D2.3

Use cases definition

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Project acronym: **IN2CCAM**

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LEGAL DISCLAIMER

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ABBREVIATIONS AND ACRONYMS

Abbreviation	Meaning
AI	Artificial Intelligence
API	Application Programming Interface
APP	Application
AV	Automated Vehicle
BLE	Bluetooth Low Energy
CAM	Cooperative Awareness Message
CCAM	Connected Cooperative Automated Mobility
CCTV	Closed Circuit TeleVision
CPM	Collective Perception Message
DATEXII	Data Exchange II
DC	Direct Current
DDNS	Dynamic Domain Name System
DENM	Decentralized Environmental Notification Message
DMEO	Development Monitoring and Evaluation Office
DRT	Demand Responsive Transport
DTA/ENAC	Air Transport Direction/National School of Civil Aviation
DVR	Digital Video Recorder
ETSI	European Telecommunications Standards Institute
EV	Emergency vehicle
FCD	Floating Car Data
FTP	File Transfer Protocol

Gbps	Giga bits per second
GLOSA	Green Light Optimal Speed Advice
GPRS	General Packet Radio Service
GPS	Global Positioning System
GTFS	General Transit Feed Specification
HDMI	High Definition Multimedia Interface
HLN	Hazardous Location Notification
HTTPS	Hyper Text Transfer Protocol (Secured)
IoT	Internet of Things
ITS	Intelligent Transport Systems
IVIM	In-Vehicle Information Message
IVMS	In-Vehicle Monitoring System
LiDAR	Light Detection And Ranging
LL	Living Lab
LPT	Local Public Transport
LTE	Long Term Evolution
LTE-V2X	Long Term Evolution-VehicleToEverything
MAAS	Mobility as a Service
OBU	On Board Unit
PC	Personal Computer
POI	Point Of Interest
PT	Public Transport
PTVC	Public Transport Vehicle Crossing
PUMS	Urban Plan for Sustainable Mobility

RCC	Remote Control Centre
ROC	Remote Operation Centre
RSU	Road Side Unit
RTK	Real Time Kinematic
RTP	Real-time Transport protocol
RTT	Round Trip Time
SAE	Society of Automotive Engineers
SHOW	Shared automation Operating models for Worldwide adoption
SMA	Sub Miniature version A
SMS	Short Message Service
SPAT(EM)	Signal Phase and Timing Message
SREM	Signal Request Message
SSEM	Signal Status Message
SUMO	Simulation of Urban MObility
SUMP	Sustainable Urban Mobility Plan
SW	Software
TCC/TIC	Traffic Control Centre / Traffic Information Centre
TCP/IP	Transmission Control Protocol/Internet Protocol
TFMP	Trikala Fleet Management Platform
TLC	Traffic Light Controller
TLCM	Traffic Light Control and Management
TM	Traffic Management
TMC	Traffic Management Centre
TRL	Tech Readiness Level

UC	Use case
UDP	User Datagram Protocol
UTC	Urban Traffic Control
UVAR	Urban Vehicle Access Restriction
V2I	Vehicle to Everything
VGA	Video Graphics Adapter
VLAN	Virtual Local Area Network
VMP	VLAN Membership Policy Server
VMS	Variable Message Sign
VPN	Virtual Private Network
VRU	Vulnerable Road Users

1 EXECUTIVE SUMMARY

Use cases are important in the IN2CCAM project. They demonstrate the practical applications and benefits of Cooperative, Connected and Automated Mobility (CCAM) technologies, showcasing how they can transform various aspects of transportation. These use cases validate the effectiveness of CCAM systems and provide valuable insights into integration and interoperability requirements. The use cases also serve as a foundation for future deployment and scalability of CCAM technologies.

The IN2CCAM project includes several use cases that demonstrate the practical applications of CCAM technologies in six different cities: Tampere, Trikala, Turin, Vigo, Bari and Quadrilatero.

In Tampere, the "UC#1: Integration of traffic and CCAM fleet (last mile mobility of people)" use case consists of three scenarios: Green light optimal speed advisory (GLOSA) test with automated vehicles (AVs), public transport vehicle crossing for AVs, and AV-detected events.

Trikala's use case "UC#2: Remote monitoring and supervision of AVs fleet for safe and efficient operations, and real-time communication between vehicles and infrastructure" includes scenarios such as implementing automated shuttles synchronized with smart traffic lights, GLOSA tests with AVs, vulnerable road user (VRU) detection, and integrating autonomous demand-responsive solutions with public transport services.

Turin's use case, "UC#3: Dynamic traffic management," includes dynamic re-routing and parking and urban vehicle access regulations (UVAR) publication scenarios.

Vigo has two use cases: "UC#4: Mutual awareness between CCAM fleet, infrastructure, and other users" with a data interchange scenario, and "UC#5: Management strategy adapted to CCAM based on V2I interaction" with scenarios like traffic light priority, green phase extension for platooning, and simulation of CCAVs' reaction to emergency vehicles entering roundabouts.

Bari's first use case "UC#6: developing and simulating a route planner" with scenarios involving CCAVs carrying able-bodied passengers, passengers with disabilities, and carpooling. On a second hand, Bari will explore automated robot delivery within "UC#7: Innovative urban freight transport and logistics".

Lastly, Quadrilatero's "UC#8: Simulation of CCAM impact on traffic flow and potential congestions in urban and peri-urban areas" focuses on simulating the impact of CCAM on traffic flow and congestion, with scenarios like road and lane blocking, parking availability changes, adapting public transportation, creating low-emission zones, and running ad-hoc simulations. These use cases collectively showcase the versatility and potential of CCAM technologies in various urban settings.

The Use Cases deliverable of the IN2CCAM project shows the practical applications of CCAM technologies in different cities. By presenting a range of scenarios, these use cases provide valuable insights into the integration, interoperability, and potential benefits of CCAM systems. The outcomes of these use cases will contribute to the advancement and implementation of CCAM technologies.

2 INTRODUCTION

2.1 Project intro

The IN2CCAM project (in extenso: Enhancing Integration and Interoperability of CCAM ecosystem) is an Innovation Action referring to the Horizon Europe call HORIZON-CL5-2022-D6-01-04: Integrate CCAM services in fleet and traffic management systems (CCAM Partnership).

IN2CCAM aims to address the three following main challenges: update new physical infrastructures, use and update novel digital infrastructures, and propose suitable operational infrastructures. In order to reach such general objectives, the overall methodology of IN2CCAM is based on the definition, organization, implementation and evaluation of a set of six Living Labs (LLs) that will be the basis for implementing a full integration of CCAM services in the transport system.

The project runs for 36 months, with a start date of 1 November 2022 and an end date of 31 October 2025, with a consortium of 21 partners. IN2CCAM develops and tests innovative services to accelerate the implementation of innovative CCAM technologies and systems for passengers and goods, integrating them into the transport system.

2.2 Purpose of the deliverable

This deliverable defines the use cases that are implemented at each Living Lab during the IN2CCAM project. This deliverable contains the functional description of services and will be used as a reference during the technical specification phase, the implementation phase and the evaluation phase.

2.3 Intended audience

The intended audience is the consortium and more specifically the development and evaluation activities. The use case definition is an important milestone to the actors of WP3 which will define, implement and test the necessary architecture, platforms and material permitting the deployment of the use cases. The evaluation actors will also base the final definition of the evaluation framework on the information provided in this deliverable. Other aspects of the project like communication will also build their documents based on the defined use cases.

2.4 Structure of the deliverable and its relation with other work packages/deliverables

Each lead and follower Living Lab is represented in its dedicated top-level section. Each use case is described in its own second-level section. For each use case, a first subsection contains a general description with the objectives of this use case and the involved stakeholders, the expected impact of this use case and a description of an existing solution, the “State of art”.

Another subsection is focusing on the functional description and requirements. This subsection will mainly be used in Task 3.1 to define a relevant architecture for each use case. The last subsection is describing the use case scenarios and will be used in WP4 for evaluation. Each scenario contains a “Related KPIs” section linked to D2.2.

3 USE CASES GENERAL OVERVIEW

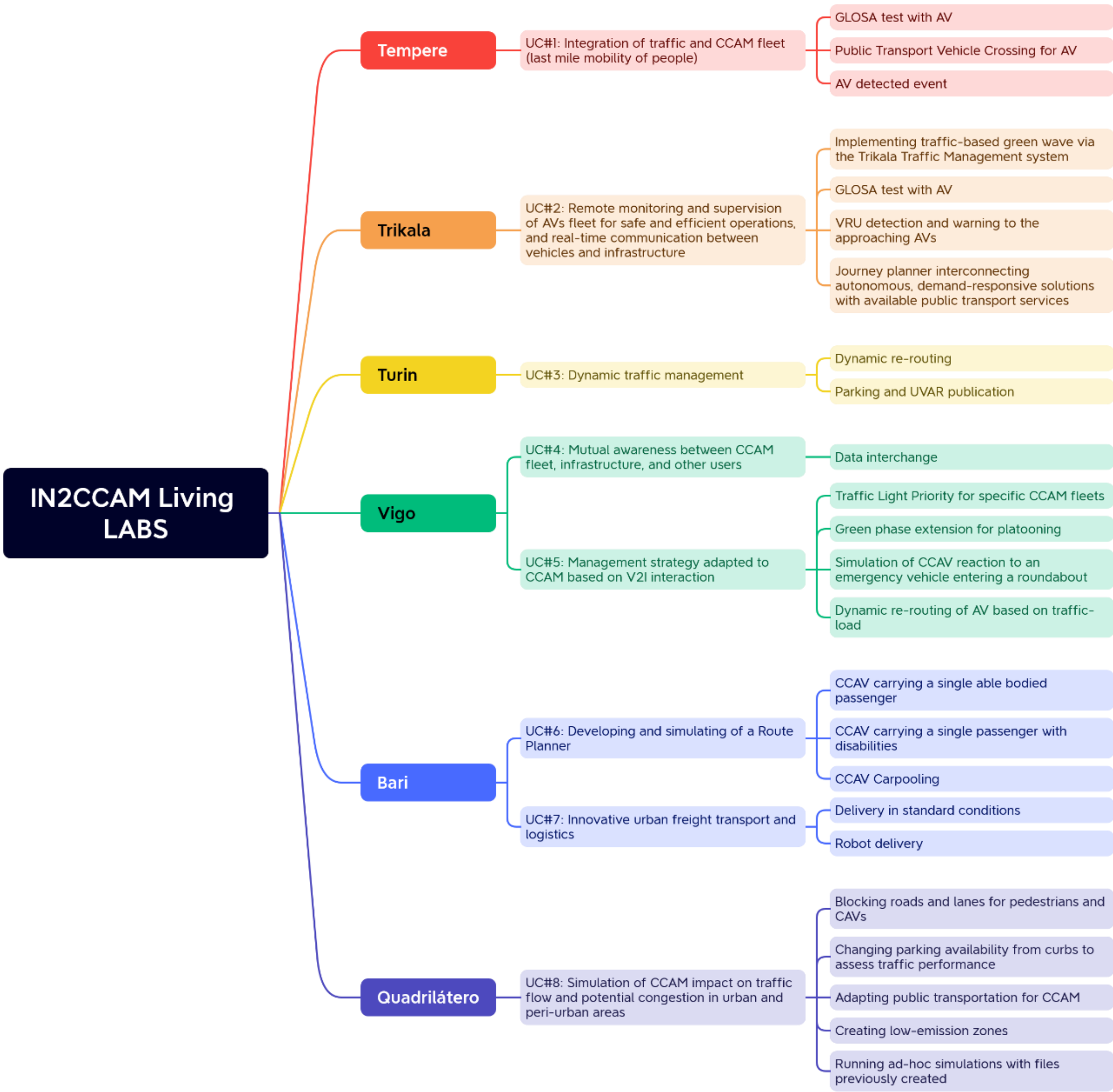

Figure 1: IN2CCAM use cases general overview

Several cities in this project demonstrate notable complementarity among their use cases, contributing to a comprehensive understanding of Cooperative, Connected, and Automated Mobility (CCAM) technologies.

Tampere's use case, focused on integrating CCAM fleet and traffic management systems, complements Trikala's use case, which emphasizes remote monitoring and supervision of AVs.

The dynamic traffic management use case in Turin aligns with Vigo's mutual awareness between CCAM fleet and infrastructure.

Bari's use case, centered around route planning, and Trikala's journey planner integration share a common goal of enhancing transportation efficiency.

Lastly, Quadrilatero's simulations provide valuable insights applicable to all use cases, further enhancing their complementarity.

Through fostering collaborative efforts and leveraging the synergies among these cities, stakeholders can drive the advancement of CCAM technologies, paving the way for the development of interconnected and sustainable solutions for urban mobility.

All those use cases are presented individually in the next chapters.

4 TAMPERE LIVING LAB

4.1 Introduction

The city of Tampere is the largest in-land city in the Nordics with more than 240 000 inhabitants and the second-largest urban area in Finland. Tampere is located on a narrow isthmus between two lakes, which limits the space for traffic. In early 2000s the local public transport was about to reach the maximum capacity in Tampere city centre. Therefore, the construction of the tram to Tampere began in 2017 and the service was launched in 2021. Today the trams are in heavy use and extensions to the tram lines are being build and planned.

Tampere has been an active smart city and Intelligent Transport Systems (ITS) developer since the late '90s. Since 2006, ITS Factory community has been established to strengthen public and private partnerships. The common goal of the community is to produce business-oriented solutions to enable fluent, sustainable, and safe transport.

City of Tampere is solely responsible for mobility and CCAM operations, development, and management within the city boundaries. Tampere serves as a living lab and testbed for smart city innovation. This has supported the adoption of new solutions in close collaboration with local businesses, R&D partners, and end-users who are actively engaged in the process as co-creators. The city of Tampere hosts and manages the Living Lab Test Bed including digital twin in Hervanta, Tampere. The Hervanta Test Bed is the leading test environment in Finland for automated driving and CCAM with excellent digital and communication networks and facilities. Over the years there have been many Automated Vehicle (AV) pilots in Tampere and a few pilots are still running. Tampere provides special environment for AV testing real condition. There are for example some challenges due to winter conditions with very cold weather and icy or snowy streets with no visible road and lane markings, etc.

4.2 UC#1: Integration of traffic and CCAM fleet (last mile mobility of people)

4.2.1 Use case presentation

4.2.1.1 Stakeholders and objectives

The objective of the Tampere Living Lab (LL) in IN2CCAM project is to develop and introduce improvements in the local last-mile mobility for people in Hervanta. Tampere LL is managed by VTT, supported by the Business Tampere. Other relevant stakeholders in Tampere LL are the following:

- End users*: commuters, students, elderly with reduced mobility, Safety Drivers and Remote Operators (for AVs), operators in (public) transport management centres
- Decision-making authorities and regulators: City of Tampere, Fintraffic
- Mobility service operators (e.g. public transport operators, private fleet operators): Tampere City Transport (bus operator), VR (Tram operator), Remoted (AV operator)
- Industry (e.g. AV manufacturers): Auvetech, EasyMile, Traffic light data providers (Nodeon)
- Others (e.g. open traffic/weather data providers): Finnish Meteorological Institute, ITS Factory, Tampere city IoT platform (Wapice)

* In general, the CCAM services are targeted for all citizens in Hervanta but with special target groups for research point of view are listed above.

4.2.1.2 Expected impact

The city of Tampere aims to develop sustainable and integrated mobility services and a transport system that will attract private car users to voluntarily start using more environmentally friendly public transport services. For this efficient public transport, last mile services are also needed. The expected impact of the improved local last-mile mobility for people in Hervanta is smooth, safe and efficient urban last-mile transport with CCAM vehicles for feeding the tram line. The CCAM fleet may provide new information sources and more accurate information from the field for operative traffic and public transport management. This increases their traffic management capabilities. Also, non-CCAM users and drivers will benefit from smoother traffic via CCAM vehicles which will adapt their driving according to information received via CCAM services.

In addition, one of the objectives is to discover feasible business model for Tampere LL to implement and maintain the CCAM services. The development and introduction of new CCAM services will increase the overall awareness in the ecosystem including all stakeholders and enable future development of new CCAM services.

4.2.1.3 State of art

Currently, there are 4 automated shuttle busses running in the Tampere LL testing area. Three shuttles from AuveTech are running in Hervanta centre route, which is the same route as the one used in SHOW project. The route is on open roads with mixed traffic, approximately 3.3 km long and includes bus stops and two roundabouts. The route runs partly on tram lines. In addition, one EasyMile shuttle is running in the end stop of the tramline in Hervanta on 1.2 km route on open roads with mixed traffic. These AVs will be used to test some of the CCAM services in the project. VTT has one shuttle bus (SAE level 4) and several automated passenger cars which will be used to test all developed CCAM services.

Remote Operation Center (ROC) for AVs is being currently developed at VTT. This ROC will be enhanced in IN2CCAM with CCAM services and connections to real-time data from Traffic Management centres, open data sources and AV fleet. In addition, there will be a private ROC in Tampere during the project as the procurement process for this is currently ongoing.

In NordicWay3 (NW3) project a Tampere NODE for C-ITS services is currently being setup. The Node receives real-time data from traffic lights from various suppliers and makes it accessible in standardized format (SPATem, MAPem). It makes it available for dissemination to connected vehicles, and various stakeholders. The Tampere Node uses the Dutch profile for SPATem and MAPem and is based on Monotch's TLEX. Three companies supply traffic lights in Tampere City. 20 signalized intersections using equipment from these three traffic light vendors have been chosen for the NW3 pilot. In Hervanta there are a few of these traffic lights. Today, the backend infrastructure for the Tampere Node has been deployed and the signalized intersections (SI) with Signal Phase and Timing Information (SI-SPTI) and with Green Light Optimal Speed Advisory (SI-GLOSA) C-ITS services are being tested. A mobile phone app for GLOSA is available for testing.

5G and 4G/LTE connectivity has been ensured commercially on the test area in Hervanta. No new cellular infrastructure will be added for this pilot. Short-range ITS-G5 communication can be utilised for VTT AV vehicles if needed.

Tampere has invested in building a significant ecosystem of both physical and digital testbeds. For IN2CCAM project the following testbeds are the most relevant:

- Autonomous driving test area for automotive cluster and SAE level 4 AVs
- 5G testbed ecosystem – towards 5G Hervanta testbed
- IOT platform – city IoT platform supporting testing and creating pioneering infra and mobility solutions
- Smart tram – physical and digital testbed for next generation rail-traffic related innovations. This also includes Tampere Tram Living Lab, called Lyyli.

4.2.2 Use case description

4.2.2.1 Functional description

Tampere LL is utilising and further elaborating the existing C-ITS components and VTT AV Remote Operation Centre for piloting new innovative services. Therefore, the backbone and many interfaces to the mobility services and data sources are already there. The goal is to adapt the existing platforms by integrating additional features for e.g., VTT ROC and AV fleet.

The Figure 2 shows the Tampere LL IN2CCAM data platform and its most relevant connected entities. On the left-hand side there are mainly data providers such as Tampere Node, and various open data sources which will be used for CCAM services. Data will be shared through a central data sharing platform that will accept connections from involved parties. On the right-hand side there are actors such as ROC and AV vehicles that will consume the data but also generates data for example for new CCAM services. The data platform allows access control for publication and subscription, so that data can be used for various purposes. In the middle on top of the data platform there is the CCAM services which gets information from various sources and outputs data (in standardised format) for CCAM services. Data is accessible only for pre-registered users or entities to guarantee privacy and security.

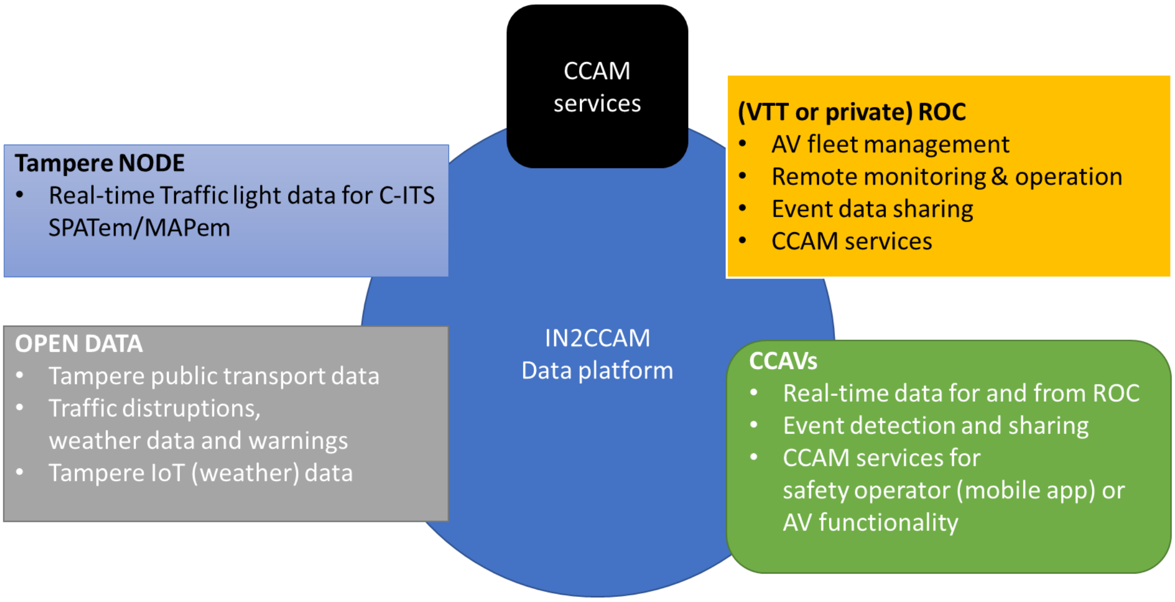

Figure 2: Tampere LL data platform

4.2.2.2 Functional and architectural requirements

The aim of Tampere LL in the IN2CCAM project is to demonstrate CCAM services and their feasibility in automated shuttles together with ROC in real traffic environment in small scale. The deployment in higher scale could be analysed later in future actions and or projects. This limitation will affect to the functional requirements listed below.

