain the traffic throughput at least at the same level, as in case of today's traffic consisted of conventional vehicles only.

Scenario 2 – Construction site / Roadworks zones

One of the major safety hotspots, with many accidents both for vehicles and for the staff on site, are roadworks zones and construction sites. In addition, they pose significant challenges for efficient coordination of mixed vehicle traffic flows. The road infrastructure can play a key role and can help all kind of vehicles (connected, automated, conventional) to safely and efficiently pass through such areas, by providing extended information in real-time, such as updated maps (e.g. including the temporary yellow lanes illustrated in Figure 3), additional traffic signs, reference points on the spot for accurate localization for AVs, new traffic control measures etc. in the particular region. Both the physical and the digital infrastructure should be prepared to accommodate for such situations. An example of this scenario is depicted in Figure 3.

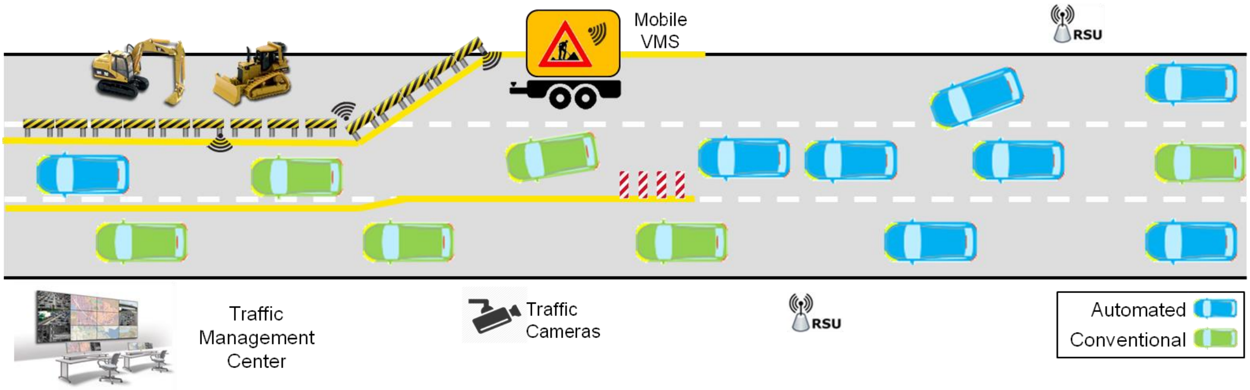

Figure 3. Schematic of construction site / roadworks zones scenario (source: Lytrivis et al. 2018)

The target of this scenario is to guide in an efficient and safe way mixed traffic through roadworks zones by providing accurate information in these areas both to AVs, through electronic signals and up-to-date digital maps (electronic horizon), and to conventional vehicles through visual signs and other physical elements (e.g. cones).

Scenario 3 – Bottlenecks

The scope of this scenario is to investigate real-time controllers, involving a variety of control measures, such as dynamic speed limits, merge assistance and ramp metering, to manage mixed traffic situations in front of bottlenecks of various kinds (on-ramps, off-ramps, lane drops, tunnels, bridges). The target is to avoid traffic flow degradation in these areas. An instance of this scenario is highlighted in Figure 4, where an on-ramp case is illustrated.

