Digital Twins for CCAM Applications - the Case of AUGMENTED CCAM and Beyond

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Abstract. Digital Twins (DT) are increasingly penetrating all sectors of digitized work, with the transport sector and especially the domain of Cooperative Connected and Automated Mobility (CCAM) following rapidly. The current manuscript provides an insight in the DT for transport and CCAM and presents the development approach to be followed in the AUGMENTED CCAM EU funded project, that encompasses in multiple ways and levels the use of DT for the Physical and Digital Infrastructure (PDI) enabled solutions that will be deployed in the test sites of Latvia, Spain and France to assist with Operational

Design Domain (ODD) extension of Connected and Automated Vehicles (CAVs).

Keywords: Digital Twins, Cooperative Connected and Automated Mobility, Infrastructure Support for Automated Driving

1 Introduction

1.1 About Digital Twins

In an increasingly more digitized world, Digital Twins (DT), standing for the virtual replication of physical counterparts being assets – objects and/or systems and/or processes, seem to be also increasingly gaining a dominating place in a series of industries (automotive and transport, manufacturing, smart cities, healthcare and construction). Companies that have implemented them have seen an average increase of 15% in efficiency and a 13% reduction in maintenance costs [1], while according to MARKETSANDMARKETS [2], the DT market is predicted to grow from \$3.5 billion in 2020 to \$73.5 billion by 2027, with their applications in automotive and transport industries accounting for the largest share of the market. Some of their recognised advantages encompass enabling predictive maintenance and decision making, fostering of collaboration among teams and potential to improve customer service; still there are challenges to be confronted, such as data integration and management, related to the accuracy and mining of data originating from multiple sensorial sources, DT complexity and scalability as well as security and privacy concerns.

DT in automotive and transport industries, have been created for design, construction and life-cycle management of different assets, such as bridges and roads, while Industry 4.0. OEMs, such as Tesla, BMW and Toyota are seeing in them the future of transportation [3, 4]. Tesla produces a DT for every car it sells while Toyota is building a connected prototype “Woven City” at the base of Mt. Fuji in Japan. In New South Wales (NSW), Australia, a real-time DT ecosystem is being developed through a multitude of projects and in China, cities like Beijing and Shanghai, are creating DT of their transport network to improve real-time efficiency through 51WORLD suite of products [5]. In specific for Cooperative Connected and Automated Mobility (CCAM), DT are applied primarily for prediction, assessment and decision-making purposes aiming to optimise novel, under-validated paradigms prior to their deployment and towards the increase of traffic safety and efficiency, counterbalancing costs and unpredicted side effects. Given the vast spectrum of data sources from the vehicles, the infrastructure, other connected users and the communication and digital enablers of short and long-range telecommunication, data integration and their scalability - directly associated with costs - constitute the key challenges.

1.2 The AUGMENTED CCAM Project & Contents of Manuscript

The current manuscript starts by presenting in section 2 an insight to DT for Transport, and, more specifically for CCAM, along with their dominating taxonomies, as they are being studied in the context of AUGMENTED CCAM EU funded

Innovation Action [6]. AUGMENTED CCAM aims to understand, harmonise and evaluate in an augmented manner, adapted and novel support concepts of Physical, Digital and Communication (PDI) infrastructure, to advance its readiness for large scale deployment of CCAM solutions for all. In this context and as a first step, it aims at a holistic and revised classification of PDI support for CCAM that consists of five (5) layers, which are assuming incremental support and readiness of Digital and Communication Infrastructure for all different vehicle cohorts placed in the context of CCAM, namely conventional vehicles, connected and cooperative vehicles, vehicles of low automation level (L1-L3) and, ultimately those of high automation levels (L4-L5), providing recommendations for road operators' priority investments in view of their mixed operation and for applicable vehicle functionalities' combinations. DT envisaged support is delineated among other elements of digital infrastructure across the layers of the emerging classification schema. Following sections 3, 4 and 5 present the objectives and development approach for the DT that will run in parallel and for various purposes with the project's physical sites in France, Latvia and Spain, that include test tracks, depos, living labs and open traffic urban, rural and highway areas. Nine out of the eleven in total novel PDI enabled solutions targeted by the project, are going to be deployed in the aforementioned test sites with the support of DT and are discussed in this manuscript. Those aiming to extend the Operational Design Domain (ODD) of automated vehicles and the functionality of all other vehicle cohorts (connected, cooperative, conventional) under mixed operation conditions. Section 4 concludes the manuscript.