UC1-FUNC-001
Data platform must be available on the Internet using a TCP/IP protocol.

UC1-FUNC-002
Data platform must allow data providers authentication using user/pass (and digital signature mechanisms if needed). It should allow non-authenticated access.

UC1-FUNC-003
Data platform must allow the exchange of predefined types of messages based on ETSI standards such as DENM, SPATEM, MAPEM, CPM.

UC1-FUNC-004
Data platform must be able to save all messages (e.g. during testing/piloting)

4.2.2.3 Interoperability and relation to other Living Labs

In order to maximise the interoperability between Tampere Living Lab and existing C-ITS platform (Tampere Node) and possible extensions in the future, the IN2CCAM data platform only publishes CCAM service data based on ETSI standardized messages.

4.2.3 Test scenarios

CCAM services in AV shuttles will be implemented in 2 phases, because there is no possibility to install any software to external AV shuttles (operated by companies outside of IN2CCAM). Therefore, CCAM services will be implemented first as a mobile phone app which will be provided to safety operators of external AV shuttles. They can use it while driving the AV. In the second phase, the CCAM services will be installed and tested with VTT AV shuttle (or other VTT AV) where they can be integrated to automated driving software (SW).

4.2.3.1 Scenario #1: GLOSA test with AV

Pre-conditions

Physical infrastructure:

- Real-time data from at least one traffic light intersection is on the route of AV

DIGITAL INFRASTRUCTURE

- Traffic Light Controller (TLC) can make accurate predictions of signal state change, and report this in the SPAT/MAP messages. (Not all controllers support this, if it is not supported, only Traffic Light Signal Information use case is possible and not GLOSA) => SPAT/MAP data available
- There is a common time synchronization defined for all the equipment.

Connected Automated Vehicle (CAV):

- Vehicle is equipped with
  - GLOSA app on mobile phone (for external AVs)
  - GLOSA functionality running together with AV driving SW (VTT AV)
- Vehicle has satellite positioning and cellular communication available
- There is implemented an internal protocol and the needed tools to translate the ETSI standardized warning messages to AV SW (VTT AV).

Scenario flow

1. AV approaches the intersection with traffic lights
2. Vehicle receives SPAT/MAP data from backend
3. GLOSA information is utilized in AV
   a. GLOSA app shows information to safety driver (external AV)
   b. AV driving function handles the data (VTT AV)
4. Vehicle adapts its speed to get through the intersection with green light without stopping if possible

Data collection

- Time stamp of initiation of test

- Time stamped Detailed position, speed and heading of AV
- Standard ETSI messages sent by Tampere Node
- Standard ETSI messages received by GLOSA app
- Non ETSI standard information exchanged among vehicle and backend platform
- Time stamp of trip finalization of test

Related KPIs

Table 1: Research Questions and KPIs for UC#1 Test Scenario 1

Research Questions	KPI Code	KPIs
• How does the automated vehicle change **behaviour** in response to the warnings and information provided by the service? • Is the vehicle's **speed** compliant with the suggested speed? • Does the vehicle start quicker after the traffic light turns green?	**TAM.1.1.01**	**Speed adaptation** (i.e., difference between the speed of the vehicle before and after the C-ITS message, instantaneous accelerations and decelerations)
	TAM.1.1.02	**Difference** between the **speed** suggested by GLOSA and the speed implemented by the vehicle or the safety driver
	TAM.1.1.03	The **frequency** of uninterrupted vehicle crossings through traffic lights due to speed adaptation (compared to crossings without the use of GLOSA)
	TAM.1.1.04	**Intersection crossing time** (compared to crossings without the use of GLOSA)
	TAM.1.1.05	**User acceptance** of the app that the safety driver will be using

4.2.3.2 Scenario #2: Public Transport Vehicle Crossing for AV

Pre-conditions

DIGITAL INFRASTRUCTURE

- Hazardous Location Notification - Public Transport Vehicle Crossing (HLN–PTVC) service is running in CCAM services module
- Tram position with certain accuracy is available in a timely manner

CAV

- Vehicle is equipped with PTVC app on mobile phone (for external AVs)

Scenario flow

1. AV approaches the predefined area where it should drive on tram line
2. Tram enters the triggering area, and this is detected in CCAM services in the backend
3. AV receives DENM message for HLN-PTVC from backend data platform
4. If tram is coming PTVC app shows (“Give priority to tram!”) warning to safety driver

5. If warning received vehicle adapts its speed or stays on the bus stop until warning is cleared in order not to block the tram
6. if no warning or warning cleared AV continues normally

Data collection

- Time stamp of initiation of test
- Time stamped Detailed position, speed and heading of AV
- Time stamped Detailed position, speed and heading of tram
- Standard ETSI messages sent by CCAM services module
- Standard ETSI messages received by PTVC app
- Non ETSI standard information exchanged among vehicle and backend platform
- Time stamp of trip finalization of test

Related KPIs

Table 2: Research Questions and KPIS for UC#1 Test Scenario 2

Research Questions	KPI Code	KPIs
• How does the automated vehicle change **behaviour** in response to the warnings and information provided by the service? • How does this service affect the **travel time** of the AV? • How does this service affect the **travel time** of the tram?	**TAM.1.2.01**	**AV driving adaptation** (difference between the AV starting time from the bus stop before and after the C-ITS message)
	TAM.1.2.02	**Stopping time** and impact on the **AV travel time**.
	TAM.1.2.03	**Impact on the tram travel time**
	TAM.1.2.04	**User acceptance** of the app that the safety driver will be using

4.2.3.3 Scenario #3: AV detected event

Pre-conditions

- VTT AV shuttle has SW which enables it to detect certain events and send warnings to the backend

Scenario flow

1. AV detects an event (e.g. slippery road, AV blocking a lane/tram line, accident, …)
2. AV sends message to ROC and CCAM services
3. ROC shares this warning to other AVs in the area

4. CCAM services shares this warning to relevant external entities (e.g. public transport management centres)

Data collection

- Time stamp of initiation of test
- Time stamped Detailed position, speed and heading of AV
- Standard ETSI messages sent by AV
- Standard ETSI messages sent by CCAM services module
- Standard ETSI messages sent by ROC
- Standard ETSI messages received by Traffic management centre
- Non ETSI standard information exchanged among vehicle and backend platform
- Time stamp of trip finalization of test

Related KPIs

Table 3: Research Questions and KPIs for UC#1 Test Scenario 3

Research Questions	KPI Code	KPIs
• How **accurate** is the AV in detecting obstacles or events on the road? • Does this service improve the **response time** required to mitigate the detected event?	**TAM.1.3.01**	**Success rate for obstacle or event detection** (difference between the number of detections by AV environment perception and detections by the safety operator)
	TAM.1.3.02	**Number of messages** between the **vehicle and** the Remote Operation Centre **(ROC)**
	TAM.1.3.03	**Reaction of the ROC operator** (i.e., manual remote operation of AV to overtake the obstacle, informing the public transport management centre, etc.)

5 TRIKALA LIVING LAB

5.1 Introduction

The city of Trikala is one of the 100 EU cities and one of the 6 Greek municipalities chosen by the EU to be part of the 'Climate Neutral and Smart Cities' mission. CCAM is an essential part of the future transport development of the city of Trikala. In this context, the city of Trikala demonstrates autonomous vehicles' integration into the transportation network. Trikala, located in the heart of continental Greece, is a medium-sized city and serves as the capital of the Trikala regional unit. The Municipality of Trikala (Trikkaion) is part of the Thessaly Region, covering an area of 608.48 km². As of 2011, the population stands at 81,355, with approximately 67,000 residents residing in the city, while the remainder live in the suburban and rural areas. Trikala will showcase the operation of automated shuttles fleet Demand Responsive Transport (DRT) service to serve a specific line connecting a suburban area with the city centre with the focus on active users working in the city centre, and on vulnerable user groups (families, students, elderly etc.).

5.2 UC#2: Remote monitoring and supervision of AVs fleet for safe and efficient operations, and real-time communication between vehicles and infrastructure

5.2.1 Use case presentation

5.2.1.1 Stakeholders and objectives

The pilot demonstration is managed by e-Trikala and ICCS. For the pilot duration, the Mobility as a Service (MaaS) service operation will be undertaken by e-trikala. Apart from the actors participating as project partners (and subcontractors to be chosen by public procurement), the following stakeholders will be involved with the pilot:

- The Municipality of Trikala is the main enabler of the site, that drives policy making and provides financial support and decisions.
- ASTIKO and YPERASTIKO KTEL TRIKALON, which are the relevant Public Transport Operators (PTOs).
- Trikala local traffic police.
- The University of Sports and Science, given the fact that students are one of the AVs Demand Responsive Transport (DRT) service's passenger groups. The University is

also located along the route of the Automated Vehicles (it constitutes the final destination).

- The cyclist union of the city, vulnerable user groups and road users as well as the youth council.
- VODAFONE GR is the telecom operator which will be involved for the operation of the local 5G network.
- The Ministry of Transport will also be an essential stakeholder, as the operation of the AVs will be aligned with the new Greek legal framework that was released in 2021 and relevant Ministerial Decision of 2022.

5.2.1.2 Expected impact

For Trikala city, the main urban mobility objectives are the following:

- Decongestion of the city centre which can be addressed by car usage reduction and modal shift towards sustainable forms of mobility;
- Unification of the bicycle path and pedestrian network, as planned in the framework of the ongoing SUMP;
- Higher adoption of shared transport services thanks to more frequent services, enhanced accessibility, and attractive fares.

The different services provided by the Trikala Use Case will contribute to the modal shift which is considered necessary for both the decongestion of the city centre, and the enhancement of the environment given that conventional motorised car is the most used mode of transport. Gas emissions will be reduced and parking slots will be freed. It will promote an efficient, reliable and high-quality shared mobility service, widely accepted and used by people living especially in the suburban areas of the city.

In a nutshell, the services and use cases in Trikala will have impact on:

- Carbon neutrality,
- Modal split in mobility,
- Reduction of ICE vehicles in the city centre,
- Enhanced mobility options for vulnerable user groups (elderly, families, women, people with disabilities),
- Enhanced mobility safety,
- New business models, and
- Traffic efficiency.

The objectives and targets are based on the strategic goals of the City of Trikala and are aligned with the city's Sustainable Urban Mobility Plan (SUMP), which promotes, among others, electromobility, active mobility, micro-mobility, automated transport, and public engagement. In addition, the SUMP aims to boost the public transportation share in daily transport patterns, which is currently dominated by private fossil-fuel vehicles.

5.2.1.3 State of art

The city of Trikala as the first Digital City in Greece offers a wide variety of enablers. Currently the following mobility policies are applied:

- ICT infrastructures (e.g. fibre optics network) and services (e.g. smart parking system) and continuously incorporating new ones.
- Initiation of autonomous buses' integration within the city's transport network in the framework of the AVINT and SHOW project that will serve the suburban areas.
- Incorporation of multimodal travel patterns and planning, taking advantage of the MaaS platform implemented in the framework of SMARTA2 project.
- Use of urban air mobility systems and services in the framework of the ongoing HARMONY project.

Several infrastructures are available concerning traffic and mobility management. These are the following:

- Smart City control centre, established in the framework of the Smart Trikala project, including smart parking system, environmental conditions monitoring system, data collection and analysis, traffic lights operation monitoring system, comprehensive geographic information system (GIS) among others.
- PT telematics service.
- Info Point in the city centre where public bicycles, smart lockers, electric light vehicles (ELVs), and a wheelchair scooter have been available to the public. All of these services are available to commuters in the city centre via a pre-booking app.
- Two public car parks and several private ones are available in the city centre.
- Two charging points for electrified vehicles are available, one located in the city centre and the other one in Matsopoulos Mill near the city centre.
- MaaS platform has been developed in the framework of the SMATRA2 project, incorporating car-pooling service, PT information service, bike, ELVs, wheelchair scooter renting service, and on demand services.
- The city of Trikala was selected to host one of the first three 5G pilot cases in Greece. This 5G pilot project will enable advanced services and the installation of a wireless network that will support both the municipality's smart city programme and relevant activities by its partners, including public safety services (security camera interconnection; interactivity with smart lighting; smart buildings etc.), transportation safety (interactivity with smart lighting; drivers' view sharing) and advanced services (autonomous vehicles), health and care (remote monitoring of residents of special needs by health-care providers), as well as a 5G integration of all the municipality's sensors (i.e. parking, lighting, traffic, waste bins, water meters, etc.).
- Environmental Conditions Monitoring System: Using special equipment for environmental readings (such as measuring the concentrations of air pollutants and particulate matter, and noise levels), the quality of the atmosphere can be evaluated and any potential impact on public health can be assessed. Also, the application displays real-time standardised indexes of environmental quality that allow for

comparative evaluations (benchmarking), real-time alerts, and the identification of trends that could or should lead to specific measures. The system has been installed in the building of the Regional Unit of Trikala.

- Data collection and analysis from wireless network: An application has been implemented that permits fast and easy user connections to the wireless municipal network in different ways, such as through users' accounts on social media platforms. Data from wireless network use will be utilised by the Municipal Authority that will use the Marera application to inform residents about cultural events and activities in the Municipality and to help them enjoy their time in the city. Furthermore, in association with the local Trade Association or other interested parties, business activity and increased consumer activity are promoted through targeted offers or other promotional activities.

In Trikala city two major CCAM pilots have been operated from 2014 till now within the CM2, AVINT and SHOW project. The first pilot has been operated within CM2 project where an autonomous shuttle served a route within the city centre on a dedicated lane and the second pilot which started within AVINT project and is running currently within the SHOW project operates on the suburbs as it is described in the next sections. Several enhancements regarding V2X connectivity, VRUs safety, and usage of the service from end users are going to be implemented within the IN2CCAM projects towards the efficient operation of the offered services, the expected impacts, user acceptance as well as future commercialisation of the services.

5.2.2 Use case description

5.2.2.1 Functional description

The Trikala pilot includes 2 CAV mini vans with 6 seats SAE level 4 and almost 9,6km long route with median road inclination <1% for the shuttles runs between the city centre and the Science and Sports University covering also specific points of interest of the citizens such as the railway station, the Thematic park of Trikala, Sports facilities as well as major suburbs and villages that are underserved from the current PT line.

The van's route will be used by inhabitants of the area as well as students. The service is offered on demand (with fixed bus stops), there are five signalized intersections with smart traffic lights installed.

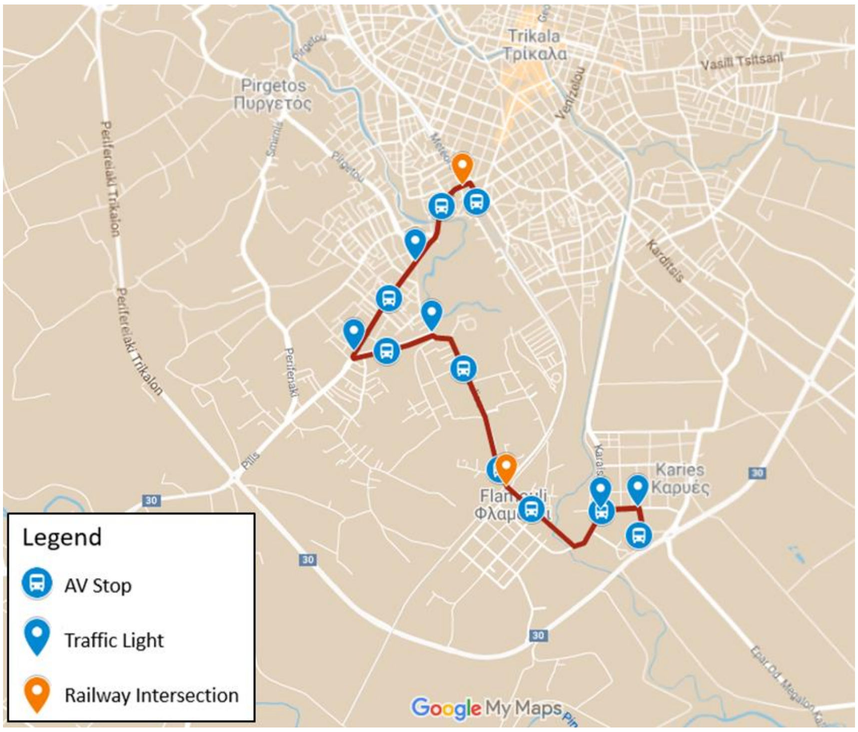

Figure 3: AV route in Trikala

Trikala pilot aims at complementing the public transport line in the suburban area that remains under served for most of the day and, thus, the citizens are currently highly depended on private cars. It aims to contribute to the development of new modes of mobility that will lead to healthier, safer, more affordable, more sustainable, more cost-effective, and responsive transport. It includes the demonstration of the integration of autonomous buses in public transport including their interconnection with other modes of transport, such as the railway station, and their integration into the overall transport system. The deployment of the service requires several interventions to the physical and digital infrastructure that led to the following components development:

- A Trikala Traffic Management System for real time continuously monitoring, remote emergency break and immobilization of the AVs as well as fleet management that orchestrates only the AVs on-demand services at the moment and provides the operators with comprehensive monitoring of vehicles and reports at all times.
- Establishment of 4G/5G network connectivity via cooperation with the telecom operator Vodafone within the whole route.
- Types of data collected include raw data for the telematics devices of the vehicles, video data, traffic and trip data.
- Information and regulatory signs along the whole route.
- Terminal and depot equipped with charging facilities.

The **Trikala Traffic Management System** is comprised of three subsystems.

- The AVs Remote Control Centre (RCC).
- The Trikala Fleet Management Platform (TFMP).

- The Traffic Monitoring Platform (TMP).

The already developed **Remote Control Centre** receives real-time feedback from the cameras installed on the automated vehicle using the existing 4G and 5G infrastructure for the communication. In more detail, a live feed of cameras mounted on the vehicle is provided using 5G/4G network communication. In addition, an emergency phone line is provided inside the vehicle (VoIP). The RCC will be also equipped with i) an emergency button giving the ability to smooth breaking and immobilization of the vehicle and ii) remote execution of overtaking manoeuvres (optionally only if safety conditions allow it).
The **Trikala Fleet Management Platform (TFMP)** includes a number of sub platforms that have been put into place to support the development of the Trikala MaaS platform ecosystem. The operator can monitor in real time the current geographical location of a vehicle on a digital map and receive information about its position, speed, direction, and other statuses of the bus, such as starting, stopping, speed, low battery, door opening. Also, the operator will be able to create itinerary reports with the above data for specific periods of his choice, so that it is possible to also monitor and assess the movement of the fleet in the past.

The **TFMP** consists of the following subsystems:

1. The AVs Fleet Service which is the main system responsible for pumping GPS data from the manufacturer's external subsystem (GPS Device Service that undertakes the communication with the devices) through API (Application Programming Interface), their processing and the synthesis of the generated information based on business logic, its storage in the System Database and finally the dissemination of information and communication with the applications used by remote operators.
2. The Fleet Vehicle Client Application (installed on the operator’s computers (PCs), which offers the overall supervision of the application and constitutes the user interface with the system.
3. The Vehicle Fleet Database, in which all the necessary data for the operation of the above two applications are stored.
4. The TFMP will be extended in order to integrate the AVs DRT service with the current PT service in the city of Trikala, thus offering multimodality to the citizens and provide them route guidance between the service’s stations in order a user to go from origin to destination. To this end, Trikala has already introduced the smartphone-app for promoting MaaS systems and services. With the project ‘SMARTA2’, Trikala offered to the residents of rural areas the concept of carpooling along with the use of alternative mobility solutions to reach the city centre or travel within. Thus, the service will be extended to include the CCAM Fleet in the MaaS platform of the city. Furthermore, as the CCAM Fleet will be operated on demand via a DRT service there will be the capability to allow a driverless vehicle to be ordered via the specific end-user mobile application or an external request (e.g. via web or telephone). The end-user application will display also traffic information such as waiting times and expected time of arrival. Finally, implementation of services related with VRUs interaction with

the autonomous vehicles will be explored with the help of Roadside Units (RSUs) that will be installed in specific signalized intersections along the route to monitor the pedestrian crossing area in order to detect possible dangerous situations and giving alerts to the users.

The **TMP** includes the **Trikala Traffic Light Control and Management** and will be able to:

i. Provide two-way communication with all traffic light controllers installed along the route,
ii. Send commands to traffic light controllers to implement a specific traffic signalling program,
iii. To receive current data of the traffic signalling programs
iv. To receive current traffic data from the infrastructure,
v. Monitor the operation of signalized junctions,
vi. To carry out diagnostic functions on field equipment,
vii. Store in the database,
viii. Provide a user-friendly interface with authorized access, and
ix. Be able to receive and sent C-ITS messages and data in order to implement GLOSA and achieve AVs priority along the route.

It will also host functionalities as regards **Interaction of the AVs with VRUs.** In Trikala pilot site one RSU has been installed in one of the main signalized intersections of the AVs route to monitor the pedestrian crossing area in order to detect possible dangerous situations. The RSU device has been placed on a traffic light pole, or in a suitable location with clear view to the zebra crossing. This device integrates many communication technologies and it has the following capabilities:

- G5 radio
- PC5 side link
- 5G/LTE/4G/3G
- Wi-Fi/BLE
- Gigabit Ethernet
- GNSS with RTK base station
- Optical Camera,
- RF mmWave RADAR
- ETSI C-ITS full V2X software stack

Additionally, in Trikala site the feasibility of the implementation of an additional user application that will be used to increase the interaction between VRUs and AVs will be examined. This application will be used to exchange awareness and notification messages with other connected actors. It will evaluate dangerous situations and will use audio and visual warning alerts via an HMI when a risky situation is predicted.