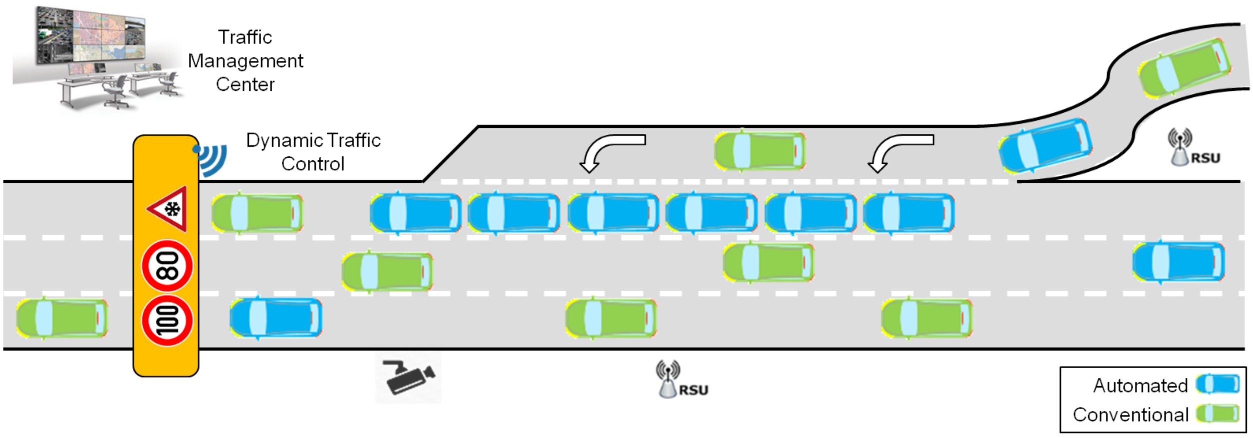

Figure 4. Schematic of a bottleneck (on-ramp) scenario (source: Lytrivis et al. 2018)

Several interesting problems and use cases will be investigated with respect to different types of bottlenecks, under various penetration rates of AVs. For example, in Figure 4 a platoon of AVs is blocking the vehicles entering the highway. In this case, we can study how the entering vehicles will smoothly join this platoon in case they are automated or how the vehicles forming the platoon will make space for the conventional ones to enter the highway. Proper guidance through the electronic horizon for AVs and the nomadic devices for the conventional ones, as well as visual and electronic signals need to be provided too. Innovative control measures to improve traffic efficiency and safety (e.g. avoid deadlocks) in such cases will be developed.

In this section, the three main scenarios are broken down into more specific use cases of interest. In that effort, the list of C-ITS services, considered by European Commission as highly beneficial to community was taken into account (European Commission 2016). The derived use cases attempt to cover the aspects of Day 1 C-ITS services list (which concern hazardous location notifications and signage applications) and additionally some of the Day 1.5 list (such as traffic monitoring and smart routing, which applies to highways). The idea behind Table 1 is to associate each use case with expected benefits and potential metrics for evaluation which are of interest.

Table 1. Use cases following the traffic scenarios (compiled from H2020 INFRAMIX project 2018)

Traffic Scenarios	**Use cases**	**Description of indicative evaluation fields**
Dynamic lane assignment (incl. speed recommendations)	Real-time lane assignment under Dynamic Penetration Rate of AVs	Evaluation of the effect of the exclusive dedication of a lane to AVs. It allows the investigation of the traffic throughput based on their penetration rate, considering also the capacity of the road for conventional traffic.
	Exceptional traffic situations- adverse weather conditions as an example	Taken adverse weather conditions as an example, the effect of situations that disturb the smooth operation of infrastructure services and traffic management is investigated. The maintenance of smooth traffic flow under adverse weather conditions consist an objective.
	A conventional vehicle drives on a dedicated lane for AVs	Investigation of the consequences to traffic efficiency and safety, when a conventional vehicle driving on or entering a lane dedicated to AVs.
Roadworks zones	Single Lane Closure (e.g. short term constructions)	Investigation of the necessary V2X communication, visual signs as well as physical elements when a construction zone is placed in a road segment and evaluates the efficiency of that communication in the aspect of safety and user's appreciation. The key aspect is to ensure that all kind of vehicles are timely and sufficiently informed about the roadworks zone to act accordingly.

	New Lane Design (e.g. long term constructions)	Investigation of V2X communication, visual signs as well as physical elements in order to reassure a smooth and efficient traffic flow when roadwork zone covers more than one lane in a road segment. It is focused on the required visual signs that depict the new lane marking, the possible eHorizon applications that help an AV to accurately follow the new lane markings and the establishment of the required interface.
Bottlenecks	AVs Driving Behavior Adaptation in Real Time at Sags	Investigation of a traffic management concept to exploit AV capabilities towards increased traffic flow efficiency by changing the AVs longitudinal driving behavior according to the traffic management requirements. More specifically, the control strategy receives real-time measurements (or estimates) of the current traffic conditions and suggests to the AVs (or to the connected conventional ones which are equipped with ACC (SAE level 2)) an appropriate value for the time-gap parameter and possibly also for the vehicle acceleration.
	Lane-Change Advice to connected vehicles at Bottlenecks	Investigation of a traffic management concept to decide on the necessary lane-changing activities in order to achieve a pre-specified (possibly traffic-dependent) lane distribution of vehicles while approaching a bottleneck, aiming at increasing the bottleneck capacity. A control strategy is fed with real-time lane-specific information about the prevailing traffic conditions in order to provide the lane –changing recommendations.
	Lane-Change Advice combined with Flow Control at Bottlenecks for all vehicles	Investigation in improving the traffic flow at bottlenecks with a control of the upstream. Several innovative flow control strategies are investigated with different approaches (ramp metering, Mainstream Traffic Flow Control (MTFC)).

