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Advances in Road Infrastructure, both Physical and Digital, for Mixed Vehicle Traffic Flows

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Abstract

Over the last years, significant resources have been devoted to developing new automation technologies for vehicles, whereas investment and resources for road infrastructure in general have steadily dwindled. INFRAMIX is preparing the road infrastructure to support the transition period and 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. Towards this objective different technologies are deployed; mature simulation tools adapted to automated vehicles characteristics, new methods for traffic flow modelling to study the traffic-level influence of different levels of automated vehicles in different penetration rates, traffic estimation and traffic control algorithms. Moreover, ways of informing all types of vehicles about the control commands issued by the road operator and new kind of visual and electronic signals are developed. The project outcomes will be assessed via simulation and in real stretches of advanced highways.

Keywords: Connected and Automated Driving; Digital Infrastructure; Hybrid Road Infrastructure; Mixed Traffic; Traffic Management; Traffic Simulation.

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1. Introduction

In the past few years, there are a lot of initiatives demonstrating automated driving functionalities and driverless cars. All over the press automotive manufacturers are competing who is going to provide reliable automated driving functions first. At the same time there are new players in the field, such as tech giants, which are threatening the leadership of traditional automotive industry in the field of automated driving. The majority of those activities are focusing on the in-vehicle technology, while ignoring the needed advances on the road infrastructure side. In order to be prepared for the gradual insertion of automated vehicles there is an inherent need for adaptations at the infrastructure side ensuring uninterrupted, predictable, safe and efficient traffic. Updating the road infrastructure is a time-consuming and costly procedure and takes place at a slower pace than in-vehicle automation developments. The average vehicle age is about 10 years, whereas the average lifecycle of the road is 20 to 30 years, thus there is a strong mismatch which does not allow infrastructure to follow the new developments in automated vehicles. Thus there is a need for intelligent, incremental and adaptable interventions in the road infrastructure that take advantage of the innovative vehicle developments and interact with them. In addition, new and existing, physical or digital infrastructure elements (e.g. traffic signs, electronic horizon) need to be designed and adapted 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.

This is the main objective of the INFRAMIX EU project, which will explore a) the needed advancements in the digital infrastructure and b) the needed upgrades in the physical infrastructure able to cope efficiently with the new safety challenges emerging from the introduction of automated vehicles and especially within the transition period. In order to achieve this goal INFRAMIX is focusing on three specific high value traffic scenarios: (1) Dynamic lane assignment (incl. speed recommendations), (2) Construction sites / Roadworks zones, and (3) Bottlenecks (on-ramps, off-ramps, lane drops, tunnels, sags). Those scenarios will be thoroughly examined in the lab, through the use of advanced simulation tools, and on real roads in Austria and Spain where the pilot sites of INFRAMIX are located. Special effort will be put in the interactions between simulations and tests on the pilot sites. Although INFRAMIX is targeting mainly highways (expected to be the initial hosts of such mixed traffic) its key results can be easily transferred to urban roads.

The paper is structured as follows. In the beginning, the three scenarios under investigation are sketched. Then some first ideas on the hybrid road infrastructure, digital and physical, and the role of advanced simulation tools in this endeavor are highlighted. The paper concludes with the outlook and next steps.

2. Scenarios under Investigation

In order to provide specific solutions with clear impact, INFRAMIX follows a bottom-up approach, building on high value traffic scenarios, in terms of importance with regard to traffic efficiency and safety. As stated in the introduction, three key scenarios are identified for the transition period, to be tackled during the project, based on four criteria: a) the expected impact on traffic flow, b) the expected impact on traffic safety, c) 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 automated vehicles on the roads, and d) the ability to generalise on the results (applicable in other scenarios and environments). The description of the three scenarios that follows, provides an overview on key aspects under investigation per scenario and also points out the expected impact for each scenario.

2.1 Dynamic lane assignments

The target of this scenario is to cater for mixed traffic on normal multilane highway segments (without tunnels, lane drops, entry or exit lanes) by assigning dynamically a lane to automated traffic. During this process, parameters such as the penetration rate of automated vehicles 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 1.

