ULTIMO

Advancing Sustainable User-centric
Mobility with Automated Vehicles

DELIVERABLE

D4.4 – Vehicles and Infrastructure Services – First version

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Acronyms

ADAS	Advanced Driver Assistance Systems
ADS	Automated Driving Systems
AI	Artificial Intelligence
AM	Automated Mobility
API	Application Protocol Interface
APT	Autonomous Public Transport
ARIMA	AutoRegressive Integrated Moving Average
AV	Automated Vehicle
BM	Bestmile
BMM	Business Modelling Manager
CAM	Cooperative Awareness Messages
CAV	Connected and Automated Vehicles
CB	Consortium Body
CCAM	Cooperative, connected and automated mobility
CERN	European Organization for Nuclear Research
CERTH	Centre for Research and Technology Hellas
C-ITS	Cooperative Intelligent Transport Systems
D7.1	Deliverable 7.1
DC	Demonstration Coordinator
DI	The department of infrastructure (Swiss Canton of Geneva)
DMP	Data Management Plan
DSES	Department of Security and Economy - Traffic Police (Swiss Canton of Geneva)
DTU test track	Technical University of Denmark test track
D2D	Device to device
EAB	External Advisory Board
EC	European Commission
ECSEL	Electronic Components and Systems for European Leadership
ECU	Electronic Control Unit
EM	Exploitation Manager
ETSI	European Telecommunications Standards Institute
EU	European Union
EUCAD	European Conference on Connected and Automated Driving
F2F	Face to face meeting
FEDRO	(Swiss) Federal Roads Office
FM	Fleet Management
FOT	(Swiss) Federal Office of Transport
GDPR	General Data Protection Regulation
GIMS	Geneva International Motor Show
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
HARA	Hazard Analysis and Risk Assessment
HEPA	High-efficiency particulate air
HVAC	Heating, ventilation, and air conditioning
HMI	Human-machine interfaces
IPR	Intellectual Property Rights
IMU	Inertial Measurement Unit
IIoT	Industrial Internet of Things
IoT	Internet of Things
IoV	Internet of Vehicles
IT	Information Technology
ITS	Intelligent transportation system
ITU	International Telecommunications Union
LA	Leading Author
LIDAR	Light Detection And Ranging
LSTM	Long Short-Term Memory
MCS	Mobile crowdsensing
MEM	Monitoring and Evaluation Manager
MEMS	Microelectromechanical system
MIMO	Multiple-input multiple-output
MPC	Model prediction control
MSE	Mean Square Error

MT	MobileThinking
OBU	On board unit
OCT	General Transport Directorate of the Canton of Geneva
ODD	Operational Domain Design
OEDR	Object And Event Detection And Response
OFCOM	(Swiss) Federal Office of Communications
PC	Project Coordinator
PEB	Project Executive Board
PGA	Project General Assembly
PRM	Persons with Reduced Mobility
PSA	Group PSA (PSA Peugeot Citroën)
PTA	Public Transportation Authority
PTO	Public Transportation Operator
PTS	Public Transportation Services
PWE	Programmable Wireless Environment
QoS	Quality of Service
QRM	Quality and Risk Manager
QRMB	Quality and Risk Management Board
RIS	Reconfigurable Intelligent Surfaces
RN	Risk Number
RSU	Road side unit
RUL	Remaining Use of LIFE
SA	Scientific Advisor
SAE Level	Society of Automotive Engineers Level (Vehicle Autonomy Level)
SAN	(Swiss) Cantonal Vehicle Service
SDK	Software Development Kit
SLA	Sales Lentz Autocars
SMB	Site Management Board
SoA	State of the Art
SOC	State of charge
SOFM	Self-organizing feature map
SOTIF	Safety Of The Intended Functionality
SOH	State of Health
SWOT	Strengths, Weaknesses, Opportunities, and Threats.
T7.1	Task 7.1
TM	Technical Manager
TPG	Transport Publics Genevois
UI	User Interface
UITP	Union Internationale des Transports Publics (International Transport Union)
UV	Ultraviolet
UV-C	Ultraviolet C
VRUs	Vulnerable Road Users
V2C	Vehicle to cloud
V2G	Vehicle to grid
V2I	Vehicle to Infrastructure
V2P	Vehicle to pedestrian
V2X	Vehicle to vehicle
V2X	Vehicle to everything
WP	Work Package
WPL	Work Package Leader
WSN	Wireless sensor network

Executive Summary

The following work is part of Work Package 4 for the ULTIMO project. WP4 is focused on the development of the MaaS and LaaS services, along with the passenger and user services. All of the services WP4 intends to develop will take into consideration the co-creative and citizen centric approach WP2 follows. Being aligned with what the passengers and citizens of each city value most, these services aim to enhance the overall urban experience and promote sustainable mobility solutions. In addition, based on the standardized interfaces established in WP3, the developed services will undergo testing and validation in WP5 deployments. By adapting, integrating, and iteratively enhancing services for AV users, especially those with special needs, the goal of this WP is to ensure a seamless and secure user experience. It also aims to maximize the efficiency of LaaS service delivery, enable secure vehicle and infrastructure services, and provide trustworthy ITS management services to support the evolving mobility paradigm.

This deliverable in particular describes the activities related to Task 4.3: Services for Vehicles and Infrastructure. The goal of this deliverable is to provide details regarding the vehicle and infrastructure services in terms of requirements, infrastructure, design and development. This deliverable exclusively covers the technical aspects, including adjustments, requirements, sensors, and infrastructure needed to support various service categories within other tasks of WP4. The interaction between the vehicle and the passenger is specifically addressed in Task 4.1, which aims to deliver the MaaS (Mobility as a Service) offering to different project sites. Finally, this deliverable also includes a detailed description of the majority of the inspiring services that were initially proposed by ULTIMO, in order to pinpoint the innovative and aspiring technologies that will support the services of WP4. A variety of sub-services based on these will be further elaborated during the second year of the project within all tasks of WP4. Lastly, the deliverable presents a preliminary analysis of the communication technologies that can be utilized in the course of the project.

In detail, Chapter 1 includes the introduction to the document and gives an overview of the ULTIMO dream for public transportation, while Chapter 2 gives an overview of the research that was conducted to understand the related work. The next Chapter 3 describes the existing technical facilities, the vehicle and infrastructure services focus, while most of the work is focused on presenting the related services in terms of functional, non-functional, technical and data requirements. Then, Chapters 4 and 5 provide an overview of the current software and hardware infrastructure respectively, while Chapter 6 presents the preliminary work performed regarding the communications network in ULTIMO. Finally, Chapter 7 concludes this report and gives information and recommendations on the next steps towards the next phase of Task 4.3.

1 Introduction

During the past few years, many projects and initiatives were undertaken deploying and testing Automated Vehicles (AVs) for public transportation and logistics. However, in spite of their ambition, all of these projects stayed on the level of elaborated experimentation and never reached the level of a large-scale commercial deployment of transport services. The reasons for this are many, the most important being the lack of economically viable and commercially realistic models, the lack of scalability of the business and operating models, and the lack of user oriented services required for large end-user adoption of the solutions.

The ULTIMO project will create the very first economically feasible and sustainable integration of AVs for MaaS public transportation and LaaS urban goods transportation. ULTIMO aims to deploy in three sites in Europe 15 or more multi-vendor SAE L4 AVs per site. A user centric holistic approach, applied throughout the project, will ensure that all elements in a cross-sector business environment are incorporated to deliver large-scale on-demand, door-to-door, well-accepted, shared, seamless-integrated and economically viable CCAM services. We target the operation without safety driver on-board, in a fully automated and mission management mode with the support of innovative user centric passenger services.

ULTIMO’s innovative transportation models are designed for a long-term sustainable impact on automated transportation in Europe, around the globe and on society. The composition of the consortium ensures the interoperability between multiple stakeholders by making adoption of new technology at minimum costs and maximum safety. The integration of the ongoing experiments of previous AV-demonstrator projects ensures highest possible technical and societal impacts from the very beginning of the project, as well as during the project lifetime and even long after its completion.

1.1 On-demand Mobility

Public transportation is a key element of a region's economic development and the quality of life of its citizens. Governments around the world are defining strategies for the development of efficient public transport based on different criteria of importance to their regions, such as topography, citizens' needs, social and economic barriers, environmental concerns, and historical development. However, new technologies, modes of transport and services are appearing, which seem very promising to the support of regional strategies for the development of public transport.

On-demand transport is a public transport service that only works when a reservation has been recorded and will be a relevant solution where the demand for transport is diffuse and regular transport is inefficient.

On-demand transport differs from other public transport services in that vehicles do not follow a fixed route and do not use a predefined timetable. Unlike taxis, on-demand public transport is usually also not individual. An operator or an automated system takes care of the booking, planning and organization.

It is recognized that the use and integration of on-demand Automated vehicles has the potential to significantly improve services and provide solutions to many of the problems encountered today in the development of sustainable and efficient public transport.

1.1.1 Fully Automated Vehicles

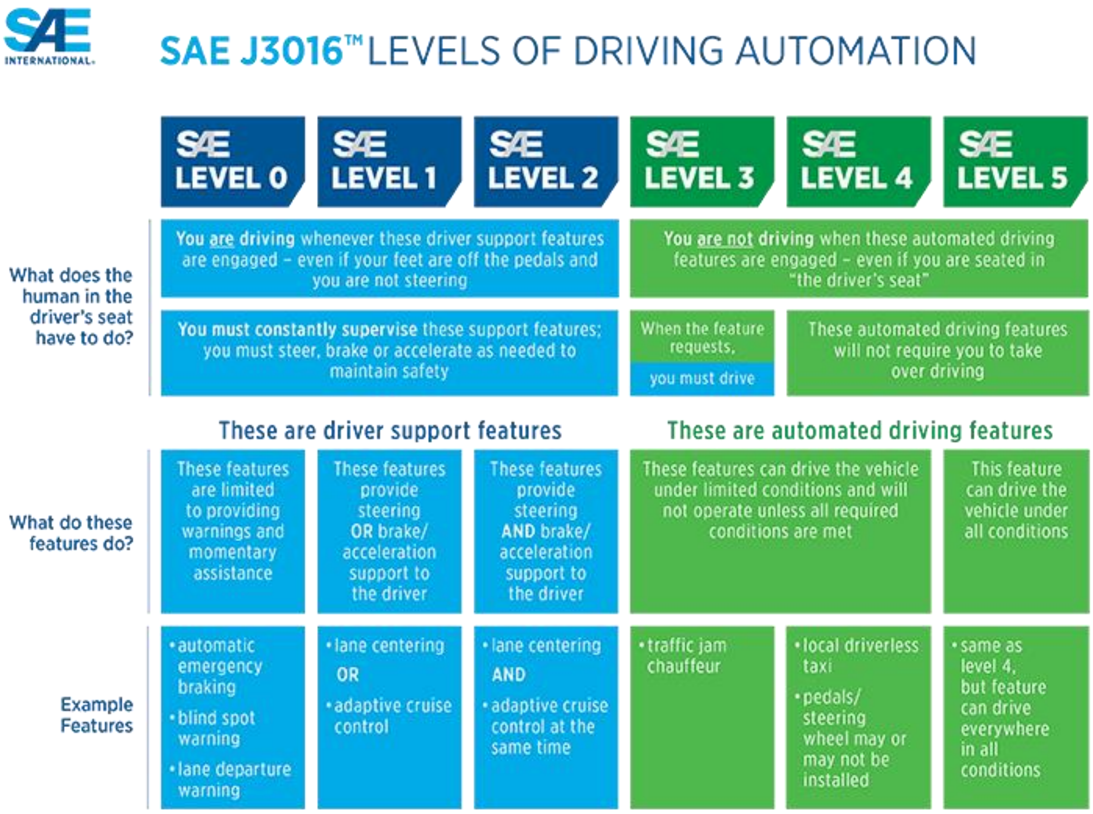
A self-driving car, referred in the ULTIMO project as a **Fully Automated Vehicle** (**AV**), is a vehicle that can sense its environment and moving safely with no human input.

The terms *automated vehicles* and *autonomous vehicles* are often used together. The Regulation 2019/2144 of the European Parliament and of the Council of 27 November 2019 on type-approval requirements for motor vehicles defines "automated vehicle" and "fully automated vehicle" based on their autonomous capacity:

An "automated vehicle" means a motor vehicle designed and constructed to move autonomously for certain periods of time without continuous driver supervision but in respect of which driver intervention is still expected or required

"Fully automated vehicle" means a motor vehicle that has been designed and constructed to move autonomously without any driver supervision

In ULTIMO we operate ***Fully Automated mini and micro shuttles for shared public transportation****.* In relation to the SAE levels, the ULTIMO project will operate SAE Level 4 vehicles.



SAE INTERNATIONAL

SAE J3016™ LEVELS OF DRIVING AUTOMATION

	SAE LEVEL 0	SAE LEVEL 1	SAE LEVEL 2	SAE LEVEL 3	SAE LEVEL 4	SAE LEVEL 5
What does the human in the driver's seat have to do?	You are driving whenever these driver support features are engaged – even if your feet are off the pedals and you are not steering			You are not driving when these automated driving features are engaged – even if you are seated in "the driver's seat"		
	You must constantly supervise these support features; you must steer, brake or accelerate as needed to maintain safety			When the feature requests, you must drive	These automated driving features will not require you to take over driving	
	These are driver support features			These are automated driving features		
What do these features do?	These features are limited to providing warnings and momentary assistance	These features provide steering OR brake/acceleration support to the driver	These features provide steering AND brake/acceleration support to the driver	These features can drive the vehicle under limited conditions and will not operate unless all required conditions are met		This feature can drive the vehicle under all conditions
Example Features	• automatic emergency braking • blind spot warning • lane departure warning	• lane centering OR • adaptive cruise control	• lane centering AND • adaptive cruise control at the same time	• traffic jam chauffeur	• local driverless taxi • pedals/steering wheel may or may not be installed	• same as level 4, but feature can drive everywhere in all conditions

Table 1: SAE Driving Automation levels (©2020 SAE International)

1.2 The ULTIMO dream for public transportation

Our city has a population of 700.000, and the local PTO (Public Transport Operator) deploys 3.000 Km of public transportation services' routes, with 4 backbone tram lines, 8 backbone large bus/trolley lines, and 340 fully automated multi-manufacturer mini and micro-shuttles in an on-demand, door-to-door shared public transport service. The fleet of the 340 automated mini-busses is composed of different vehicle generations and models from different manufacturers, as it was purchased in different batches during the last 12 years (it all started with the first 15 bought by a European project in 2023/24). It is today composed of the first 15 twelve-years old vehicles from manufacturer A, 160 eight-years old vehicles from manufacturer B and 160 two-years old vehicles from manufacturer A, which are the new generation of manufacturer's A vehicles. These last 160 vehicles re-placed the last 70 old, driver based, thermic busses that reached the end of their life after 18 years in operation. The change from driver large busses to automated mini-buses and from fixed line service to on-demand, door-to-door, for the last area of the city, was decided 6 years ago, and was based to the great success of the already deployed AV-based services in the other parts of the city.

The integration of new vehicles in the PTO fleet was done within just a few days, thanks to the now standardised APIs of the automate vehicles' connection with the AV fleet management and orchestration service, that allows a plug-and-operate functionality, but also enables the combination of AVs with all other means of transport, offering a seamless citizen centric journey to the users. Similarly, the now standardized High Definition (HD) maps between the vehicle manufacturers, allowed us to reuse the maps created in the past for the 3.000 Kms of routes of the city, with small adaptations for the new vehicle capabilities. At the same time of the purchase of the last 160 AVs, we also switched to a new AV fleet management and orchestration service, from another provider, which offers more precise trip time estimations, considering also traffic jams in the city and weather conditions (that affect traffic in the city). The replacement was made within just two weeks, thanks to the new standardised interfaces between AV fleet management and PTO MaaS services.