Having an overview of the “hybrid” road infrastructure and its potential functionalities (sections 2 and 3 respectively), the following section contains a preliminary work on its evaluation, while providing an overview of the existing evaluation methodologies and efforts.

4 EVALUATION METHODOLOGY FOR HYBRID ROAD INFRASTRUCTURE

Over the past decade, a large number of Field Operational Tests (FOT) have been conducted in Europe, the US, Japan, Australia, and other countries to test Intelligent Transport Systems (ITS). The European Commission has sponsored several large-scale FOTs (Barnard et al. 2015). As outlined in (Barnard et al. 2016), Advanced Driver Assistance Systems (ADAS), including cooperative systems (with communication between vehicles or between vehicles and infrastructure), have been tested with thousands of drivers in real traffic conditions. Examples of these FOTs were euroFOT (Kessler et al. 2012), TeleFOT (Mononen et al. 2013), DRIVE C2X (Schulze et al. 2014) and FOTsis (Alfonso et al. 2015). The FOTs had as an objective to comprise a comprehensive program of research to assess the impacts of Information Communication Technology (ICT) systems on driver behavior, both in terms of benefits for drivers (e.g. more comfort and increased safety) and of larger scale socio-economic benefits (e.g. less congestion and fewer accidents) (Barnard & Carsten 2010). A handbook was developed with many practical recommendations by the FESTA consortium that was granted to develop a FOT methodology before large-scale FOTs would be funded (FESTA 2016; Regan & Richardson 2009). The basis of this handbook was a methodology, to be followed by the FOTs in order to ensure scientifically sound studies and allowing comparability between FOTs (Carsten & Barnard 2010). Since 2008 this methodology has not only been adopted by FOTs funded by the European Commission but also by many nationally (or otherwise) funded projects, and has influenced FOTs outside Europe. The methodology has been regularly updated by the FOT-Net support actions, taking into account the lessons-learned (www.fot-net.eu). The FESTA methodology is summarized in Figure 5. There are several steps, which although described in a linear way, are performed in iteration.

The V-shape shows the dependencies between the different steps on the left and right-hand side of the V. The steps can be summarized as:

- Defining the study: Defining functions, use cases, research questions and hypotheses
- Preparing the study: Determining performance indicators, study design, measures and sensors, and recruiting participants
- Conducting the study: Collecting data

- Analyzing the data: Storing and processing the data, analyzing the data, testing hypotheses, answering research questions
- Determining the impact: Impact assessment and deployment scenarios, socio-economic cost benefits analysis

The hybrid road infrastructure examined in this paper is a relatively new research domain, for which new evaluation methods might be needed. As a first step the evaluation method that is currently utilized in the discussed study is the FESTA V-process methodology. As already mentioned in the introduction, the FESTA Handbook v.7 (2017)[3], is formulated with the target to evaluate ADAS and in-vehicle information systems for vehicles through FOTs. The latest version of the handbook includes apart from in-vehicle systems also nomadic and cooperative ones, which are intended as a combination of hardware and software enabling one or more ICT functions in vehicle level.

The proposed methodology attempts to adapt FESTA, so as to be able to evaluate the so called "hybrid" infrastructure in terms of traffic safety, traffic efficiency, users' appreciation and technical feasibility. The remainder of this section focuses on the left half of the adapted FESTA V model (Preparing).