Data transmission

The types of data transmitted from the vehicle to the TMP via the network are:

- Raw data that will come from the telematics device and will include GPS coordinates of the bus position, speed, direction, odometer & events of interest for the vehicles on a digital map (e.g. start, stop, engine start-up, peripheral status if the corresponding information is received from the vehicles, etc.) which are sent by the vehicle via TCP/IP to a central server, within a certain period of a few seconds. For this type of data, the GPRS service is considered sufficient for transmission.
- VoIP communication through a network telephone device.
- Video data from the 5 cameras placed on the vehicle in order to provide to the RCC a complete view mainly of the external but also of the internal environment of the vehicle, as according to the regulation.

Traffic controllers

Traffic controllers are going to be deployed within the Trikala site route in major crossings. The controllers will meet the requirements of the Technical Regulation "For the Determination of National Requirements for traffic light and pedestrian traffic controllers" (Decision DMEO / o / 1925 / g / 254, Government Gazette 1321 / 23.5. 2014, issue B!).

Router

The 4G (router) technology (ethernet to gateway) for mobile networks will allow the traffic controller to be connected to the Light Signalling Centre via the internet. The router will have at least one digital input and one digital output, with the possibility of remote management via SMS messages from default mobile phones (e.g., the contractor and the competent service body) so that an immediate warning in case of failure can be executed as well as telematics control on the controller.

The dedicated router should have the following technical characteristics:

- Web management
- Firewall
- Secure access via VPN
- 2 Ethernet ports
- Transmission speed 10/100 Mbps
- Supported protocols: TCP/IP, UDP/IP, FTP, HTTP(S)
- Antenna: SMA antenna socket
- SIM slot
- 1 digital input and 1 digital output
- Possibility of remote management via SMS
- Operating voltage range: 10V DC - 30V DC
- Power consumption: <10 W
- Operating temperature range: -20°C to + 70°C.

Equipment for enabling *magnetic* type vehicle detection (optional, might be included at a later stage of the project)

Wireless vehicles' detection sensors of magnetic type
The principle of operation of magnetic type vehicle detectors is based on detecting the presence and / or passage of vehicles, by measuring the change in the earth's magnetic field caused by the presence above their sensors of the metal mass of vehicles. The magnetic type sensor has a function similar to induction loop detectors and is used to detect the presence and / or passage of vehicles in a traffic lane. The sensor detection zone extends in a circle, about 2 meters in diameter.

Wireless access point (Access Point)
The wireless interface module is mounted on a mast near the traffic controller at a height of approximately 6 meters and communicates wirelessly with the local magnetic sensors and / or their transponders. The output and transmission of the signals from the interface to the inputs of the traffic controller is achieved through building units (boards) that have a relay with the necessary contacts or by another suitable method compatible with the respective traffic controller, such as e.g., via TCP / IP communication protocol.

Wireless transponders for magnetic vehicle detection sensors
The transponder is used for the restoration of communication in case one or more magnetic sensors are planned to be placed at the point of intersection outside the scope of the corresponding interface unit and will have built-in batteries for its autonomous operation. The data transmission frequency, the communication protocol and its other technical characteristics will be suitable and compatible for its communication both with the interface unit and with the corresponding magnetic sensors.

5.2.2.2 Functional and architectural requirements

Physical Infrastructure (PI) requirements

FUNC - 001: Smart traffic lights installed on signalised junctions.
FUNC - 002: Designated AV stops along the AV route. As part of this trial phase, the AV stops are going to be pre-determined pickup or drop-off points for passengers.
FUNC - 003: At least one pedestrian crossing.

Digital Infrastructure (DI) requirements

FUNC - 004: Roadside Units (RSUs) deployed at intersections along the AV's route.
FUNC - 005: On-Board Units (OBUs) installed on the AVs.
FUNC - 006: VRU detection sensors installed on at least one pedestrian crossing.

FUNC - 007: AVs equipped with satellite positioning and cellular communication capabilities.
FUNC - 008: Reliable and uninterrupted wireless communication between the AVs, the RSUs, and the Traffic Management System (TMS).
FUNC - 009: Interoperability and consistency across different C-ITS systems (e.g. use of standardised messages and protocols).
FUNC - 010: Operational Traffic Light Controller (TLC).
FUNC - 011: Deployment of traffic management strategies (e.g. traffic-based green wave).
FUNC - 012: Advanced algorithms for the detection of VRUs on the pedestrian crossing.
FUNC - 013: Speed advisory applications (e.g. GLOSA) installed on smartphones within the vehicles (if there are drivers).
FUNC - 014: A mobile application that acts as a journey planner, interconnecting AVs and public transport.

5.2.2.3 Interoperability

High levels of interoperability, with the other Living Labs and with other platforms, can be achieved since standardised European Telecommunications Standards Institute (ETSI) messages are going to be implemented.

5.2.3 Test scenarios

The objective of the following test scenarios is to thoroughly evaluate and enhance the safety, reliability, and performance of how infrastructure and AVs communicate and interact. They have been designed to:

- Test the system's compatibility with different hardware configurations,
- Evaluate the system's responsiveness and latency under various situations,
- Validate the system's integration with external systems or APIs,
- Assess the system's compliance with industry standards and regulations,
- Verify the system's usability and user interface intuitiveness, and
- Evaluate the system's interoperability with different systems or platforms, among others.

5.2.3.1 Scenario #1: Implementing traffic-based green wave via the Trikala Traffic Management system

Pre-conditions

Physical Infrastructure

- Smart traffic lights installed on signalised junctions.

Digital Infrastructure

- Two or more RSUs deployed at successive intersections along the AV route.

- Seamless wireless communication between the AVs, the RSUs, and the Traffic Management System (TMS).
- Operational Traffic Light Controller (TLC).
- Standardisation, structure, and content of messages between vehicles, infrastructure, and other users to ensure interoperability and consistency across different C-ITS systems.
- A cooperative traffic control framework to optimise the travel time of the automated vehicles (i.e. traffic-based green wave).
- On-Board Units (OBUs) installed on the AVs.
- AVs equipped with satellite positioning and cellular communication capabilities.

Scenario flow

1. The level of traffic along the AV route is estimated using video processing (e.g. vehicle detection and counting algorithms) from stationary cameras.
2. According to the level of traffic along the route, the optimal green wave strategy is deployed by the TMS.

Data collection

- Near-time traffic data from traffic counting cameras installed along the route.
- Signal timing data exchanged between the TMS and the smart lights along the AV route.

Related KPIs

Table 4: Research Questions and KPIs for UC#2 Test Scenario 1

Research Questions	KPI Code	KPIs
• How are the **travel times** of the AV affected by the implementation of a traffic-based green wave? • How is the **travel experience** of the passengers affected by the implementation of a traffic-based green wave (i.e., smoother travel experience due to less decelerating and accelerating at the signalized junctions)?	**TRI.1.1.01**	**Travel time** (i.e., changes to the overall travel time due to the optimization of the phases at the signalized junctions)
	TRI.1.1.02	The **frequency** of uninterrupted vehicle crossings through traffic lights due to the traffic-based green wave in place

5.2.3.2 Scenario #2: GLOSA test with AV

Pre-conditions

Physical infrastructure

- Smart traffic lights installed on signalised junctions.

Digital Infrastructure

- RSUs deployed at intersections along the AV route.
- Seamless wireless communication between the AVs, the RSUs, and the Traffic Management System (TMS).
- Operational Traffic Light Controller (TLC).
- Standardisation, structure, and content of messages between vehicles, infrastructure, and other users to ensure interoperability and consistency across different C-ITS systems.
- On-Board Units (OBUs) installed on the AVs.
- AVs equipped with satellite positioning and cellular communication capabilities.
- Green Light Optimised Speed Advisory (GLOSA) application installed on smartphones within the vehicles (if there are drivers).
- Standardisation, structure, and content of messages between the OBUs and the driving functions of the AVs.

Scenario flow

1. The AV approaches one of the junctions with smart traffic lights in Trikala.
2. The AV OBU receives C-ITS messages from the RSU.
3. GLOSA information is utilised in the AV:
    a. The GLOSA app shows information to the safety driver (if there is a driver).
    b. The AV driving function receives the messages and handles the data.
4. The vehicle adapts its speed according to GLOSA to get through the intersection with green light without stopping if possible.

Data collection

- Test start timestamp.
- Time stamped detailed position, speed and heading of the AV.
- Standard ETSI (and non ETSI-standard) messages exchanged.
- Test completion time stamp.

Related KPIs

Table 5: Research Questions and KPIs for UC#2 Test Scenario 2

Research Questions	KPI Code	KPIs
• How do vehicles change their **behaviour** in response to the warnings and information provided by the service? • Is **safety** affected by changes in driver behaviour due to GLOSA? • Is the vehicle's **speed** compliant with the suggested speed? • Does the vehicle start **quicker** after the traffic light turns green?	**TRI.1.2.01**	**Speed adaptation** (i.e., difference between the speed of the vehicle before and after the C-ITS message, instantaneous accelerations and decelerations)
	TRI.1.2.02	**Difference** between the speed suggested by GLOSA and the speed implemented by the vehicle or the safety driver
	TRI.1.2.03	The **frequency** of uninterrupted vehicle crossings through traffic lights due to speed adaptation (compared to crossings without the use of GLOSA)
	TRI.1.2.04	**Intersection crossing time** (compared to crossings without the use of GLOSA)
	TRI.1.2.05	**User acceptance** of the GLOSA app that the safety driver will be using

5.2.3.3 Scenario #3: VRU detection and warning to the approaching AVs

Pre-conditions

Physical infrastructure

- Pedestrian Crossing

Digital Infrastructure

- VRU detection sensors (e.g. vision-based sensors such as cameras) installed on a pedestrian crossing.
- RSU deployed near the crossing (unless an existing RSU of a nearby intersection can be utilised).
- Seamless wireless communication between the AVs, the RSUs, and the Traffic Management System (TMS).
- Advanced algorithms for the detection of VRUs on the pedestrian crossing.
- Standardisation, structure, and content of messages between vehicles, infrastructure, and other users to ensure interoperability and consistency across different C-ITS systems.
- On-Board Units (OBUs) installed on the AVs.
- AVs equipped with satellite positioning and cellular communication capabilities.

- Green Light Optimised Speed Advisory (GLOSA) application installed on smartphones within the vehicles (if there are drivers).
- Standardisation, structure, and content of messages between the OBUs and the driving functions of the AVs.

Scenario flow

1. VRU detection sensors detect pedestrian activity on the selected pedestrian crossing.
2. An awareness message is sent from the RSU, which is installed on the crossing, to the OBUs of the nearby AVs.
3. The nearby AVs adjust their speeds accordingly.

Data collection

- Test start timestamp.
- Time stamped detailed position, speed and heading of the AV.
- Standard ETSI (and non ETSI-standard) messages exchanged.
- Test completion time stamp

Related KPIs

Table 6: Research Questions and KPIs for UC#2 Test Scenario 3

Research Questions	KPI Code	KPIs
• How do vehicles change their **behaviour** in response to the warnings and information provided by the service? • Is **safety** affected by changes in driver behaviour due to GLOSA? • How **safe** and **comfortable** do VRUs feel when they cross the road with this service in place?	**TRI.1.3.01**	**Speed adaptation** (i.e., difference between the speed of the vehicle before and after the C-ITS message, instantaneous accelerations and decelerations).
	TRI.1.3.02	The **frequency** of interrupted vehicle crossings (e.g., other the vehicle had to decelerate or completely stop to allow the VRU to cross safely).
	TRI.1.3.03	**User acceptance** of VRUs (i.e., how safe and comfortable do they feel when they cross the road with this service in place).

5.2.3.4 Scenario #4: Journey planner interconnecting autonomous, demand-responsive solutions with available public transport services

Pre-conditions

Physical infrastructure

- Designated AV stops along the AV's route. As part of this trial phase, the AV stops are going to be pre-determined pickup or drop-off points for passengers.

Digital infrastructure

- Mobile application (i.e. customer app) that:
  - enables authorised users to book AV vehicles to make trips between pre-defined origin and destination locations (i.e. AV stops), and
  - integrates the timetables and services of Trikala city buses.
- Fleet Management Platform.
- Driver app (if there is a driver).
- The vehicles can maintain a reliable and uninterrupted connection to the network infrastructure.
- Standardisation, structure, and content of messages between vehicles, infrastructure, and other users to ensure interoperability and consistency across different C-ITS systems.
- On-Board Units (OBUs) installed on the AVs.
- AVs equipped with satellite positioning and cellular communication capabilities.
- Green Light Optimised Speed Advisory (GLOSA) application installed on smartphones within the vehicles (if there are drivers).
- Standardisation, structure, and content of messages between the OBUs and the driving functions of the AVs.
- The vehicles are equipped with a mobile application that receives and then accepts or rejects trip requests made by authorised users (in case of a safety driver).

Scenario flow

1. An authorised user wishes to make a journey in the city of Trikala.
2. The user uses a dedicated mobile application and selects the origin and the destination of the journey they want to make.
3. The application acts as a journey planner:
   a. takes into account the real-time locations, directions, and seat availabilities of the AVs, and the timetables of the local bus services, and
   b. recommends a list of available routes to the users, using either buses, AVs, or a combination of both.
4. In the case where a user chooses to make a trip (or a part of it) by using an AV, the application will enable them to conveniently book their AV ride within the app.

Data collection

- Time stamped booking request, origin and destination of the journey they intend to make, and relevant user info.
- Time stamped detailed positions, vehicle and seat availabilities, speeds, and headings of the AVs.

Related KPIs

Table 7: Research Questions and KPIs for UC#2 Test Scenario 4

Research Questions	KPI Code	KPIs
• Is the service considered **valuable** or **beneficial** by its users? • Do users perceive the deployment of this service as **advantageous** in **promoting** further utilisation of IN2CCAM services? • How **pleasant** was it to use the service? • Was the **service available** when the service was needed? • Was the **information correct** when the service was active? • Was the **service accurate** (geographical accuracy)? • Was the **service up-to-date**?	**TRI.1.4.01**	**User acceptability, acceptance, and appropriation** before, during, and after the pilots (in terms of performance, efficiency, safety, comfort, user-friendliness of the app, etc.)

5.2.3.5 Scenario #5: Simulation of future scenarios with larger fleets of AVs

Pre-conditions

Digital infrastructure

- Simulation software (e.g. AIMSUN).
- Traffic model with roads, intersections (signalised and non-signalised ones), RSUs, smart traffic lights, public transport stops, parking conditions, zebra crossings, etc.

- Traffic data (e.g. traffic counts, turning counts, pedestrian counts, vehicle classification, observed speeds)
- Schedules and itineraries of public transport (i.e., buses and trains)

Scenario flow

1. A base scenario is simulated (i.e. base transport demand, public transport, intersections, etc.). This includes a fleet of 2 CAVs.
2. Future scenarios will be simulated. This includes larger fleets of CAVs, different sets of parameters, and other assumptions.
3. The outputs between the scenarios will be calculated, compared, and analysed.

Data collection

- Impact on traffic conditions (e.g. travel times, waiting times)
- CCAV speed profile during the travel
- CO_2, NO_x, PM emissions

Related KPIs

Table 8: Research Questions and KPIS for UC#2 Test Scenario 5

Research Questions	KPI Code	KPIs
• Are the findings of the previous scenarios **dependent** on the **fleet size of AVs**? Would the results be **different** if **larger fleets of AVs** were used instead? • What would be the impact on **traffic congestion** if **larger fleets of AVs** were used instead? • What would be the impact on **emissions** and **air pollution** if **larger fleets of AVs** were used instead?	**TRI.1.5.01**	Impact on **traffic congestion** (i.e., travel times, queues, delays, LOS of intersections) if **larger fleets of AVs** were used instead.
	TRI.1.5.02	Impact **on emissions and air quality** (e.g., total CO_2, NO_x, PM emissions) if **larger fleets** of AVs were used instead**.**

6 TURIN LIVING LAB

6.1 Introduction

The city of Turin is an important business and cultural center in Northern Italy. It is the capital city of the Piedmont region and of the Metropolitan City of Turin. It is mainly situated on the western bank of the Po River, and it is surrounded by the western Alpine arch and the eastern Turin hills. With more than 800,000 inhabitants (according to January 2022 data), Turin is the second most populous city in the northwest of Italy, and it is part of an urban area with 1.7 million inhabitants.

In 2021 the City adopted the new SUMP, whose strategies are mainly oriented towards fostering multimodality and improving accessibility through actions to complete and improve the PT system (i.e., metropolitan rail services, metro lines 1 and 2, tramway network), the cycling and walking network and the ITS infrastructures and services. In this context, the Municipality intends to trigger the penetration of autonomous mobility facilitating the process, fostering the cooperation among private enterprises, local facilities, academia and civil society, and investors.

Since 2018 the City has been running the SMART ROAD project by setting up a Local Working Group (9 Automotive companies, 7 TELCOs, 4 Universities and research centers, 4 Utilities) to carry out research activities, experimentation and prototyping in Torino in the field of autonomous and connected vehicles, in accordance to the Italian Ministerial Decree n.70/2018, which set ground rules for autonomous driving testing in Italy. A road network dedicated to autonomous vehicle testing in Torino was clearly identified (i.e., SMART ROAD circuit) and could potentially be extended. Moreover, the City of Turin in July 2018 also defined a Protocol with the Ministry of Infrastructure and Transport, with the common interest to promote the initiative "Turin - City Laboratory for the Autonomous and Connected Drive in the urban environment".

Turin is taking part in the European project SHOW (SHared automation Operating models for Worldwide adoption) focused on the urban adoption of shared, connected, electrified and autonomous vehicles with demos in 20 European cities. It is the only Italian city in the project, and it represents Italy's first automated collective transport service on public roads in mixed traffic.

6.2 UC#3: Dynamic traffic management

6.2.1 Use case presentation

6.2.1.1 Stakeholders and objectives

The Turin LL will be coordinated by TTS with the support of LINKS Foundation and 5T. Apart from these actors who participate as project partners, the following stakeholders will support the pilot:

- The Municipality of Turin, that will be crucial for the selection of testing area, for providing the clearance for automated vehicles' circulation on public roads, and for collecting potential users' needs and requirements;
- GTT s.p.a., the local public transport operator, that will provide safety operators needed to supervise the automated shuttle, and will be in charge of its maintenance;
- The automated shuttle provider, not yet identified;
- The Italian Ministry of Infrastructure and Transport, who will have to authorize the automated experimentation, in collaboration with the Italian Department for Digital Transformation;
- The insurance company of the automated shuttle, not yet identified;
- All the potential users of the automated transport service.

For the Turin LL, one SAE level 3 automated shuttle with at least a 10-passengers capacity will be used. It will circulate in real mixed traffic conditions, in 2 months of operation, for testing an innovative passenger transport service.
The trial is aimed to:

- Complete an urban CCAM ecosystem for the city of Turin;
- Apply and demonstrate new traffic management dynamic strategies supported by the CCAM ecosystem, also with the aim of balancing traffic flow, trying to avoid congestion events;
- Simulate and evaluate the impacts on the road network of traffic management strategies in different CAV adoption scenarios.

6.2.1.2 Expected impact

The Turin LL outcomes, during or immediately after the end of the project, will be mainly technological and scientific oriented. In fact, the LL will:

- Provide in-vehicle information using V2I technologies, both over short-range and mobile communications;
- Provide the integration within the Turin Traffic Control Centre (TCC) of functionalities based on V2I technologies, both over short-range (currently ITS-G5, possibly C-V2X) and mobile communications, to improve the information reliability and allow vehicles to optimize their navigation throughout the city;
- Provide data, information and description of the geographical and digital infrastructures to design and implement new and different large-scale tests or realizations;
- Design and implement new optimization strategies by using innovative approaches (i.e., AI, machine learning, deep reinforcement learning algorithms).

The expected impacts of Turin LL, on the long term and when tested on a large scale, will be related to:

- Safety, since the use of automated shuttles for local public transport (LPT) services will reduce the possibility of human errors and, therefore, accidents;

- Traffic efficiency and environment, as the use of automated and connected vehicles for public transport services and the possibility of redirecting traffic in a dynamic and balanced way will increase the efficiency of the transport system and reduce traffic congestion and, as a consequence, decrease energy consumption and emissions.

6.2.1.3 State of art

Currently, no direct re-routing strategies are implemented. The City's TCC/TIC, operated by 5T, provides users with updated information about road network and traffic conditions (e.g., roadworks, closures, congestions) via VMS text messages, *MuoversinPiemonte* website,radio announces and bulletins, to enable users autonomously taking route diversion decisions. Such information is also published by a DATEXII Node, so can reach GPS navigation devices through standard interfaces.
The Dynamic Re-Routing use case will integrate both traditional and automated vehicles pursuing the optimization of the overall traffic scenario also on the basis of prediction and traffic simulation models. The integration of real-time parking lot availability and UVAR activation will provide a further optimization.