The study of this scenario, in simulation and in real conditions, will give us insights on how to manage in an efficient manner mixed traffic flows on normal highway segments. It will provide proper indicators for activation and deactivation of lanes assigned to automated vehicles, customised 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.

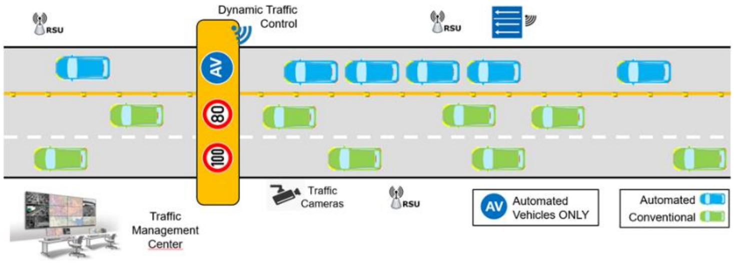

Fig. 1 Schematic of dynamic lane assignment scenario

The assignment of a dedicated lane to automated traffic is expected to reduce the safety concerns around the penetration of the automated vehicles 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.

2.2 Construction site / Roadworks zones

Roadworks zones are major safety hotspots with many accidents both for vehicles and for the staff on site (Atahan et al (2016), ERF (2015), Gwebu (2015)). They pose interesting challenges for efficient coordination of mixed traffic flows, where the infrastructure should help the vehicles by providing extended information in real-time such as updated maps (e.g. including the temporary yellow lanes illustrated in Figure 2), additional traffic signs, reference points on the spot for accurate localisation for automated vehicles, 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 2.

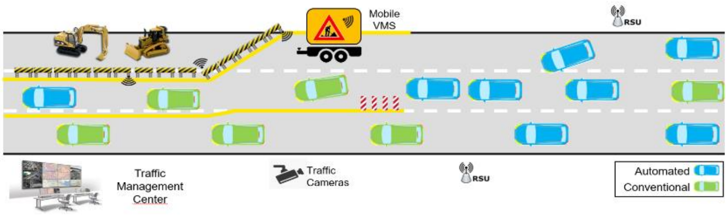

Fig.2 Schematic of construction site / roadworks zones scenario

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 automated vehicles through electronic signals and up-to-date digital maps (electronic horizon) and to conventional vehicles through guidance to their nomadic devices, visual signs and other physical elements (e.g. cones).

2.3 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, sags) and avoid traffic flow degradation. In addition, solutions for in-vehicle and on-road signage will be examined. An instance of this scenario is highlighted in Figure 3, where an on-ramp case is illustrated.

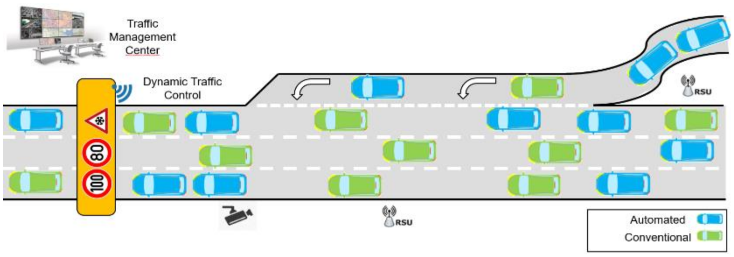

Fig.3 Schematic of a bottleneck (on-ramp) scenario

An analysis of several use cases regarding different types of bottlenecks, with different penetration rates of automated vehicles, will take place. In addition, innovative control strategies, such as the exploitation of the automated vehicles capabilities by suggesting (real-time) an appropriate value for the time-gap parameter and vehicle acceleration (Ntousakis et al (2015)), the distribution of the vehicles across lanes so as to match a pre-specified opportune lane distribution scheme depending on traffic, as well as the Mainstream Traffic Flow Control (MTFC) (Carlson R. et al (2012), Iordanidou G. et al.(2016)), will be investigated, aiming to improve traffic efficiency and safety (e.g. avoid deadlocks) in such cases. Proper guidance will be provided both for automated and for conventional vehicles.