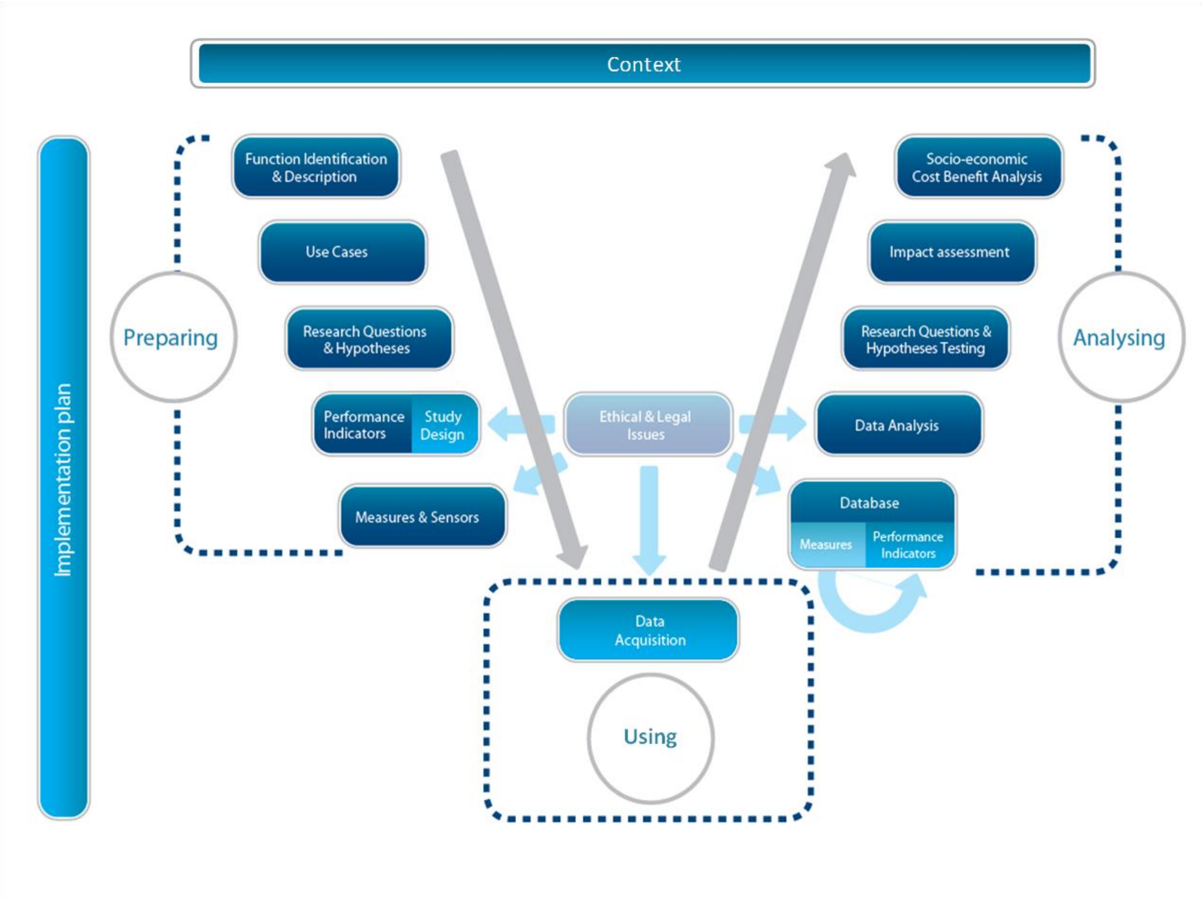

Figure 5. Festa V-model (source: FESTA 2016).

Step 1 Function identification and description:

In this study, the functions to be evaluated are formulated in terms of traffic scenarios that the infrastructure should be able to handle (during the transition period, so as to become the basis for future automated transport systems).

A clear method was followed, as mentioned in section 3 (see also Figure 6), in order to select the following three key traffic scenarios:

S1 (Scenario 1): Dynamic lane assignment (incl. speed recommendations)
S2 (Scenario 2): Construction sites / Roadwork zones and
S3 (Scenario 3): Bottlenecks (on-ramps, off-ramps, lane drops, tunnels, sags).