Passengers are now able to reserve, via their mobile phone app, on the fly or with pre-reservation trips from one side of the city to another, using the optimal transport mode available for them, with a combination of different transport modes, and having the automated vehicle arriving next (or almost) to their door entrance and bringing them to their final destination or to a backbone transport connection. All trips are offered with highly reliable and accurate transport and arrival times, based on real time, dynamic route changes of the vehicles, responding to the passenger needs. Many passenger services are available in the AVs via a mobile phone app, adapted to all passengers' needs, from special needs passengers (visually impaired, wheel-chair users, pregnant women, elderly, children), to persons transporting suitcases or a baby-stroller, providing adapted information of their trip (where to get-off, PTO general information, and even infotainment, like city related information and historical facts and anecdotes, related to their current position).

With the full suppression of on-board operators, automated in-vehicle monitoring provides a multitude of passenger services, which were, and are developed with a continuous collaboration and innovation between users and the PTO. An on-board unit identifies locally (that is, in the bus) incidents and events, like aggressions, vandalism, forgot-ten objects, littering, accidents, etc., and raises incident alarms to the PTO back-office. The PTO officer at the back-office evaluates the incident and decides, based on the operator policies, what action to take: dismiss the incident, or stop the vehicle and call one of the intervention teams to go the vehicle and take the required action. The back-office operator, based on the number of incidents and intervention time legal obligations, can deploy any of the 15 intervention teams available in the city, ready to reach within a few minutes any AV. At the back-office, service operators are able, with one set of screens linked to the fleet management, to follow the vehicle status, trip reservations, routes chosen, open and closed road segments (due to works, accidents, etc. thus adapting dynamically the trip routings), while in a second set of screens, the back-office operators can follow the passenger services' incidents and the status and location of the intervention teams. The two systems, although independent, are linked so that the back-office operator can transfer incidents to intervention teams and turn-on, when possible and under the local legal restrictions, video connection to inspect the incident.

The public transport services are operating 24/7 with different active vehicles, de-pending on passenger transport demands. The PTO, being eco-sensible, has defined that the vehicle must have an average occupancy of at least 3 passengers. This of course has implications, especially in off-peak hours, in the transport delays, but it is fully justified for an optimal and eco-responsible operation. Exceptions are made for people with special needs or when the passenger is ready to pay an additional price.

While at peak-hours the full 340 strong fleet of AVs is in service for public transportation, in the off-peak and night hours, due to the reduced transportation needs, part of the fleet is not serving passenger transportation. However, because having a vehicle waiting idly is a waste of resources, the PTO has signed an agreement with Logistics as a Service (LaaS) Service providers. During the off-peak hours the unused vehicles are dynamically chartered by the different LaaS providers to be used for other types of incidental transport of goods or even non-public transportation of passengers. Local shops and enterprises use the service, on demand with dynamic reservation, to offer home delivery of on-line purchases, or B2B delivery of goods from an urban consolidation center to the distribution center (hub, many to one or one to many [7], or even transport their VIP customers directly to their offices or exposition centers. This way they can deliver the goods to their customers in the city, with a delay of just 60 minutes with affordable prices, as the last mile is the most inefficient part of the goods delivery chain. The goods send can include books from local bookshops or libraries, supermarket bags or even documents exchanged between companies or waste. The local shops are even using the service in the early hours (5 o'clock in the morning) for re-provisioning their shops for the day. The so chartered AVs are "returned" to the PTO for public transport at the peak-hours automatically, at the end of the chartered time period.

1.3 Preamble – Vehicle and Infrastructure Services

WP4 is dedicated in the activities related to the AI leveraged Services for ULTIMO ITS/CCAM ecosystem. Specifically, the goal of WP4 is to develop, in an iterative and co-creative manner, the MaaS and LaaS service, along with the passenger and user services, that will be built upon the standardized interfaces that are established and developed in WP3. The outcomes of this WP will undergo testing and validation through deployments in WP5. The main objectives of different tasks of WP4 are:

- To adapt, integrate, and iteratively develop services to support users of AVs.
- To provide MaaS services for passengers to demonstrate seamless and secure user experience.

- To apply LaaS services in a novel way by maximizing efficiency of delivery.
- To enable vehicle and infrastructure services.
- To deliver secure and trustworthy ITS management services to facilitate adherence of the new mobility paradigm.

Deliverable D4.4 is related to Task 4.3, and is the first version report on Vehicles and Infrastructure Services development and adaptation. It provides an overview of the first set of Vehicle and Infrastructure services that are planned and prioritized for development, along with the technologies used for the development, the adaptation and the support of passenger and transport services. Lastly, it describes the software and hardware infrastructure that interacts with vehicles, and gives a general overview of the communication ecosystem in ULTIMO.

2 Related work

Autonomous vehicle transportation systems, which operate without an in-vehicle operator, will bring about a significant improvement in the quality of public transportation services. However, self-driving vehicles require diverse sensor data to support complex decision-making algorithms in swiftly adapting to constantly changing road conditions [1][2], but also passengers' demands. Vehicle and infrastructure services are developed to improve the overall autonomous vehicle travelling experience, while in parallel they aim to enhance the physical and digital security of the vehicles and to ensure the continuous operation and performance of the vehicle.

Connected and Automated Vehicles (CAVs) are becoming a reality, but for them to operate more safely and consistently, the AVs' function and wireless communication technology should be able to share and coordinate information with other vehicles, road users and infrastructure [3]. In the context of the ULTIMO project, several vehicle and infrastructure services will be developed and proposed in order to support a holistic service for travelers commuting with the AVs. The main features of these services are the following:

- Security and trust services focused on detecting and recognizing abnormal events (aggression, littering, bag snatching, etc.), but also enhancing the confidence of non-fully autonomous people.
- Incident analysis and management services that will allow operators to promptly receive real-time notifications and intervene when necessary.
- V2X services allowing for the interaction with non-vulnerable and vulnerable road users through several ways, that will enhance road safety, traffic efficiency, energy savings, and will unlock automated vehicle deployment.
- Predictive services for evaluating the condition of the vehicle(s) and ensuring the optimum performance of the offered services.
- Real-time passenger presence to allow passengers to better plan their journey, but also assist operators in better route optimization and resource allocation.
- Health-related and in-shuttle environment assessment services that help mitigate disease spread (e.g., COVID-19), while also maintaining environmental in-vehicle conditions at optimum levels.

A comprehensive overview of the considerable advancements and developments in the aspects related to the aforementioned services is presented in the following Section 2.1.

2.1 Enabling technologies

Numerous recent studies in the bibliography have explored the development of algorithms and software services akin to those mentioned in the previous section, which aligns with the goals of the ULTIMO project, and particularly the objectives of Task 4.3. For example the concept of in-cabin monitoring to enhance the sense of security and the overall safety when travelling with AVs was mentioned in Mishra et al's work [4], which focuses on designing a resilient in-cabin monitoring system, tailored for safety, security, surveillance, and monitoring within autonomous vehicles, employing suitable Artificial Intelligence (AI) models. Other studies combined audio and image approaches [5][6] to have a better overview of the overall in-vehicle situation and utilize the developed technologies to detect abnormal events. Lastly, there are studies that have explored the concept of facial recognition for passenger identification and enhanced personalization within autonomous vehicles [7][8], contributing to a comprehensive understanding of the potential advancements in in-cabin monitoring and safety measures in the context of AVs.

Health-related and in-shuttle environment assessment services have also been explored in numerous studies, with the COVID-19 pandemic also enabling researchers and organizations to develop solutions that aim to mitigate disease spread between passengers. For instance, Simsek et al. [9] introduce an innovative application that harnesses autonomous vehicles and mobile crowdsensing (MCS) data to improve the early detection of COVID-19. In addition, Goh et al. [10] have developed a real-time cloud-based in-vehicle air quality monitoring system, while Mishra et al. [4] utilize object detection algorithms to oversee the act of lighting cigarette and their investigation encompasses a range of smoking-related objects, such as cigarettes, cigarette lighters, cigarette cases, and e-cigarettes.

Another important area of interest that is being explored in the context of WP4, are incident analysis and management services. Through these services, operators will be able to receive real-time notifications and make quick and informed decisions. In the context of incident resolution, it is crucial that the system can detect any deviations from what is deemed normal operation and accurately map these anomalies for visualization, ensuring effective information communication. An incident can be defined as an occurrence that disrupts the usual state, standing as an outlier within statistical measures. Substantial progress has been made in the realm of outlier detection. Techniques rooted in distance metrics, such as Mahalanobis distances, are employed to distinguish between clean data and outliers. When identifying outliers in multivariate datasets, it is customary to estimate the data's central tendency and spread using robust estimators. Examples of these robust and affine equivariant estimators for location and scatter include the MCD-estimator [11] and the Stahel-Donoho estimator [12].

Furthermore, predictive services for evaluating the condition of the vehicle(s) to better schedule maintenance and/or optimize battery health of autonomous vehicles that rely on batteries, are invaluable for the optimum performance of the vehicles and the overall autonomous mobility service. Towards that goal, Massaro et al. [13] introduced an intelligent Electronic Control Unit (ECU) designed for monitoring bus fleets. This system leverages the Internet of Things (IoT) and artificial intelligence (AI), incorporating an MLP-ANN model to forecast maintenance needs by analyzing driver behavior. Another study from Chen et al. [14] employed Long Short-Term Memory (LSTM) networks in conjunction with empirical mode decomposition to anticipate battery faults. Lastly, as part of the AVENUE H2020 project, a five-week data collection effort was carried out to investigate and analyze patterns and trends in the battery levels of autonomous vehicles (AVs).

Additionally, the concept of V2X will be largely explored in the context of the ULTIMO project. V2X communication is a technology that enables vehicles to communicate with other vehicles (V2V), infrastructure (V2I), pedestrians (V2P), and the cloud (V2C). It allows for the exchange of critical information such as safety warnings, traffic data, and more to improve road safety and traffic efficiency. Within our focus area, [15] conducts a performance evaluation of two primary messaging protocols for V2X communication involving Vulnerable Road Users (VRUs). In the first protocol, sensors in vehicles and roadside units passively detect VRUs and share this data through dedicated messages. The second protocol empowers VRUs to actively transmit messages, alerting nearby road users. Simulation outcomes indicate that the optimal performance results from combining sensor data sharing and active VRU transmissions. However, the concept of V2X with non-connected users must be explored as well, as an important issue to address for V2X communications. The authors in [16] devise a safety strategy for Vulnerable Road Users (VRUs) that encompasses both centralized and decentralized system architectures. Simulation scenarios encompass equipped VRUs and passive VRUs, all set within a 3D multi-sensor environment.

Another important aspect that is being explored as part of WP4 is the development of an anti-jamming service. Anti-jamming refers to techniques and technologies designed to protect wireless communication systems, including V2X, from intentional interference or jamming. Jamming involves the transmission of signals on the same frequency as the target communication system, disrupting or blocking the intended communication. Numerous algorithms have been suggested for dealing with jamming attacks in wireless sensor networks. Noubir and Lin [17] fused error-correction codes with robust interleaving techniques to enhance the chances of decoding corrupted packets, while Xu et al. [18] introduced two tactics, namely "channel surfing" and "spatial retreats," aimed at bolstering resistance to jamming attacks by minimizing interference either in the transmission frequency or physical location.

Finally, in the context of the ULTIMO project, the concept of real-time passenger presence has been explored and will serve as a key element for both operators and passengers, since both can make informed real-time decisions to better plan their routes. For example, in [19] a video and audio-based software was implemented for the detection of passenger onboarding and offboarding.

A more concise and straightforward state-of-the-art analysis was conducted for each individual service and is thoroughly presented in the corresponding subchapters of Chapter 3.

3 Vehicle and Infrastructure Services

This chapter presents the initial ULTIMO Vehicle and Infrastructure Services that will be further developed and evaluated in the pilot sites in the following months. Building on the experience and lessons learned from past and ongoing initiatives, ULTIMO aspires to surpass the accomplishments already achieved or currently targeted in the field. Each service is accompanied by an array of functional and non-functional requirements, in tandem with specified technical and data requirements. Lastly, an account is provided of the existing technical facilities employed within the ambit of the ULTIMO project.

3.1 Existing technical facilities

In the context of the ULTIMO project, various technical facilities are already in place that will enable and will serve as foundational elements for the integration and provision of passenger, vehicle and infrastructure, operator, and management services. The following subsections 3.1.1 and 3.1.2 describe what's already in place per operator site and the existing vehicle services respectively. Some of the info regarding the existing situation in the different pilot sites was extracted from Deliverable "D5.1 Large Scale Demonstration Report" of WP5 [20].

3.1.1 Existing Autonomous Vehicles per operator site

3.1.1.1 TPG – Geneva operator site

TPG currently has 4 Navya Arma shuttles capable of self-driving on 99% of all routes of the estate. They are 100% electric capable of providing on-demand and door-to-door services. The vehicles mentioned were tested in real-life operations that took place in the context of the AVENUE project. Apart from the above functionalities, the Navya autonomous vehicle comes with certain functions which will be integrated in the provision of vehicle and infrastructure services. These features are emphasized with the aim of integrating them into the ongoing service development process. The technical functions are as follows:

Open/close doors button

Manual buttons located within the vehicle that passengers can press, and in addition to that, the doors automatically open at each stop.

Wheelchair ramp button

Manual button inside the vehicle. The button can be used be either the passenger or safety officer (if any) in order to activate the automatic wheelchair ramp. This function is not installed in all Navya autonomous vehicles as a standard. It must be installed on the shuttle by Navya.

Real time visualization of route and stops (service screen)

A screen inside the shuttle showing a map of the route along with the stops. As of now, the screen is also used by the safety officer to restart the vehicle or detect issues during operation. The screen is currently not designed for passengers, but for the safety officer. In the context of the ULTIMO project, since the idea is for the safety driver to be removed from the vehicles, the screen will function as the main interaction point between the travelers and the service.

Speaker system

Speakers placed within the vehicle that facilitate communication from supervision to passengers in emergency situations. In the context of the ULTIMO project, the PTOs may utilize this system for service announcements, safety procedures, or routine communication, particularly once the safety officer is no longer present in the autonomous vehicles.

Emergency call button

A manual button situated beneath the service screen enabling passengers to establish communication with the supervision team. In the context of the ULTIMO project, the idea is for this button to connect travelers directly with the operators' own supervision.

Emergency stop button

A manual button positioned on either side of the central large window that can be used to manually apply the brakes to the vehicle.

Emergency door opening handle

A manual handle located on each side of the doors that if used can force the doors to open.

Emergency Glass breaking hammer

There is a readily accessible hammer inside the vehicle for passengers to use if they become blocked and need to exit through the window of the e-minibus.

Emergency First Aid Kit

A First Aid kit located inside the vehicle which is easily accessible in case of need.

Fire extinguisher

A fire extinguisher that is installed for use in case of any emergency.

Interior camera

A fisheye camera that records the inside of the shuttle and can be used by the operators to assess the situation inside the shuttle.

3.1.1.2 Ruter – Oslo operator site

As of now, the Oslo site operated by Ruter does not offer any AVs for public transport, which will arrive in the coming weeks. The as-is situation is that Ruter will use the type Nio ES8, retrofitted with Mobileye autonomous hardware and software. They are equipped with an additional in-vehicle passenger screen, visualizing how the SDS system acts in the traffic and relates to other objects. Other functions and capabilities, like the ones the NAVYA AV has, are to be decided in the coming months.