6.2.2 Use case description

6.2.2.1 Functional description

The Traffic Control Centre (TCC) of the City of Turin, developed and managed by 5T under mandate of the Municipality, consists of the following ICT platforms, devoted to fleet and traffic management:

- **Urban Traffic Control** (UTC): monitoring and adaptive control of the traffic light system, it provides traffic fluidization and PT priority services for the City of Turin;
- **Traffic Supervisor** (SVR): software platform devoted to real-time traffic status estimation and short-term forecast (1-hour horizon) across the whole city and region road network. It Integrates real-time data from traffic sensors, FCDs, UTC system and all other devices connected to 5T Traffic Control Center (TCC);
- **DATEXII Node**: System devoted to real-time Traffic and Road network status information exchange with other Traffic Information Centres (TIC), in Datex2 Standard format. 5T Node provides regional data to CCISS, the Ministry of Transport TIC (the Italian NAP according to D.R. 2015/962);
- **Urban underpass monitoring system**: traffic monitoring infrastructure within the "Piazza Statuto" underpass in Turin, placed along the "Torino Smart Road" route; it provides traffic alarms able to trigger C-ITS messages;

- **Integrated urban video surveillance network:** 5T will manage, under the ownership of the local police, a wide deployment of video surveillance devices all over the Turin urban environment.

The following figure shows the overall architecture of Turin TCC.

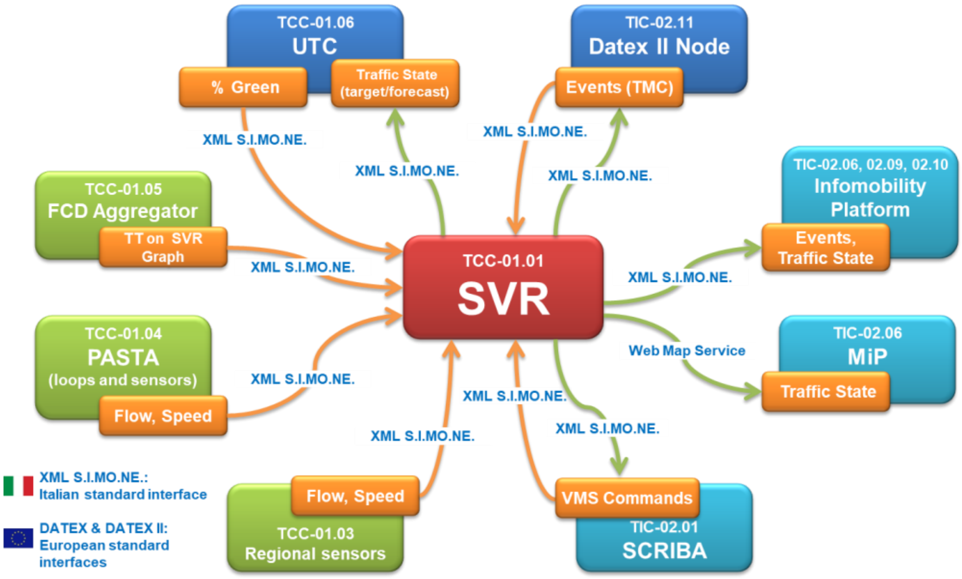

Figure 4: 5T TCC/TIC architecture

The above-described systems (DATEXII node, Traffic Light system, Traffic sensors, tunnel monitoring, V2I road-side units) feed several ITS services, some of which are focused on urban vehicular traffic, basically providing safety-related in-vehicle information by means of short-range and mobile communications (hybrid V2I): In-Vehicle Signage, Hazardous Location Notification, Road Works Warning, Signalized Intersections, Probe Vehicle Data.

The CCAM ecosystem will support specific Traffic Management (TM) strategies, demonstrated and/or simulated in different CAV adoption scenarios to evaluate their impacts on the road network in terms of improved congestion control, safety for VRU and drivers and emission reduction. TM strategies will be accomplished not only addressing single vehicle routes, but mostly through an optimization of the overall traffic scenario also based on prediction and traffic simulation models. Strategies shall include:

- Issuing warnings about the presence of Urban Vehicle Access Restriction areas (UVARs), allowing the CCAM vehicle to take decisions
- Suggesting optimized routes including real-time parking availability
- Providing re-routing advice in the event of traffic disruption
- Suggesting the optimal speed needed to relieve traffic congestion
- Using dynamic dedicated lanes for public and private CCAM traffic.

6.2.2.2 Functional and architectural requirements

Infrastructure requirements:

a. Availability of current C-ITS services implemented by the TCC/TIC over the urban area in Turin;
b. Accessibility of the TCC/TIC platform by the involved CAV;
c. Accessibility of TCC/TIC platform by the LL traffic simulation platform;
d. Availability of a C-ITS-S platform to acquire information from the various TCC/TIC components and translate into CCAM specific exchange logics and protocols.

CAV requirements:

a. Availability of a proper interface for real-time data exchange to/from the TCC/TIC platform;
b. Availability of a proper interface for real-time data exchange to/from the traffic simulation platform;
c. Availability of C-ITS communication technologies on-board;
d. Availability of specific information required by Italian Ministries to authorize CAV operations and the impacted urban area.

Connected vehicles requirements:

a. Availability of a proper interface for real-time data exchange to/from the TCC/TIC platform;
b. Availability of C-ITS communication technologies on-board.

6.2.2.3 Interoperability

The interoperability between the Turin LL and other existing and future platforms (e.g., C-ITS-S, TCC, TIC) will be granted by implementing standardized technical and service specifications (ETSI messages, DATEXII protocol, C-Roads service recommendations, etc.) and exchanging data through the IN2CCAM data platform.

6.2.3 Test scenarios

The Italian LL will employ a simulation environment strictly connected to the real world to assess the impact of connected and automated vehicles interacting with several road users (e.g., cars, VRUs). The simulation environment will be based on the well-known open-source SUMO software. Its role will be twofold: from one side, it will be used for traffic simulation; on the other hand, it will feed a simulator (internally developed by LINKS) that can send fake CAM messages based on the SUMO vehicle's position and dynamics.

The interaction between SUMO and a real automated shuttle (and/or other connected cars) will be studied in the framework of the IN2CCAM project.

The level of interaction with the automated shuttle will depend on the capabilities of the vehicle that will be externally procured by involvement of a third party in due course. However, the basic functionality required is the capability to exchange standard C-ITS messages using cellular connectivity.

The following figure depicts a functional overview of the test scenarios:

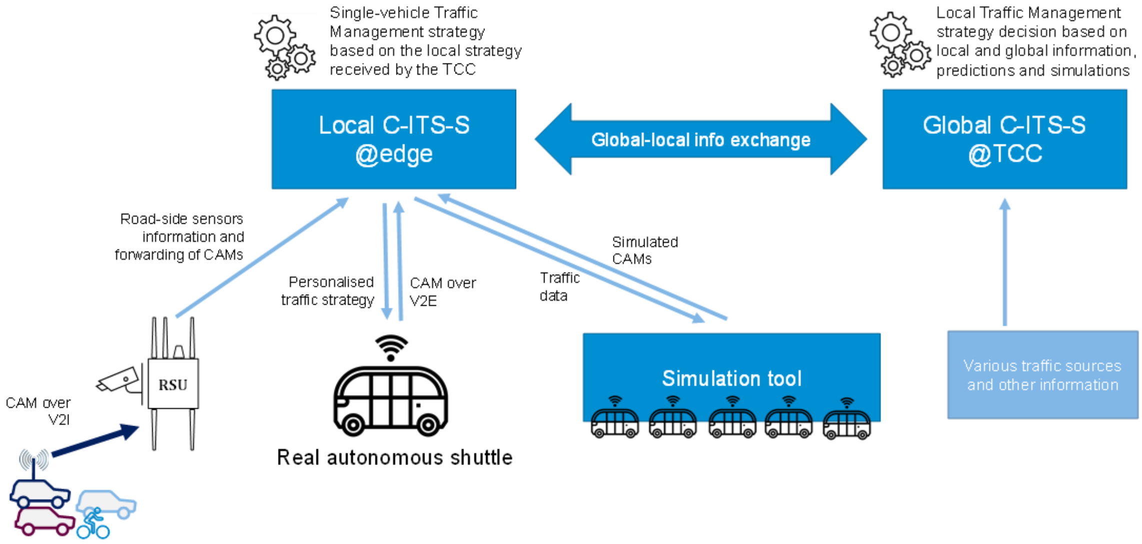

Figure 5: Test scenarios functional architecture

Data collection is performed by a local edge server with a detailed picture of the traffic status in a specific area. The local server will exchange information with the TCC to 1) send information about the local traffic status and 2) retrieve the whole network status. In this way, the local server acquires all the needed data to provide an effective re-routing strategy that considers the single vehicle position and the local plus global status of the network.

Information about non-connected vehicles in defined road locations can be retrieved using an intelligent Road Side Unit equipped with a camera and LiDAR. Moreover, the RSU can provide data about Vulnerable Road Users that can be used to enhance safety by sending feedback to the connected vehicles.

6.2.3.1 Scenario #1: dynamic re-routing

Pre-conditions

Physical infrastructure

- Road Side Unit with camera and LiDAR for detection of non-connected actors like vehicles and VRUs
- A Traffic Control Centre (TCC) monitoring the overall status of the urban traffic

Digital infrastructure

- C-ITS-S message server to exchange ETSI compliant C-ITS messages using short range (G5 or LTE-V2x) or mobile communication or a mix of those
    - Messages sent over the cellular network should follow the main C-ROADS recommendation
    - At least CAM, DENM, SPATEM, MAPEM, SSEM and SREM messages should be supported

Scenario flow

The main scenario that will be demonstrated is the following: an accident blocks a main road, and all the local traffic must be re-routed smartly. The local server uses its fine-grained knowledge of the traffic situation, along with information about the entire traffic network, to compute a dedicated re-routing for each vehicle based on its position.

To enable demonstration in the real environment, a virtual environment based on a traffic microsimulator will be developed. The microsimulator will allow to simulate and evaluate different dynamic re-routing strategies (scenarios) that will be communicated to the connected vehicles present in the simulation model.

Traffic scenarios may include:

- different accident events and resulting impacts on road or intersection capacity (e.g., from 2 to 1 lane, complete road closure)
- different accident locations (e.g., at intersection, on road section)
- different levels of traffic (e.g., at peak, off-peak hours)

Moreover, the impact of different penetration rate of connected vehicles on the effectiveness of the implemented dynamic re-routing strategies will be assessed. Additionally, the microsimulation model will allow estimating the optimal rate of connected vehicles needed to improve the re-routing strategy in order to reduce road congestion.

CCAM vehicles can be used as additional information sources to improve information reliability and allow the infrastructure to optimize car navigation solutions from the perspective of safety and sustainability.

Subsequently, some co-simulations using a real automated shuttle and simulated vehicles (coming from microsimulations) will be performed. Both will send real and simulated CAM messages to the local C-ITS server thanks to a tool made available by LINKS Foundation. In addition, the non-connected users will be detected and tracked by RSU and their position will be sent to the same server. The best re-routing algorithm achieved in microsimulations will run on this data and send feedback both to simulated cars and to the real shuttle (depending on the capabilities of the vehicle provider, in the form of information or real command for the automated driving functions).

Data collection

The data that will be collected are basically ETSI ITS messages coming from the automated vehicle and from the simulated ones.

Related KPIs

Table 9: Research Questions and KPIs for UC#3 Test Scenario 1

Research Questions	KPI Code	KPIs
• What would be the impact on **traffic conditions** due to the dynamic re-routing? • What would be the impact on **safety** due to the dynamic re-routing? • What would be the impact on **emissions and energy consumption** due to the dynamic re-routing? • What would be the impact on the **service** of **data availability and consistency**?	**TUR.1.1.01**	Impact on the **CAV energy consumption** of rerouting strategies.
	TUR.1.1.02	**Travel time for CAVs** (i.e. changes to the overall travel time due to the dynamic re-routing strategy).
	TUR.1.1.03	Impact on **traffic congestion** (i.e. travel times, queues, delays, LOS of intersections) of rerouting strategies **if larger fleets of CAVs** were used instead (different penetration rates will be investigated).
	TUR.1.1.04	Impact on **emissions and air quality** (e.g. total CO2, NOx, PM emissions) of rerouting strategies if **larger fleets of CAVs** were used instead (different penetration rates will be investigated).
	TUR.1.1.05	The **frequency** of green-light intersection crossings due to managed traffic-light priority service for CAVs.
	TUR.1.1.06	Impact on **safety** (e.g. accidents, conflicts) of rerouting strategies if **larger fleets of CAVs** were used instead (different penetration rates will be investigated).
	TUR.1.1.07	Impact on **rerouting algorithm efficiency** of data availability **V2X communication**

6.2.3.2 Scenario #2: Parking and UVAR publication

Pre-conditions

Physical infrastructure

- A Traffic Control Centre (TCC) monitoring the overall status of the urban traffic

- A Traffic Information Centre (TIC) providing real-time information about parking availability and UVAR status

Digital infrastructure

- Most suitable existing standard interfaces to exchange messages using short range communication

Scenario flow

The Scenario #1 previously described, will be integrated with real-time information about Parking lot availability and UVAR activation status, in order to allow a further optimization of suggested routes. Real and simulated data could be combined together to achieve a more realistic result.

Data collection

The collected data will be parking slot availability and UVAR activation status in addition to the ETSI ITS messages collected in the scenario #1.

Related KPIs

Table 10: Research Questions and KPIs for UC#3 Test Scenario 2

Research Questions	KPI Code	KPIs
• What would be the impact on **traffic conditions** due to the dynamic re-routing? • What would be the impact on **safety** due to the dynamic re-routing? • What would be the impact on **emissions and energy consumption** due to the dynamic re-routing? • What would be the impact on the **service** of **data availability and consistency**?	**TUR.1.2.01**	Impact on the **CAV energy consumption** of rerouting strategies.
	TUR.1.2.02	**Travel time for CAVs** (i.e. changes to the overall travel time due to the dynamic re-routing strategy).
	TUR.1.2.03	Impact on **traffic congestion** (i.e. travel times, queues, delays, LOS of intersections) of rerouting strategies if **larger fleets of CAVs** were used instead (different penetration rates will be investigated).
	TUR.1.2.04	Impact on **emissions and air quality** (e.g. total CO2, NOx, PM emissions) of rerouting strategies if **larger fleets of CAVs** were used instead (different penetration rates will be investigated).
	TUR.1.2.05	The **frequency** of green-light intersection crossings due to managed traffic-light priority service for CAVs.
	TUR.1.2.06	Impact on **safety** (e.g. accidents, conflicts) of rerouting strategies if **larger fleets of CAVs** were used instead (different penetration rates will be investigated).
	TUR.1.2.07	Impact on **rerouting algorithm efficiency** of data availability **V2X communication**

	TUR.1.2.08	Impact on **rerouting strategies** of **UVAR/Parking** data availability **V2X communication**.

7 VIGO LIVING LAB

7.1 Introduction

The city of Vigo has been a pioneer city in Europe in deploying C-ITS services as a mobility management tools available for operators, citizens and professionals. This is described in this document as state of the art.

CCAM and autonomous vehicles has been identified by the city authorities as new actors that, in the short and medium term, may play a relevant role within the mobility of the city. The announced potential benefits of CCAM by industry and technology community have to be proven in order to convince decision makers in industry and administration authorities to allocate the resources needed to make them reality. With this in mind, the objectives of Vigo LL in IN2CCAM are, at this early stage of CCAM uptake:

- Exploring how the existing V2I infrastructure can contribute to CCAM in order to get benefits to the citizens, professionals and stakeholders.
- Which adaptations may be needed in fleets and infrastructure to maximize the interaction benefits among vehicles and mobility operators.
- Draft and analyse coordinated actions among involved actors in traffic and mobility management in the way of CCAM services.

According to the experience of local stakeholders and the Mobility and Safety Area of Vigo, the IN2CCAM use cases and scenarios have been drafted in Description of Action (DoA) and will be elaborated and detailed in this document.

The scope of the Vigo LL contribution it is focused on information sharing and interaction based on such shared information.

The CCAM fleet side will be addressed and analysed using 2 research prototypes equipped will all the needed technology to achieve SAE level 3 to 4.

The services and use cases will be addressed in such a way that can be applied to different fleet uses (passengers, goods, delivery or other services)

The actions and strategies included in both use cases are designed to be very elemental (as building blocks) in such a way that they can be replicable, combinable and scalable to more complex scenarios with the intervention of a higher number of actors. The aim of Vigo LL is to demonstrate its feasibility in real environment and confirm their benefits in a short scale.

The deployment in a higher scale over particular fleets (passengers, logistics, delivery…), or user communities could be analysed later on with future actions and or projects.

7.2 UC#4: Mutual awareness between CCAM fleet, infrastructure, and other users

7.2.1 Use case presentation

7.2.1.1 Stakeholders and objectives

The use case "Mutual awareness between CCAM fleet, infrastructure, and other users" is about the creation of a data interchange framework which will enable building a virtual precise map shared among all the involved parties:

- CCAM fleet, composed by 2 prototypes of automated vehicles.
- Infrastructure (Traffic Management System).
- Drivers using the public large-scale cellular C-ITS services application.
- ITS-G5 connected emergency vehicles of municipality fleets (firefighters and police)

Each involved entity will be able to share and receive relevant data from terrain or infrastructure.

7.2.1.2 Expected impact

The expected impact of this data sharing is enabling a smooth, safe and efficient urban circulation aligning synergies between CCAM fleet operative interest and traffic management interest.

Non-CCAM users will have access to data coming from the CCAM vehicles, and CCAM vehicles will benefit from multiple external information sources.

This use case will increase the overall awareness in the ecosystem. Each entity will be able to consume data based on its needs, in order to enable CCAM services.

7.2.1.3 State of art

The City of Vigo deployed in the period 2020-2022 the C-ITS Platform.

ICT platform for fleet and traffic management

Traffic management centre of Vigo has deployed the MISTRAL Smart City platform which integrates all vertical information flow from the different traffic and mobility systems and enables actuation over traffic systems, information VMPs, among other systems. This platform integrates the C-ITS platform devoted to the management of C-ITS services. The connected vehicle services in Vigo (with TRL7) take the form of a full deployed Hybrid C-ITS Platform with Day 1 and Day 1.5 C-ITS services working over Cellular/ITS-G5/IoT communication. The performance of this platform is based in a robust on street set up with:

- 160 km of municipality owned optic fiber network
- 170 connected and centralized Traffic light controllers connected to centralized traffic management system and with C-ITS firmware and protocol deployed
- 69 Bluetooth sensors for traffic status monitoring
- 386 inductive loops
- 110 CCTV cameras
- 12 Variable Message Panels

Vigo site has one of the best-connected vehicle infrastructures in terms of quality and availability of C-ITS services in Europe, which are integrated by the city of Vigo in the mobility management services 24/7. The services available are:

- GLOSA/SPAT (Green Light Optimal Speed Advisory/Signal Phase and Timing): Provides the time to green/red light change of the traffic light and a speed recommendation if it is possible to cross during green phase.
- Road Hazard Warning: Alerts drivers of upcoming incidents such as accidents, works, retentions, pedestrians on the road...
- In Vehicle Information: Information on travel times, traffic cuts or other incidents by replicating the content of physical variable message panels or generating them virtually at strategic points in the city.
- Red light violation warning
- Parking information: location and parking spaces availability.

Figure 6: Use case example in Vigo Driving application

Figure 7: VMS replication example

Nevertheless, the deployment of CCA fleets in the city has a lower uptake. To address the tests, automated CCA prototypes including the last technologies will be used with the aim of maximizing the data acquisition in different use cases which will allow to extrapolate the results to different user profiles such as particular drivers, passengers transport or delivery.

IN2CCAM will mean a big step forward from the current state of the art of the Vigo C-ITS Platform.
The main advances are listed below:

- Adapted access to all available information and services for CCAM fleets
- New data sources to be integrated with new elements. This source comes from the CCAM fleets and the information shared will be the real time position, speed and destination planed of each of their vehicles.
- The perception environment of automated vehicles will be available for traffic management purposes (detected vehicles, pedestrians, other users…)
- Adapted C-ITS services to CCAM vehicles based on extended perception of infrastructure with artificial vision cameras.:
    - Enhanced GLOSA: human drivers may have a better perception of the existing queue of vehicles before the stopping line (either stopping at red light or moving in an open green light) when distance to traffic light is long. When using GLOSA/SPAT service they have to take that into account to adapt their speed accordingly. The margin of anticipation of an automated vehicle may be in this case lower and the vehicle would react when its sensors detects the last vehicle of the queue. Provide the length of the queue or a speed advice which have that parameter into account may provide a more complete information and allow earlier reactions avoiding hard braking and accelerations, achieving a more efficient speed profile.
    - Proximity of Pedestrians and VRUs warnings will be generated by infrastructure based in cameras and artificial vision technology.

7.2.2 Use case description

7.2.2.1 Functional description

The picture below shows the four main actors of the data sharing ecosystem. Each actor will provide data to the ecosystem based on local sensors and interfaces to mobility systems.