2 Insight into Digital Twins for Transport

With advancements in technologies such as Internet of Things (IoT), big data, and artificial intelligence (AI), DT have increasingly penetrated various fields of transportation, such as transportation infrastructure, traffic management, vehicle automation, transport planning, etc. DT in vehicle automation has more agile attention and affinity due to the involvement of commercial stakeholders. CCAM, combining all the aforementioned fields, is evolving into the proliferating era of DTs. DT can be broadly classified into three different classes based on the connection between the physical and digital asset/environment, namely: Digital Model (DM), Digital Shadow (DS), and Digital Twin (DT) [7]. A DM is a virtual representation of the whole/ all elements of the transport system. It may include 3D modelling, simulations, or other types of digital representations that can be used for various purposes, such as design, analysis or visualization, while is no exchange of information between the digital and the physical worlds. A DS is a digital model of the transport system that is updated in real-time based on data collected from sensors or other sources in the physical environment. This can be a simulation platform integrated with data captured from the physical system to design/predict/analyze the traffic behaviour/state. Therefore, DS systems require unidirectional flow of information from the physical system to the digital world. DTs allow the bidirectional exchange of information between the digital and the physical worlds in both directions. A DT uses data from simulations run in the DS to intervene in active elements of the physical infrastructure and inform custom strategies to connect fleets of automated vehicles in order to avoid hazardous outcomes and optimize vehicle flow.

There is a handful of studies exploring the DT concepts for automated driving. China Academy of Information and Communications Technology (CAICT) developed a DT for an autonomous driving test system, using V2X communication technology to fulfill sensor data [8] upload and virtual scenario information dissemination process [9], while on-road vehicle tests have been conducted to facilitate low latency communication. In [10], a DT framework is proposed for connected vehicles (CVs) consisting of a physical layer and a cyber layer with an advisory speed-based Advanced Driver Assistance System (ADAS) using V2C (Vehicle to Cloud) communication with a case study of cooperative ramp merging using three passenger vehicles under mixed traffic conditions. In [11], developed a DT of autonomous driving test platform has been developed with functional units such as simulation test tools, communication equipment, and test vehicles to carry out real vehicle testing and verification in complex virtual scenes under the condition of limited resources. In [12], a run time synchronized DT of Geneva Motorway (DT-GM) has been developed using SUMO and Traffic Control Interface (TraCI) to experiment with real-time predictive analytics to support safety-critical decisions in traffic management. DT-GM has been reported to provide low latency response for motorways. In [13], a DT for autonomous driving was developed using a game engine, which includes graphics and physics engines for 3D modeling, image rendering, and physical simulation, allowing for the representation of structural, physical, and behavioral information in a virtual world. Research institutions and communities involved in DT research define DT based on the context under development. The widely accepted definition of DT is more specific to the manufacturing industry, hence there is a need to inspect the taxonomies that are relevant to transportation and CCAM in specific. An architecture for a typical DT development for CCAM is presented in Figure 1 and its key elements are as follows:

Physical Space: The physical space in the DT architecture is composed of the CAV (Connected and Automated Vehicle) itself, the physical road network, and the various traffic participants in that environment. For the Physical CAV, this is the perception layer where information about the dynamically changing road environment is sampled by the onboard sensors. The data sampled by the CAV sensors are used by the Autonomous Driving Stack (ADS) for the perception (localization and detection), planning, and control of the vehicle. An onboard High-Definition (HD) map is also often used to aid in the localization of the vehicle as it navigates the road environment [14]. Vehicle Drive by Wire (DbW) is the electronic control (in this case autonomous electronic control) over vehicle propulsion steering and braking. This requires intra-vehicle communication between the sensing, ADS, and DBW. Controller Area Network (CAN) is the standard communication method for the wired intra-vehicle network of control modules and sensor connections [15].