3. Hybrid Road Infrastructure for Automated Driving

Although in the far future, we foresee a fully automated transport system, where automated vehicles will travel within an intelligent, connected and automated road infrastructure, (Amditis A et al. (2015)), in the meantime, there will be a challenging and long transition period with gradually increasing penetration of different levels of automated vehicles, gradually changing road infrastructure, lack of standardisation etc. The coexistence of automated and conventional vehicles could lead to confusing and potentially unsafe situations, among other things, due to the unforeseeable human driving. Road infrastructure will play a major role in managing this transition period in order to make the introduction of automated vehicles on the roads faster, smoother, safer, acceptable and socially beneficial to all traffic participants.

Despite the fact that it is essential to prepare, as early as possible, to face the evolving challenges and exploit the increasing opportunities, 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 (towards the EU target of cutting European road deaths by 50 % by 2020, as placed by European Transport Safety Council, (2010)). At the same time building new roads or severely upgrading existing ones is a quite long and costly procedure. Thus there is a need for intelligent, incremental and adaptable interventions in the infrastructure that take advantage of the innovative vehicle developments and interact with them. In addition, new and existing, physical or digital infrastructure elements (e.g. segregation, traffic signs, electronic horizon etc.) need to be designed and adapted 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. This will lead to a “hybrid” infrastructure (physical and digital) able to cope efficiently with the new safety challenges emerging from the introduction of automated vehicles and especially within the transition period.
INFRAMIX 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, in specific scenarios, ensuring an uninterrupted, predictable, safe and efficient traffic; the key outcome will be a “hybrid” road infrastructure able to handle the transition period and become the basis for future automated transport systems.

To achieve this goal INFRAMIX will employ new advanced microscopic traffic flow models, advanced simulation techniques, innovative traffic estimation and control strategies, as well as appropriate new and adapted existing physical and digital infrastructure elements.

3.1 Physical Road Infrastructure

The way physical infrastructure is designed and visualized today is based on the capabilities of conventional vehicles and the cognitive abilities of human drivers. The lack of a standardised interaction among conventional and automated vehicles as well as forms for coherently informing all traffic participants at the same time, is leading to low users' appreciation for automated vehicles. Very few works are undergoing in the field of physical infrastructure design and adaptation for mixed traffic such as the CEDR's DRAGON project *(http://www.cedr-dragon.eu/)*.

INFRAMIX will propose adaptations of the current road infrastructure (at minimum cost), e.g. the need for segregation elements to separate automated vehicles from conventional ones, the need for installing additional communication units at the roadside, CCTV based incident detection etc. This activity will include road side elements and related upgrades of today traffic management centers (TMCs).

Furthermore, INFRAMIX will develop new forms of visual and electronic signalling to inform and guide both conventional and automated vehicles through the current infrastructure adaptations and the traffic regulations in force. Different alternatives will be investigated such as extended use of smartphones or other nomadic devices for in-vehicle signalling and guidance, installation of dedicated equipment at the roadside requiring minor investment, alternatives to expensive gantries (as depicted in Figure 4) and variable message signs and more.

Today Tomorrow

Fig.4 Physical road infrastructure vision in the frame of INFRAMIX (credits to ASFINAG)

3.2 Digital Road Infrastructure

This is one of the key areas discussed at international level; considered also in the trilateral (EU-US-Japan) working group on road transport automation. A lot of initiatives and platforms have been created recently to promote digital infrastructure works. Two of the basic aspects in this area are the High Definition (HD) maps and the accurate localisation (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.

The basis in INFRAMIX will be highly accurate digital maps and lane-level positioning technologies (vehicle and infrastructure support), and will work towards a digital transport infrastructure that can support the vehicles with accurate and reliable positioning information in real time enabling them to execute safety manoeuvres (e.g. in road works). This will be done through enhancing the digital infrastructure by the addition of dynamic information both from the traffic management center (e.g. traffic density) and from the connected vehicles (probes). Enhanced digital infrastructure will be the basis for the extraction of the electronic horizon and will help both automated and conventional vehicles to perform challenging manoeuvres with increased safety and comfort.

The main work available today is on ways of extending the electronic horizon of vehicles via integrating low level automated functions (up to SAE level 2). The electronic horizon is static and based on the digital map of the road. Ongoing projects aim at improving the electronic horizon by learning from fleet data quickly and thus improving the digital map. But it remains static.