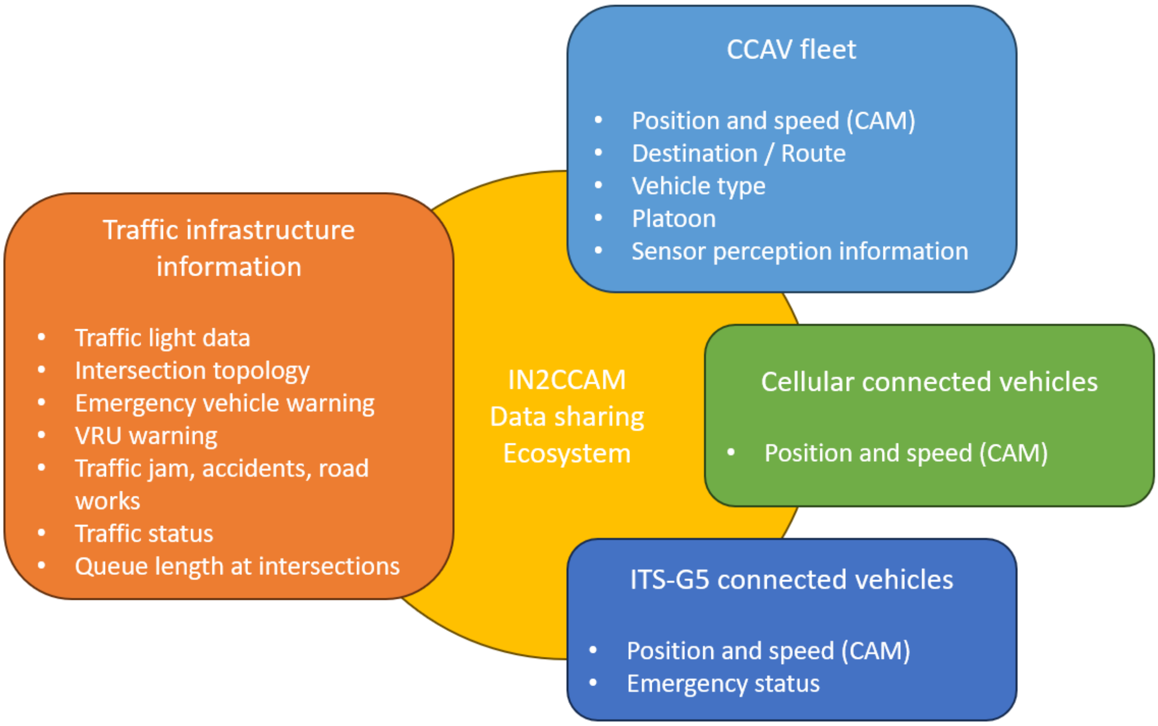

Figure 8: Data sharing ecosystem involved parties and their provided data

This data will be shared through a central and unique data sharing platform that will accept connections from involved parties.
This platform should allow access control for publication and subscription, so that any user cannot abusively publish any type of data. For example, a cellular connected vehicle (Vigo Driving APP) should not be allowed to publish surrounding perception info. Those restrictions will guarantee a certain level of data quality within the ecosystem.
Some type of data should be accessible only for pre-registered users to guarantee privacy.

7.2.2.2 Functional and architectural requirements

UC1-FUNC-001
Data sharing platform must be available on the Internet using a TCP/IP protocol.

UC1-FUNC-002
Data sharing platform must allow data providers authentication using digital signature mechanisms. It should allow non-authenticated access for public data subscription.

UC1-FUNC-003
Data sharing platform must manage a high load of users (>1000) and a high amount of data (>500 messages/s).

UC1-FUNC-004
Data sharing platform must allow the exchange of predefined types of messages based on ETSI standards: CAM, DENM, IVIM, POI, SPATEM, MAPEM, SREM, SSEM, CPM.

UC1-FUNC-005
Data sharing platform must allow filtering based specific indicators per message type.

7.2.2.3 Interoperability

In order to maximise the interoperability between Living Lab and existing C-ITS vehicles, the IN2CCAM data sharing platform will be based on ETSI standardized messages.

7.2.3 Test scenarios

7.2.3.1 Scenario #1: data interchange

Pre-conditions

Physical infrastructure:

- A specific lane for CAV has been physically separated by the appropriate barriers from normal traffic.
- Specific vertical signals to redistribute the traffic flow out of CCAM lane.
- ITS-G5 coverage available across all the testing area working according ETSI standard.
- At least one RSU installed per intersection.
- Cameras are installed in place to allow detection of events.

DIGITAL INFRASTRUCTURE

- All HW elements (TLC, RSUs, Cameras, sensors…) are connected to Mobility Vigo network.

- Server with needed resources is up and running hosting platform.
- Defined architecture with needed interfaces is working including connectivity with vehicles (Both autonomous and human driven)
- There is a common time synchronization defined for all the equipment.

CAV:

- Vehicle is equipped with all the needed sensors which allow the perception capabilities required to perform Autonomous driving SAE 3 to 4 levels.
- Vehicle is equipped with ITS-G5 communication unit working according ETSI standards
- Vehicle has installed a satellite positioning system
- There is implemented an internal protocol and the needed tools to translate the elements perceived (vehicles, pedestrians, cyclist, other…) into ETSI standardized warning messages.

Scenario flow

1. CAV enters in dedicated CCAM lane.
2. The vehicle connects to platform
3. Vehicle and platform information exchange starts in the form of ETSI messages:
    - Vehicle provides:
        - CAM messages
        - Information of its driving mode (manual or auto) destination and planned route
        - Data about the type of vehicle, service (delivery, passengers…) if it is part of a platoon…
        - All elements perceived by its sensors in the form of standard ETSI CPM
    - Infrastructure provides:
        - Vigo C-ITS platform cooperative services
        - Real time position of users connected to C-ITS platform by Vigo Driving App
        - Real time position of Municipality ITS-G5 connected fleets (police, firefighters)
4. Vehicle receives authorization to activate autopilot after checking all system, on board and infrastructure are up and running.
5. Vehicle drives through the CCAM dedicated lane interchanging aforementioned information in real time.
6. Vehicle stops after finalize the defined trip through CCAM lane.

Data collection

Time stamp of initiation

Time stamped Detailed position of vehicle per trip.

Time stamped Speed profile

Standard ETSI messages sent by RSUs

Standard ETSI messages sent by OBUs

Standard ETSI messages received by RSUs

Standard ETSI messages received by OBUs

Non ETSI standard information exchanged among vehicle and infrastructure.

Time stamp of trip finalization.

Related KPIs

Table 11: Research Questions and KPIs for UC#4 Test Scenario 1

Research Questions	KPI Code	KPIs
• Is **data sharing** between the CCAV, the vehicles with the Vigo Driving App, Emergency Vehicles using ITS-G5, and the traffic management system **feasible** in Vigo? • Will the implementation of such an ecosystem **increase** the **overall awareness** in the ecosystem and ensure **smooth**, **safe**, and **efficient** urban trips?	VIG.1.1.01	**Messages** between the **vehicles** (CCA fleet, cellular-connected vehicles and ITS-G5 connected Emergency Vehicles) and the **traffic management system** (e.g., warnings of approaching emergency vehicles, VRUs, accidents, road works, emergency status activation, real-time position of vehicles, routes).

7.3 UC#5: Management strategy adapted to CCAM based on V2I interaction

7.3.1 Use case presentation

7.3.1.1 Stakeholders and objectives

The use case “Management strategy adapted to CCAM based on V2I interaction” is based on priority and adaptive regulation in traffic light network to raise capacity of urban network by enabling a more efficient performance of CCAV fleets.

- CCAM fleet, composed by 2 prototypes of automated vehicles.
- Infrastructure (Traffic Management System).
- Drivers using the public large-scale cellular C-ITS services application.
- ITS-G5 connected emergency vehicles of municipality fleets (firefighters and police)

Each involved entity will be able to share and receive relevant data from terrain or infrastructure.

The traffic management centre will apply specific regulation strategies to enable a more efficient circulation of CCAV fleets. This interaction is carried out in defined CCAM corridors.

7.3.1.2 Expected impact

The expected impact of this UC #2 reinforces the impact of data sharing implemented in UC #1, enabling a smooth, safe and efficient urban circulation aligning synergies between CCAM fleet operative interest and traffic management interest. This use case, in particular, goes one step forward from UC #1 by applying specific regulation strategies in the intersections of the CCAM corridor. Pursued impacts are:

- Smoother circulation of CCAM fleets reducing stop & start events increasing its medium speed per trip.
- Avoiding platoon splitting
- Safety increasing avoiding mixed traffic scenarios in complex intersections.

7.3.1.3 State of art

The City of Vigo deployed in the period 2020-2022 the C-ITS Platform. In this platform, traffic light priority strategies are used to enable a safer and more efficient circulation of emergency vehicles driving in emergency services (firefighters, police). These strategies are the basis for this use case #2 which will evolve the connectivity technology and actuation strategies over Traffic Light network from this deployed capability of C-ITS Platform of Vigo.

7.3.2 Use case description

7.3.2.1 Functional description

This UC #2 takes as a basis all the details in UC #1, so all the functional description of previous UC #1 applies to this UC#2.
CAVs will circulate by CCAM corridor defined by an influence area, specific intersections and senses of circulation. According to if CAVs are within the influence area and to their position and heading within it, a specific traffic light timing will be applied in real time while the vehicles are in the intersection/s environment and will go back to normal as the CAV leaves the intersection or the CCAM corridor influence area.

In addition, some scenarios will be tested within a simulation software. Carla has been selected in the IN2CCAM project to simulate controlled manoeuvres between a CCAV and an emergency vehicle. In the real demonstrations of the project, one of the lanes of the “Gran via” road of Vigo will be closed in order to perform driving manoeuvres. The following roundabout of Figure 9. is part of the Gran via and will be the target of the simulations.

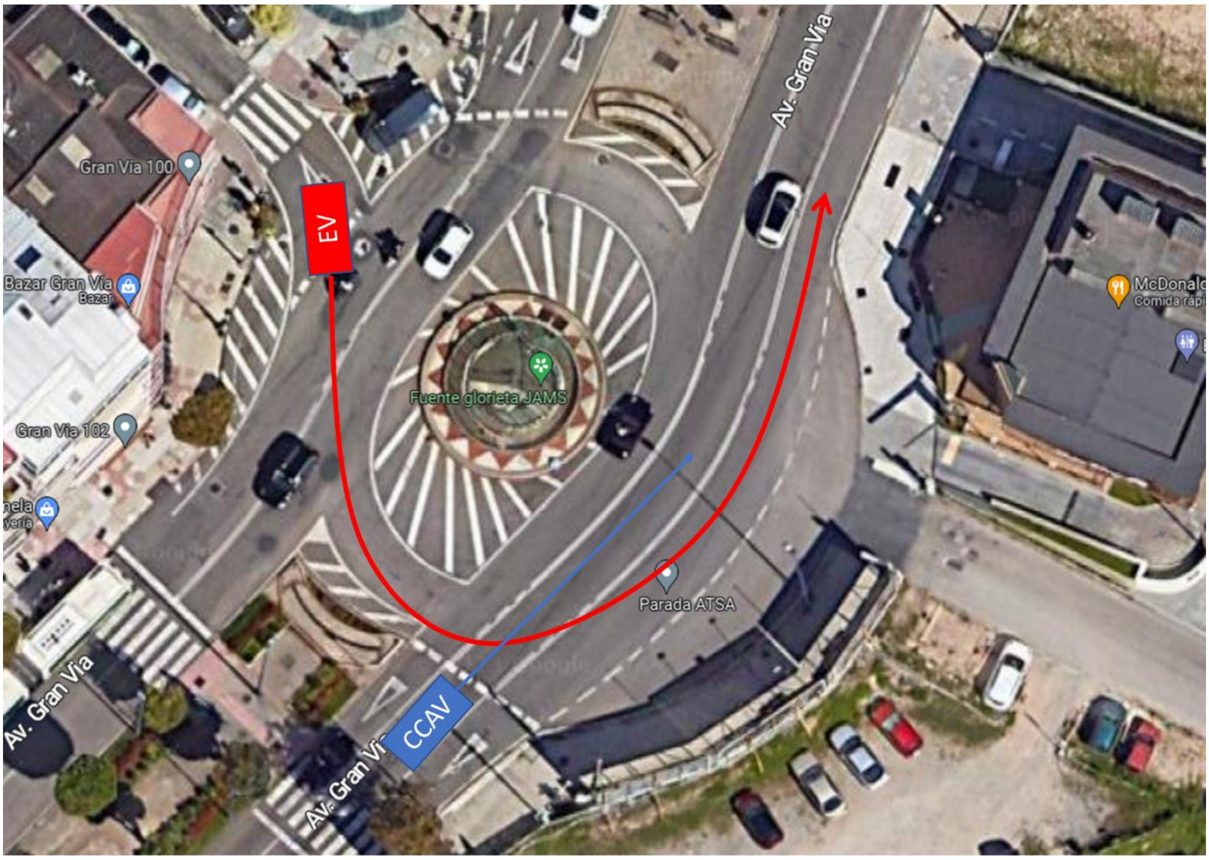

Figure 9: Proposed roundabout in Vigo’s Gran via

As these manoeuvres cannot be performed in real driving scenarios due to traffic restrictions and regulations, they will be measured in simulation environments. The proposed scenarios will be variations of an emergency vehicle and a CCAV entering the proposed roundabout.

7.3.2.2 Functional and architectural requirements

All UC #1 requirements described in the previous part.

UC2-FUNC-001
CCAM corridor must have a defined area

UC2-FUNC-002
CCAM corridor must have defined a number of intersections

UC2-FUNC-003
Upstream and downstream senses of circulation must be defined in CCAM corridor

UC2-FUNC-004
The regulation strategy has to be applied to one or more intersections.

UC2-FUNC-005
The regulation strategy can be different according the sense of circulation (upstream or downstream).

7.3.2.3 Interoperability

In order to maximise the interoperability between Living Lab and existing C-ITS vehicles, the IN2CCAM data sharing platform will be based on ETSI standardized messages.

7.3.3 Test scenarios

7.3.3.1 Scenario #1: Traffic Light Priority for specific CCAM fleets.

Pre-conditions

Preconditions of UC #1 – Scenario #1 described in section 4.2.3.1 apply to this Scenario.

A Priority corridor is defined by

- A set of intersections
- The order of those intersections which will define upstream and downstream directions.
- The strategies of Priority activation for each sense of circulation (upstream/downstream)
- An influence area

- Priority is granted only in the main direction of the corridor. The Priority won't be enabled in the secondary accesses of the intersections, only in the main avenue.
- When the CAV approach to an intersection driving in the corridor direction priority will be activated in this access in the intersection to which it is approaching. Also, in a configurable number of intersections upstream or downstream, depending on the sense of circulation of the CAV.
- In case of several CCAM corridors, each corridor would work independently. That means that there is no interaction between RSUs of different corridors.
- CCAM corridor and strategies has been defined and configured

Scenario flow

1. CAV initiates circulation according Scenario #1- UC#1 flow to ensure connectivity and data interchange
2. CAV sends Priority request from OBU (messages and activation interface)
3. RSU receives request and reacts if according to CAM messages identify that the vehicle is approaching to the RSU within the influence area of the CCAM corridor.
4. The RSU triggers traffic light priority (HURRY CALL) in the TLC
5. If this intersection has a pedestrian traffic light regulated crossing, RSU must monitor and check the status of the corresponding traffic light group before activating Priority Cycle in TLC. If pedestrian TL is in green phase, the activation of HURRY CALL must wait until a defined time (end of green pedestrian phase or some seconds earlier)
6. Depending on the position of this intersection in the particular corridor, the RSU must simultaneously trigger hurry call in a defined number of intersections upstream or downstream within the corridor, depending on the sense of circulation of CAV.
7. The activation of Hurry call ends when:
    a. The CAV crosses the intersection (checking position from CAM messages)
    b. Defined expiration time ends
    c. CAV deactivates Priority request
    d. CAV leaves influence Area.

Data collection

Time stamp of initiation

Time stamped Detailed position of vehicle per trip.

Time stamped Speed profile

Standard ETSI messages sent by RSUs

Standard ETSI messages sent by OBUS

Standard ETSI messages received by RSUs

Standard ETSI messages received by OBUs

Non ETSI standard information exchanged among vehicle and infrastructure.

Fuel/energy consumed

Time stamp of trip finalization.

Related KPIs

Table 12: Research Questions and KPIs for UC#5 Test Scenario 1

Research Questions	KPI Code	KPIs
• How do vehicles change their **behaviour** in response to the information provided by the service? • Is **safety** increased due to avoiding mixed traffic (automated and non-automated) in complex intersections (e.g., roundabouts)? • How are the **travel times** of the AV affected by the implementation of a traffic light priority system?	**VIG.2.1.01**	**Speed adaptation**.
	VIG.2.1.02	**Travel Time / Average Speed.**
	VIG.2.1.03	Reduction in **mixed traffic interactions.**

7.3.3.2 Scenario #2: Green phase extension for platooning

Pre-conditions

Preconditions of UC #1 – Scenario #1 described in section 4.2.3.1 apply to this

CAV must have implemented platooning capabilities

There is a defined format and messages defined to communicate the platoon parameters to infrastructure

Scenario flow

1. CAV initiates circulation according Scenario #1- UC#1 flow to ensure connectivity and data interchange
2. CAV establishes platoon and starts circulating on CCAM corridor
3. CAV Platoon sends its data within CAM messages from OBU which may include priority request (messages and activation interface)
4. RSU receives data and reacts if according to CAM messages identify that the platoon is approaching to the RSU within the influence area of the CCAM corridor.
5. The RSU trigger traffic light priority (HURRY CALL) in the TLC
6. If this intersection has a pedestrian traffic light regulated crossing, RSU must monitor and check the status of the corresponding traffic light group before activating Priority Cycle in TLC. If pedestrian TL is in green phase, the activation of HURRY CALL must wait until a defined time (end of green pedestrian phase or some seconds earlier)
7. Depending on the position of this intersection in the particular corridor, the RSU must simultaneously trigger hurry call in a defined number of intersections upstream or downstream within the corridor, depending on the sense of circulation of EV.
8. The activation of Hurry call ends when:
    a. All the vehicles of the platoon cross the intersection (checking position from CAM messages)
    b. Defined expiration time ends
    c. Platoon deactivate Priority request
    d. Platoon leave influence Area.

Data collection

Time stamp of initiation
Time stamped Detailed position of vehicle per trip.
Time stamped Speed profile
Standard ETSI messages sent by RSUs
Standard ETSI messages sent by OBUs
Standard ETSI messages received by RSUs
Standard ETSI messages received by OBUs
Extended GLOSA information
Non ETSI standard information exchanged among vehicle and infrastructure.
Fuel/energy consumed
Time stamp of trip finalization.

Related KPIs

Table 13: Research Questions and KPIs for UC#5 Test Scenario 2

Research Questions	KPI Code	KPIs
• How are the **queues of CAVs** affected by the adjustment of green phases?	**VIG.2.2.01**	**Number** of **CAV platoons** split by a red light.

7.3.3.3 Scenario #3: Simulation of CCAV reaction to an emergency vehicle entering a roundabout

Pre-conditions

- Simulation model
- Position of an emergency vehicle can be simulated in the simulation model

Scenario flow

In order to measure the impact of an emergency vehicle approaching a roundabout where a CCAV wants to enter, two actors will be spawned into the simulation, a CCAV and an emergency vehicle. The CCAV will be equipped with the following sensors replicating the real setup of Vicomtech's Toyota Prius:

- 1x IMU
- 1x GPS
- 4x Cameras
- 1x Lidar

A set of short simple scenarios will be simulated in CARLA while logging all vehicle dynamics and sensor data.

During these scenarios, two alternatives will be considered. The first option will consider that the CCAV does not receive any information from the infrastructure, thus, entering the roundabout without knowing that an emergency vehicle is approaching it. The second option, will consider that the infrastructure already warned the vehicle via V2X and thus it has its real-time information beforehand.

Reaction to the presence of emergency vehicle detected by its own sensors and through connected infrastructure can be considered in this model)

The KPI to measure in order to analyse the improvement of IN2CCAM solution will be improvement in time of CAV awareness of approaching emergency vehicle and, if possible, improvement in the time of reaction (this reaction may be CAV detention or CAV speed reduction).

Iterations of this scenario in different use cases (for instance, considering which access or direction the emergency vehicle is approaching to CAV in the intersection) may allow address the evaluation of KPI “reduction of Hard braking events”.

Data collection

Vehicle dynamics and sensor data

V2X information (CAM) with reception timestamp

Object detection range

Object detection processing against V2X Latency

Related KPIs

Table 14: Research Questions and KPIs for UC#5 Test Scenario 3

Research Questions	KPI Code	KPIs
• How do vehicles change their **behaviour** in response to the information provided by the service? • Is **safety** increased by allowing EVs to enter roundabouts without conflicting with CCAVs?	**VIG.2.3.01**	**Speed adaptation**.
	VIG.2.3.02	Reduction **in mixed traffic interactions.**

7.3.3.4 Scenario #4: Dynamic re-routing of AV based on traffic-load

Pre-conditions

Preconditions of UC #1 – Scenario #1 described in section 4.2.3.1 apply to this

C-ITS platform must have traffic-load map ready and available.

Scenario-flow

1. The CCAM vehicle drives in the city and forwards its destination and position to the C-ITS platform through the data-sharing architecture.
2. The C-ITS platform uses the computed traffic-load information and the CCAM vehicles position and destination in order to compute the best route to the destination. The route is computed using load-balancing algorithms.
3. The C-ITS platform provides routing information to the CCAM vehicle using the data-sharing architecture.

4. The CCAM vehicle uses routing information in its automated driving decision algorithm. Due to driving restrictions in Vigo CCAM corridor, this part will also be simulated to analyse the impact of load-balancing.

Data collection

Time stamp of trip start.
Destination information of CCAM vehicle
Position information of CCAM vehicle
Routing information generated by C-ITS platform
Time stamp of trip finalization.

Related KPIs

Table 15: Research Questions and KPIs for UC#5 Test Scenario 4

Research Questions	KPI Code	KPIs
• How do vehicles change their **behaviour** in response to the information provided by the service? • How does this service affect the **travel time** of the AV? • What would be the impact on **traffic conditions** due to the dynamic re-routing?	**VIG.2.4.01**	**Number** of **re-routing messages** received by CCA fleet.
	VIG.2.4.02	**Travel time.**
	VIG.2.4.03	**Transferred traffic load** in terms of average daily load (vehicles/day)

8 BARI FOLLOWER LIVING LAB

8.1 Introduction

Bari is the chief town of the metropolitan city of Bari and the Puglia Region and it is one of the most important economic centres in southern Italy. The city covers 117 square kilometres with a population of over 325,000 inhabitants, while the metropolitan area has over 1.3 million, spread over approximately 3,800 square kilometres.