3.1.1.3 DB – Herford operator site

Currently, the Herford site operated by DB does not offer any autonomous vehicle services in operation. DB plans to incorporate the same NAVYA vehicles that TPG is currently utilizing, as the intention of the first round of operations is to first familiarize the citizens by demonstrating the capabilities of autonomous driving systems, as the region did not have any previous exposure to autonomous vehicle projects before.

3.1.2 Existing Vehicle services

As of today, the sole existing vehicle services in the project are services that were developed in the context of other EU-funded HORIZON projects as seen in Table 2. These services will be further evolved in the context of the ULTIMO project as new needs and requirements will arise that will require further technical development.

Table 2: Existing Vehicle Services from other EU projects

Service title	Description	Project
Enhance the Sense of Security and Trust	The service "Enhance the sense of security and trust" aims to detect properly, precisely, and automatically various petty crimes and instances of abnormal behavior (bag snatching, indoor fighting, etc.). The service utilizes certain surveillance equipment (based on sensors, cameras, and algorithms) that were installed in the vehicles. The real-life tests during the AVENUE project helped to further assess the impact of the proposed solution and to test if the service can solve the main technical issues and the main challenges and instances that could arise due to the drivers' absence.	AVENUE
Automated Passenger Presence	The "Automated Passenger Presence" service aims to assist transport operators to better schedule their itineraries according to the vehicles' occupancy levels and the exact number of the in-vehicle passengers. In addition, the same information regarding the availability and the free space will be shared with the prospective passengers, thus enhancing their travelling experience. The service will continuously provide reports regarding the vehicle occupancy and the passenger capacity.	AVENUE
Follow my Kid/Grandparent	The goal of the "Follow my Kid/Grandparents" service is two-fold. The first is to enhance the confidence of non-fully autonomous people to travel with public transport on their own, and the second is to allow parents and caretakers to monitor their beloved member during their trip, and allow the designated "guardians" to receive in-app notifications.	AVENUE
Shuttle Environment Assessment	The service automatically and accurately maintains the in-vehicle environmental conditions at the minimum acceptable and satisfactory levels, thus handling in a timely and robust manner any possible instance (CO_2 exposure, a passenger lights a cigarette, high or low temperature, etc.) that the driver used to handle. Through system alerts, notifications, and instructions, and by utilizing certain environmental and smoke sensors, the service will preserve a comfortable environment for most of the passengers.	AVENUE

Smart Feedback System	This service aims at allowing travelers to give their feedback about liking/disliking the service experience as easy as possible. Since the safety driver will no longer be present to support and assist, knowing whether the passengers are satisfied or disappointed can be even more important. This will be done by instructing the travelers to give a hand gesture to one of the cameras inside the shuttle. This will allow the passengers to effortlessly say “I like” or “I don’t like” the experience with a thumbs up or a thumbs down.	AVENUE
Camera Attack Detection	This service aims to detect anomalies in external vehicle camera streaming and to alert timely the site operators by combining deep learning techniques (Recurrent Neural Networks & Convolution operations) for normal operation estimation and similarity techniques (Mean Squared Error and Structural Similarity Index) for comparison between estimated and actual frame.	NIOVE

3.2 Provisional ULTIMO Vehicle and Infrastructure Services

In the context of the ULTIMO project and, more specifically, as outlined in the Grant Agreement [22], several services have been identified for further development. These services stand to benefit a range of stakeholders, including passengers, transport operators, research institutes, and academia, among others. The services were divided into five main categories (some may be on more than one category): a) Passenger services, b) Operator services, c) Intervention services, d) Vehicle services and e) Management services. The allocation of services into these categories aligns with a comprehensive approach, catering to a diverse array of challenges and requisites. It enables a well-rounded and targeted deployment of solutions, addressing multifaceted aspects of operational, technical, and passenger-centric dimensions.

It should be mentioned that the categorization of each service is not exclusive to a certain category, as for a service to work properly, certain adjustments or additions (in terms of hardware and/or software requirements) need to take place inside the vehicles and the overall infrastructure. Sections 3.5 to 3.17 only present the technical implementation that needs to take place inside or outside the vehicles, and does not include information regarding the passenger interaction with the different services. How these services will be integrated in the overall MaaS offerings and how the interaction between passenger and vehicle will take place, it will be addressed in Task 4.1 and the respective deliverables of that task. Lastly, as already mentioned in the Executive Summary, this deliverable provides a comprehensive account of most of the inspiring services originally suggested by ULTIMO. This is done to identify the cutting-edge and aspiring technologies that will support the services in WP4. Throughout the second year of the project, various sub-services built upon these ideas will be developed across all tasks in WP4.

Each individual service will undergo a comprehensive analysis to assess its current state of maturity and developmental status. Detailed descriptions of the services will be presented in Sections 3.5 to 3.17 . However, a concise overview of each service is provided in the accompanying Table 3 below:

Table 3: Overview of IoV Services from the Grant Agreement

Service Title	Service Description
Augmented security and trust	Enhance security in AVs, addressing passenger behaviour (vandalism, anxiety, forgotten items, and passenger security) and safety concerns arising from driver absence and potential threats.
Follow my kid/grandmother/father	Ensure the safety of non-autonomous individuals (e.g., children, elderly) by enabling family members to monitor their well-being during public transit.
Shuttle environment assessment	Maintain favourable interior conditions in the vehicle, discouraging harmful behaviours, regulating temperature, and monitoring air quality.
Automated passenger presence	Accurately count passengers within AVs, prevent overcrowding, and provide notifications or instructions to maintain optimal occupancy.
Smart feedback system	Gather quick and effortless passenger feedback to gauge satisfaction with services and transportation.
Mitigation of Disease Spread	Improve public health by implementing measures to mitigate the spread of diseases, prioritizing health in public transportation.
V2X with connected (vulnerable) road users	Enhance CAV perception of vulnerable road users and alert them about potential dangers.
V2X with non-connected (vulnerable) road users	Improve CAV perception at critical locations through infrastructure-installed sensors, enhancing situational awareness.
Predictive Maintenance	Optimize AV maintenance to ensure optimal operational conditions, enhancing vehicle longevity.
Optimizing Battery Health	Enhance AV performance by optimizing power battery parameters, improving overall efficiency.
Manage the incident resolution	Empower site operators to effectively manage intervention teams during abnormal events or accidents, ensuring quick resolution.
Anti-jamming defence mechanism	Implement countermeasures to prevent system disruptions, ensuring continuous vehicle operability.
Anticipate and mitigate the security incidents	Provide intelligence for forecasting abnormal event peaks and placing intervention teams as a preventive measure.
Manage the incident response interventions	Equip intervention teams with necessary information to address emerging situations promptly.
Ensure public health	Notify intervention teams in real time to address violations of public health measures promptly.
Manage accidents	Provide intervention teams with essential information for effectively managing accidents on the road.

3.3 ULTIMO evolution

In the conventional landscape of public transportation services, the bus driver or in-vehicle operator assumes a multifaceted role, encompassing diverse responsibilities such as furnishing passenger information, overseeing passenger safety, managing incidents, and monitoring vehicle maintenance status. The exclusion of the in-vehicle operator necessitates the provision of an alternative means to continue rendering these essential services to both passengers and Public Transport Operators (PTOs), if not more.

In the context of the ULTIMO project, a preliminary array of services has been identified to serve as replacements for the current offerings by the in-vehicle operator. The scope of the identified services encompasses the detection of aggressive behavior, littering, vandalism, health-related concerns, infotainment provisions, management of in-vehicle ambiance including temperature and odor, monitoring of tire pressure, and more. ULTIMO’s endeavor also encompasses the development and implementation of incident anticipation and mitigation services by enabling the intervention teams across all project sites to intervene when necessary. Capitalizing on the accrued experience of PTOs, this existing knowledge will be seamlessly integrated into the management of AV-related incidents within the ULTIMO project.

Drawing from analogous EU-funded initiatives like AVENUE (Figure 1), SHOW, NIOVE among others, ULTIMO will leverage the insights acquired to amplify the existing solutions. The aim is to substantiate the efficacy of the evolved systems and services through large-scale deployments of multi-vendor AV fleets. This endeavor necessitates the establishment of uniform systems applicable to all multi-vendor vehicles. In this context, the seamless transfer of each installation between different vehicles is a paramount consideration.

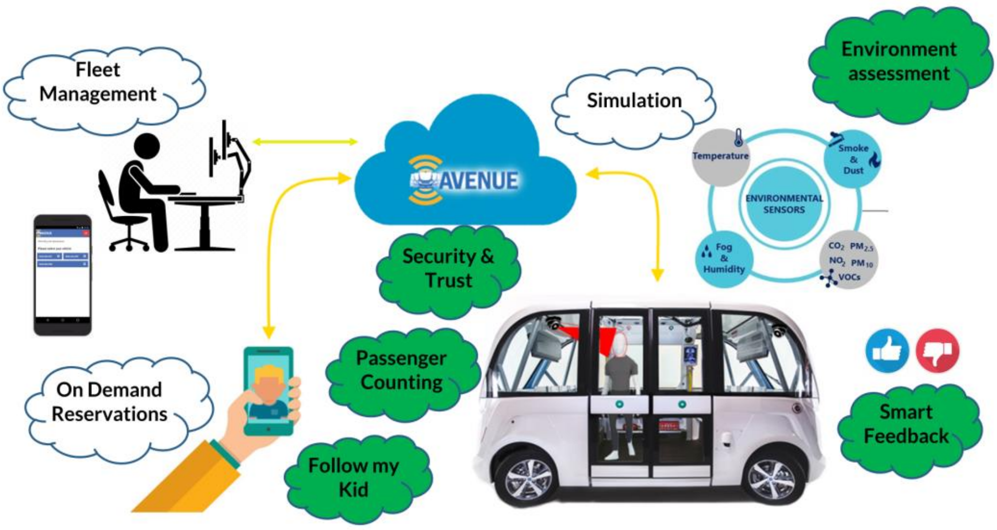


Figure 1: AVENUE In-Vehicle Services Paradigm

3.4 Vehicle and Infrastructure Services focus

As outlined in the Grant Agreement of the project, the objective of Task 4.3 is to enable vehicle and infrastructure services, allowing connection with non-connected users, ensuring physical security, and enhancing operational performance of the vehicle(s) [22]. Additionally, the aim is to maximize the utilization of pre-existing technologies and expertise held by the project collaborators, which can be readily customized and incorporated into the ULTIMO framework. Hence, we will place greater emphasis on services that not only cater to users' needs but also demand minimal initial adjustments and integration efforts. This strategy aims to facilitate their swift incorporation into the demonstrator phase.

To achieve these goals within the forthcoming 12-16 months, Task 4.3 will undertake two concurrent development phases. The first phase will entail the expansion of the AVENUE services. However, in parallel we will embark on developing provisional services tailored to the distinct demands of each operator. The rationale behind these parallel phases lies in maximizing efficiency and effectiveness, optimizing the project's progress, and capitalizing on synergy. This approach is substantiated by the following factors, as explained below.

Reusing same technology:

- **Efficiency**: Utilizing pre-existing technologies fosters a streamlined development process, saving time and resources.
- **Familiarity**: Collaborator expertise with these technologies ensures smoother implementation and integration.
- **Cost-Efficiency**: Building upon existing solutions minimizes investment in new technology development.
- **Interoperability**: Compatibility with already established systems facilitates seamless integration across various services and modules.

Development of new services:

- **Customization**: Designing and developing services tailored to operators' and passengers' unique needs and requirements ensures optimal alignment with operational needs.
- **Enhanced User Experience**: New services aim to elevate passenger satisfaction, offering improved onboard experiences.
- **Enhanced Security, Communication and Resilience**: Incorporating the V2X and anti-jamming services, can lead to better communication between AVs and other road users, promoting safer interactions, while the anti-jamming service safeguards against disruptions, ensuring continuous vehicle operability even in adverse conditions.
- **Operational Efficiency**: Services like "Predictive Maintenance" and "Optimizing Battery Health" address vehicle performance, optimizing maintenance and energy utilization.
- **Data-Driven Insights**: Incident resolution services can yield insights into optimizing response procedures and improving overall incident management strategies.

The dual approach of reusing existing technologies while tailoring new services is pivotal in efficiently advancing the ULTIMO project and realizing its multifaceted objectives.

Furthermore, it should be mentioned that the prioritization of the development phases regarding the services and the different requirements defined for each service in the next sections, was also based on the requirements defined in WP2. From the analysis done in WP2, it can be deducted that services tailored to enhance the overall security and safety feeling when travelling with an AV is of high importance and will be given priority in terms of development. Simultaneously, efforts will be directed towards optimizing communication, improving elements of the infrastructure, and enhancing back-office operations to create a holistic and seamless AV experience.

Finally, the partners of WP2 have carried out an extensive requirements analysis in their respective deliverable "D2.1 Passenger and PTO requirements, needs, and use cases - First version" [23], by also matching these requirements to the vehicle capabilities in terms of hardware, software and other specifications. The process of determining which vehicle capabilities are essential to meet each of the specified requirements, also assists in identifying the requirements of the vehicle and infrastructure services that will be developed. However, as mentioned in D2.1 [23], the capabilities presented in that deliverable are not tailored exclusively to vehicles or pilots, and once the pilot configurations, intended use cases, and the selection of vehicles for each pilot have been finalized, it will become feasible to pinpoint the capabilities that are truly accessible. This will, in turn, allow the development teams of WP4 to determine which requirements can be actually met when developing and testing the services.

3.5 Service: Augmented Security & Trust

3.5.1 Concept of service

The "Augmented Security and Trust" service will allow for petty crimes detection inside the autonomous shuttle (e.g., vandalism, passengers fighting and/or falling down, bag snatching events, etc.) as a way of offering enhanced security and trust among the involved parties. The proposed module provides real-time feed and detection of petty crimes, allowing for immediate notifications to the operator for undertaking necessary actions/instructions, if needed. Necessary actions will be taken, based on real-time notifications and video footage of the incident if needed. This service is categorized as a "Passenger Service".

Additional advantages that can be derived from the "Augmented Security and Trust" service include:

- Real-time, continuous and accurate monitoring of the in-cabin environment.
- Real-time, continuous and accurate detection of any petty crime that may occur inside the shuttle for the entirety of its route.
- Effective use of state-of-the-art equipment and technologies for detecting every event that occurs inside the autonomous vehicle.
- Facilitation of enhanced security during transportation, thus leading to trustworthy commuting in public transportation.

3.5.1.1 Use Case

Use Case: Facilitation of Augmented Security and Trust for Public Transportation.

Actors:

- *Public Transportation Authority:* The organization responsible for managing and continuously monitoring the in-cabin environment.
- *Passengers:* People who use public transportation services.

Scenario: The Public Transportation Authority implements the "Augmented Security and Trust" service by equipping their autonomous buses with on-board cameras and audio devices (microphones) and implementing the provided real-time abnormal event detection framework. The Public Transportation Authority will be able to access the provided video footage of the incident and/or will be notified regarding the occurrence of an abnormal event inside the shuttle through a dashboard, enabling them to make informed decisions and take actions if necessary. The Passengers will be notified from the Public Transportation Authority if any changes must be made (e.g., stop the bus).

By implementing the "Augmented Security and Trust" service, the Public Transportation Authority can provide a safer and passenger-friendly public transportation experience while optimizing their operations based on real-time data.

3.5.2 User Story

As a passenger, I wish to feel secure any time I use the autonomous mini-bus (especially in the absence of the driver).