Communication Layer: For bidirectional information to flow between the CAV and the digital space, a wireless communication network is required so that information can be transmitted between the CAV and the cloud (V2C). The CAV, therefore, is required to have onboard wireless communication modules leveraging technology such as 5G [16]. Vehicle to everything (V2X) refers to inter CAV communications and communications between the CAV and connected infrastructure. The two primary communication standards used for V2X are Dedicated Short-Range Communication (DSRC) relying on CAV On-Board Units (OBUs) and Road-Side Units (RSUs) and Cellular Communication (C–V2X) relying on base stations [17, 19]. As the physical road environment changes over time, so must the HD maps embedded within the CAVs and being used within the Digital Space. HD maps can be updated by using recorded sensor data from the CAVs as they navigate the road environment. Once this data has been collected and a ‘ground truth’ HD map is established, it can then be communicated to the CAVs and the digital space. This data collection, processing and data fusion would happen in a cloud environment.

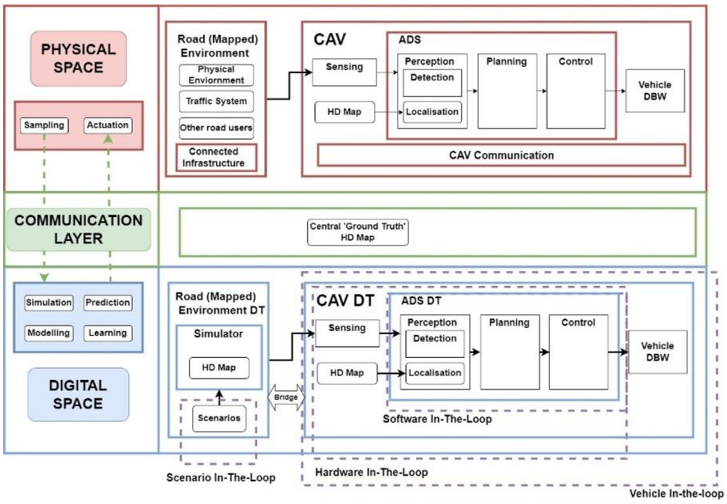

Fig. 1. DT Architecture for CCAM.

Digital Space: A DT provides two distinct functions for CAVs which depend on the phase of the CAV development lifecycle. The first is the use of a DT for testing and training the CAV which includes virtual simulation-based testing & training and ‘In-the-loop’ testing. The second is the use of DT within the real-world environment, to dynamically inform and optimize CAV behavior in real-time. The distinction between these two functionalities is important as it informs the software requirements of the digital model/space, the data to flow between the physical and digital, and the communication requirements.

When a CAV is in development and testing, a DT provides a ‘virtual proving ground’ [19] for testing of the vehicle response to multiple scenarios and use cases, known as Scenario-In-The-Loop (ScIL). A virtual proving ground allows the development team to fill the gap between software and hardware simulations and full road testing and train AI models on different scenarios before being uploaded to the physical self-driving vehicle. The closer the digital environment simulates the physical environment and the digital CAV the software of the actual CAV, known as ScIL, the more accurate the testing will be. These software-based simulations can run faster than real-time tests and are effective in verifying multiple scenarios quickly. This requires a full 3D rendering of the road environment within the simulation engine, built on HD maps collected from the road environment. For continuous testing, these HD maps can be updated periodically as the environment changes. As the testing progresses, increased numbers of digital components of the CAV can be replaced by physical components. Hardware in the loop (HIL) uses physical test benches in a lab environment that send inputs from actual radars and cameras to an electronic control unit (ECU). Vehicle-In-The-Loop (VIL) testing involves a full physical CAV with the digital twin of a road environment and scenarios providing an augmented reality to the CAV. Once a CAV has been deployed and is functioning within a real-world environment, DT can be utilized to dynamically optimise the behavior of CAVs as they operate within this environment. The purpose is to optimise CAV behaviour both locally for individual vehicles to predict incidents and avoid hazards, and to globally optimise traffic flow across the road network. Depending on the goals of a live digital twin, a full 3D rendering may not be required as in the testing and training development stages.

3 Digital Twins in Latvia

3.1 Test sites and PDI Enabled Solutions in Latvia

In Latvia, there are two test sites, namely the closed racing track Biķernieki in Riga operated by Latvian Mobile Telephone (LMT) and an open traffic rural and sub-rural area near Ādaži town operated by Latvian State Roads (LVC). The closed test site of 5,5 km simulates cross-border 5G connectivity, using Latvia’s LMT and Estonia’s Telia 5G networks, to imitate the fully functioning international connectivity needed to test cross-border mobility solutions. Being a fully functional racetrack, various use cases are available to test in high speed, including teleoperation.