From this number, it is evident that a quarter of the metropolitan population is concentrated in Bari with a population density of over 1,000 inhabitants per square kilometre. The city of Bari is home to three universities, major research centres, a commercial port, an airport, and the second industrial area of the Adriatic home to numerous companies of international importance in the mechanical, aerospace, chemical and logistics sectors.

The Municipality of Bari has launched a program of interventions called "Bari Smart City" of over 50 million euros that will lead to the creation of urban connectivity infrastructure, the massive use of the IoT and emerging technologies for the provision of services public and urban infrastructure management. Numerous collaborations have been started with public and private partners to develop international research and technology transfer projects (currently 3 H2020 projects are active) in order to make the territory of Bari and its metropolitan area a living lab to experiment with new technologies, processes and operational protocols for the cities of the future.

8.1.1 Use cases presentation

8.1.1.1 Stakeholders and objectives

The Follower LL of Bari will be coordinated by the Municipality of Bari with the support of Polytechnic University of Bari. Apart from these actors who participate as project partners, the following stakeholders will support the pilot:

- Pikyrent
- Poste Italiane –SDA
- Afhass Onlus Bari

The use case “**Developing and simulating of a Route Planner**” aims to support users of different social groups to overcome acceptance barriers in the usage of CCAVs, calculating and proposing different plans based on user class and preferences and real-time availability of travel roads concerning traffic. Datasets and applications will include traffic forecasts, support for cycling, inclusion of relevant locations such as schools, public areas and parking.

The route planner will include the assistance for people with disabilities and will provide gender-specific assistance.

The route planner will be designed by applying AI solutions, machine learning techniques in order to enable the suggestion of the best route also including the traffic light control and management. The route planner will include urban and peri-urban areas.

Another use case in Bari Follower LL is: “**Innovative urban freight transport and logistics**”. The aim of the UC is proposing and simulate new urban freight transport and last mile logistics to reduce the circulation of vehicles especially in urban areas. The idea is to create several HUBs networked together, which act not only as storage of goods, but also as the shunting and distribution of goods. Innovative strategies to localize the micro HUBs, optimize loads, reduce empty miles, utilization of dynamic routing and on demand services will be proposed: the novel approaches will use tools based not only on classic optimization algorithms but also AI tools, Intelligent Data processing and analysis. The assessment of the UC will be performed by the simulation and a digital twin. The general issue is to create a virtual network able to study the methods to insert progressively the autonomous vehicle in the city for freight transport by considering new delivery strategies for instance considering the hour of the night. The proposed solutions and simulations will use historical and real data provided by the Municipality of Bari, georeferenced information (images, data, texts, reports, videos) from various sources (web, repository, open data, sensors and citizens). Moreover, forecasting models and algorithms will be integrated in order to provide a vision of the future reduction of traffic and emission.
It will provide advanced simulation models for digital twin implementation based on traffic data and information and high quality of digital satellite maps for an up-to-date location in order to optimize the movement of people and goods based on Galileo and Copernicus services.

8.1.1.2 Expected impact

The services and use cases in Bari will have the following expected benefits:

- Develop and simulate a route planner for people and goods involving AI solutions to overcome acceptance barriers in the usage of CCAVs.
- Develop and simulate innovative urban freight transport and logistics in the city centre involving autonomous vehicles and optimization and AI tools to reduce empty miles and traffic.
- Provide usable digital tools for citizens.

8.1.1.3 State of art

The Sustainable Urban Mobility Plan (SUMP) is the tool through which the various plans/initiatives of the mobility sector can be "networked" with particular attention to environmental sustainability issues.

In 2012 the EU issued the guidelines for «Developing and implementing a Sustainable Urban Mobility Plan» [1].

The general intervention strategies of the SUMP can be summarized as follows:

- Develop the infrastructures according to a logic consistent with the objectives of environmental sustainability;
- Improve local public transport infrastructures and services;
- Address the mobility needs, generated by urban transformations, mainly towards alternative methods to the private car;
- Promote interventions in favour of road safety, the creation of pedestrian areas, limited traffic zones and environmental islands;
- Introducing the use of ITS (Intelligent Traffic System)
- Promote cycling in urban areas;
- Improve the urban parking system;
- Promote and optimize the logistics of goods in urban areas;
- Promote the elimination of architectural barriers for a city accessible to all (PEBA - Plan for the elimination of architectural barriers).

The Municipality of Bari has launched a structural reorganization of urban mobility based on the principles of environmental sustainability and open to the innovation of the Smart City.

This Plan is divided into 8 strategic lines of intervention which are the constituent elements of the SUMP:

- ✓ Bike plan.
- ✓ Metropolitan transport and intermodality.
- ✓ Urban Public Transport reorganization plan.
- ✓ Intelligent mobility.
- ✓ City logistics.
- ✓ Shared mobility.
- ✓ Mobility management.
- ✓ Road network and parking reorganization plan.

The SUMP will represent a starting point to understand needs of people and businesses in the city of Bari.

More information about the SUMP adopted by the Municipality of Bari can be found on “PUMS Bari website” [2].

Furthermore, a specific plan is being developed for the reduction of vehicular traffic of goods in the city centre based on the regulation of the last mile of distribution logistics.
It is based on the enhancement and rationalization of the use of the network of loading / unloading areas dedicated to cargo and couriers and with a re-organization and optimization of the goods routes in the city centre od Bari, through “Proximity Logistics Terminals” with specific areas of competence (see Figure 10 and Figure 11).

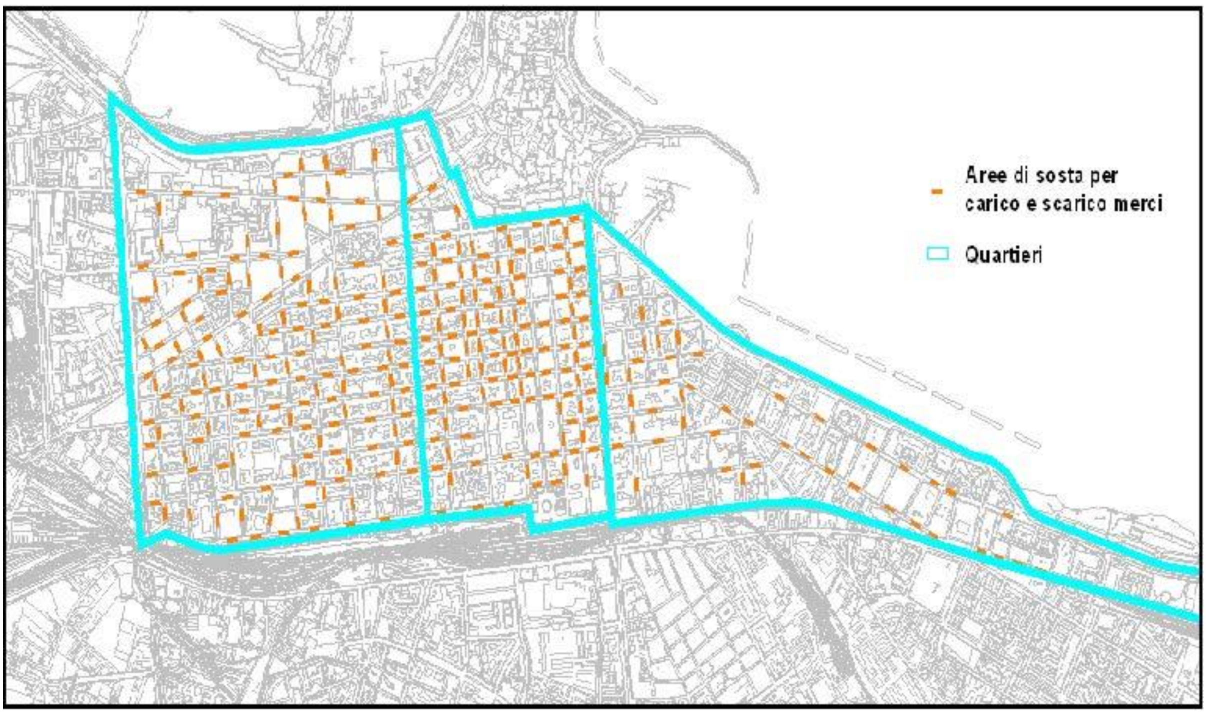

Figure 10: Enhancement and rationalization of the use of the network of areas for loading/unloading cargo

Figure 11: “Proximity" logistics organization for the optimization of goods routes within the city centre

Moreover, the city of Bari has implemented a traffic management solution called "**MONKEY – Mobility Network: KEY smart solutions**" in its ICT traffic infrastructure.

The Smart Traffic Management Unit that is an Urban traffic monitoring and control application that, using heterogeneous data from different territorial systems (Municipal Police, traffic light gates, security cameras, satellite images, parking lots), are able to offer intelligent indicators and dashboards on the status of the mobility and traffic instantly and, if necessary, to act directly on the timing of the traffic lights in order to decongest the blocks.

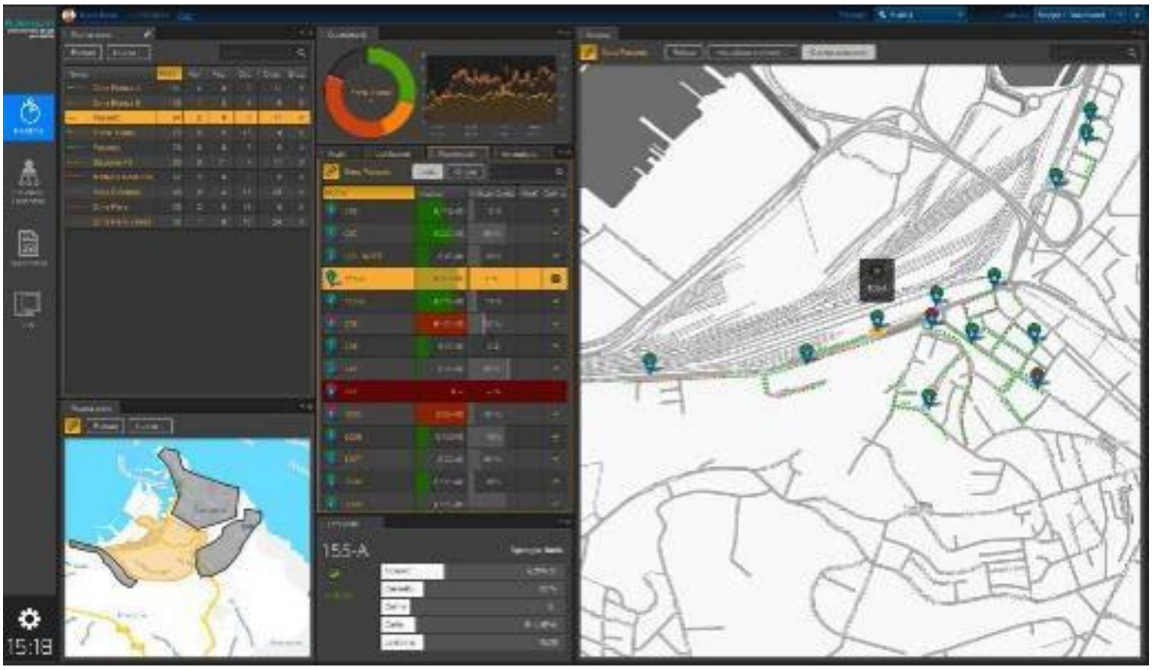

Figure 12: Urban traffic monitoring and control application

The Enabling Platform of Middleware that lets the effective communication between the different territorial and central urban information systems, integrating data of different nature and coming from heterogeneous systems, including proprietary ones, allowing the intelligent collection and management of data, their publication and access controlled by public and private stakeholders.

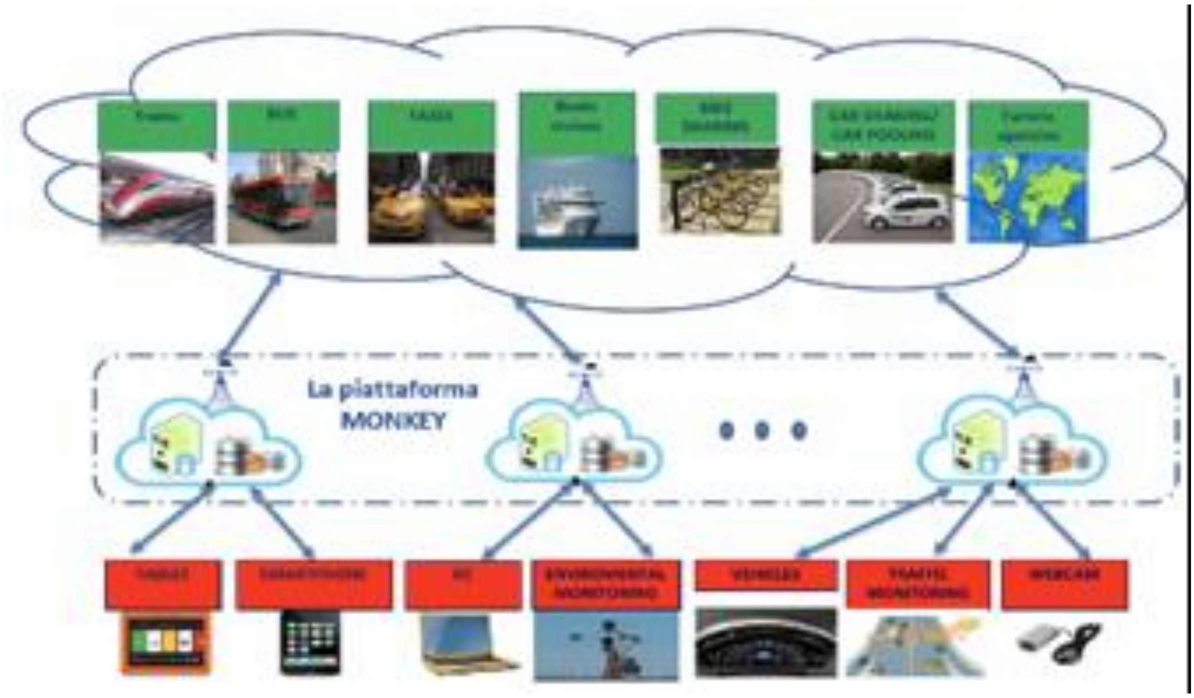

Figure 13: Smart platform "MONKEY" in BARI Follower LL.

The Smart Traffic Lights and Cameras equipped with sensors and remotely controllable that, on the basis of traffic measurements from various territorial sensory systems (including smart traffic lights), allows to remotely control the integrated management of traffic lights, with the aim of promptly decongesting the heaviest traffic situations in real time, or implement a sort of virtual green lanes, in case of emergency vehicles.

Bari Open Innovation Hub that represents an extremely qualified public-private partnership able to ensure the necessary skills to carry out innovation activities and technology transfer to companies. In particular, a basic activity will be the study and analysis of the CCAM integration in the city of Bari by the infrastructural interventions and the creation of IT platforms for transportation.

Another project under development consists in the creation of the **House of Emerging Technologies** in the metropolitan area of Bari, which involves the implementation and integration of 4.0 solutions within the urban context, guaranteed by the deep experience and broad complementarity of the project partnership. Each partner is functional to specific project areas and will deal with the development and validation of some applications within an integrated and functional urban framework. The main theme of the project concerns the creation of innovation demonstrators capable of showing interested stakeholders the potential of new technologies included in the context of Smart Cities and Industry 4.0. In addition to the Municipality of Bari, are also involved as Project Partners: University of Bari – Aldo Moro, LUM University “Giuseppe Degennaro”; Enac – National Civil Aviation Authority, Meditech – Competence Center, Aerospace Technology District, Consortium for the Industrial Development Area of Bari, Cnr - National Research Council, Exprivia, Amt Services and Tim.

Bari Open Innovation Hub involves the creation of a series of demonstrators of innovation and technological solutions, with particular reference to the theme of autonomous and semi-autonomous driving through the use of the 5G network. in fact, the activation of an infrastructure of the area with IoT smart devices is foreseen, such as, for example, intelligent traffic lights, sensor hubs to be integrated with existing ones, smart lighting, etc. Thanks to this intelligent infrastructure, it will be possible to define a route for self-driving SAE 4 and electric vehicles. The project activities include, among other things, the definition of two application scenarios to be implemented with DTA/ENAC drones to experiment with new forms of surveillance on the territory and for integrated logistics (drones + self-driving vehicles) for Delivery 4.0 activities.

On the software side, a specific analysis dashboard (made by Exprivia) and dedicated apps will be implemented for tracking cycle-pedestrian mobility, as well as for traditional vehicular mobility.

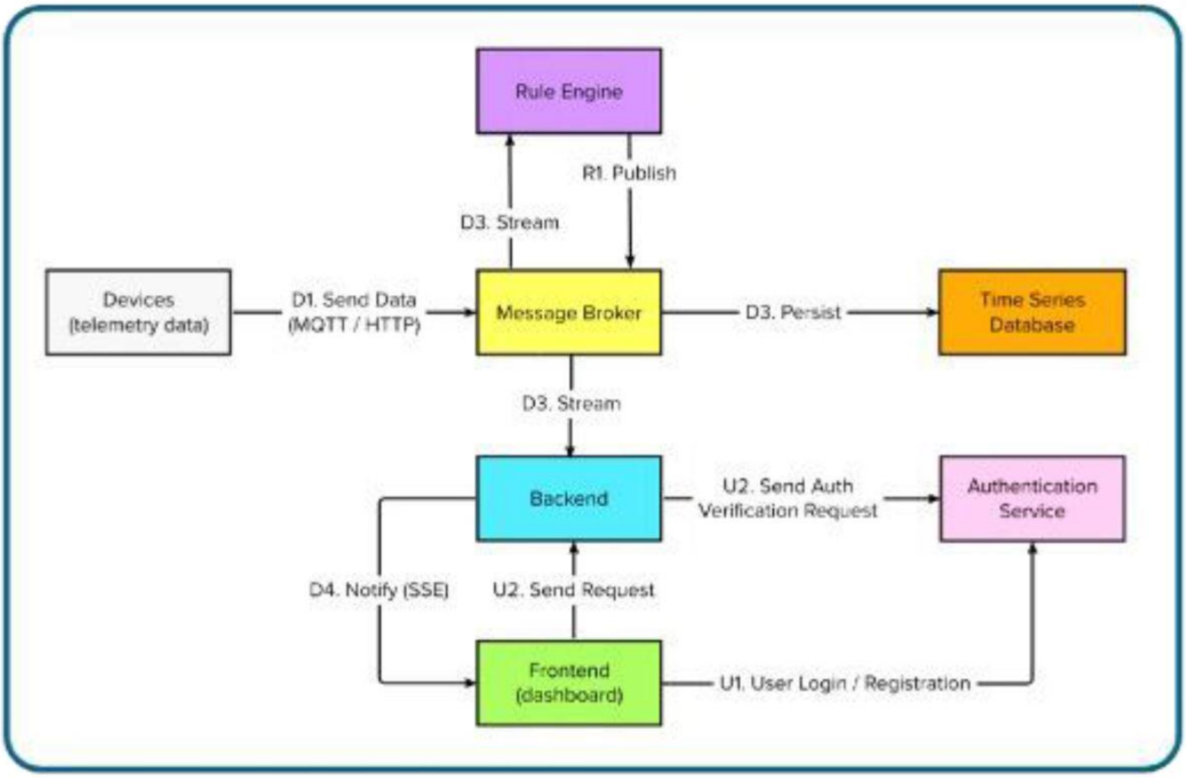

Figure 14: Architecture and data flow of the Exprivia dashboard

8.2 UC#6: Developing and simulating of a Route Planner

8.2.1 Use case description

A Route Planner will be simulated by the co-simulation between a mobility simulation software and an optimization tool, also able to implement Artificial Intelligence strategies. The development and simulation of a route planner will support users of different social groups to overcome acceptance barriers in the usage of CCAVs, calculating and proposing different plans based on user class and preferences and real-time availability of travel roads concerning traffic. The route planner will include the assistance for people with disabilities and will provide gender issues.

The picture below shows the five main actors of the Developing and simulating of a Route Planner.