3.5.3 Description of Service

The purpose of this service is to offer a solution for both the absence of a bus driver inside the shuttle and the increased threat resulting from terrorist attacks across many European cities. For this purpose and due to the suppression of the driver, in this service, the automatic, timely, accurate and robust detection of various types of petty crimes is presented. By employing cameras for surveillance along with smart AI-based software in the shuttle, the actual security level will be upgraded, while still protecting the passengers' privacy from the acquired camera data. More specifically, the onboard unit (OBU) equipped with the appropriate sensors is specifically designed for the identification of a variety of abnormal behaviors, including bag snatching, unaccompanied luggage, falling down, as well as many abnormal audio events like shots, explosions and so forth. Following the event detection, the OBU will push a notification to the supervision dashboard, where the site manager or the intervention team will connect to the vehicle's camera and visually confirm the occurrence of an abnormal event inside the shuttle. This way, the authorities and/or the passengers of the vehicle can be properly notified and intervene accordingly.

3.5.4 Stakeholders

The main stakeholders involved in the "Augmented Security and Trust" service can be classified into three distinct categories, including **operators**, **security supervisors**, and **passengers**. More specifically, as **operator** is regarded every organization that will be responsible for implementing the proposed abnormal event detection algorithm inside the autonomous vehicle during transportation, while a **security supervisor** is the actor employed by the operator that will be responsible for continuously monitoring video feed from the in-cabin environment. On the other hand, **passengers** are considered all the commuters that will be using the autonomous vehicle for their transportation. Additional stakeholders may also include **data analysts** and **software developers** responsible for deriving insights and managing the detection framework, respectively, as well as **local government agencies**, **vehicle manufacturers**, **vehicle maintenance teams** and **technology providers** that collaborate for the continuous improvement of the provided detection framework and dashboard.

3.5.5 State of the art analysis

There are several similar approaches proposed in the most recent bibliography regarding the detection of abnormal events inside autonomous vehicles (AVs) in order to establish a sense of security and trust inside the shuttle despite the absence of the driver. In this context, Nandwana and Hasan proposed an acoustic event recognition framework for smart cars for detecting abnormal audio events on the road [5]. On the other hand, Mishra et. al. developed a robust in-cabin monitoring system specifically targeted for safety, security, surveillance and monitoring in AVs using appropriate Artificial Intelligence (AI)-based models [4]. Finally, some of the most relevant studies include those by Tsiktsiris et. al. where they used surveillance footage from cameras [21] and a combination of image and audio-based approaches [6], supported by novel AI algorithms, to identify abnormal passenger behavior. Finally, this service was designed and implemented under the name "Enhance the sense of security and trust" for the scope of the AVENUE project, and therefore is considered for further improvement and development in the ULTIMO ecosystem.

3.5.6 Functional Requirements

In this section, the functional requirements of the "Augmented Security and Trust" service are presented in detail in the following Table 4.

Table 4: List of functional requirements for the "Augmented Security and Trust" service.

Req_Id	Description
Req_01_001	The vehicle shall be able to detect abnormal events occurring inside the shuttle.
Req_01_002	The operator or the security supervisor shall be notified upon detection of an abnormal event.
Req_01_003	The operator or the security supervisor shall take decisions regarding the course of the trip (stop the vehicle or notify the commuters).
Req_01_004	The commuter shall receive appropriate notifications and/or instructions to implement actions accordingly, in case of an abnormal event.
Req_01_005	The vehicle shall receive appropriate notifications and/or instructions to implement actions accordingly, in case of an abnormal event.
Req_01_006	The vehicle shall be able to track luggage for the entirety of the route.
Req_01_007	The vehicle shall be able to identify luggage that have been unmoved from their designated position for a prolonged period of time.
Req_01_008	The security operator shall receive a notification in case of a detected luggage that has been unmoved for a prolonged period of time.
Req_01_009	The security operator shall monitor the captured clips of the unaccompanied luggage and evaluate the criticality of the situation.
Req_01_010	In case of a critical situation for an unaccompanied luggage, the security operator shall intervene accordingly.
Req_01_011	The vehicle shall be able to detect a bag snatching scenario and notify the operator accordingly.
Req_01_012	In case of a bag snatch detection scenario, the operator shall decide to stop the

Req_Id	Description
	vehicle or notify the commuters via the radio system.
Req_01_013	The vehicle shall be able to identify a commuter that is committing vandalism inside the shuttle and notify the operator accordingly.
Req_01_014	In case of a vandalism detection scenario, the operator shall warn the commuter responsible through the radio system or shall request the security personnel to intervene by stopping the vehicle.
Req_01_015	The vehicle shall be able to identify if any commuter is fighting inside the shuttle and notify the operator accordingly.
Req_01_016	In case of a fighting scenario, the operator shall decide to provide a verbal warning to the commuter(s) via the radio system or stop the vehicle.

3.5.7 Non-Functional Requirements

The following non-functional requirements are proposed for ensuring the smooth, effective and compliant to existing security guidelines operation of the proposed “Augmented Security and Trust” service. Considering that the aforementioned service is still under development, main non-functional requirements include:

- **Responsiveness:** The system shall provide real-time video feed from the in-cabin environment and instant notifications in case of an abnormal event detection.
- **Scalability:** The service should scale seamlessly to accommodate an increasing number of passengers, vehicles, and routes as the transportation network expands.
- **Reliability:** The system should aim for high availability, with minimal downtime, especially during peak commuting hours. Redundancy mechanisms should be in place for critical components to ensure continuous operations, even in case of a hardware of software malfunction.
- **Privacy:** Passengers’ data should be anonymized to protect individual privacy while still providing aggregated occupancy information. The service must adhere to data privacy regulations (GDPR) and maintain compliance with industry-specific standards.
- **Data Reliability:** The system must provide continuous and real-time data while also protecting the passengers’ privacy from the acquired camera feed.
- **Latency:** The system should provide data with minimal latency so as to offer real-time notifications regarding the state of the in-cabin environment.
- **Regulatory Compliance:** The system should comply with industry standards and regulatory requirements related to managing data containing passengers’ private information.
- **User-Friendly User Interface (UI):** The provided UI should be accessible to and easy to use by all transportation authorities and operators that will manage the detection framework.

3.5.8 Technical Requirements

For integrating the “Augmented Security and Trust” service into the ULTIMO ecosystem as seamlessly as possible, a collection of technical requirements classified as hardware requirements (Table 5), software requirements (Table 6) and interface requirements (Table 7) is provided.

Table 5: List of hardware requirements for the “Augmented Security and Trust“ service.

Technical Req_Id	Hardware Requirements	Definition
TReq_01_001	Optical cameras.	High quality optical cameras capable of capturing real-time

Technical Req_Id	Hardware Requirements	Definition
		feed from the in-cabin environment, thus allowing for immediate detection of abnormal events.
TReq_01_002	Depth cameras.	High quality depth cameras that are used as a way of inferring the distance of the passengers from any other object inside the AV that is present in the scene.
TReq_01_003	Acoustic sensors.	High quality acoustic sensors that will allow for continuously monitoring additional audio feed from inside the shuttle, making the detection task easier and more efficient.
TReq_01_004	Vehicle integration kits.	Necessary equipment for the seamless integration of the cameras and the sensors into the public transport shuttles.
TReq_01_005	Data Transmission equipment.	5G modems and/ or antennas, Wi-Fi routers, etc. for real-time data transmission to the ULTIMO DMP.
TReq_01_006	Redundancy mechanisms.	Backup cameras and sensors, as well as failover data transmission equipment to ensure system reliability.

Table 6: List of software requirements for the “Augmented Security and Trust“ service.

Technical Req_Id	Software Requirements	Definition
TReq_01_007	Data processing software.	Software for efficient collection, processing and management of the in-vehicle data.
TReq_01_008	User Interfaces.	User friendly software interface for commuters, operators and local authorities, to access real-time event detection and receive immediate notifications regarding an incident.
TReq_01_009	Web Service/Dashboard.	Development of a web service or a dashboard for operators and security supervisors to check the in-vehicle status and receive immediate alerts in case of an abnormal event being detected.
TReq_01_010	Data analytics tools.	Data analytics software for transportation planners and analysts to derive insights from passenger data and optimize routes and schedules.
TReq_01_011	Integration APIs.	APIs for seamless integration with third-party systems, such as transportation management software and emergency services.
TReq_01_012	Remote monitoring software.	Software for remote monitoring of the system performance, including alerts and notifications for detected abnormal events inside the shuttle.
TReq_01_013	Data Security software.	Security software to protect passenger data and ensure compliance with privacy regulations, including encryption and access controls.

Table 7: List of interface requirements for the “Augmented Security and Trust“ service.

Technical Req_Id	Interface Requirements	Definition
TReq_01_014	User Interfaces.	User-friendly interfaces to interact with the system, including web-based dashboards and operator consoles.
TReq_01_015	API Documentation.	Comprehensive documentation for APIs integration to facilitate third-party system integration.
TReq_01_016	Accessibility Features.	Incorporation of accessibility features in user interfaces to ensure compliance with accessibility standards and regulations.

Technical Req_Id	Interface Requirements	Definition
TReq_01_017	Training Materials.	Creation of training materials for operators, maintenance staff, and system administrators to effectively use and maintain the system.
TReq_01_018	Reporting Interfaces.	Interfaces for generating and accessing reports and analytics, allowing operators and security supervisors to make informed decisions.
TReq_01_019	System Status Alerts.	Real-time alerts and notifications interfaces to inform transportation authorities and operators of in-vehicle events, system status, data transmission issues, and hardware failures.

3.5.9 Data Requirements

Data requirements are imperative for the proper functioning of the proposed "Augmented Security and trust" service by enabling accurate abnormal event and petty crimes detection and data analysis, while simultaneously addressing privacy and compliance consideration. The complete list of the proposed data requirements is presented in detail in the following Table 8.

Table 8: List of data requirements for the "Augmented Security and Trust" service.

Data Req_Id	Data Requirements	Definition
DReq_01_001	Passenger Data.	Raw data collected by in-vehicle cameras and sensors, including timestamps and detection of passengers present inside the AVs.
DReq_01_002	Real-time Abnormal Events Detection.	Real-time calculations for detecting any abnormal event (e.g., passengers fighting) that may have occurred inside the vehicle.
DReq_01_003	Real-time Petty Crimes Detection.	Real-time calculations for detecting any petty crime (e.g., bag snatching, vandalism) that may have occurred inside the vehicle.
DReq_01_004	Route and Scheduling.	Information on routes, schedules and stops, including geospatial data, to allow operators and security supervisors to know of the vehicle's route in case it needs to be stopped.
DReq_01_005	System Configuration.	Configuration settings for cameras and sensors, data processing and user interfaces.
DReq_01_006	Geolocation.	Geographic information, including maps, GPS coordinates, and geofencing data to determine vehicle locations.
DReq_01_007	Security Logs.	Logs of security-related activities, including access attempts, authentication and data encryption status.
DReq_01_008	Emergency Data.	Data related to emergency situations, such as emergency stops or requests for assistance from passengers.
DReq_01_009	Notifications.	Records of notifications sent to operators and security supervisors, such as real-time alerts.
DReq_01_010	System Performance Metrics.	Metrics related to system performance, including response times, server load and data transmission efficiency.
DReq_01_011	Accessibility Data.	Data related to the accessibility of user interfaces and services, including compliance with accessibility standards.
DReq_01_012	Data Backups.	Copies of data backups, including timestamps and locations of backup files.

Data Req_Id	Data Requirements	Definition
DReq_01_013	Retention Policies.	Policies specifying how long different types of data are retained and when they are purged.

3.6 Service: Follow My Kid/Grandmother/father

3.6.1 Concept of service

The "Follow My Kid/Grandmother/father" service is categorized as "Passenger Service" and is proposed as a platform that will allow for identifying commuters that board the autonomous vehicle, as well as continuously detecting in real time if that commuter is still inside the shuttle. The prospective passengers may enroll to the service using photos of their facial characteristics. The proposed service provides real-time facial recognition and detection of enrolled commuter, thus allowing their caretakers or family members to "follow them" on their route. The purpose of this proposed service is to offer an additional level of security for disabled people or minors by letting their close ones continuously tracking them while they are onboard.

Additional advantages that can be derived from the "Follow My Kid/Grandmother/father" service include:

- Real-time, continuous and accurate facial recognition of every commuter that boards the autonomous vehicle.
- Real-time, continuous and accurate detection of every commuter that boards a specific vehicle.
- Effective use of state-of-the-art equipment and technologies for recognizing and detecting all the commuters that enter the shuttle.
- Facilitation of enhanced security during transportation, thus leading to trustworthy commuting in public transportation, even in case of disabled people, elderly, as well as minors.

3.6.1.1 Use Case

Use Case: Facial Recognition and Real-time Detection of Passengers for Public Transportation

Actors:

- *Public Transportation Authority:* The organization responsible for managing and continuously monitoring the in-cabin environment.
- *Caretakers/Family Members:* Close family and nursing staff that wish to check if the commuter has boarded a specific vehicle.
- *Passengers:* Commuters who use public transportation services.

Scenario: The Public Transportation Authority implements the "Follow My Kid/Grandmother/father" service by equipping their buses and trains with on-board cameras and implementing the provided real-time and continuous facial recognition and detection framework. The Caretakers/Family Members will be able to know if the commuter has boarded a specific autonomous vehicle for the entire time there are in it. The passengers will feel an additional sense of security knowing that someone from their close environment tracks them.

By implementing the “Follow My Kid/Grandmother/father” service, the Public Transportation Authority can provide a safer and passenger-friendly public transportation experience for non-fully autonomous people, while also optimizing their operations based on real-time data.

3.6.2 User Story

As a user, I would like to see that my relative/friend is safe.

As a user, I would like to feel safe when travelling with the autonomous vehicles.

3.6.3 Description of Service

The purpose of this service is to increase the autonomy of non-fully autonomous people, such as kids, grandparents, disabled people, etc. Through this service, the caretakers and/or the family members will be assured of the beloveds’ safety during their transportation around the city. On the other hand, will also help these more vulnerable passengers gain confidence in using public transportation by knowing that their family “follows them”. The goal of this service is to act as a fully-fledged solution that will allow the designated caretakers to follow the autonomous public transportation (APT) journeys of non-fully autonomous family members or patients simply by using a dashboard or a mobile app to check the trip’s route, receive notifications and add people to their “guarded” list as well.

3.6.4 Stakeholders

The main stakeholders involved in the “Follow my Kid/Grandmother/father” service can be classified into three distinct categories, including **caretakers**, **family members**, and **passengers**. More specifically, as **caretaker** is regarded every doctor/nursing staff that has the specific commuter as a patient, while **family members** are the family of that commuter. On the other hand, **passengers** are considered all the commuters that will be using the autonomous vehicle for their transportation. Additional stakeholders may also include **operators**, being every organization that will be responsible for implementing the proposed facial recognition and passenger detection algorithm inside the autonomous vehicle during transportation. Other categories of stakeholders include **data analysts** and **software developers** responsible for deriving insights and managing the detection framework, respectively, as well as **local government agencies**, **vehicle manufacturers**, **vehicle maintenance teams** and **technology providers** that collaborate for the continuous improvement of the provided detection framework and dashboard.