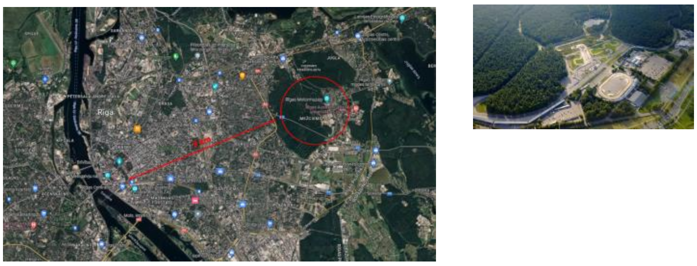

Fig. 2. Test site at Biķernieki racing track in Riga, including cross-border 5G mobile network simulation options and high-speed tests.

The rural/suburban test site of 7,65 km, situated 25 km from Riga, is part of the Ādaži town and its connecting access roads and comprises roads with different pavement and traffic intensities. Most speed limits around the town are 30-50 km/h; still some surrounding roads can be classified as rural roads with low traffic intensity. The neighborhood, including all road intersections, has 5G connectivity provided by LMT.

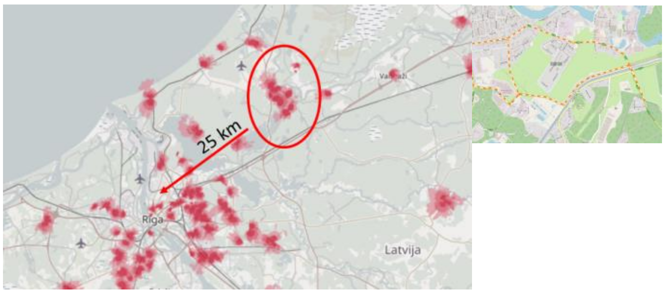

Fig. 3. Test site around Ādaži City has 5G connectivity and enables rural and peri-urban use cases testing.

There are four new PDI enabled solutions that are going to be deployed in the Latvian test site. Three of them are being developed by the Institute of Electronics and Computer Science (EDI). The first one, called *Non-equipped vulnerable road users (VRU) protection* aims to augment the safety of VRUs in the vicinity of CCAVs. This safety enhancement process leverages the sophisticated interplay of data sharing between RSUs and OBUs to pinpoint and anticipate any risks associated with the presence of VRUs, initiating a calculated response on the part of the CCAV. In turn, the *Temporary road works* solution aims to facilitate seamless traffic flow and enhance safety in temporary roadwork areas by providing vehicles with crucial information. This includes specifics about the location, dimensions and rules associated with the roadwork area. The objective is to safeguard road workers, minimize traffic incidents, and mitigate the severity of any such incidents in the roadwork vicinity. The *emergency vehicle approaching* solution is designed with the aim of alerting connected vehicles - both automated and non-automated - about the impending approach of an emergency vehicle. The ultimate goals are to bolster road user safety by minimizing accidents and collision risks, reducing emergency vehicle travel time, and decreasing overall congestion. All three abovementioned services rely on a hybrid PDI solution, which integrates vehicle-based with infrastructure-based approaches in order to support the intended CCAM services. Both infrastructure (RSU) and vehicle segments have perception and communication capabilities, with the aim of exchanging and augmenting information about the surrounding environment. Finally, LMT will work on *localization of assets and CCAV*, testing new options of 5G positioning, as the precision of geospatial data in PDI is of high importance for CCAVs, especially for remote driving. The 5G implementation will impart a new level of precision – not only improving horizontal positioning data but also vertical ones, even indoors. Compared to GPS, 5G could be installed and enable positioning data above ground level as well. PDI with a 5G connection will be able to enable GPS-independent geopositioning services. Three CCAVs (KIA eSoul SAE L3) will be deployed in the two test sites for the testing of the PDI enabled services, equipped with DbW systems along with a variety of OBUs including Lidars, Stereo Cameras, GNSS receivers and Automotive Radars.

3.2 Digital Twins for Test sites in Latvia

A Digital Twin for both test sites in Latvia will be developed. The information exchanged between the infrastructure and vehicle will take place in the core element of the Digital Map (DM) (Figure 4).