In the frame of INFRAMIX the electronic horizon will be extended, based on a combination of data from vehicles and the infrastructure, to 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 information, considering traffic control strategies, will be delivered through the electronic horizon to enable smoother and safer operation in dense mixed traffic, allowing for a reduction of both traffic jams and dangerous manoeuvres. Efforts to standardise the developments in this area will take place (e.g. towards NDS and ADASIS consortia).

Considering the real-time traffic data required for extending the electronic horizon, INFRAMIX will develop practicable and robust traffic flow estimation methods and software tools for mixed traffic, comprising conventional and connected vehicles at any (even low) penetration rates. 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; and will 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. In addition, INFRAMIX will investigate the possibility of distributed estimation and data fusion on-board of connected vehicles by exploiting V2V communication capabilities. The interconnection of the estimation tools with existing travel time estimation tools, which are based on connected vehicles only and are hence not able to deliver total traffic estimates (density or traffic volumes), will be also investigated. All developed estimation methods and tools will be tested exhaustively using traffic simulation as well as real data, taking into account all involved measurement errors and possible communication delays. The developed tools will provide a necessary basis for real-time traffic control tasks with various requirements regarding the estimation granularity (e.g. estimation per lane), the estimated variables or the underlying architecture.

INFRAMIX will address the major novel traffic management opportunities arising from the emergence of a variety of automation and connectivity capabilities with various penetration rates. Within this context, INFRAMIX will investigate different novel traffic management architectures (vehicle-based, cluster of V2V connected vehicles, V2I-based traffic control) and combinations, which are applicable at different phases of mixed traffic evolution, different infrastructure capabilities etc. The usage of some developed strategies (e.g. lane navigation) as a complement or extension of existing tools by INFRAMIX industrial partners will be thoroughly investigated. All developed control methods and tools will be tested using traffic simulation as well as real data, while several of them will reach the maturity allowing for immediate practical usage at the project's test sites, and exploited further. In order to perform advanced traffic management, the proper bidirectional communication between vehicles and infrastructure/traffic management center (TMC) is needed. There are several communication standards for exchanging messages among connected vehicles and the infrastructure, such as CAM, DENM, SPAT, MAP and IVI. Furthermore, several EU projects, such as TEAM and AutoNet2030, are working on specific extensions on message sets and alternative technologies, in order to propose possible extensions to standards.

Although a lot of standardisation efforts have been carried out for short range connected vehicles, there are not enough standardisation initiatives to accommodate for the needs of the infrastructure / TMC within the automated driving era. INFRAMIX will address the gap in the communication of automated vehicles with the infrastructure / TMC and will specify and standardise the needed messages and interfaces and enhance existing connectivity for enabling bidirectional communication for automated driving (vehicle probe data, control messages). This will include the usage of short range (e.g. ITS-G5, WiFi) and long range (cellular) communication and the definition of dedicated ITS specific messages. This work will be promoted to standardisation bodies (ETSI/ISO-CEN/SAE).

4. Simulation Environments

The INFRAMIX Simulation Environment is an important building block in the project, since the majority of the activities mentioned above need mixed traffic conditions to be tested which is not the case today. Therefore, the main objective to employ simulation in INFRAMIX is twofold:

1. Offline assessment of the developed algorithms for traffic flow estimation and strategies for traffic control in a pure virtual environment
2. Hybrid testing of the developed solutions in a real-world setting, which covers virtual models for the aspects of the traffic environment, traffic management etc. as well as one test vehicle on a real road

This kind of simulation requires modelling approaches from different domains. Hence, a new Co-Simulation Environment is to be created, based on the existing simulation infrastructures, VSimRTI (Vehicle-2-X Simulation Runtime Infrastructure, (Protzmann et al (2017))) and ICOS (Independent Co-Simulation) (Karner et al (2013)).