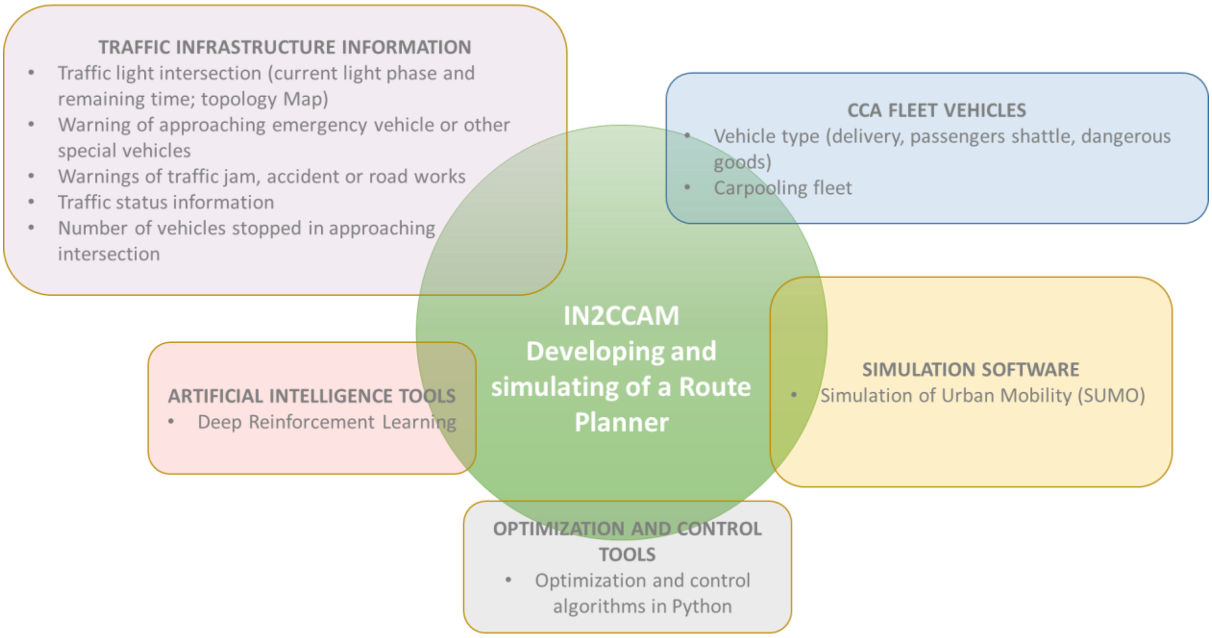

Figure 15: Use Case Developing and simulating of a Route Planner

8.2.1.1 Functional description

The aim of the use case “Developing and simulating of a Route Planner” in the Follower LL of Bari is proposing a simulator able to determine a best route, also considering traffic light control and management. The whole use case is based on simulation. In particular, information about traffic conditions will be simulated taking in account the real traffic status in Bari. The use case consists of a CCAV that needs to travel from point A to point B in Bari. Multiple routes are available with different dedicated CCAV lanes and other features as curvatures, slopes, complex intersections, traffic conditions, etc. A best route will have to be chosen by an AI tool that will consider not only travel times or distances, but also the kilometres of dedicated CCAV lanes, safety in general, and the route characteristics based on the carried passenger class and preferences. The development and simulation results of the route planner will be shown to user groups in specific workshops to overcome acceptance barriers in the usage of CCAVs.

8.2.1.2 Functional and architectural requirements

UC1-FUNC-001
Data sharing platform must be available (MONGO DB, APACHE CASSANDRA or similar data sharing platform).

UC1-FUNC-002
Simulation Software (Urban Mobility simulation software, SUMO simulator or similar simulation software).

UC1-FUNC-003
Optimization and control tools (optimization and control strategy described in Python or similar optimizers).

UC1-FUNC-004
AI Tools (Machine learning to estimate traffic conditions, Deep reinforcement learning to perform optimization strategies (Python or similar framework).

8.2.1.3 Interoperability

In order to maximise the interoperability between Living Lab and Follower LLs, the IN2CCAM data sharing platform will be used to exchange information, data and application tools.

8.2.2 Test scenarios

The following scenarios consider different ways to use a CCAV to travel from an origin to a destination. More in detail, the route planner will be configurated differently depending on whether a single user or multiple users are carried by the CCAV. Furthermore, the vehicle could choose different routes based on the user physical conditions (the CCAV could also transport people with disabilities).

8.2.2.1 Scenario #1: CCAV carrying a single able bodied passenger

Pre-conditions

The goal of a CCAV is to reach its destination automatically, considering the various passenger requirements. In this scenario, a single able bodied passenger requires to the CCAV to be picked up to an origin point and to be carried to a destination point considering some requirements such as safety, time, and energy.

Data:

Locations (origin, destination) ;
Pick-up and maximum arrival time to reach the destination;
Requirements about safety, comfort, time, and energy;
Passenger class;
Traffic conditions;
Traffic lights;
Traffic rules;
Maps: roads' geometry and attributes of the area, dedicated CCAV lanes, intersection with complex topologies are required.

Scenario flow

The CCAV receives locations, times and requirements by the passenger.
An environment model that contains all of the information about the roads is provided to the planning simulation system, such as traffic conditions, traffic lights, traffic rules, road attributes, dedicated CCAV lanes, intersection with complex topologies.
The CCAV reaches the passenger at the origin point at the indicated time. The passenger is picked-up and the CCAV determines the best route taking in account passenger destination, maximum arrival time and requirements.
The CCAV performs the best route determining the route and the reference speed. Other parameters as time gap to the car in front, acceleration, deceleration, etc. are calculated automatically by the software SUMO during the simulation. If connected traffic lights are met, the connected traffic lights facilitate the passage of the vehicle from the intersection.
The CCAV can update its best route periodically.
The CCAV reaches the destination within the time set by the passenger.

Data collection

Travel distance (km)

Travel time (hh:mm)
Origin and destination timestamps (hh:mm)
Waiting times in queue at the intersections (minutes)
Kilometres travelled on dedicated CCAV lanes (km)
Number of vehicles met during the travel (unit)
Best route attributes (unit)
Intersections with complex topology met during the travel (unit)
CCAV speed profile during the travel (km/h)

Related KPIs

Table 16: Research Questions and KPIs for UC#6 Test Scenario 1

Research Questions	KPI Code	KPIs
• Is the Route Planner **efficient**? In other words, does it successfully select the **optimal route** according to a set of given parameters?	**BAR.1.1.01**	**Success** in finding an **optimal route** (i.e. does the simulator always suggest an optimal route without errors?).
	BAR.1.1.02	**Computation time** required for the Route Planner to find the optimal route given the number of conditions (e.g., curvatures, slopes, traffic light timings).
	BAR.1.1.03	Surveys to assess **user acceptance** in areas where this scenario could be implemented.

8.2.2.2 Scenario #2: CCAV carrying a single passenger with disabilities

Pre-conditions

The goal of a CCAV is to reach its destination automatically, considering the various requirements of passengers. In this scenario, a single passenger with disabilities requires to the CCAV to be picked up to an origin point and to be carried to a destination point considering some requirements such as safety, comfort, time, and energy.

Scenario flow

The CCAV receives not only locations, times and requirements by the passenger, but also his/her disabilities.

An environment model that contains all of the information about the roads is provided to the planning simulation system, such as traffic conditions, traffic lights, traffic rules, road surfaces, dedicated CCAV lanes, intersection with complex topologies, narrow curves and acute angles (comfort requirements).

The CCAV reaches the passenger at the origin point at the indicated time. The passenger is picked-up and the CCAV determines the best route taking in account passenger requirements and disabilities.
The CCAV performs the best route. If connected traffic lights are met, the connected traffic lights facilitate the passage of the vehicle from the intersection.
The CCAV can update its best route periodically.
The CCAV reaches the destination within the time set by the passenger.

Data collection

Travel distance (km)
Travel time (hh:mm)
Origin and destination timestamps (hh:mm)
Waiting times in queue at the intersections (minutes)
Kilometres travelled on dedicated CCAV lanes (km)
Number of vehicles met during the travel (unit)
Best route attributes (unit)
Intersections with complex topology met during the travel (unit)
CCAV speed profile during the travel (km/h)

Related KPIs

Table 17: Research Questions and KPIs for UC#6 Test Scenario 2

Research Questions	KPI Code	KPIs
• Is the Route Planner **efficient**? In other words, does it successfully select the **optimal route** according to the **increased** set of parameters?	BAR.1.2.01	**Success** in finding an **optimal route** (i.e. does the simulator always suggest an optimal route without errors?).
	BAR.1.2.02	**Computation time** required for the Route Planner to find the optimal route given the **increased number** of conditions (e.g., curvatures, slopes, traffic light timings, safety, comfort, time, energy).
	BAR.1.2.03	Surveys to assess **user acceptance** in areas where this scenario could be implemented.

8.2.2.3 Scenario #3: CCAV carpooling

Pre-conditions

A set of passengers with different origins and destinations point requires to use a CCAV. The goal of a CCAV is to pick-up the passengers and to reach their destinations automatically, considering their different requirements, such as safety, comfort, time, and energy.

Scenario flow

The CCAV receives locations, times and requirements by the passengers in addition to their disabilities, if present.

An environment model that contains all of the information about the roads is provided to the planning simulation system, such as traffic conditions, traffic lights, traffic rules, road surfaces, dedicated CCAV lanes, intersection with complex topologies, narrow curves and acute angles.

The CCAV determines the best route with intermediate stops (at the passenger origin and destination points) taking in account requirements and disabilities.

The CCAV performs the best route. If connected traffic lights are met, the connected traffic lights facilitate the passage of the vehicle from the intersection.

The CCAV can update its best route periodically. At each stop, the CCAV checks if the best route must be changed.

The CCAV reaches the destinations within the time set by the passengers.

Data collection

CCAV travel distance (km)
CCAV travel time (hh:mm)
Travel distance per passenger (km/passenger)
Travel time per passenger (hh:mm/passenger)
Origins’ and destinations’ timestamps (hh:mm)
CCAV waiting times in queue at the intersections (minutes)
Waiting times in queue at the intersections per passenger (minutes/passenger)
CCAV kilometres travelled on dedicated lanes (km)
Kilometres travelled on dedicated CCAV lanes per passenger (km/passenger)
Total number of vehicles met during the travel (unit)
Number of vehicles met during the travel per passenger (unit/passenger)
Best route attributes (unit)
Best route attributes per passenger (unit/passenger)
Intersections with complex topology met during the CCAV travel (unit)
Intersections with complex topology met during the travel per passenger (unit/passenger)
CCAV speed profile during the travel (km/h)

Related KPIs

Table 18: Research Questions and KPIs for UC#6 Test Scenario 3

Research Questions	KPI Code	KPIs

• Is the Route Planner **efficient**? In other words, does it successfully select the **optimal route** according to the **increased** set of parameters? • How does carpooling affect **travel time** compared to using a non-carpooling service? • What is the **impact** of carpooling in the **reduction** of **emissions** and the **number of trips**?	**BAR.1.3.01**	**Success** in finding an **optimal route** (i.e., does the simulator always suggest an optimal route without errors?).
	BAR.1.3.02	**Computation time** required for the Route Planner to find the optimal route given the **increased number** of conditions.
	BAR.1.3.03	Impact on **travel time** compared to using a non-carpooling service.
	BAR.1.3.04	**Estimation** of the **reduction of total emissions** (e.g., CO2, NOx, PM) due to carpooling based on saved km.
	BAR.1.3.05	**Reduction** of **total number of trips** made
	BAR.1.3.06	Surveys to assess **user acceptance** in areas where this scenario could be implemented.

8.3 UC#7: Innovative urban freight transport and logistics

8.3.1 Use case description

The idea is to create several HUBs networked together, which act not only as storage of goods, but also as the shunting and distribution of goods. Innovative strategies to localize the micro HUBs, optimize loads, reduce empty miles, utilization of dynamic routing and on demand services will be proposed: the novel approaches will use tools based not only on classic optimization algorithms but also AI tools, Intelligent Data processing and analysis. The assessment of the UC will be performed only by simulation.

The picture below shows the four main actors of the Innovative urban freight transport and logistics.

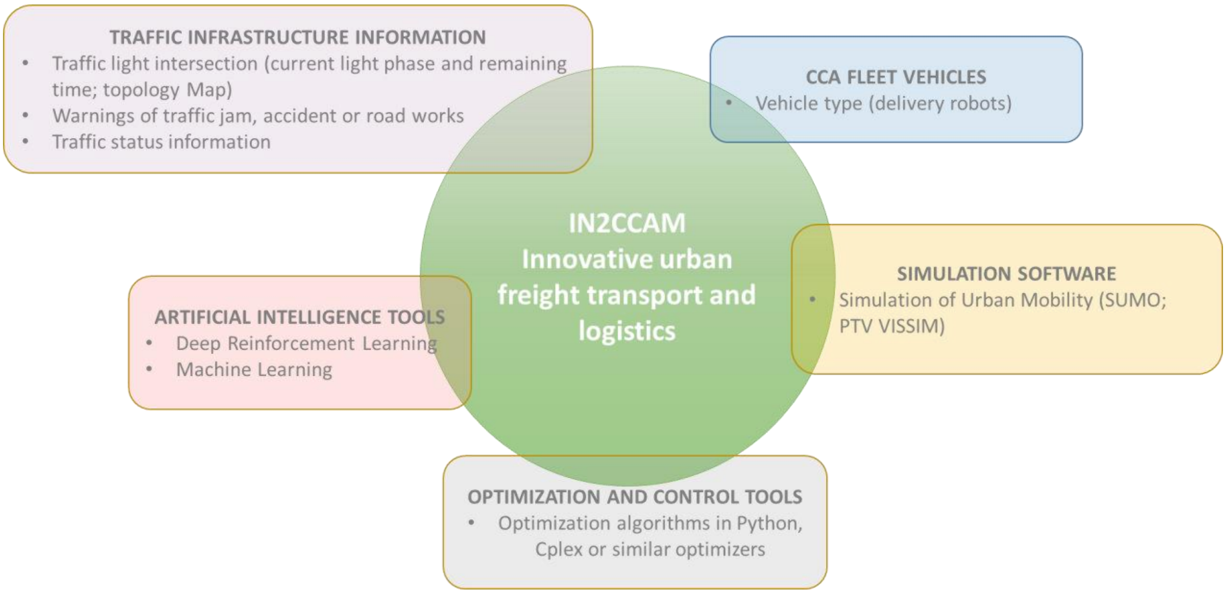

Figure 16: Use Case Innovative urban freight transport and logistics

8.3.1.1 Functional description

The aim of the use case in Bari “Innovative urban freight transport and logistics” is proposing and simulate new urban freight transport and last mile logistics to reduce the circulation of vehicles especially in urban areas. The idea is to create a truck-and-robot system with robot depots, as they enable significant cost and traffic reduction compared to classic truck deliveries. The system relies on small autonomous delivery robots to cover the last meters to a customer. A delivery robot is an autonomous robot that provides “last mile” delivery services. Delivery robots can be used in different settings such as food delivery, package delivery, hospital delivery, and room service. Existing concepts consider home deliveries by robots, while trucks are only used to transport robots and not for deliveries.

8.3.1.2 Functional and architectural requirements

UC2-FUNC-001
Data sharing platform must be available (MONGO DB, APACHE CASSANDRA or similar data sharing platform).

UC2-FUNC-002
Simulation Software for Digital Twin (Urban Mobility simulation software (SUMO), Traffic Simulation software (PTV –VISSIM) or similar simulation software).

UC2-FUNC-003
Optimization and control tools (optimization and control strategy described in Python or Cplex or similar optimizers).

UC2-FUNC-004
AI Tools (Machine learning to estimate the client demand, Deep reinforcement learning to perform optimization strategies (Python or similar framework).

8.3.1.3 Interoperability

In order to maximise the interoperability between Living Lab and Follower LLs, the IN2CCAM data sharing platform will be used to exchange information, data and application tools.

8.3.2 Test scenarios

8.3.2.1 Scenario #1: Delivery in standard conditions

Pre-conditions

In this scenario, a truck driver is primarily responsible for transporting and delivering products to customers, ensuring accuracy and timeliness. They are responsible for the loading and unloading of packages, the handling of goods according to schedules and routes.

Scenario flow

To analyse and to simulate this scenario we will distinguish three principal actors:

- the road infrastructure,
- the delivery truck and the truck driver,
- the customer.

The road infrastructure - we will consider some neighbourhoods and, for every of them, we will identify a number of parcels to deliver. In order to model a neighbourhood, we will require a road infrastructure that the driver will can use to deliver.

The delivery truck and the truck driver - a delivery truck, is used to carry the parcels from a local distribution centre to the customer. The driver assembles the customer's order, reaches the delivery point (the customer) with the truck and is able to deliver one parcel at a time with a fixed speed.

The customer - every side-street has houses on both sides of the street. These houses are the delivery locations. In current operations, the vehicle is parked near the customer's house and delivery is a manual operation performed by the truck driver. After each delivery the truck driver reaches new customer crossing the urban areas with the truck.

Figure 17: Delivery in standard condition

The picture below shows the main actors of the ***scenario #1*** where the truck driver delivers the parcel.

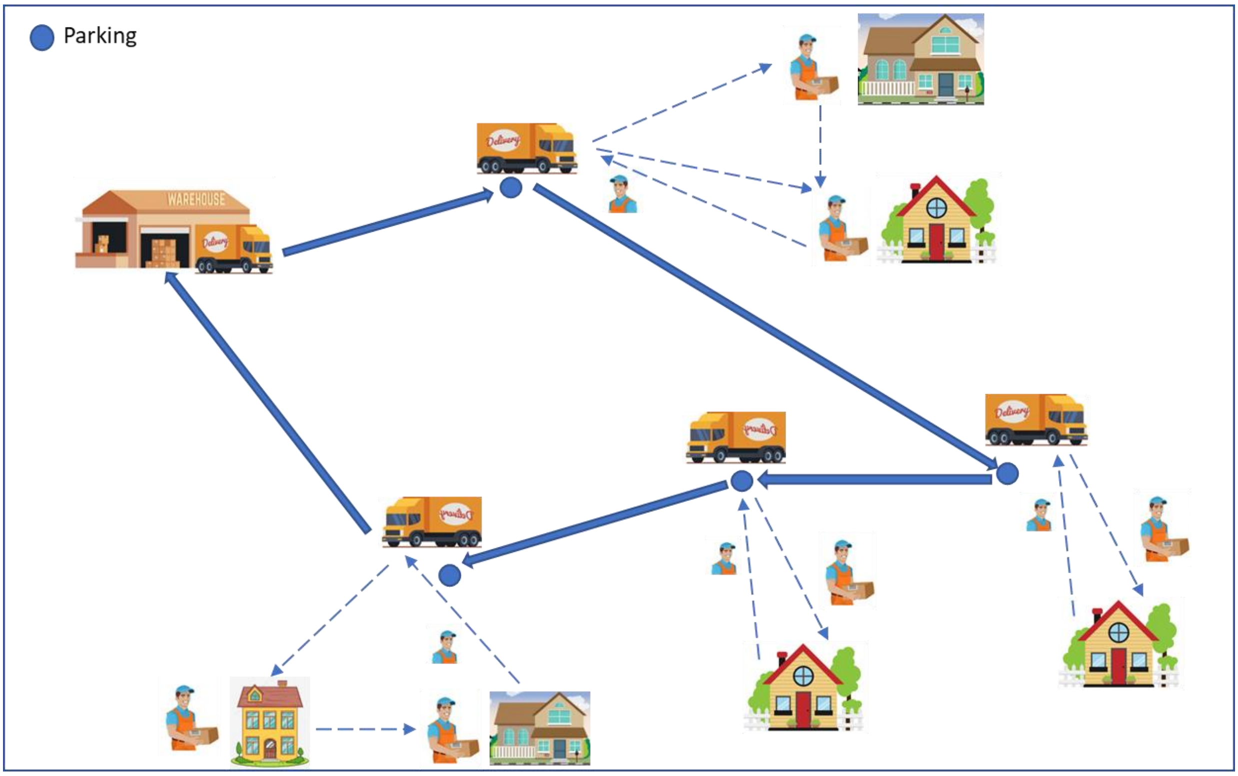

Figure 18: SCENARIO#1: Delivery in standard condition flow

Data collection

INPUT

- Length street (km)
- Number of parcels to be delivered per day (n°/day)
- Working days per week (day/week)
- Working time per day (h/day)
- Speed truck (km/h)
- Walking speed driver (m/sec)
- Load measures (Kg, m^3)
- Truck's container dimensions (m^3)

OUTPUT

- Completion Time (makespan) per day (h/day)
- Number of parcels delivered per day (n°/day)
- Storage capacity of container (m^3)
- Routing (Km/day)
- Sum of the empty miles (Km/day)

8.3.2.2 Scenario #2: Robot delivery

Pre-conditions

In this scenario we propose a last-mile delivery concept, in which a truck carries a fleet of robots, but also a truck driver that has an active role in the loading process. The system is based on the use of relies on small autonomous delivery robots to cover the last mile to a customer. In this context, Load optimization, Empty miles reduction and Dynamic routing utilization, based on client's demand, will be performed.

Scenario flow

Bari is the chief town of the metropolitan city of Bari and it covers 117 square kilometres with a population of over 325,000 inhabitants. From this number, it is evident that the city is divided in different neighbourhood.

To analyse and to simulate this scenario we will distinguish four principal actors:

- the road infrastructure,
- the truck and the truck driver,
- the customer,
- the street robots.

The road infrastructure - We will consider some neighbourhoods and, for each of them, we will identify a parking area (Delivery centre) where the truck driver can load the robots. In order to model a neighbourhood, we will require a road infrastructure that t street robots will can use to deliver parcels.

The truck and the truck driver - The truck transports the delivery robots and the goods and releases them at dedicated parking near the urban area. A location where the truck can safely stop, loading the goods on the robot and release robots. In this system only driving the truck and loading of goods remain manual tasks.

The truck driver enters the front part of the cargo bay, retrieves the goods from the shelf system, loads the robots, and then, these leave the truck via a ramp to the side. After each delivery the robots return to dedicated loading location and after the new loading, they will be ready for later tours.

Figure 19: Specialized truck with freight containers and delivery robots

The customer - Every side-street has houses on both sides of the street. These houses are the delivery locations.

***Street robots* -** The street robots can be used to deliver parcels as a ground vehicle and are stored and dispatched from the delivery truck. A maximum of street robots are available, as this is the maximum capacity of the delivery truck. A street robot can carry one parcel at a time and travels with a fixed speed.
The picture below shows the main actors of the ***scenario #2*** where the delivery including a robot.