[3] Available at http://fot-net.eu/Documents/festa-handbook-version-7/

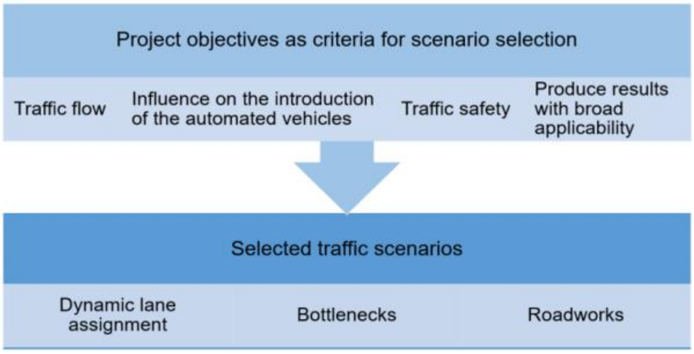

Figure 6. Extraction of the traffic scenarios (source: H2020 INFRAMIX project 2018).

Step 2 Use Cases:

Following the identification of the scenarios and the description of the associated infrastructure functionalities, a set of use cases was developed. These use cases constitute a set of representative traffic situations for each scenario. The formulation of the use cases was performed based on the current technological level of the road infrastructure (based on the status and expert opinions of two major European infrastructure operators) and the issues that are expected to evolve within the transition period. The first use case for the Dynamic Lane Assignment scenario is provided hereafter as an example.

ID	S1-DLA-UC1-DPR
Name	Real time lane assignment under Dynamic Penetration Rate of AVs
Overview	A lane is assigned dynamically to AVs in mixed traffic, when their percentage is above a certain limit, taking also into account the capacity of the road portion left for conventional traffic

Step 3 Research Questions and Hypotheses*:*

After the definition of the functions and the use cases, the research questions and hypotheses are formulated. The first step was the analysis of the original objectives and visions. This work feeds top-down the definition of the use cases, success criteria, evaluation methods and tools to evaluate the functionalities under study. These high level objectives are expressed in the form of research questions, which are grouped into the three main evaluation fields:

- The assessment of the impacts on traffic efficiency and traffic safety,
- The evaluation of the user appreciation, such as drivers/travelers and infrastructure operators,
- The evaluation of technical performance and technical feasibility of the selected road infrastructure scenarios.

For example, for the first use case (S1-DLA-UC1-DPR) the evaluation should target providing insights on the changes in traffic efficiency when a lane is dedicated to AVs under different penetration rates. It would also be meaningful to understand how the users react or if the users appreciate the infrastructure physical adaptations and investigate stakeholders' benefits (e.g. freight companies) related to functionality of different groups of AVs using a permanently dedicated lane at different time intervals.

Following the aforementioned reasoning, a set of potential Research Questions (RQs) for the first use case (S1-DLA-UC1-DPR) could include the following:

- RQ1: At which % of automated vehicles a dedicated lane is more appropriate in terms of traffic efficiency?
- RQ2: How the throughput of conventional vehicles is affected when there is a lane assigned to AVs?
- RQ3: How does the way of providing information about a lane assignment affect the driver/passenger attitude?
- RQ4: Which is the adequate number of gantries per kilometric distance that should be installed to inform the non-connected vehicles about the dynamical lane assignment?
- RQ5: How much does the location of the dedicated lane (left or right) affect the traffic throughput?
- RQ6: Is the signaling comprehensible by the road users?
- RQ7: Do the road users appreciate the information provided during the activation/deactivation of the dedicated lane?

This approach is followed for the formulation of the research questions for all use cases that the system is intended to address. It should be noted that this process may lead to the formulation of a number of research questions. In this case a proper prioritization scheme should be applied, in order to conclude which research questions should be tested during the study. As an example, the research questions could be further prioritized based on the relevance of the assumed impact with regard to the purpose of the scenario, or for example the assumed size of the impact in the transport system.