3.6.5 State of the art analysis

In the state-of-the-art there are a variety of approaches that could be taken into consideration for the development of the “Follow My Kid/Grandmother/father” service. For this specific service, the main target is to recognize the facial characteristics of each passenger so that the vehicle’s system can effectively track them for the entirety of its route. For this purpose, Tsiktsiris et. al. proposed an image-based service, supported by AI-based algorithms, to increase autonomy of non-fully autonomous people by identifying passengers via facial characteristics while also efficiently ignoring facial masks [7]. Furthermore, Monteiro proposed the development of a face detection and recognition approach for in-vehicle passengers for facial and facial key point detection, face recognition, as well as and drowsiness monitoring [8] by using thermal images taken from inside the vehicle. Finally, this service was initially designed and implemented as part of the AVENUE project, and therefore will act as the basis for further improvements in the context of the ULTIMO project.

3.6.6 Functional Requirements

In this section, the functional requirements for the "follow my kid/grandmother/father" scenario are presented in detail in Table 9.

Table 9: List of functional requirements for the "Follow My Kid/Grandmother/father" scenario.

Req_Id	Description
Req_02_001	The vehicle shall be able to receive colour depth images of the commuters.
Req_02_002	The vehicle shall feed the given colour depth images of the commuter to the system's video analytics algorithms.
Req_02_003	The vehicle's system shall be able to identify the commuter based on the provided colour depth image.
Req_02_004	The vehicle's system shall be able to determine the vehicle in which the commuter boarded.
Req_02_005	The caretakers/family members of the commuter shall be able to monitor if they are inside the vehicle via a designated dashboard or a mobile app.
Req_02_006	The caretakers/family members shall be able to know the designated route of the trip in which their patient/family member travels by knowing the ID of the vehicle.
Req_02_007	The caretakers/family members shall receive notifications regarding their patients/family members via the mobile app.
Req_02_008	The vehicle's system shall provide the caretakers/family member with a guarded list for each commuter.
Req_02_009	Each caretaker/family member shall be able to add people to the commuter's guarded list.

3.6.7 Non-Functional requirements

The following non-functional requirements are proposed for ensuring the smooth, effective and compliant to existing security guidelines operation of the proposed "Follow my Kid/Grandmother/father" service. Considering that the aforementioned service is still under development, main non-functional requirements include:

- **Responsiveness:** The system shall provide real-time facial recognition and passenger detection from the in-cabin environment.
- **Scalability:** The service should scale seamlessly to accommodate an increasing number of passengers and vehicles as the transportation network expands.
- **Reliability:** The system should aim for high availability, with minimal downtime, especially during peak commuting hours. Redundancy mechanisms should be in place for critical components to ensure continuous operations, even in case of a hardware of software malfunction.
- **Privacy:** Passengers' data should be anonymized to protect individual privacy while still providing aggregated occupancy information. The service must adhere to data privacy regulations (GDPR) and maintain compliance with industry-specific standards.

- **Data Reliability:** The system must provide continuous and real-time data while also protecting the passengers' privacy from the acquired camera feed.
- **Latency:** The system should provide data with minimal latency so as to offer real-time facial recognition and passenger detection inside the vehicle.
- **Regulatory Compliance:** The system should comply with industry standards and regulatory requirements related to managing data containing passengers' private information.
- **User-Friendly User Interface (UI):** The provided UI should be accessible to and easy to use by all caretakers/family members through which they will be able to monitor if their beloved ones are boarded on the vehicle.

3.6.8 Technical Requirements

For integrating the "Augmented Security and Trust" service into the ULTIMO ecosystem as seamlessly as possible, a collection of technical requirements classified as hardware requirements (Table 10), software requirements (Table 11) and interface requirements (Table 12) is provided.

Table 10: List of hardware requirements for the "Follow My Kid/Grandmother/father" service.

Technical Req_Id	Hardware Requirements	Definition
TReq_02_001	Optical cameras.	High quality optical cameras capable of capturing real-time feed from the in-cabin environment, thus allowing for immediate facial recognition and detection of passengers.
TReq_02_002	Vehicle integration kits.	Necessary equipment for the seamless integration of the cameras and the sensors into the public transport shuttles.
TReq_02_003	Data Transmission equipment.	5G modems and/ or antennas, Wi-Fi routers, etc. for real-time data transmission to the ULTIMO DMP.
TReq_02_004	Redundancy mechanisms.	Backup cameras and sensors, as well as failover data transmission equipment to ensure system reliability.

Table 11: List of software requirements for the "Follow My Kid/Grandmother/father" service.

Technical Req_Id	Software Requirements	Definition
TReq_02_005	Data processing software.	Software for efficient collection, processing and management of the in-vehicle data.
TReq_02_006	User Interfaces.	User friendly software interface for caretakers/family to access real-time detection of the commuter in case they are inside the AV.
TReq_02_007	Web Service/Dashboard.	Development of a web service/dashboard or a mobile app for caretakers and family members to check if the commuter is inside the shuttle. The app will also provide a guarded list for each commuter and allow to each caretaker/family member to add people to the commuter's list.
TReq_02_008	Remote monitoring software.	Software for remote monitoring of the system's performance in detecting a commuter for the entirety of their trip.
TReq_02_009	Data Security software.	Security software to protect passenger data and ensure compliance with privacy regulations, including encryption and access controls.

Table 12: List of interface requirements for the "Follow My Kid/Grandmother/father" service.

Technical Req_Id	Interface Requirements	Definition
TReq_02_010	User Interfaces.	User-friendly interfaces and mobile apps that will allow caretakers/family members to check if the commuter is on board.
TReq_02_011	API Documentation.	Comprehensive documentation for APIs integration to facilitate third-party system integration.
TReq_02_012	Accessibility Features.	Incorporation of accessibility features in user interfaces to ensure compliance with accessibility standards and regulations.
TReq_02_013	Training Materials.	Creation of training materials for operators, maintenance staff, and system administrators to effectively use and maintain the system.
TReq_02_014	Reporting Interfaces.	Interfaces for generating and accessing reports and analytics, allowing operators to make informed decisions.
TReq_02_015	System Status Alerts.	Real-time alerts and notifications interfaces to inform transportation authorities and operators of the system's status, data transmission issues, and hardware failures.

3.6.9 Data requirements

Data requirements are imperative for the proper functioning of the proposed "Augmented Security and trust" service by enabling accurate abnormal event and petty crimes detection and data analysis, while simultaneously addressing privacy and compliance consideration. The complete list of the proposed data requirements is presented in detail in the following Table 13.

Table 13: List of data requirements for the "Follow My Kid/Grandmother/father" service.

Data Req_Id	Data Requirements	Definition
DReq_02_001	Passenger Data.	Raw data collected by in-vehicle cameras, including timestamps and facial recognition and detection of passengers present inside the AV.
DReq_02_002	System Configuration.	Configuration settings for cameras, data processing and user interfaces.
DReq_02_003	Security Logs.	Logs of security-related activities, including access attempts, authentication and data encryption status.
DReq_02_004	Emergency Data.	Data related to emergency situations, such as emergency stops or requests for assistance from passengers.
DReq_02_005	Notifications.	Records of notifications sent to operators and transportation authorities in case of a system malfunction.
DReq_02_006	System Performance Metrics.	Metrics related to system performance, including response times, server load and data transmission efficiency.
DReq_02_007	Accessibility Data.	Data related to the accessibility of user interfaces and services, including compliance with accessibility standards.
DReq_02_008	Data Backups.	Copies of data backups, including timestamps and locations of backup files.
DReq_02_009	Retention Policies.	Policies specifying how long different types of data are retained and when they are purged.

3.7 Service: Shuttle environment assessment

3.7.1 Concept of Service

The "Shuttle Environment Assessment" belongs to the "Passenger Services" category, and its objective is to maintain satisfactory environmental conditions within the vehicle interior, given the absence of a driver to oversee the shuttle. The minimum acceptable conditions and comfort necessary for safe transportation include good air quality, acceptable odours, and the absence of smoke. These standards are vital for the viability of the entire service, as the lack of them could significantly discourage potential passengers. The service will operate in real-time, and passengers will be notified via notifications in case the conditions fail to meet the expected standards.

3.7.1.1 Use Case

Use Case: Enhancing Shuttle Services with Shuttle environment assessment.

Actors:

- *Public Transportation Authority:* The organization responsible for managing and operating public transportation services.
- *Passengers:* Individuals, including elderly passengers and people with disabilities, who rely on shuttle services for their transportation requirements.

Scenario:

The "Shuttle Environment Assessment" service is seamlessly integrated by the Public Transportation Authority, enhancing the autonomous vehicle experience with the deployment of cutting-edge environmental and smoke sensors. These sensors work in real-time to gather essential data about the shuttle's surroundings. Passengers gain access to this valuable information through user-friendly mobile apps, electronic signs, or the authority's official website. Essentially, the service has the capability to promptly send notifications whenever the environmental conditions surpass safe thresholds.

Leveraging the data collected by this system, the authority is continuously monitoring the shuttle environment, ensuring that passengers are kept informed of any deviations from the acceptable conditions. This empowers passengers to take timely action, thereby enhancing their safety and comfort during their autonomous journeys. By embracing the "Shuttle Environment Assessment" service, the transportation authority demonstrates its strong commitment to passengers’ safety, as well as its dedication to elevating the overall experience of traveling in autonomous vehicles.

3.7.2 User Story

As a passenger, I wish to feel comfort within a clean environment at any time I use the autonomous mini-bus.

3.7.3 Description of Service

The objective of the “Shuttle environment assessment” service is to uphold the suitable environmental circumstances within the autonomous vehicle, which might lack proper regulation due to the absence of a human driver or safety operator. It is crucial to maintain the minimal acceptable conditions and comfort, ensuring good air quality, minimal odors, and the absence of smoke. These factors are essential not only for the secure transportation of passengers but also for the overall success of the autonomous service. Failing to meet these conditions inside the vehicle could significantly discourage potential passengers. Overseeing the environmental conditions permits the provision of alert and warning services to passengers through notifications, thereby enriching the user’s experience and ensuring safety throughout their journeys. The environment monitoring will be conducted through environmental sensors along with smoke sensors and smoking detection sensors.

The proposed service offers several key advantages to enhance the autonomous vehicle experience and ensure passengers’ safety:

- **Optimal Environment:** Maintains comfortable and safe conditions within autonomous vehicles, compensating for the absence of a human driver.
- **Safety and Comfort:** Ensures passenger well-being by upholding good air quality, low odor levels, and a smoke-free interior.
- **Viability Boost:** Contributes to the success of autonomous transportation by meeting passengers’ expectations and encouraging consistent ridership.
- **Attractive Service:** Prioritize passengers comfort and safety, eliminating discomfort factors that might deter them.

3.7.4 Stakeholders

The "Shuttle Environment Assessment" service engages a diverse set of stakeholders. The primary participant is the **Public Transportation Authority**, charged with implementing and supervising the service. **Passengers** directly benefit by accessing real-time environmental data and receiving emergency alerts when needed. **Vehicle maintenance teams** ensure the precision of sensors and equipment, while **data analysts** extract insights, and **software developers** manage the data systems. Collaboration extends to **local government** entities, **vehicle manufacturers**, and **technology providers**, who cooperate to integrate and enhance the service. These stakeholders collectively contribute to shaping the effectiveness and efficiency of this service in the field of public transportation.

3.7.5 State of the art analysis

Numerous studies have explored into enhancing passengers safety and trust in vehicle services. Specifically, in the context of environmental assessment, Mishra et al. [4] employ object detection algorithms to monitor cigarette lighting. Their study includes various smoking-related items, including cigarettes, cigarette lighters, cigarette cases, and e-cigarettes.

Furthermore, Blaschke et al. [24] propose a new method for assessing cabin environments, including odor events like cigarette smoke, fast-food odors, manure, and bioeffluents. They use a microelectromechanical-system (MEMS) metal-oxide-sensor array and human sensory ratings on a 0 to 5 scale. Two algorithms, one based on normalized conductance and the other on signal variance, process the data and suppress false events. This system enables the design of a demand-controlled ventilation system, improving air quality management for passengers in varying conditions.

Another study [10], introduces a real-time cloud-based in-vehicle air quality monitoring system that predicts cabin air quality and detects driver drowsiness and fatigue. It employs five sensors for CO2 levels, particulate matter, vehicle speed, temperature, and humidity. Machine learning models, including multilayer perceptron, support vector regression, and linear regression, analyze the data and predict future in-vehicle air quality. Support vector regression stands out with excellent performance, achieving high linearity. This research focuses on machine learning models for in-vehicle air quality prediction, with potential applications in reducing accidents caused by driver fatigue.

Lastly, Waworundeng et al. [25] outline the development of an air quality monitoring system for vehicle cabins, designed to promote awareness and enable users to monitor air quality. The system employs air quality, temperature, humidity, carbon-monoxide, and dust sensors, along with a microcontroller and IoT platforms (Blynk Apps and ThingSpeak). Results can be viewed graphically on a smartphone. The system demonstrates its ability to effectively monitor and detect air quality as intended. Finally, this service was initially designed and implemented as part of the AVENUE project, and therefore will act as the basis for further improvements in the context of the ULTIMO project.

3.7.6 Functional Requirements

This section presents the functional requirements for the "Shuttle Environment Assessment" service. The outlined requirements (Table 14) define the primary functionalities of the service, considering the broader ULTIMO architecture to address specific service needs.

Table 14: Shuttle environment assessment functional requirements.

Req_Id	Description
Req_03_001	The system should continuously monitor interior environmental conditions in real-time.
Req_03_002	The system should collect data from in-vehicle sensors to assess air quality, temperature, humidity, and smoke levels.
Req_03_003	The system should transmit environmental data to the ULTIMO Data Management Platform.
Req_03_004	The system should analyse the data and detect deviations from acceptable environmental conditions.
Req_03_005	The system should trigger notifications to passengers and operators if unacceptable environmental conditions are detected.
Req_03_006	Environmental data should be securely transmitted and stored to prevent unauthorized access.
Req_03_007	Passengers and operators should receive real-time alerts in case of abnormal environmental conditions.
Req_03_008	The system should be adaptable to different autonomous vehicle models and manufacturers
Req_03_009	The system should maintain a historical log of deviations over time, allowing for trend analysis.

3.7.7 Non-Functional Requirements

In order to ensure the effective and secure operation of the "Shuttle Environment Assessment" service and to be in accordance with relevant standards and regulations while maintaining a positive user experience, several non-functional requirements are essential. The primary non-functional requirements are outlined as follows:

- **Responsiveness**: The system is required to deliver real-time environmental data with minimal latency, ensuring that passengers receive timely information regarding the shuttle's conditions.
- **Scalability**: The service should have the capacity to smoothly adapt to the growth in shuttles, passengers, and routes as the transportation network expands.
- **Reliability**: Ensuring high availability is a priority, minimizing downtime, especially during peak usage hours. Incorporating backup mechanisms for critical components is vital to ensuring continuous service even in the event of hardware or software failures.
- **Privacy**: The service must ensure that any data collected for environmental monitoring is completely anonymized, preventing the identification of individual passengers. Moreover, passengers' explicit consent should be obtained before collecting any data related to environmental conditions within the shuttle while all data transmissions between sensors, system and user-interfaces should be encrypted to prevent unauthorized access.
- **User-Friendly**: Interfaces should provide ease of use and accessibility for passengers, as well as transportation authorities and operators, ensuring an intuitive experience for all stakeholders involved.
- **Accessibility**: The system should comply with accessibility standards to ensure it is usable by individuals with disabilities.
- **Interoperability**: The service should be able to integrate seamlessly with third-party systems, such as transportation management software or emergency services. Moreover, it should demonstrate flexibility by adapting to diverse types of public transportation vehicles, regardless of their manufacturer or model.