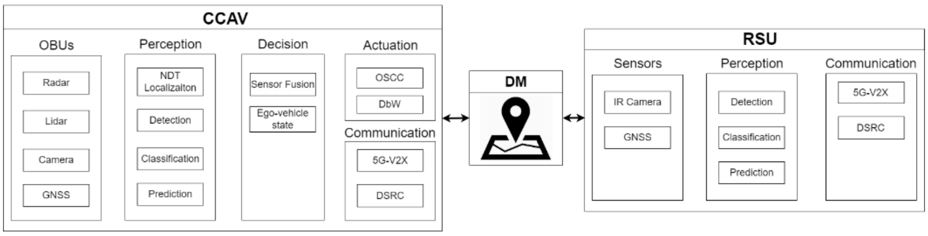

Fig. 4. PDI solution architecture.

It will be built in three stages. In the first stage, there will be a 3D model of test sites created. Then through different kinds of sensors connected to 5G it will be a Digital Shadow created to illustrate and monitor the real-time situation in the test sites including changes in road traffic infrastructure and traffic flow. In the last stage, the full DT will be developed, and knowledge provided by the DT will be automatically integrated and implemented in the physical objects at test sites. The perception, detection and classification capabilities of the surrounding environment are considered to be the foundation of the CCAM platform developed by EDI. The on-going modeling of the digital environment for the Biķernieki testing site will enable lidar-based navigation and high precision localization within the modelled environment, while the succeeding step will be to position and combine the perceived dynamic elements of road (i.e. road users) in the digital environment. The representation of the environment's static features along with the exchanged dynamic information between CCAVs, RSUs and the Traffic Management Center (TMC) over the DM would make up the complete up-to-date DT of the road network. Upon the information provided by the DT, CCAVs navigating in each road section will be able to perform the necessary maneuvers to ensure the continuity of their ODD. The DM is planned to have global instance that will live in the TMC, whereas local DMs instances will be clones of the global DM, living in each CCAV platform. Any authentic change taking place in one of the local DM instances will be reflected in the global DM to keep the DT of the road updated, while sharing the changes with other road users.

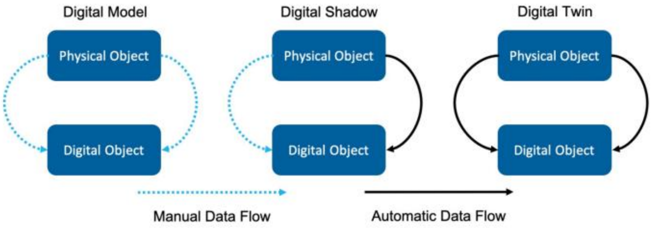

Fig. 5. Different levels of integration for a Digital Twin defined by A. Fuller et al [7].

4 Digital Twins in Spain

4.1 Test sites and PDI Enabled Solutions in Spain

In Spain, there are two test sites, both located in the city of Madrid, namely an open-traffic urban area and a test site located inside and around an EMT bus depot. The open-traffic urban area will be placed at Villaverde neighborhood, in the south of Madrid, of a 3.5 km perimeted, in which different routes will be performed in order to demonstrate the services. The speeds around the area are 30-50 km with a middle traffic intensity. The bus depot is located in Carabanchel at the south of Madrid, with capacity for more than 400 buses. The route planned at the depot's surroundings has a length of 6.5 km in which the vehicles shall find signalized intersections, roundabouts, pedestrian crossings, etc.

Fig. 6. Open-traffic urban area (left) & Bus depot surroundings (right) test sites in Madrid.