4.1. Qualification

VSimRTI enables the coupling of different event-based simulators for investigations with a realistic modeling of connected and automated driving. Aspects such as microscopic vehicle traffic, wireless communication and applications for mobility strategies and control could be investigated in a combined manner with VSimRTI

(Protzmann et al (2017)). The named domains are modeled in individual simulators. An important advantage of VSimRTI is the synchronization of the various simulators and the facilitation of the information exchange between the simulators at runtime. Microscopic traffic simulation in the context of VSimRTI means that each vehicle is simulated individually. It is possible to model a small number of vehicles and their features and applications very precisely. Large-scale simulations of more than hundred thousand vehicles are also well possible. Hence, VSimRTI allows very flexible scaling according to the scenarios to be investigated.

ICOS is a co-simulation platform that allows the integration of a variety of engineering domains based on advanced coupling algorithms (such as Waveform Relaxation or multi-rate approach), Karner et al (2013). The focus of the ICOS simulation lies on the very precise modeling of a single vehicle. In addition to the vehicle itself, ICOS considers the vehicle environment and its influences as well as the behavior of the driver. The ICOS interdisciplinary modeling approach provides a detailed view of the interaction between automated and conventional vehicles as well as infrastructure measures. On the one hand, this leads to a realistic behavior of vehicles in the microscopic simulation and, on the other hand, enables a detailed investigation of safety-relevant situations of individual vehicles. In addition, ICOS is able to integrate real-time systems. Especially this co-simulation interface is used for the hybrid test, in which a real-world vehicle is embedded in the virtual environment on the INFRAMIX test site.

4.2. Simulation Architecture

For INFRAMIX, the challenge is to combine the both worlds. The concept for the architecture envisions the connection of both simulation environments according to the High Level Architecture (HLA) principle as standardized by the IEEE Std. for HLA (2010) and implemented byVSimRTI. This means, VSimRTI is used to couple ICOS with the other needed simulators. Figure 5 depicts the architectural design for this approach. Each VSimRTI simulator as well as ICOS is embedded in a Federate and implements an interface, namely the Ambassador, only towards VSimRTI.

VSimRTI handles the three management functions:

- **Federation Management:** to control the lifecycle of all connected simulators and ICOS. More precisely, to start, join, and stop the individual simulators in the federation during the configured time frame of the simulation
- **Time Management:** to synchronize the time between the independent processes of the simulation federates. In a joint procedure with the federates, VSimRTI performs the time advance grants for local events that could be either come from the simulator itself or produced by another regulated simulator in the federation.
- **Interaction Management:** to coordinate the information exchange between all simulators. All simulators communicate messages only with VSimRTI, which then distributes the messages to all other federates that have subscribed to the according information.

ICOS manages the effective scheduling of all domain specific models and numerical solvers for the sub-microscopic simulation in ICOS. One specific challenge is the synchronization of time steps for the simulation events. It would occur that e.g. the sub-microscopic Vehicle Dynamics model in ICOS simulates a shorter step size than the Traffic Simulator coupled to VSimRTI. The use of several different step sizes leads to a multi-rate simulation, where information exchange between the simulators is only performed at the longer step size.

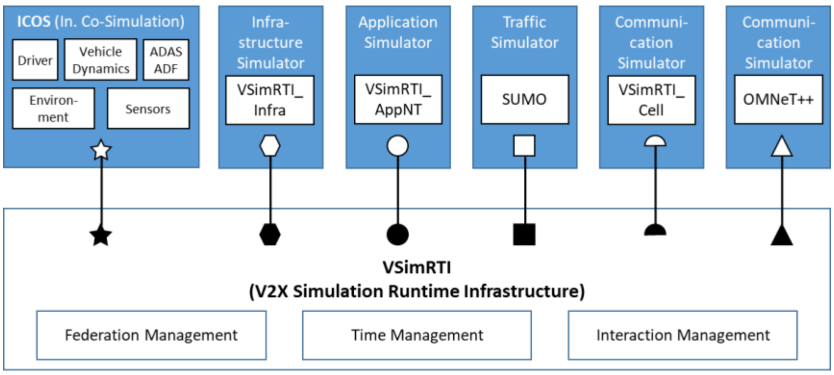

Fig.5 Technical architecture for the connection of VSimRTI and ICOS

For the calculation of the simulation state at intermediate shorter time steps, extrapolation techniques have to be applied (Benedikt and Hofer (2013)).