The hypotheses translate the research question into a more specific and statistically testable statement. For example, for the first research question the formulation of the hypothesis could be the following:

- RQ1-H1: Traffic efficiency will increase if a dedicated lane for AV is set when AV % is over X

Step 4 Performance Indicators

The next step to the definition of statistically testable hypotheses for the prioritized research questions is to find measurable indicators to test the hypotheses. Whereas research questions are general questions phrased as real questions ending with a question mark to be answered by compiling and testing related specific hypotheses; hypotheses are statements which can either be true or false. Hypotheses will be tested by statistical means. Defining testable hypotheses may be quite a challenge for road automation studies, as we cannot always predict what the effects are going to be. Hypotheses can only be tested by means of performance indicators (PI). So after establishing these indicators, measures need to be defined and an experimental design to be developed. A matrix was developed for this purpose, which helps to associate the use cases with the research questions, the hypotheses and the performance indicators.

Following the previous example, for RQ1-H1 the PI could be the measurement of the throughput under different penetration rates of AVs and compare it to the baseline (derived from historical data on the conventional traffic). The measures needed in order to calculate the PI are the number of AVs against the number of conventional vehicles in a highway section, logged in a traffic simulation scenario.

It should be noted that this work is in progress within the research team; in this paper we present the approach followed in order to evaluate the hybrid road infrastructure. It is acknowledged that FESTA has a strong focus on the drivers of vehicles, and the changes in their behavior when driving a vehicle that is instrumented with new systems. Here, the main target is to design, upgrade, adapt and test (in simulation and in real-world) both physical and digital elements of the road infrastructure, to enable the coexistence of automated and conventional vehicles, ensuring an uninterrupted, predictable, safe and efficient traffic. Although FESTA is focused on the vehicle functionalities evaluation, it was deemed realistic to adapt the process to a road infrastructure evaluation perspective. According to (Barnard, Y., et al. 2016) this could be considered as a context centred test, addressing questions of how mobility changes, how this affects mobility services, what the impacts are on traffic flow level or on transport system level, what ethical choices might be involved, and what would be the impacts on the built-up environment and society. These types of questions are extremely important but not easy to investigate as these impacts typically take a longer period of time to evolve than the duration of a typical test and, certainly, these changes do not take place with the penetrations that a test study is able to put up.

5 FUTURE WORK

As previously mentioned, the evaluation methodology described in this paper is still at its initial phase, thus further iterations and refinement is needed. FESTA methodology, on which this work is based, is well established for evaluation of ADAS functions, however further work is needed for the needs of connected and automated mobility and especially for the needs of road infrastructure and mixed vehicle traffic flows, as described in the last part of section 4. Ongoing supportive work in this field is carried out in sibling projects such as L3Pilot[4], which is dealing with pilot activities involving automated vehicles of SAE level 3. Several aspects on the novel automated functionalities of these vehicles (such as their operational context) and their implications on the traffic flow would give valuable information on the evaluation.

An important step towards this direction is the collection of related data and potentially big data. The more data available, the better for improving the evaluation process. Currently, the existence of AVs (of SAE level greater than 1) in the highways is very limited. Consequently, there is a lack of real data and statistics related to safety, users'

[4] http://www.l3pilot.eu/index.php?id=26

appreciation and traffic efficiency of mixed vehicle traffic flows. This fact makes the advanced simulation in such cases an indispensable part of the evaluation of the "hybrid" infrastructure and the corresponding developments. Extended simulations will be performed, within INFRAMIX project, using an advanced simulation environment. The INFRAMIX Co-simulation environment (Lytrivis et al. 2018), combines the modelling of the vehicle behavior with the traffic simulation, thus enabling the testing of the developed traffic control algorithms:

- with increased traffic densities in exceptional conditions (e.g. bottlenecks)
- with different rates of the targeted vehicle types (conventional, automated).

The intention is to compare the data from these simulation tests with the respective real data from traffic flow with conventional vehicles. This way, the current traffic situation will be the baseline in order to demonstrate the deviation of traffic efficiency indicators with different penetration rates of AVs.

Considering the co-existence of conventional and AVs, especially in traffic scenarios such as roadworks, new safety challenges which are related to "hybrid" infrastructure design parameters (such as the latency of different networks (C-ITS G5 and LTE)) are expected. Apart from the pure simulation of the traffic scenarios, coupling virtual traffic with real world is expected to give unique and valuable data for the evaluation analysis. This will be realized though hybrid testing, which will make use of a real vehicle driving through virtual traffic. Hybrid testing permits the assessment of critical traffic situations in a safe artificial environment (Lytrivis et al. 2018).