3.7.8 Technical Requirements

The "Shuttle Environmental Assessment" service is guided by a set of technical requirements covering hardware, software, and interface aspects. These elements collectively form the foundation for smooth integration and efficient operation within the ULTIMO ecosystem. Hardware specifications (Table 15) include crucial sensors for accurate data collection, while software considerations (Table 16) involve algorithms for real-time analysis and anomaly detection. Finally, interface requirements (Table 17) focus on user-friendly notifications and secure data handling, reinforcing the service's commitment to accuracy, reliability, and a user-centric approach.

Table 15: Hardware requirements for "Shuttle Environment Assessment" service.

Technical Req_Id	Hardware Requirements	Definition
TReq_03_001	Environmental sensor.	High quality sensor that capture environmental data enabling the assessment of the shuttle's environment.
TReq_03_002	On-board hardware.	Hardware components for on-board installation, such as power supply systems, processing units and connectivity modules.

Technical Req_Id	Hardware Requirements	Definition
TReq_03_003	Vehicle integration kits.	Necessary equipment for seamless integration of sensors into the public transport shuttles.
TReq_03_004	Data Transmission equipment.	5G modems and/ or antennas, Wi-Fi routers, etc. for real-time transmission of the shuttle's environmental conditions to the ULTIMO DMP.
TReq_03_005	Redundancy mechanisms.	Backup sensors and failover data transmission equipment to ensure system reliability.

Table 16: Software requirements for "Shuttle Environment Assessment" service.

Technical Req_Id	Software Requirements	Definition
TReq_03_006	Data processing software.	Software for efficient collection, processing and management of the environmental data.
TReq_03_007	User Interfaces.	User friendly software interface for commuters, operators and local authorities, to access real-time shuttle's environment conditions, historical data and system status.
TReq_03_008	Mobile Applications.	Development of mobile apps for passengers to check environment status on smartphones or tablets.
TReq_03_009	AI model.	AI model using as input the environmental data to identify irregular environmental conditions.
TReq_03_010	Integration APIs.	APIs for seamless integration with third-party systems, such as transportation management software and emergency services.
TReq_03_011	Remote monitoring software.	Software for remote monitoring of the system performance, including alerts and notifications for system issues.
TReq_03_012	Data Security software.	Security software to protect passenger data and ensure compliance with privacy regulations, including encryption and access controls.

Table 17: Interface requirements for "Shuttle Environment Assessment" service.

Technical Req_Id	Interface Requirements	Definition
TReq_03_013	User Interfaces.	User-friendly interfaces to interact with the system, including web-based dashboards, mobile app interfaces and operator consoles.
TReq_03_014	API Documentation.	Comprehensive documentation for APIs integration to facilitate third-party system integration.
TReq_03_015	Accessibility Features.	Incorporation of accessibility features in user interfaces to ensure compliance with accessibility standards and regulations.
TReq_03_016	Training Materials.	Creation of training materials for operators, maintenance staff, and system administrators to effectively use and maintain the system.
TReq_03_017	Reporting Interfaces.	Interfaces for generating and accessing reports and analytics, allowing transportation planners to make informed decisions.
TReq_03_018	System Status Alerts.	Real-time alerts and notifications interfaces to inform transportation authorities and operators of system status, data transmission issues, and hardware failures.
TReq_03_019	Passenger	Interfaces for sending real-time notifications to passengers in

Technical Req_Id	Interface Requirements	Definition
	Notifications.	case of irregular environmental conditions through mobile apps, electronic signs, or other communication channels.

3.7.9 Data requirements

The "Shuttle Environment Assessment" service relies on the following crucial data requirements (Table 18) for its effective operation. These requirements ensure precise monitoring of environmental conditions and the ability to notify passengers in the event of abnormal environmental situations.

Table 18: Data requirements for "Shuttle environment assessment" service.

Data Req_Id	Data Requirements	Definition
DReq_03_001	Environmental Data.	Raw data collected by sensors, including CO2, NO2, temperature, humidity, PM2.5, TVOC and dust particle concentration.
DReq_03_002	Vehicle Information.	Data about each vehicle in the fleet, including vehicle type, capacity, and unique identifiers.
DReq_03_003	Historical Data.	Archived environmental data for trend analysis.
DReq_03_004	Mobile App Usage.	Data on how passengers use the mobile app, such as login times, search queries and notifications received.
DReq_03_005	System Configuration.	Configuration settings for sensors, data processing and user interfaces.
DReq_03_006	Geolocation.	Geographic information, including maps, GPS coordinates, and geofencing data to determine vehicle locations.
DReq_03_007	Security Logs.	Logs of security-related activities, including access attempts, authentication and data encryption status.
DReq_03_008	Emergency Data.	Data related to emergency situations, such as emergency stops or requests for assistance from passengers.
DReq_03_009	Notifications.	Records of notifications sent to passengers, including the content and delivery status.
DReq_03_010	System Performance Metrics.	Metrics related to system performance, including response times, server load and data transmission efficiency.
DReq_03_011	Accessibility Data.	Data related to the accessibility of user interfaces and services, including compliance with accessibility standards.
DReq_03_012	Data Backups.	Copies of data backups, including timestamps and locations of backup files.
DReq_03_013	Retention Policies.	Policies specifying how long different types of data are retained and when they are purged.

3.8 Service: Automated Passenger Presence

3.8.1 Concept of Service

The “Automated Passenger Presence” service aims to create an advanced system for public transportation that uses sensors and software to automatically detect, count, and manage passenger occupancy on vehicles. It provides real-time information to passengers, enabling efficient journey planning, while also helping transportation authorities to optimize routes and resources for a smoother and more responsive public transportation experience. The target audience is mainly the fleet operators and the passengers that use Public Transport methods. This service is categorized as an “Operator Service” but could also be applied to the “Passenger Services” field, as a part of the MaaS ecosystem.

The “Automated Passenger Presence” service creates value by exhibiting a variety of advantages, which include:

- Real-time, accurate, and continuous passenger counting and vehicle occupancy calculation.
- Could held avoid overcrowding inside the shuttles, and meaningless stops when the bus is in full capacity.
- The space occupation assessment could also assist passengers to determine whether to board the vehicle or not, thus helping to better plan their trip.
- The use of the same equipment and the use of effective analysis approaches as the other In-Vehicle services will render the service a low-cost solution, providing maximum value to all stakeholders.

3.8.1.1 Use Case

Use Case: Optimizing Public Transportation with Automated Passenger Presence.

Actors:

- *Public Transportation Authority:* The organization responsible for managing and operating public transportation services.
- *Passengers:* Commuters who use public transportation services.

Scenario:

The Public Transportation Authority implements the "Automated Passenger Presence" service, equipping their buses and trains with automated passenger counting sensors to collect real-time occupancy data. Passengers can access this data through mobile apps, electronic signs, or the authority's website, enabling them to make informed decisions about their commute. The authority uses the data to optimize route scheduling, increase service frequency where needed, and allocate resources efficiently. It generates reports and historical data for long-term planning and can expand the service to new routes and emerging transportation technologies, ensuring an improved and adaptive public transportation experience.

By implementing the "Automated Passenger Presence" service, the transportation authority can provide a more efficient and passenger-friendly public transportation experience while optimizing their operations based on real-time data.

3.8.2 User Story

As an operator, I wish to be aware of the number of passengers on-board at any time, in order to keep record of the passenger demand.

3.8.3 Description of Service

The target of this service is to address a fundamental problem of operator services, related to vehicle occupancy and the awareness of the volume of on-board commuters, to facilitate route scheduling. For the commuters' side, it would be nice to be notified of the vehicle space and seat availability in advance, for efficient planning. In conventional transportation, drivers and inspectors filled those roles. However, with the emergence of automated and driverless vehicles, automated passenger counting is an emerging field to fulfil such requirements. This service acts as an automated system, capable to detect and count passenger presence efficiently and calculate vehicle occupancy.

3.8.4 Stakeholders

The "Automated Passenger Presence" service involves a diverse range of stakeholders. The primary actor is the **Public Transportation Authority**, responsible for implementing and overseeing the service. **Passengers** are direct beneficiaries, gaining access to real-time occupancy data for informed commuting decisions. **Transportation planners** use the collected data for optimizing routes and schedules, while **vehicle maintenance teams** ensure the sensors and equipment remain accurate. **Data analysts** derive insights, and **software developers** manage the data systems. **Local government** agencies, **vehicle manufacturers**, and **technology providers** collaborate on integration and improvements. These stakeholders collectively shape the success and efficiency of this service in the field of public transportation.

3.8.5 State of the art analysis

A number of studies have been carried out that tackle the issue of passenger presence. A real-life experiment was implemented in Marysville, Ohio, USA [26] that used passenger presence as a means to calculate the efficiency of commuting pickup and drop-off, using connected graphs. The authors of [19] created a software, based on video and audio analysis, for detection of passenger onboarding and offboarding. Another study occurred in Bursa, Turkey [27] that takes vehicle occupancy and vehicle capacity into consideration, to solve the problem of efficient commuting in Shared Autonomous Vehicles. In [28], Hyun et.al have created an in-vehicle passenger monitoring system, based on 2D images, by developing a 2D deep learning model for passenger counting. Last, but definitely not least, a similar service was developed in the context of AVENUE H2020 project, a predecessor of ULTIMO and, therefore, this service is considered the continuation of the previous work in the new ULTIMO ecosystem.

3.8.6 Functional Requirements

In this section, the functional requirements of the "Automated Passenger Presence" service are presented (Table 19). The listed requirements describe the main functionalities of the service, taking the overall ULTIMO architecture into consideration, in order to address the needs of the specific service.

Table 19: Automated Passenger Presence functional requirements.

Req_Id	Description
Req_04_001	The operator should know the number of passengers at any given time.
Req_04_002	The operator should know the in-vehicle seat occupancy at any time.
Req_04_003	The vehicle should collect passenger presence data.

Req_Id	Description
Req_04_004	The vehicle should transmit passenger occupancy data to the ULTIMO Data Management Platform.
Req_04_005	The vehicle should detect the passenger presence using in-vehicle sensors.
Req_04_006	The vehicle should detect the passenger allocation using in-vehicle sensors.
Req_04_007	The commuter should be able to know a vehicle's capacity and occupancy in advance.
Req_04_008	The operator shall know the number of onboarding and offboarding passengers in every stop.
Req_04_009	The operator shall be able to schedule routes efficiently, depending on the commuters' demands.
Req_04_010	The operator shall communicate with the ULTIMO Data Management Platform for efficient booking and scheduling
Req_04_011	The vehicle shall take incoming requests from passengers for commuting.
Req_04_012	The commuter shall decide pickup and drop-off locations.
Req_04_013	The commuter shall be able to know the vehicles' schedules and routes.
Req_04_014	The commuter shall receive notifications considering the vehicle capacity and availability.
Req_04_015	The operator could change the commuter allocation in the seats.
Req_04_016	The commuter could book a seat in advance in case of vacancies.

3.8.7 Non-Functional requirements

The following non-functional requirements are crucial for ensuring that the "Automated Passenger Presence" service operates effectively, securely, and in compliance with relevant standards and regulations while providing a positive user experience. Taking into account that the aforementioned service is still under development, the main non-functional requirements are as follows:

- **Responsiveness**: The system shall provide real-time passenger occupancy data with minimal latency, ensuring passengers receive timely information.
- **Scalability**: The service should scale seamlessly to accommodate an increasing number of passengers, vehicles, and routes as the transportation network expands.
- **Reliability**: The system should aim for high availability, with minimal downtime, especially during peak commuting hours. Redundancy mechanisms should be in place for critical components to ensure continuous operation even in the event of hardware or software failures.
- **Privacy**: Passenger data should be anonymized to protect individual privacy while still providing aggregated occupancy Information. The service must adhere to data privacy regulations, such as GDPR, and maintain compliance with industry-specific standards.
- **User-Friendly**: User interfaces should be intuitive and accessible to passengers, transportation authorities and operators, while promoting ease of use.
- **Accessibility**: The system should comply with accessibility standards to ensure it is usable by individuals with disabilities.
- **Data Reliability**: The system must maintain the integrity of passenger count data, ensuring it is accurate and consistent. Regular data backups and a robust data recovery plan should be in place to prevent data loss.
- **Interoperability**: The service should be able to integrate seamlessly with third-party systems, such as transportation management software or emergency services. It should

be compatible with various types of public transportation vehicles, irrespective of manufacturer or model.

- **Data Scalability**: The database system should scale to handle the growing volume of passenger data efficiently.
- **Regulatory Compliance**: The system should comply with industry standards and regulatory requirements related to passenger counting and data management.

3.8.8 Technical Requirements

For the seamless integration of this service into the ULTIMO ecosystem, a table of technical requirements is provided. The goal is to incorporate this service to the ULTIMO vehicles as effortlessly as possible, given the restrictions of the fleet equipment. These categorized hardware (Table 20), software (Table 21), and interface (Table 22) requirements are essential for the successful implementation and operation of the "Automated Passenger Presence" service, ensuring accurate data collection, reliable system performance and user satisfaction.

Table 20: Hardware requirements for "Automated Passenger Presence" service.

Technical Req_Id	Hardware Requirements	Definition
TReq_04_001	Passenger counting sensors.	High quality sensors capable of accurate detection and counting commuters onboarding and offboarding.
TReq_04_002	On-board hardware.	Hardware components for on-board installation, such as power supply systems, processing units and connectivity modules.
TReq_04_003	Vehicle integration kits.	Necessary equipment for seamless integration of sensors into the public transport shuttles.
TReq_04_004	Data Transmission equipment.	5G modems and/ or antennas, Wi-Fi routers, etc. for real-time passenger count/presence transmission to the ULTIMO DMP. Backup communication mechanisms.
TReq_04_005	Redundancy mechanisms.	Backup sensors and failover data transmission equipment to ensure system reliability.

Table 21: Software requirements for "Automated Passenger Presence" service.

Technical Req_Id	Software Requirements	Definition
TReq_04_006	Data processing software.	Software for efficient collection, processing and management of the passenger data.
TReq_04_007	User Interfaces.	User friendly software interface for commuters, operators and local authorities, to access real-time occupancy, historical data and system status.
TReq_04_008	Mobile Applications.	Development of mobile apps for passengers to check vehicle occupancy status on smartphones or tablets.
TReq_04_009	Data analytics tools.	Data analytics software for transportation planners and analysts to derive insights from passenger data and optimize routes and schedules.
TReq_04_010	Integration APIs.	APIs for seamless integration with third-party systems, such as transportation management software and emergency services.
TReq_04_011	Remote monitoring software.	Software for remote monitoring of the system performance, including alerts and notifications for system issues.

Technical Req_Id	Software Requirements	Definition
TReq_04_012	Data Security software.	Security software to protect passenger data and ensure compliance with privacy regulations, including encryption and access controls.

Table 22: Interface requirements for "Automated Passenger Presence" service.

Technical Req_Id	Interface Requirements	Definition
TReq_04_013	User Interfaces.	User-friendly interfaces to interact with the system, including web-based dashboards, mobile app interfaces and operator consoles.
TReq_04_014	API Documentation.	Comprehensive documentation for APIs integration to facilitate third-party system integration.
TReq_04_015	Accessibility Features.	Incorporation of accessibility features in user interfaces to ensure compliance with accessibility standards and regulations.
TReq_04_016	Training Materials.	Creation of training materials for operators, maintenance staff, and system administrators to effectively use and maintain the system.
TReq_04_017	Reporting Interfaces.	Interfaces for generating and accessing reports and analytics, allowing transportation planners to make informed decisions.
TReq_04_018	System Status Alerts.	Real-time alerts and notifications interfaces to inform transportation authorities and operators of system status, data transmission issues, and hardware failures.
TReq_04_019	Passenger Notifications.	Interfaces for sending real-time occupancy notifications to passengers through mobile apps, electronic signs, or other communication channels.