There will be four PDI enabled solutions, three of which are addressed in the current manuscript, as they are directly related to the DT that will be developed. The first one, called *Equipped VRUs protection*, aims to enhance the CAVs' ODD by warning them about the presence of VRUs. VRUs will be detected via AI cameras and a VRU application. The infrastructure will be monitoring the VRUs and the CVs and the DT will evaluate the potential risks and send them the proper warnings. This solution testing will be performed at the EMT depot gate during the exit manoeuvres of an autonomous Gulliver minibus. The *Emergency vehicle approaching* service aims to minimize the travel time of a connected priority vehicle. To do so, the DT will calculate the CVs routes and send warnings to those that are on the emergency vehicle's path. Then, it will broadcast the adequate cooperative manoeuvres to clear the way. In addition, the DT will recommend the emergency vehicle the most optimal route to reach its destination, while the Traffic Management System (TMS) will support it with traffic lights priority in the chosen route. This solution will be tested in the EMT bus depot surroundings (Figure 6), along a meshed path of a couple of kilometres in which the connected emergency vehicle will have, at least two alternative routes to reach the emergency spot. Finally, the *Traffic Management optimization* solution goal is to improve TM strategies by the information obtained from CVs. Thanks to this data, the DT will be able to generate O-D matrices, which will be used to inform CVs and CAVs about the road network status and provide them with the optimal routes to reach their destinations. This solution will be tested in the open-traffic urban area (Figure 7). Two Renault Twizys (SAE L3-4), a Gulliver minibus (SAE L3-4) and a Renault Zoe will be deployed. The testing of the *Equipped VRUs protection* solution will be conducted with the Gulliver minibus, while the other two services testing will engage the whole fleet. For the *Traffic Management optimization* service, all vehicles will be deployed in only connected mode, whereas the *Emergency vehicle approaching* service will have both CAVs and CVs.

4.2 Digital Twins for Test Sites in Spain

Urban mobility management requires the cooperation of the different actors that interact in a multimodal transport network. In this test site, multimodal management is carried out by the MISTRAL platform [20], which integrates information from the different modes of transport. Part of this multimodal mobility management is carried out by the traffic light control system that has been distributed among the devices located on the road network (sensors and traffic controllers) and the MISTRAL intelligence. MISTRAL includes a DT that performs a representation of the state of the road network based on its model. This model integrates and merges the information from the sensors and actuators, converting measurements into the different variables that describe the behaviour of the system. In the AUGMENTED CCAM project, the MISTRAL DT will be extended to include the information shared from CAVs and also required by them.

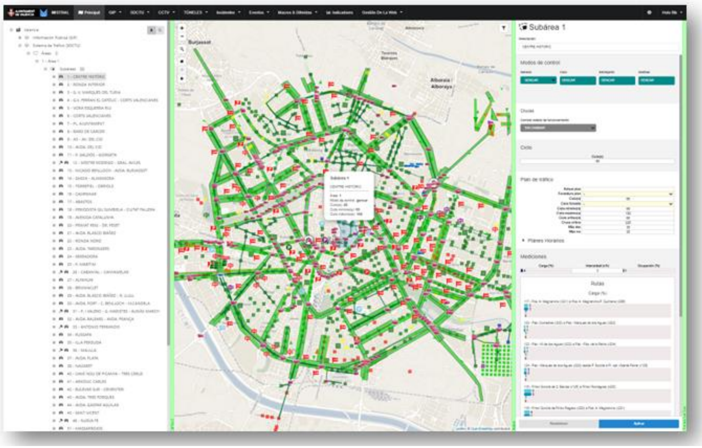

Fig. 7. MISTRAL DT web interface.

The use of data from the CVs for traffic control constitutes a new paradigm in which information based on measurements that will be carried out at certain points of the road network (loops, artificial vision cameras) is replaced by the information provided by the CVs, shifting from a Eulerian model to a Lagrangian one. In addition, the support to CAVs requires expanding the spatiotemporal resolution of the model to cover the needs of CAVs in their interaction with the environment, especially in their interactions with VRUs. The DT includes a representation of the physical reality described by the different variables of the model used, but also includes a series of additional information that does not correspond to a direct description of what can be measured, such as the expected destination of a CAV or the control actions carried out by MISTRAL. All this information is supported by an HD map with the resolution required in each case, following the logic of local HD Maps supporting CAVs.

5 Digital Twins in France

5.1 Test sites and PDI Enabled Solutions in France

Two of the AUGMENTED CCAM test sites in France are discussed in the current manuscript; one is in a controlled and closed environment (Satory test tracks) in Versailles (Paris' suburb) and another one is an open site located close to Bordeaux. The closed environment, operated by University Gustave Eiffel (UGE), involves three different tracks (main road of 3.4 km, speed road of 2.2 km, rural road of 2 km). UGE is deploying a set of dedicated experimental resources and facilities for the development, testing, validation and evaluation of CAVs in real in virtual conditions (Figure 8). The open site, 20 km of motorway (A63), is equipped with specific PDI and key technologies, namely a full ITS-G5 full coverage, 30 RSUs and CCTV (Closed-Circuit Television)), a C-ITS (Cooperative Intelligent Transport System) equipped OBU, a TMS and an external server dealing with data and C-ITS messages (CAM, DENM, IVIM, CPM, etc.) collected and exchanged by vehicles and infrastructure. The first PDI enabled service that will be deployed in the test sites is called *Road workers in the field* and is dedicated to the management of road work areas with the interaction of the CAV trajectory and the roadworkers in order to guarantee a high level of safety. The second one, the so-called *Insertion on motorway*, addresses the management of the motorway on-ramp with CAV and support service from the infrastructure. The purpose consists to optimize the entrance of the CAV with specific and efficient negotiation strategies using HD map, embedded perception, and perception from roadside equipment.