Another important future activity, in the area of evaluation, is the appreciation of the users in the corresponding developments. In order to realize and perform the three INFRAMIX scenarios new visual and electronic signals that communicate information, issue warnings or provide guidance to all highway users (conventional and automated vehicles) need to be implemented. As a major challenge, to achieve the greatest possible impact in the transport community, regarding investments and development of new road infrastructure elements, is users' acceptance. The last part of the communication chain are the signals with which the users have direct contact. The adequateness, comprehension as well as the social acceptance (pleasantness) of the visual signs are evaluation areas of high importance. The collection of the proper data in order to evaluate these areas is critical for the evaluation. Real users' responses and attitude to the specific signals would be of great value.

At this point, another important future development is briefly highlighted. This is linked with evaluation, in an indirect way, however its usefulness and impact are expected to be much broader within the transport community. This is named hereafter as the "infrastructure classification scheme". This scheme, proposed within INFRAMIX, is analogous to the different initiatives for classifying automated driving systems, ranging from "no automation" to "full automation" with the most prevalent one being the SAE taxonomy (SAE 2014). The target here is the road infrastructure. Such a classification scheme will indicate the connectivity, the provided ITS services and in general the capability to host vehicles of different levels of automation in a specific road infrastructure. The status of the digital infrastructure, such as the availability of highly accurate maps, as well as the facilities of the physical infrastructure, e.g. the lane markings condition, the availability of roadside C-ITS units, the presence of segregated or dedicated lanes and other parameters (e.g. presence of VRUs), will be taken into account in order to classify the infrastructure, matching it to a specific level of automation. This work will be accompanied by a guide of how to incrementally upgrade levels of infrastructure. This is expected to support significantly the step-wise introduction of automated driving systems, and their wide adoption.

6 CONCLUSIONS

In this paper, an overview of the challenges on the implementation and assessment of a road infrastructure capable to accommodate mixed vehicle traffic flows (co-existence of conventional and automated vehicles) was presented. This was based on the "hybrid" infrastructure concept, as conceived in the H2020 INFRAMIX project. The preliminary work on the approach to the evaluation of this concept, in terms of technical feasibility, users' appreciation and traffic efficiency, provided important considerations and set the initial steps to a structured evaluation methodology for road infrastructure, which considers the increasing penetration of AVs in the near future.

An attempt is made to adapt the FESTA evaluation methodology, which is focused on vehicle functionalities evaluation, to a road infrastructure perspective, in order to exploit the maturity and the know-how of the existing methodology. Following the FESTA structure with slight adaptations in the different perspective, seems to be a realistic approach. Several aspects of the infrastructure have already been considered to FESTA. As mentioned in section 4, (Barnard, Y., et al. 2016) considers context centred test, addressing several questions relevant to the impacts on the traffic flow and on the built-up environment. It is important to point out that this kind of research questions, typically require a longer period of time to evolve that the duration of a typical test, attempted to be identified also in this work along with the parameter of various AVs penetration rates.

Three traffic scenarios (dynamic lane assignment, roadworks and bottlenecks) were used as a basis for the evaluation of such concept. The three scenarios were further divided into eight use cases. These use cases were extracted taking into account the current technological level of the road infrastructure and the anticipated challenges during the transition period while targeting to demonstrate and assess the impact of the infrastructure developments. Those scenarios and use cases, although targeting highways, can provide important insights to the evaluation work, which without loss of generality can be applied also to urban environments.

Another important concept introduced in this paper is the infrastructure classification scheme. A scheme similar to SAE levels of automation for automated driving, but for the needs of the infrastructure this time. The work regarding this scheme will make road infrastructure owners and road operators to be more involved in the discussion regarding automation and be more active and supportive and in fact promoting early adoption of automated vehicles. Already several international stakeholders have expressed interest in the area of infrastructure classification and it is expected to be an important step towards a holistic automated transport system in the future.

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