3.8.9 Data Requirements

The following data requirements (Table 23) are essential for the proper functioning of the "Automated Passenger Presence" service, enabling accurate passenger counting, data analysis and service optimization, while also addressing privacy and compliance considerations.

Table 23: Data requirements for "Automated Passenger Presence" service.

Data Req_Id	Data Requirements	Definition
DReq_04_001	Passenger Count Data.	Raw data collected by sensors, including timestamps, vehicle IDs, and the number of passengers boarding and exiting.
DReq_04_002	Vehicle Information.	Data about each vehicle in the fleet, including vehicle type, capacity, and unique identifiers.
DReq_04_003	Passenger Information.	Anonymized passenger data, including age groups, gender (if available), and mobility needs, for demographic analysis.
DReq_04_004	Route and Scheduling.	Information on routes, schedules and stops, including geospatial data to link passenger counts to specific locations.
DReq_04_005	Real-time Vehicle Occupancy.	Real-time calculations of vehicle occupancy levels based on passenger count data.
DReq_04_006	Historical Data.	Archived passenger count data for trend analysis, route

Data Req_Id	Data Requirements	Definition
		optimization and long-term planning.
DReq_04_007	User Data.	User account information, including usernames, roles and access permissions.
DReq_04_008	Mobile App Usage.	Data on how passengers use the mobile app, such as login times, search queries and notifications received.
DReq_04_009	System Configuration.	Configuration settings for sensors, data processing and user interfaces.
DReq_04_010	Geolocation.	Geographic information, including maps, GPS coordinates, and geofencing data to determine vehicle locations.
DReq_04_011	Security Logs.	Logs of security-related activities, including access attempts, authentication and data encryption status.
DReq_04_012	Emergency Data.	Data related to emergency situations, such as emergency stops or requests for assistance from passengers.
DReq_04_013	Notifications.	Records of notifications sent to passengers, including the content and delivery status.
DReq_04_014	System Performance Metrics.	Metrics related to system performance, including response times, server load and data transmission efficiency.
DReq_04_015	Accessibility Data.	Data related to the accessibility of user interfaces and services, including compliance with accessibility standards.
DReq_04_016	Data Backups.	Copies of data backups, including timestamps and locations of backup files.
DReq_04_017	Retention Policies.	Policies specifying how long different types of data are retained and when they are purged.

3.9 Service: Smart Feedback

3.9.1 Concept of Service

Smart Feedback empowers daily commuters using autonomous shuttles to provide real-time feedback using hand gestures. This user-friendly service, with advanced gesture recognition and potential sound sensors, ensures immediate insights for operators, enabling rapid issue resolution and ongoing service enhancements. Smart Feedback enhances the commuting experience, making it more convenient and secure, catering to daily commuters seeking responsive transportation solutions. This service is categorized as an "Operator Service". The "Smart Feedback System" service creates value by exhibiting a variety of advantages, which include:

- Effortless feedback, enabling just a hand gesture to one of the in-vehicle cameras to be required for the commuters to give their feedback (satisfaction or dissatisfaction).
- Monitoring passenger (dis)satisfaction can lead to improved services and advanced public transportation in general.
- The awareness of the end-users‘ satisfactory levels will enhance the in-shuttle traveler assistance.

3.9.1.1 Use Case

Use Case: Smart Feedback for Commuter Shuttles.

Actors:

- **Commuter**: The primary user of the "Smart Feedback" service. Commuters are passengers who regularly use autonomous commuter shuttles for their daily transportation needs.
- **Operator/Service Provider**: The organization responsible for operating and managing the autonomous commuter shuttle service. They use the feedback provided by commuters to enhance the quality of their services.

Scenario:

As a commuter boards an autonomous shuttle for their daily commute, 'Smart Feedback' offers them an effortless way to provide feedback during the journey. This commuter, noticing something they like or dislike about the journey, can simply raise their hand and use a thumbs-up or thumbs-down gesture to convey their satisfaction or dissatisfaction. In-vehicle cameras equipped with advanced gesture recognition technology capture these gestures, instantly transmitting the feedback to the shuttle's operator or control center. The operator receives real-time data on passenger feedback, which could potentially include sound sensors that can capture verbal comments for more detailed input. With this feedback loop in place, operators can take immediate actions, such as investigating and addressing issues if multiple commuters signal dissatisfaction, leading to continuous improvements in the shuttle service over time and enhancing the overall commuter experience.

The 'Smart Feedback' service provides numerous advantages. Commuters can effortlessly provide feedback with simple hand gestures, eliminating the need for cumbersome forms or apps and increasing the likelihood of receiving genuine input. Operators benefit from real-time insights into passenger satisfaction, enabling immediate actions to address any issues that arise. This continuous feedback loop leads to ongoing service enhancements, making the autonomous commuter shuttle an even more appealing and secure transportation option. Overall, 'Smart Feedback' ensures that passengers' opinions are not only heard but also acted upon promptly, ultimately resulting in a significantly improved and safer commuting experience.

3.9.2 User Story

As an operator, I wish to be aware of the opinion of the passengers for the provided services, in order to ameliorate the end users' experience.

3.9.3 Description of Service

The purpose of this service is to allow commuters to provide easy and effortless in-shuttle feedback to the operators in case the safety driver is absent from the vehicle. The operators' knowledge of the commuters' level of satisfaction with the services and transportation is important. "Smart Feedback" enables the passengers to wave a hand gesture to the in-vehicle cameras, allowing them to effortlessly say "I like" or "I do not like" the travel experience, either with a thumbs up or a thumbs down. Sound sensors and more gestures could also be tested.

3.9.4 Stakeholders

The success of the "Smart Feedback" service relies on a collaborative effort among several key stakeholders. Daily **commuters** are at the forefront, benefiting from the user-friendly feedback mechanism. The **service providers** and **operators** play a pivotal role, using the real-time insights to enhance shuttle services and address passenger concerns promptly. The **technical team** responsible for developing and maintaining the gesture recognition technology and sound sensors ensures the service's seamless operation. Additionally, **local authorities** may have an interest in overseeing the implementation of this feedback system to enhance public transportation safety standards. Collectively, these stakeholders contribute to a more responsive and passenger-centric autonomous shuttle commuting experience.

3.9.5 State of the art analysis

Even though the field of autonomous shuttles and automated mobility is emerging rapidly in the recent years, the feedback from the end users is typically collected manually (i.e. through questionnaires) [29][30][31] and, to the best of our knowledge, a fully automated system has not been incorporated into an autonomous shuttle. However, it is important to note that a number of in-shuttle human-machine interfaces (HMI) have been created in a similar scope. For example, a system to enable elderly passengers to interact with an autonomous vehicle has been proposed in [32], to tackle the problem of low interaction with AVs from people with lower confidence towards automation. This solution was proposed within a VR testbed ecosystem. VR testbeds provide trust in autonomous vehicles [33], to facilitate commuter willingness to use real-life AVs. Concurrently, a real-life vehicle was tested in Sion, Switzerland [34] that, among others, includes a human-machine interaction interface to monitor passenger reaction when riding the shuttle. It is important to note that, during a 2016 challenge, a number of HMI designs were proposed and are listed in [35]. Finally, the "Smart Feedback" service was designed and implemented for the scope of the AVENUE project, and therefore consists a basis for further improvement and development in the ULTIMO ecosystem.

3.9.6 Functional Requirements

In this section, the functional requirements of the "Automated Passenger Presence" service are presented (Table 24). The listed requirements describe the main functionalities of the service, taking the overall ULTIMO architecture into consideration, in order to address the needs of the specific service.

Table 24: "Smart Feedback" service functional requirements.

Req_Id	Description
Req_05_001	The operator should provide a system that recognizes "thumbs up" and "thumbs down" as positive and negative feedback respectively.
Req_05_002	The operator should provide a user manual/training for commuters on how to use the feedback system.
Req_05_003	The operator should communicate with the ULTIMO DMP to receive and process feedback in real time.
Req_05_004	The operator should implement a secure data transmission ecosystem for commuter privacy protection.
Req_05_005	The operator should ensure that the "Smart Feedback" service can be integrated into all the Autonomous Shuttles of their fleet.
Req_05_006	The service shall provide a visual indicator (e.g green LED) confirming that the feedback was submitted successfully.
Req_05_007	The service provider shall ensure that this service does not disrupt the commuter safety and does not interfere with the journey completion.
Req_05_008	The service provider shall embed the feedback outcome to an app or website to track

Req_Id	Description
	service improvements.
Req_05_009	The service could allow commuters to provide detailed comments and share their experience via voice feedback, along with the hand gestures.
Req_05_010	The service could expand the feedback system to include a wider range of gestures
Req_05_011	The service could integrate facial recognition and / or sentiment analysis algorithms for more accurate feedback.
Req_05_012	The service could utilize machine learning algorithms to identify recurring issues and proactively suggest improvements.
Req_05_013	The service could allow commuters to provide feedback on specific parts of the journey.
Req_05_014	The service could allow operators to respond directly to passenger feedback.
Req_05_015	The service could offer multi-language support for diverse demographics and better inclusion.

3.9.7 Non-Functional Requirements

The following non-functional requirements are crucial for ensuring that the "Smart Feedback" service operates effectively, securely, and in compliance with relevant standards and regulations while providing a positive user experience. Taking into account that the aforementioned service is still under development, the main non-functional requirements are as follows.

- **Responsiveness**: The system should provide immediate feedback acknowledgment, with a response time minimal latency after a commuter's gesture or voice feedback.
- **Scalability**: The service should scale seamlessly to accommodate an increasing number of commuters and feedback submissions as the transportation network expands.
- **Reliability**: The system should aim for high availability, with minimal downtime, especially during peak commuting hours. Redundancy mechanisms should be in place for critical components to ensure continuous operation even in the event of hardware or software failures.
- **Privacy**: Passenger data should be anonymized to protect individual privacy while still providing aggregated occupancy Information. The service must adhere to data privacy regulations, such as GDPR, and maintain compliance with industry-specific standards.
- **User-Friendly**: User interfaces should be intuitive and accessible to passengers, transportation authorities and operators, while promoting ease of use.
- **Intuitiveness:** The feedback process should be straightforward, requiring minimal effort and no special training for commuters to use effectively.
- **Accessibility and Inclusivity**: The system should comply with accessibility standards to ensure it is usable by individuals with disabilities. including those with visual or hearing impairments. It should adhere to WCAG (Web Content Accessibility Guidelines) standards. It should also take special notice of people of color and other minorities.
- **Reporting:** Operators should have access to performance reports and analytics to track passenger satisfaction and system efficiency.
- **Data Reliability**: The system must maintain the integrity of passenger count data, ensuring it is accurate and consistent. Regular data backups and a robust data recovery plan should be in place to prevent data loss.
- **Interoperability**: The service should be able to integrate seamlessly with third-party systems, such as transportation management software or emergency services. It should

be compatible with various types of public transportation vehicles, irrespective of manufacturer or model.

- **Data Scalability**: The database system should scale to handle the growing volume of passenger data efficiently.
- **Regulatory Compliance**: The system should comply with industry standards and regulatory requirements related to passenger counting and data management.

3.9.8 Technical Requirements

For the seamless integration of this service into the ULTIMO ecosystem, a table of technical requirements is provided. The goal is to incorporate this service to the ULTIMO vehicles as effortlessly as possible, given the restrictions of the fleet equipment. These categorized hardware (Table 25), software (Table 26), and interface (Table 27) requirements are essential for the successful implementation and operation of the "Smart Feedback" service, ensuring accurate data collection, reliable system performance and user satisfaction.

Table 25: Hardware requirements for "Smart Feedback" service.

Technical Req_Id	Hardware Requirements	Definition
TReq_05_001	In-Vehicle sensors.	High resolution cameras with advanced gesture recognition capabilities, optional sound sensors for capturing voice feedback and noise-cancelling technologies. LEDs that confirm the feedback submission. Sufficient processing power to detect gestures real-time.
TReq_05_002	On-board hardware.	Hardware components for on-board installation, such as power supply systems, processing units and connectivity modules.
TReq_05_003	Vehicle integration kits.	Necessary equipment for seamless integration of sensors into the public transport shuttles.
TReq_05_004	Data transmission equipment.	5G modems and/ or antennas, Wi-Fi routers, etc. for real-time passenger count/presence transmission to the ULTIMO DMP. Backup communication mechanisms.
TReq_05_005	Redundancy mechanisms.	Backup sensors and failover data transmission equipment to ensure system reliability.

Table 26: Software requirements for "Smart Feedback" service.

Technical Req_Id	Software Requirements	Definition
TReq_05_006	Data processing software, for gesture recognition (and optional voice recognition).	Software for efficient collection, processing and management of the passenger feedback. Specialized software recognizing and interpreting hand gestures. Voice recognition software (optional) that converts speech to text.
TReq_05_007	User Interfaces.	User friendly software interface for commuters, operators and local authorities, to access real-time feedback, historical data and system status.
TReq_05_008	Mobile Applications.	Development of mobile apps for passengers to check user satisfaction on smartphones or tablets.
TReq_05_009	Data analytics tools.	Data analytics software for transportation planners and analysts to derive insights from passenger feedback and optimize Quality of Experience.
TReq_05_010	Integration APIs.	APIs for seamless integration with third-party

Technical Req_Id	Software Requirements	Definition
		systems, such as transportation management software and emergency services.
TReq_05_011	Remote monitoring software.	Software for remote monitoring the system performance, including alerts and notifications for system issues.
TReq_05_012	Data Security software.	Security software to protect passenger data and ensure compliance with privacy regulations, including encryption and access controls.

Table 27: Interface requirements for "Smart Feedback" service.

Technical Req_Id	Interface Requirements	Definition
TReq_05_013	User Interfaces.	User-friendly interfaces to interact with the system, including web-based dashboards, mobile app interfaces and operator consoles.
TReq_05_014	API Documentation.	Comprehensive documentation for APIs integration to facilitate third-party system integration.
TReq_05_015	Accessibility and Inclusivity Features.	Incorporation of accessibility/inclusivity features in user interfaces to ensure compliance with accessibility standards (WCAG) and regulations.
TReq_05_016	Training Materials.	Creation of training materials for operators, maintenance staff, and system administrators to effectively use and maintain the system.
TReq_05_017	Reporting Interfaces.	Interfaces for generating and accessing reports and analytics, allowing transportation planners to make informed decisions.
TReq_05_018	System Status Alerts.	Real-time alerts and notifications interfaces to inform transportation authorities and operators of system status, data transmission issues, and hardware failures.
TReq_05_019	Multi-Language Support.	Support for multiple languages to cater to a diverse commuter demographic.

3.9.9 Data Requirements

The following data requirements (Table 28) are essential for the “Smart Feedback” service to collect, process, and manage user feedback, ensure system performance, maintain security, privacy and comply with relevant regulations and standards.

Table 28: Data requirements for "Smart Feedback" service.

Data Req_Id	Data Requirements	Definition
DReq_05_001	Feedback Data.	Gesture-based feedback data (thumbs-up, thumbs-down). Voice feedback data (if voice feedback is supported). Timestamps for when feedback is submitted.
DReq_05_002	Feedback Categorization.	Categorized feedback data (positive, negative). Sentiment analysis results (if implemented).
DReq_05_003	Vehicle Information.	Data about each vehicle in the fleet, including vehicle type, capacity, and unique identifiers.
DReq_05_004	Passenger Information.	Anonymized passenger data, including age groups, gender (if available), and mobility needs, for demographic analysis.