Fig. 8. Satory's test tracks with the UGE's facilities (real and virtual) in France.

Fig. 9. A63 motorway open site with on-ramps and off-ramps, toll area, and rest area in France.

In both cases, the upper level objective is to manage efficiently the risk level in two ways, namely 1) to warn the road workers and the other road users of the presence of a potentially dangerous vehicle, and, 2) to send HD map tiles of the specific area (roadwork and on-ramp) and dedicated messages containing information about the traffic (obstacles dynamics) and appropriate trajectory/behavior/maneuver that the CAV has to follow in order to avoid a forbidden area or to enter safely in the motorway traffic. The CAV will have to consider this information merged with the information coming from its embedded perception and from the other vehicles.

There will be two SAE L4 CAV demonstrators for the deployment of the PDI enabled solutions; an automated Zeo Renault and a scenic Renault (with communication and perception means). An immersive and dynamic simulation platform, and roadside equipment (communication and perception means) are also inherent elements of the solution. In simulation, a specific dynamic clustering algorithm will be implemented and studied in order to optimize the efficiency of the communication means and the multiple level risk assessment. In this context, several levels of HD maps will be built from the same 3D Point cloud, namely an HD Map for TMC operational purposes, an HD Map that will be embedded in the CAVs and a Renault ZOE and an HD Map for simulation purposes. Moreover, different level of information about environment (useful for the ADS) will be generated. The first one is the LDPM (Local Dynamic Perception Map) and the second one is the LEDPM (Local Extended Dynamic Perception Map) which merges the data (LDPM) coming from the vehicles involved in a cluster of vehicles. The third level will be the GDPM (Global Dynamic Perception Map) which considers the perception maps coming from the different clusters and from the infrastructure. These three levels of perception modeling (information about obstacles, road, ego-vehicle, environment, and potentially the driver) will be useful for the computation of several levels of risk (local, local extended, extended, global) and in order to build a multiple level strategy of automated driving, as follows: a) short time range for reactive behavior; b) middle time range to anticipate and predict hazardous area requiring either to have a driver intervention, or generate an adapted trajectory with safety and comfort constraints; c) long time range to modify the long-term trajectory with possible route changing.

5.2 Digital Twins for Test Sites in France

For the Satory’s test track, a realistic DT has been generated by using a topographic survey including all the static environment, including buildings, vegetation and infrastructure furniture. For the representation of the embedded and roadside sensors and the localization and communication means, a set of realistic models have been developed and validated with specific equipment (i.e. DXO bench for cameras). The sensors are fed with specific materials like HDR texture and BRDF for cameras, RCS and material properties for RADAR, igs file and parameters for atmospheric layers models (Klobuchar, NHopfiels, etc.) for GPS. Communication means use an interconnection between NS3 (modeling of OSI layers) and Pro-SiVIC (propagation channel modeling built from a real WiFi dataset). The main adverse and degraded weather conditions are modeled with physical models (fog, rain, rain drops, sun effects). A detailed presentation of this realistic simulation platform, called Pro-SiVIC, involving vehicles, pedestrian, sensors, communication, and environment modeling is available in [21]. The road network is modeled with both OpenDrive format and trk format. HD maps will be upgraded with the addition of layers involving temporary static/dynamic objects, the weather and visibility conditions and the PDI type/position/quality). The ZEHNS (A63) motorway area DT is in progress. A unified framework will be proposed for all the maps and information involved in. Finally, it is expected to provide a ViL platform involving both real and virtual facilities with a real time communication between both. DTs in this site will aim to address three main objectives. The first on is dedicated to the implementation and test of specific hazardous and adverse real time conditions with a high-fidelity environment (textures, materials, properties of objects, light and shadows, etc.) feeding the sensors and communication models. This level of DT allows to test the efficiency and the performances of the deployed PDI-based services in a controlled, reproducible, and repeatable virtual environment. In these conditions, DT will involve not only road network model (with road marking and traffic sign) nor 3D object modeling, but also propagation channel for communication means and test of CBL [21] and CBL-G [22] strategies with data fusion and crowd-sourcing in a space limited by a cluster of connected vehicles.