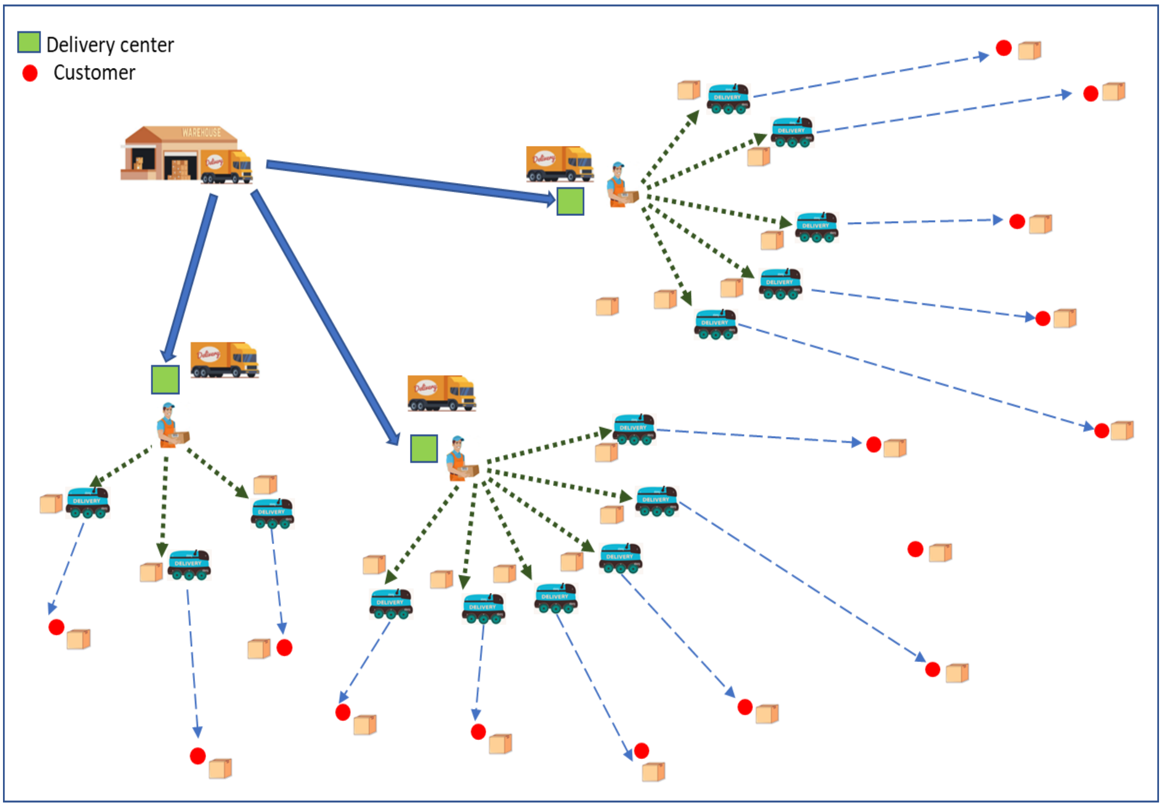

Figure 20: SCENARIO#2: Robot delivery flow

Data collection

INPUT

- Length street (m).
- Street robot capacity (Kg).
- Speed street robots (m/sec).
- Number of parcels to be delivered per day (n°/day).
- Number of robots per truck (n°/truck).
- Working days per week (day/week).
- Working time per day (h/day).
- Load measures (Kg, m^3).
- Truck's container dimensions (m^3).

OUTPUT

- Completion Time (makespan) per day (h/day).
- Number of parcels delivered per day (n°/day).
- Storage capacity of container (m3).
- Best routing (Km/day).
- Sum of the empty miles (Km/day).

Related KPIs

Table 19: Research Questions and KPIs for UC#7 Test Scenarios 1 & 2

Research Questions	KPI Code	KPIs
• Is the use of robots in goods delivery **efficient**? In other words, do the **delivery times and costs improve** when robots are used in the delivery process? • What are the **impacts** on **traffic congestion** and **pollution** within urban areas?	**BAR.2.1.01**	**Difference** in **efficiency** between the two delivery systems (e.g., delivery times, punctuality, damages, etc.).
	BAR.2.1.02	**Impact** on **reducing traffic congestion** within urban areas.
	BAR.2.1.03	Surveys to assess **user acceptance** in areas where this scenario could be implemented.

9 QUADRILÁTERO FOLLOWER LIVING LAB

9.1 Introduction

Quadrilátero is a non-profit association that aims to continue the partnership network formed by the cities of Barcelos, Braga, Famalicão and Guimarães, with the vision to be the pole of territorial competitiveness of excellence in the northwest peninsular, reference as a laboratory of urban and business innovation, resulting from the cooperation between industry, scientific-technological fabric, local administration and end users, and integrated into international networks, and with the mission to boost the innovative ecosystem and the brand "Quadrilátero", raising funds for cooperation projects that promote innovation, creativity and research applied to companies and cities. Ubiwhere has already installed Connected Street Furniture in Guimarães, a modular concept of a lamppost with bleeding-edge technology, which allows municipalities to future-proof their smart city and Mobile Network Operators to deploy their 5G solution cost-effectively.

Connected Urban Furniture solutions are complemented with a management platform that allows tenants and owners/landlords to perform lease and asset management tasks. Additionally, Ubiwhere is carrying out the largest smart parking project ever implemented in Portugal: the company is deploying a management system to collect real-time data in the Municipality of Guimarães (one of Quadrilatero's associated cities) that will allow the city to monitor more than 900 on-street and off-street parking spaces. Moreover, the city has implemented Ubiwhere's urban data platform, where multiple sets of information have been integrated (such as traffic flow observations, incidents, weather and buildings), being a case study by "Gartner on Location Intelligence" [3], and a "best practice by the European Commission" [4]. This solution sets the baseline for the city to experiment with new mobility scenarios and use cases with AI and simulation for greater efficiency and better quality of life.

9.2 UC#8: Simulation of CCAM impact on traffic flow and potential congestion in urban and peri-urban areas

9.2.1 Use case presentation

9.2.1.1 Stakeholders and objectives

The use case "**Simulation of CCAM impact on traffic flow and potential congestions in urban and peri-urban areas**" aims to assess the environmental and mobility impacts of CCAM through a web service that implements and runs the simulation environments (e.g.

traffic flow analysis, ITS evaluation, environmental impact assessment, autonomous vehicle testing), leveraging data about the autonomous shuttles (dimensions, speed, and other performance data), historical travel itineraries samples for simulation, road infrastructure data (number of lanes, properties, rules and restrictions, etc.), data about public transportation usage and schedules for multimodal integration. The edge/lane based vehicular emission outputs for the environmental impact are absolute and normed values of vehicular pollutant emissions collected on edges or lanes, which hold the sum of each of the pollutants emitted on each edge/lane, and the normed values for the interval duration and the edge's/lane's length.

The use case brings Ubiwhere's expertise in data aggregation for analysis and simulation, leveraging existing information and data from the lead LLs about the shuttle performance and other sources. Ubiwhere will use the following datasets available in Guimarães:

a) Real-time traffic information courtesy of HERE Technologies [5]
b) Off-street Parking occupancy information provided by the municipality via existing third-party information systems and IoT platforms [6]
c) Electrical Vehicle charging stations' locations provided by the municipality
d) Touristic and social events data provided by the municipality [7]
e) Mobility and Civic Incidents and planned roadworks courtesy of the city council and the citizens' community through a mobile application [8]
f) Air quality and Weather observations provided by the municipality
g) Foot and bicycle traffic information generated by IoT devices installed in crucial points of the city
h) Geospatial data of the region (from ESRI and OpenStreetMap).

This will allow Ubiwhere to perform: the assessment of the best itineraries for the shuttle; the simulation of CCAM vehicles for passengers transportation to assess the impact on traffic and infrastructure based on existing public transportation ticketing data and demographic information collected by the municipalities.

9.2.1.2 Expected impact

The service and use case in Quadrilátero will have the following expected benefits:

- Optimise urban space, loads and reduce empty miles through dynamic routing by simulating different deployment scenarios for CCAM vehicles;
- Increased quality and liveability of urban and metropolitan areas by reducing congestion, air and noise pollution via decisions made based on the impact assessment of diverse mobility scenarios;
- Provide usable digital tools (such as Ubiwhere's Urban Platform [9], with its user interface) for municipalities for urban planning and traffic management;

- Provide valuable data (for city management) to several decision makers, from city councils to transportation operators.

9.2.1.3 State of art

Quadrilátero has been working and developing an Intelligent Mobility Centre (CIMOB) that supports the region's implementation of the cities' SUMPs through the development of three main programs:

Portugal 2020 - Notice Nº NORTE-06-2016-22 (Strategic Urban Development Plan, in Investment Priority 4.5):

- NORTE-05-1406-FEDER-000200 – Real-Time Information Systems;

Development of 2 types of actions:
In collective public passenger transport, with real-time information on information panels in terminals and stops;
In traffic management and parking, with the implementation of 3 pilot projects, which provide real-time information to drivers and urban traffic management.

- NORTE-05-1406-FEDER-000208 – Integrated ticketing.

To be implemented in all Quadrilátero cities and extended to all municipalities that are part of the Intermunicipal Communities of Ave and Cávado.
It is intended as a solution that can be extended to all modes and operators of public passenger transport. It presupposes the definition of a tariff model, the creation of new tickets or forms of validation and greater integration of existing services with direct gains for the user and the development of the system.

CEF Programme - Ongoing operations under the grant agreement INEA/CEF/TRAN/M 2018/1796634.

- Action: Cooperative Streets (C-Streets), Action number: 2018-PT-TM-0099-S, Project Leader: IMT – Instituto de Mobilidade e dos Transportes, I.P... Cofinanciado pelo Mecanismo interligar Europa – União Europeia - C-Roads – Cooperative Streets.

Sharing and connecting information on all aspects of mobility. Build pilots and implement initiatives, with interconnection and sharing information on transport services, development of initiatives that ensure connected and shared mobility services, and the availability of more and better information about transport and traffic in the urban environment. Implement the principles of multimodality and interoperability between existing information systems through EU standardised formats, expanded data sharing, evolution to real-time data management systems and digitisation of transport data. Predicted static data (minimum) - Public transport network; Timetables; location of stops; public transport routes; Accessibility; prices and types of travel tickets; location of electric charging stations; localisation of interface locations (multimodal). Predicted dynamic data (minimum) - Schedules updated in real-time; the location of vehicles; status of transportation services; status of charging stations.

One of the cities that is part of Quadrilátero is Guimarães, which has implemented Ubiwhere's Urban Platform and has been considered a best practice by the European Commission [4]. The Guimarães' instance of the Urban Platform is a city dashboard with mapping support displaying information in different domains. The platform supports operational activities such as routing to traffic accidents and the availability of parking spaces. It also provides information to inform policy, e.g. on energy consumption of street lighting or reporting on SDG goals in different domains (mobility, environment, tourism, energy, waste). The platform gathers data from different sources, from sensors, platforms or services via APIs, or directly from citizens (e.g. street problems). There is integration with different partner information sources (e.g. HERE, Waze). Centralisation and data harmonisation provides real-time and batch analysis opportunities, giving insights for informed decisions. For example, it is possible to understand how an event (e.g. concert, sports event) has impacted traffic flows and parking, air quality and noise levels. This allows impact analysis which can be used to take preventive action in the future.

9.2.2 Use case description

9.2.2.1 Functional description

The aim of the use case "Simulation of impact on traffic flow and potential congestions in urban and peri-urban areas" in the Follower LL of Quadrilátero is proposing the integration of an open-source, highly portable, microscopic and continuous traffic simulation package designed to handle large networks. It allows for intermodal simulation including pedestrians and comes with a large set of tools for scenario creation, being capable of determining the performance and impact of different routes to help determine the best one for CCAM in the region, also considering traffic light control and management. It should allow users to simulate traffic flow in different urban scenarios, including various vehicle types, traffic rules, and infrastructure layouts.

The simulation capabilities must be highly customisable, allowing users to specify details such as vehicle behaviour, traffic light timing, and road networks based on microscopic traffic flow simulation, which simulates the movement of individual vehicles in a given traffic scenario. This simulation engine must allow the simulation of connected and automated vehicle (CAV) behaviour in urban traffic. It should model the behaviour of CAVs in different traffic scenarios, such as platooning, merging, and lane changes. CCAM can also simulate the communication between CAVs and infrastructure, such as traffic lights and road sensors, allowing for testing new CAV technologies and traffic management systems.

The simulation results provided by the engine should help researchers, engineers, and city planners design and optimise transportation systems, evaluate the impact of new policies and technologies, and improve traffic flow and safety in the urban areas of Quadrilátero.

9.2.2.2 Functional and architectural requirements

UC1-FUNC-001
As a user, I want to select some roads and lanes to be closed for a time period to analyse the impact of the alterations on the city flow and mobility. **UC1-FUNC-001-01: Block road** As a user, I want to select a particular road so that it can be blocked. As a user, I want to choose a certain period so that the road can be blocked for that time. **UC1-FUNC-001-02: Block lane** As a user, I want to choose a certain road lane so that it can be blocked.

UC1-FUNC-002
As a user, I want to change the speed limits and the number of parking spots around some regions of the city to analyse the impact of the changes on all the surrounding areas. **UC1-FUNC-002-01: Change speed limit** As a user, I want to select a particular road segment so that it can be altered. As a user, I want to choose a certain period so that the road can have its speed limit changed for that time. **UC1-FUNC-002-02: Add some parking spots** As a user, I want to select a road segment so that parking spots can be added. As a user, I want to choose the number of parking spots so that it can be added to the road.

As a user, I want to select a certain period so that the changes to the parking spots be effective in that time.

UC1-FUNC-002-03: Close some parking spots

As a user, I want to select a group of parking spots so that they can be closed.

As a user, I want to choose a certain period so that the changes to the parking spots be effective in that time.

UC1-FUNC-003

As a user, I want to create and change some public transportation routes and schedules to analyse the impact of the changes on the city's overall mobility.

UC1-FUNC-003-01: Create public transportation route/schedule

As a user, I want to add specific points in the map so that a new public transportation route can be created

As a user, I want to select the schedule of the public transportation route so that a new public transportation route can be created with a set of trips and calendars

As a user, I want to select the number of public transportation vehicles so that a new public transportation route be created

UC1-FUNC-003-02: Change public transportation route/schedule

As a user, I want to select a public transportation route so that its schedule or stops can be altered

UC1-FUNC-003-03: Delete public transportation route/schedule

As a user, I want to choose a public transportation route so that it can be deleted.

UC1-FUNC-004

As a user, I want to select a particular city zone to block all the roads for specific vehicles and evaluate a possible low-emissions zone.

UC1-FUNC-004-01: Choose an area to be evaluated

As a user, I want to select a certain zone drawing a polygon so that its roads can be blocked.

As a user, I want to select a certain period of time so that the roads can be blocked for that time period.

UC1-FUNC-005

As a user, I want to view all the simulation results so that I can make better decisions about the flow of the city/zone.

UC1-FUNC-005-01: Run the simulation
As a user, I want to simulate traffic scenarios with the configurations so that I can see the results and analyse the impact on traffic and the environment.
UC1-FUNC-005-02: Save simulation results
As a user, I want to save the results to analyse them later.

9.2.2.3 Interoperability

To maximise the interoperability between Living Lab and Follower LLs, the IN2CCAM data-sharing platform will be used to exchange information, data and application tools via REST APIs that comply with best practices in software development and R&I projects.

9.2.3 Test scenarios

9.2.3.1 Scenario #1: blocking roads and lanes for pedestrians and CAVs

Pre-conditions

- Model of the city is created based on OpenStreetMaps, OpenStreetBuildings, GTFS and other data, and ready to be used in the simulation process.
- Map visualisation of the city.

Scenario flow

4. The user specifies the network roads to be blocked during the simulation.
5. The user determines the period during which the lanes will be blocked.
6. The user's data is transmitted to the simulation module, where it will be subjected to a simulation process.
7. The unprocessed outcomes of the simulation are analysed.
8. The output data is communicated to the user via graphical representations and map data visualisations.

Data collection

Period of time (hh:mm)
Road/Lane identificator (map selection)
Simulation results

Related KPIs

Table 20: Research Questions and KPIs for UC#8 Test Scenario 1

Research Questions	KPI Code	KPIs
• How does blocking roads and lanes to be utilised by pedestrian and CAVs impact **traffic congestion** nearby? • Is the **accessibility** of pedestrians and VRUs upgraded by those interventions?	**QUA.1.1.01**	Impact on **traffic congestion** nearby (e.g., queues, travel times, average speed).

9.2.3.2 Scenario #2: changing parking availability from curbs to assess traffic performance

Pre-conditions

- Model of the city is created, ready to be used in the simulation process.
- Map visualisation of the city.

Scenario flow

1. The user designates the network roads for which the number of parking spaces will be altered during the simulation.
2. The user specifies the network roads that will have their speed modified during the simulation.
3. The user specifies the time interval during which the lanes will have a different maximum velocity.
4. The user’s data is transmitted to the simulation module, where it will be subjected to a simulation process.
5. The unprocessed outcomes of the simulation are analysed.
6. The output data is communicated to the user via graphical representations and map data visualisations.

Data collection

Speed limit
Number of parking spots
Period of time (hh:mm)
Road/Lane identificator (map selection)
Simulation results

Related KPIs

Table 21: Research Questions and KPIs for UC#8 Test Scenario 2

Research Questions	KPI Code	KPIs

• What is the impact of the **available on-street parking space** on traffic congestion? • How is such a measure going to be implemented? How **straight-forward** is it going to be for road-users to **adopt** quickly and safely to the changing parking conditions? • Is it going to be **accepted by public** (especially in areas where parking spaces are already limited)?	**QUA.1.2.01**	Impact on **traffic congestion** nearby (e.g., travel times, queues, delays, LOS of intersections).
	QUA.1.2.02	**Survey** to collect feedback and assess **user acceptance** in areas where this measure could be implemented (e.g., stated-preference surveys)

9.2.3.3 Scenario #3: adapting public transportation for CCAM

Pre-conditions

- Model of the city is created, ready to be used in the simulation process.
- Map visualisation of the city.
- Data on public transportation is stored in GTFS

Scenario flow

1. The user modifies the public transportation data using GTFS formatting).
2. The user submits the modified data to the platform.
3. The user's data is transmitted to the simulation module, where it will subjected to a simulation process.
4. The unprocessed outcomes of the simulation are analysed.
5. The output data is communicated to the user via graphical representations and map data visualisations.

Data collection

Public transportation information (GTFS)
Simulation results

Related KPIs

Table 22: Research Questions and KPIs for UC#8 Test Scenario 3

Research Questions	KPI Code	KPIs
• Do the **number** and the **frequency** of public transport options affect the deployment of CCAVs (i.e., CCAVs will first be deployed in areas with inadequate public transport options)?	**QUA.1.3.01**	**Frequency** and **number of AVs** according to the availability of public transport options in the area.

9.2.3.4 Scenario #4: creating low-emission zones

Pre-conditions
- Model of the city is created, ready to be used in the simulation process.
- Map visualisation of the city.

Scenario flow
1. The user designates a specific zone on the city map to be blocked.
2. The user chooses the type of vehicles that will be allowed and disallowed to use the lanes in the zone.
3. The user's data is transmitted to the simulation module, where it will subjected to a simulation process
4. The unprocessed outcomes of the simulation are analysed.
5. The output data is communicated to the user via graphical representations and map data visualisations.

Data collection
City zone to be blocked
Pollutants emissions
Simulation results

Related KPIs

Table 23: Research Questions and KPIs for UC#8 Test Scenario 4

Research Questions	KPI Code	KPIs
• How does the **creation** of **low-emission zones** impact the utilisation of AVs? • What is the **impact** on **traffic congestion**? • What is the **impact** on **air pollution**?	**QUA.1.4.01**	Survey to assess **user acceptance** of low emission zones.
	QUA.1.4.02	Impact on **traffic congestion** on the affected parts of the network.
	QUA.1.4.03	Impact on **emissions and air quality** (e.g., total CO2, NOx, PM emissions).

9.2.3.5 Scenario #5: running ad-hoc simulations with files previously created

Pre-conditions

- Model of the city is created, ready to be used in the simulation process.
- Map visualisation of the city.
- Previously conducted simulations have been generated and stored.

Scenario flow

1. The user chooses a previously conducted scenario.
2. The results of the stored simulation are requested
3. The unprocessed outcomes of the simulation are analysed.
4. The output data is communicated to the user via graphical representations and map data visualisations.

Data collection

Simulation results

Related KPIs

Table 24: Research Questions and KPIs for UC#8 Test Scenario 5

Research Questions	KPI Code	KPIs
• How to organise an **efficient system** that can conduct **several model runs** (e.g., required to test several different scenarios) with little or no manual effort?	**QUA.1.5.01**	Impact on **effort** and **time** required to set up and run several model runs.

10 CONCLUSION

In conclusion, the use cases and scenarios presented in this deliverable, across multiple cities, demonstrate the wide range of applications for Cooperative, Connected, and Automated Mobility (CCAM) technologies.

While each city's use case has its unique focus, several common themes emerge. Tampere, Trikala, and Vigo emphasize the integration of CCAM technologies into traffic management systems and the importance of real-time communication between vehicles and infrastructure.

Safety measures for vulnerable road users are highlighted in the scenarios from Tampere and Trikala, while Turin and Vigo showcase dynamic traffic management strategies. Furthermore, the use cases collectively demonstrate the feasibility and effectiveness of CCAM solutions in improving urban mobility.

By recognizing these commonalities and cultivating collaboration among cities, stakeholders can enhance the integration and interoperability of the CCAM ecosystem, leading to safer, more efficient, and sustainable transportation systems.

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