4.3 Advantages of the proposed solution

The resulting solution for the INFRAMIX Co-simulation is depicted in Figure 6. It shows the possible simulation domains that can be addressed for investigations within INFRAMIX.

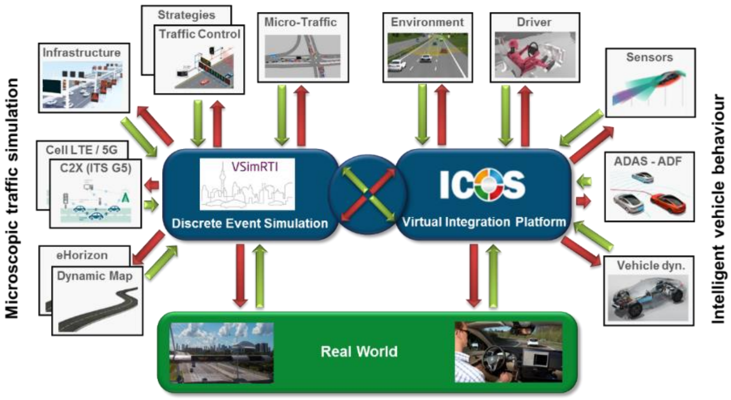

Fig.6 Domains of the overall INFRAMIX Co-Simulation environment

The individual Simulation Domains:

Microscopic Traffic: Provides realistic mobility pattern for a multitude of vehicles and generates the overall traffic flow in the investigated scenarios. All simulated vehicles in the Traffic Simulator, such as SUMO (Krajzewicz et al (2012)), have a corresponding agent in the Application Simulator and could be equipped with models to provide the dedicated functionality of e.g. behavior of conventional vehicles or communication capabilities of connected vehicles. Furthermore, this approach allows the modeling of different vehicle types such as trucks and passenger cars.

Infrastructure (Sensors, VMS): Includes two different functionalities. It could sense information on the traffic pattern from the Traffic Simulator, using sensor models such as counters or induction loops. For the functionality of informing vehicles with Variable Message Signs, a new simulator VSimRTI_Infra has to be developed within the INFRAMIX project.

Traffic Control Strategies: Are, in real world, implemented in a solution from a Traffic Service Provider (e.g. TomTom) or a Traffic Management Center from an Infrastructure Provider / Road Operator. In the simulation, these control algorithms are equipped on specific server entities in the VSimRTI_AppNT simulator. These servers could have a possibly different communication channel towards the vehicles or connected infrastructure elements depending on the investigated scenario variation.

Data Management for Dynamic Map: Is also directly included in the Application simulator and provides the data basis for the Traffic Control Strategies.

Communication: Is realized over two different technologies, using two different simulators in the VSimRTI federation. Cellular (LTE or even 5G) communication is simulated with the VSimRTI_Cell simulator (Protzmann et al (2014), while WLAN based ad hoc communication (ETSI ITS) is simulated with either OMNeT++ (Varga et al. (2008)) or ns-3.

Environment, Sensors: Enables the information exchange between the microscopic part of the simulation with several vehicles and the sub-microscopic part for the very detailed simulation of one individual vehicle.

Vehicle Dynamics: Simulates the physical properties of the vehicle, such as engine acceleration, brakes, suspension in close detail within ICOS. Thus, it provides more realism compared to applied Car Following models in the microscopic simulator.

Driver (Behavior), ADAS-AD Functions: Calculate the detailed trajectory for the single vehicle, either as a conventional vehicle (including the human behavior model) or as an automated vehicle.

In general, the simulation accompanies the development of the INFRAMIX components for the real world tests. With simulation, certain parts can be pre-tested and assessed before deployed in the field. In this way, the Co-simulation environment will be employed for later evaluation of all proposed use cases for the three INFRAMIX scenarios of 1) Dynamic Lane Assignment, 2) Roadworks zones and 3) Bottlenecks.

In fact, there will be cases of these scenarios, which could only be investigated with simulation. For instance, for scenario 1, adverse weather conditions will be considered. Since certain weather conditions like Fog or Snow could not be guaranteed anytime in the real world, the simulation is the preferred tool for such investigations. Therefore, specific parametrizations and extensions for several models as the Sensor models, the Traffic and Driver models and further need to be derived.