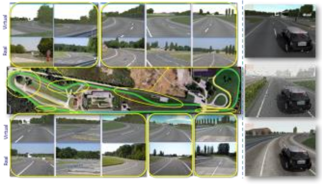

Fig. 10. Digital Twin of Satory’s test track and rendering with Pro-SiVIC: comparison between real pictures and simulation.

This first using of DT also is useful for the optimization of road side equipment deployment. DT and simulation environment will allow to answer to the following question: which PDI and which topology for an optimal result in term of risk minimization, high quality of service (according to a set of Key Performance Indicators), and continuity of service. The second one is more focused on the evaluation and validation process with the generation of representative scenarios and the generation of datasets involving controlled traffic (Symuvia), uncommon and unusual events and situations, adverse and degraded conditions, and very accurate ground truths [23]. The third one is dedicated on ViL and will allow to have at the same time and in the same environment (real and virtual) an automated vehicle with a human in the loop, and a CAV dynamic simulator with a human driver too. This architecture merging real and virtual data allows to generate virtual data usable from the real vehicle, and state of the real vehicle usable and visible in the simulation platform. Specific objects, furniture, and equipment can be generated and visible by real embedded sensors or embedded perception architecture.

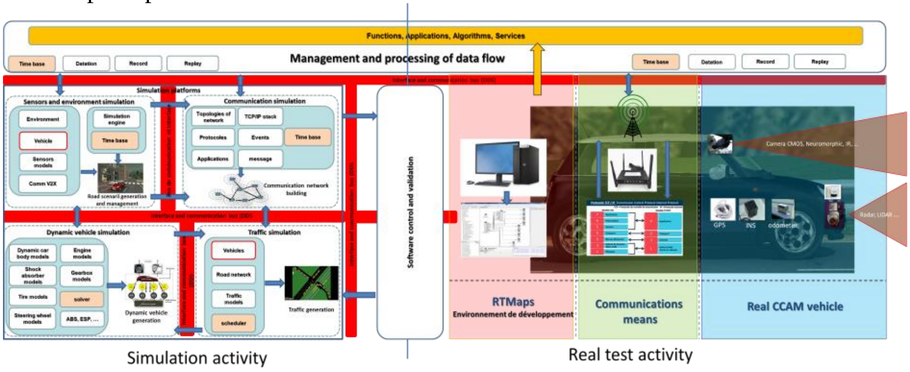

Fig. 11. ViL platform coupling real automated vehicle with dynamic simulation platform using Pro-SiVIC/RTMaps/Symuvia.

6 Conclusions

Depending the DT context and purpose - i.e. study of driving/ vehicle behaviour and interaction with traffic participants on microscopic driving level vs the study of new CCAM services design and impacts on macroscopic / network level - requirements for development and use differ substantially. In addition, most of the applications so far are not developed for bilateral real-time operational response which is essential to CCAM, where the DT, to be worth investing, needs to be an accurate representation of the cyber-physical system (CPS) and to replicate, apart from the static physical environment and its attributes, real time operation of different generation of connected and automated vehicles, that involves V2X and I2V communications, 4G and 5G networks, IoT devices, cloud services, stakeholders, etc. Bidirectional exchange between the digital and the physical world is required to turn the DT to an active system of the transport ecosystem, which goes beyond off-line assessment purposes, and is expected to feed in real time High-Definition maps and other third-party services. The DTs that will be developed in AUGMENTED CCAM project and as presented in the current manuscript will aim in some cases to validate the novel PDI enabled solutions impacts in addition to the field trials validation and in synergy with validation activities in AV and driving simulators as well as microscopic and macroscopic traffic simulations, while in other cases will constitute an inherent element of the PDI enabled solutions of CAVs and the transport network operation manner. The multiple approaches of DT deployment anticipated in the project aim to serve as a best practice ground in DT for CCAM.

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