In scenario 2, several cases with safety critical impact are envisioned. Especially for such cases, the evaluations benefit from the hybrid testing concept, where real test sites including different infrastructure measures are coupled with the virtual environment. Therefore, the virtual vehicle captures the simulated environment with sensor and communication models (V2X) as well as signals from the road infrastructure and transmits relevant signals to the real world vehicle in real time. The real vehicle sends its exact lane-specific position back to the virtual environment to close the loop.

Scenario 3 is very well suited for investigations with the Co-simulation environment as well. A main benefit of the INFRAMIX traffic control strategies for bottlenecks is the improvement of traffic efficiency, while preserving safe conditions for all participants. Simulation not only allows, to model the same traffic flow conditions, which could be provided from the test sites. Moreover, it could assume increased traffic densities to test the developed traffic control algorithms in exceptional conditions. Finally, it is also relatively straightforward to perform comprehensive evaluation series of with different equipment rates of the targeted vehicle classes (conventional, connected-conventional, automated and connected-automated) with the INFRAMIX Co-Simulation environment.

5. Outlook and Next Steps

In order to support the transition to automation and the coexistence of conventional and automated vehicles on the same network infrastructure, INFRAMIX is working on the needed adaptations on the physical infrastructure (avoiding major investments) and the needed advances on the digital infrastructure. Both will be tested on real roads and in simulation while taking into account users' appreciation.

Following a bottom up approach, three critical scenarios in the aspect of safety and efficiency have already been defined; dynamic lane assignment, roadworks zone and bottlenecks (as described in section 2). Currently, several use cases for each scenario are considered attempting to detect specific challenges, provide realistic solutions, point out important aspects of each scenario and investigate the research questions in a well-structured sequence. In this stage, the technical concept for each use case is being developed. Specifically, a use case driven process has been followed in order to define the required equipment and software components, the interaction of different technologies, as well as the required level of innovation. Moreover, the requirement capture for the concept of each use case has started and several challenges have already been detected due to the novel nature of the project such as the lack of real traffic data from automated vehicle behaviour and mixed traffic situations. Another challenging part in the use case based analysis is to specify the aspects that are important as well as feasible, to be tested on the real road. Based on the outcome of this analysis, the upgrade of the test sites will follow in order to integrate and test the INFRAMIX developments in real-world conditions at the test sites and collect data for the evaluation.

The majority of the evaluation work, in order to investigate the several different use cases of each scenario, including different types of automated vehicles and various penetration rates, will be carried out in simulation. The ability to study implications from the introduction of different levels of automated vehicles in the traffic flow enables simulation up to whole test sites, visualization of traffic signs, and real-time coupling of real sites with simulations and models (e.g. of novel roadside elements) for efficient "hybrid development and testing".

6. Conclusions

The expected mixing of automated with conventional vehicles, as well as the technologies involved in the near future, will be challenging. Numerous problems will arise, especially for the coordination and cooperation between those different types of vehicles on the same road infrastructure and their interaction. INFRAMIX aims to prepare the road infrastructure for the transition period and enable the introduction of automated vehicles in real traffic. In order to provide specific adaptations of the road infrastructure and provide concrete suggestions for future road operators, INFRAMIX developments are driven by three critical traffic scenarios in terms of traffic efficiency and safety; dynamic lane assignment, roadworks zones and bottlenecks. Several use cases per scenario will be evaluated through simulation as well as in real world. Due to the innovative nature of the project as well as safety concerns, the majority of the INFRAMIX developments will be evaluated in simulation, using the mature simulation infrastructures, VSimRTI (Vehicle-2-X Simulation Runtime Infrastructure) and ICOS (Independent Co-Simulation). In order to combine the modelling of the vehicle behaviour with the traffic simulation a Co-Simulation Environment is to be created based on the cooperation of the two simulation infrastructures. The co-simulation environment enables also the evaluation and optimisation of the infrastructure and the traffic control measures considering real-time communication with real-world vehicles and this will help to timely prepare the infrastructure for future uninterrupted mixed traffic. All the developments offered by INFRAMIX expected to boost EU innovation in Automated Road Transport.

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