Data Req_Id	Data Requirements	Definition
DReq_05_005	Route and Scheduling.	Information on routes, schedules and stops, including geospatial data to link passenger feedback to specific locations.
DReq_05_006	Commute Performance Data.	Response times for acknowledging feedback. Feedback processing times. Availability and uptime data. Aggregated performance metrics for commuter satisfaction. Reports on feedback trends and patterns.
DReq_05_007	Historical Data.	Archived passenger feedback data for trend analysis, route optimization and long-term planning.
DReq_05_008	User Data.	User account information, including usernames, roles and access permissions.
DReq_05_009	Usage Statistics.	Usage statistics of the Smart Feedback system, including the number of feedback submissions.
DReq_05_010	Geolocation.	Geographic information, including maps, GPS coordinates, and geofencing data to determine vehicle locations.
DReq_05_011	Compliance Records.	Records of compliance with data protection regulations and standards (e.g., GDPR, WCAG).
DReq_05_012	Security Logs.	Logs of security-related activities, including access attempts, authentication and data encryption status.
DReq_05_013	Emergency Data.	Data related to emergency situations, such as emergency stops or requests for assistance from passengers.
DReq_05_014	System Performance Metrics.	Metrics related to system performance, including response times, server load and data transmission efficiency.
DReq_05_015	Accessibility Data.	Data related to the accessibility of user interfaces and services, including compliance with accessibility standards.
DReq_05_016	Data Backups.	Copies of data backups, including timestamps and locations of backup files.
DReq_05_017	Retention Policies.	Policies specifying how long different types of data are retained and when they are purged.

3.10 Service: Mitigation of Disease Spread

3.10.1 Concept of Service

The “Mitigation of Disease Spread” belongs to the “Passenger services” category and focuses on enhancing public health and safety within public transport systems. It involves continuous monitoring of indoor air quality, including CO2 levels, to ensure proper ventilation. Automatic HVAC adjustments are made based on environmental parameters to maintain optimal conditions. HEPA filters and UV-C lamps are utilized to purify the air and disinfect surfaces. Moreover, thermal cameras measure passengers' body temperature for health alerts. Electronic ticketing enables contact tracking for disease prevention, while occupancy is managed to prevent overcrowding and maintain safe distancing.

3.10.1.1 Use Case

Use case: Enhancing Public Health with Disease Mitigation Service.

Actors:

- *Public Transportation Authority:* The organization responsible for managing and operating public transportation services.
- *Passengers:* Commuters who rely on public transport for their daily travel needs.

Scenario:

The "Mitigation of Disease Spread" service is seamlessly integrated by the Public Transportation Authority, reinforcing the commitment to passenger safety and public health. This service employs advanced technologies and measures to confront the spread of diseases within public transportation systems. It encompasses real-time indoor environment monitoring, automatic HVAC interventions, HEPA filters, discreet health alerts through thermal cameras, and electronic ticketing for contact tracking. Passengers benefit from accessible information through user-friendly mobile apps and electronic signs. Importantly, the service empowers the Public Transportation Authority to promptly notify passengers whenever health-related conditions surpass safe thresholds or if a passenger appears unwell and aiding in contract tracking to minimise disease transmission.

3.10.2 User Story

As a passenger, I want to feel safe using a mean of public transport with regards to public health and sanitation

3.10.3 Description

The "Mitigation of Disease Spread" prioritizes public health and safety, especially during health crises like the COVID-19 pandemic. This innovative service employs a versatile approach to mitigate disease spread within public transport systems. Firstly, it involves the real-time monitoring of indoor environments, particularly focusing on factors like CO2 levels, which indicate ventilation adequacy. Automatic HVAC interventions based on environmental parameters help maintain optimal conditions within vehicles. The inclusion of HEPA filters in HVAC systems ensures the purification of air, while UV-C lamps and aerosols are utilized to disinfect surfaces effectively.

Moreover, thermal cameras are employed to measure occupants' body temperatures, providing health notifications to those who may be unwell. Electronic ticketing not only facilitates efficient passenger management but also aids in contact tracking to hinder disease transmission. Additionally, the service includes occupancy monitoring using either electronic tickets or image recognition, preventing overcrowding and allowing for safe distancing among passengers. By implementing this service, the transportation authority showcases its unwavering commitment to public health and safety while improving the overall commuter experience within public transportation systems.

Some of the advantages of the proposed service are outlined below:

- **Disease Spread Prevention:** By employing cutting-edge technologies and real-time monitoring, the service effectively confronts the spread of diseases within public transportation systems, reducing the risk of outbreaks.

- **Public Health Focus:** The service demonstrates a strong commitment to public health and community well-being, providing passengers with the assurance that their health is a top priority.
- **User-Friendly service:** Passengers can easily access information and health alerts through user-friendly mobile apps and electronic signs, ensuring ease of use.
- **Efficient Contact Tracking:** Electronic ticketing facilitates efficient contact tracking, enabling authorities to identify potential disease clusters or outbreaks, thus minimizing transmission.

3.10.4 Stakeholders

The "Mitigation of Disease Spread" service involves a diverse range of stakeholders. The **Public Transportation Authority** takes the lead in implementing and supervising the service. **Passengers** become direct beneficiaries, empowered with real-time health-related data to make informed decisions about their safety. **Epidemiologists** and **healthcare professionals** utilize the collected data for tracking and controlling the spread of diseases, while **maintenance teams** ensure the reliability of data collection tools. **Data analysts** play a crucial role in deriving insights from the gathered information, and **software developers** are responsible for maintaining the data systems. Collaboration between **local health authorities**, **medical equipment manufacturers**, and **technology providers** is instrumental in integrating and advancing the service. These diverse stakeholders collectively contribute to the effectiveness and efficiency of this service in safeguarding public health.

3.10.1 State of the art analysis

Various strategies have been explored to prevent the spread of COVID-19 in indoor environments. Simsek et al. [9] present a novel application using autonomous vehicles and mobile crowdsensing (MCS) data to enhance the early detection of COVID-19. The method involves collecting MCS data from smart devices using wireless communication technology. An AI engine based on self-organizing feature map (SOFM) optimizes test locations and positioning for autonomous test vehicles. Results show that recruiting 30% of MCS participants allow for accurate prediction of daily use sites and identification of infected individuals, even in the worst-case scenarios, and eventually it enhances epidemic response efforts.

Research conducted by Prem et al. [36] regarding the effects of social distancing on curbing virus transmission found that it has the potential to gradually reduce the intensity of virus outbreaks. The researchers propose practical solutions that leverage surveillance videos along with computer vision, machine learning, and deep learning techniques to accurately assess and monitor compliance with social distancing measures. Punn et al. [37] initially employ the YOLOv3 model to detect humans and subsequently utilize the Deepsort technique for tracking these detected individuals, utilizing both assigned ID information and bounding boxes for precise tracking. In terms of the dataset, the researchers utilized an open image dataset and compared their findings with those obtained using faster-RCNN and SSD.

In another study, Sathyamoorthy et al. [38] use an autonomous robot equipped with an RGB-D and a 2-D lidar sensor to identify social distance in an indoor setting. It can identify human partners in a crowded situation that are not maintaining social distance, or a distance of roughly 2 meters. The system uses a mounted display to warn the appropriate parties to step apart. Additionally, it uses a thermal camera to send thermal images to security staff who can detect COVID symptoms like fever.

In addition to image sensors and autonomous robots, another study investigated acoustic detection algorithms to detect COVID-19 virus, based on signals from breath, speech and cough [39]. They applied transfer learning techniques using bottleneck features in order to address the challenge of limited data. The architectures tested included a CNN, an LSTM and a Resnet50 while a smaller dataset was used to fine-tune using nested k-fold cross validation. The results demonstrated that ResNet50 classifier outperformed the others, achieving an area under the ROC curve (AUC) of 0.982 for cough, followed by and AUC of 0.942 for breathe and 0.923 for speech.

3.10.2 Functional Requirements

In this Section the functional requirements for the "Mitigation of Disease Spread" service are presented. In order to satisfy the particular service needs, the described requirements specify the service's core functionality while taking into account the larger ULTIMO architecture. Table 29 presents in detail the functional requirements of this service.

Table 29: Mitigation of Disease Spread functional requirements.

Req_Id	Description
Req_06_001	The system should continuously monitor interior environmental conditions in real-time.
Req_06_002	The system should be able to perform automatic HVAC interventions based on the environmental parameters.
Req_06_003	The system should be able to measure occupants' body temperature using thermal cameras
Req_06_004	The system should inform passengers that may be unwell in a discrete way.
Req_06_005	Passengers should receive real-time notifications if their body temperature increases.
Req_06_006	The system should be able to keep track of passengers through their electronic tickets.
Req_06_007	The system should be able to count occupants using either electronic tickets or image recognition algorithms.
Req_06_008	Passengers and environmental data should be securely transmitted and stored to prevent unauthorized access.
Req_06_008	The system should be adaptable to different autonomous vehicle models and manufacturers
Req_06_009	The system should maintain a historical log file.

3.10.3 Non-Functional Requirements

In addition to the core functional requirements, the non-functional requirements play a crucial role in ensuring the effectiveness, security and user experience of the proposed service. The non-functional requirements of the "Mitigation of Disease Spread" service are the following:

- **Responsiveness**: The system needs to transmit data to transportation authorities and passengers real-time, minimizing any delays.
- **Scalability**: The service should have the capability to adjust to different conditions including shuttle types, passenger numbers and route variations.

- **Reliability**: The system should have backup mechanisms in case of hardware or software failures.
- **Compliance Regulations**: Concerning passengers‘ data, the service must align with data privacy regulations including GDPR or relevant local data protection laws.
- **User-Friendly**: The interface should provide ease of use and accessibility to the passengers and operators in order to have a user-friendly experience and interaction with the system.
- **Accessibility**: The system should comply with accessibility standards to ensure it is usable by individuals with disabilities.
- **Interoperability**: The service should be able to integrate seamlessly with third-party systems, such as transportation management software or emergency services.

3.10.4 Technical Requirements

In this Section are described the hardware (Table 30), software (Table 31) and interface (Table 32) requirements for the Mitigation of Diseases spread service.

Table 30: Hardware requirements for "Mitigation of Diseases spread" service.

Technical Req_Id	Hardware Requirements	Definition
TReq_06_001	Environmental sensor.	High quality sensor that captures environmental parameters.
TReq_06_002	Thermal camera.	Use of thermal camera to measure occupants’ body temperature.
TReq_06_003	HEPA filters.	Use of HEPA filters combined with UV-C filter disinfection.
TReq_06_004	On-board hardware.	Hardware components for on-board installation, such as power supply systems, processing units and connectivity modules.
TReq_06_005	Vehicle integration kits.	Necessary equipment for seamless integration of sensors into the public transport shuttles.
TReq_06_006	Data Transmission equipment.	5G modems and/ or antennas, Wi-Fi routers, etc. for real-time transmission of the shuttle’s environmental conditions to the ULTIMO DMP.
TReq_06_007	Redundancy mechanisms.	Backup sensors and failover data transmission equipment to ensure system reliability.

Table 31: Software requirements for "Mitigation of Diseases spread" service.

Technical Req_Id	Software Requirements	Definition
TReq_06_008	Data processing software.	Software for efficient collection, processing and management of the environmental and passengers data.
TReq_06_009	User Interfaces.	User-friendly software interface for commuters, operators and local authorities, to access real-time shuttle’s environment conditions, passenger’s data, historical data and system status.
TReq_06_010	Mobile Applications.	Development of mobile apps for passengers to check environment status on smartphones or tablets.
TReq_06_011	AI model.	AI model using as input the environmental data to identify irregular environmental conditions.
TReq_06_012	AI model.	AI model using the thermal camera’s input to identify extremely high passengers’ temperature.
TReq_06_013	Integration APIs.	APIs for seamless integration with third-party systems, such

Technical Req_Id	Software Requirements	Definition
		as transportation management software and emergency services.
TReq_06_014	Remote monitoring software.	Software for remote monitoring the system performance, including alerts and notifications for system issues.
TReq_06_015	Data Security software.	Security software to protect passenger data and ensure compliance with privacy regulations, including encryption and access controls.

Table 32: Interface requirements for "Mitigation of Diseases spread" service

Technical Req_Id	Interface Requirements	Definition
TReq_06_016	User Interfaces.	User-friendly interfaces to interact with the system, including web-based dashboards, mobile app interfaces and operator consoles.
TReq_06_017	API Documentation.	Comprehensive documentation for APIs integration to facilitate third-party system integration.
TReq_06_018	Accessibility Features.	Incorporation of accessibility features in user interfaces to ensure compliance with accessibility standards and regulations.
TReq_06_019	Training Materials.	Creation of training materials for operators, maintenance staff, and system administrators to effectively use and maintain the system.
TReq_06_020	Reporting Interfaces.	Interfaces for generating and accessing reports and analytics, allowing transportation planners to make informed decisions.
TReq_06_021	System Status Alerts.	Real-time alerts and notifications interfaces to inform transportation authorities and operators of system status, data transmission issues, and hardware failures.
TReq_06_022	Passenger Notifications.	Interfaces for sending real-time alerts to passengers in the event of abnormal environmental conditions and rising temperatures via mobile applications, digital displays, or alternative communication channels.

3.10.5 Data Requirements

The "Mitigation of Disease Spread" service relies on the following crucial data requirements for its effective operation (Table 33).

Table 33: Mitigation of Disease Spread data requirements.

Data Req_Id	Data Requirements	Definition
DReq_06_001	Environmental Data.	Raw data collected by environmental sensors.
DReq_06_002	Passengers Data.	Passengers' data regarding their body temperature collected by thermal cameras.
DReq_06_003	Vehicle Information.	Data about each vehicle in the fleet, including vehicle type, capacity, and unique identifiers.
DReq_06_004	Historical Data.	Archived environmental and passengers data for trend analysis.
DReq_06_005	Mobile App Usage.	Data on how passengers use the mobile app, such as login times, search queries and notifications received.

Data Req_Id	Data Requirements	Definition
DReq_06_006	System Configuration.	Configuration settings for sensors, data processing and user interfaces.
DReq_06_007	Geolocation.	Geographic information, including maps, GPS coordinates, and geofencing data to determine vehicle locations.
DReq_06_008	Security Logs.	Logs of security-related activities, including access attempts, authentication and data encryption status.
DReq_06_009	Notifications.	Records of notifications sent to passengers, including the content and delivery status.
DReq_06_010	System Performance Metrics.	Metrics related to system performance, including response times, server load and data transmission efficiency.
DReq_06_011	Accessibility Data.	Data related to the accessibility of user interfaces and services, including compliance with accessibility standards.
DReq_06_012	Data Backups.	Copies of data backups, including timestamps and locations of backup files.
DReq_06_013	Retention Policies.	Policies specifying how long different types of data are retained and when they are purged.

3.11 Service: V2X with Connected (vulnerable) Road Users

3.11.1 Concept of service

The “V2X with Connected (vulnerable) Road Users” service aims to provide a safer and more sustainable transportation ecosystem by enabling seamless communication between AVs, vehicles, roadside units (RSUs) and connected vulnerable road users (VRUs), including pedestrians, cyclists, as well as individuals with disabilities or reduced mobility and orientation. It is the basis for real-time Vehicle-to-Vehicle (V2V), Vehicle-to-Infrastructure (V2I) and (Vehicle-to-Pedestrian) V2P communication, between RSUs, AVs and VRUs that are equipped with the appropriate hardware devices. In favour of passengers and VRUs safety, this capability can be exploited to create a more responsive and predictive transportation system. The target audience is mainly the traffic users and the fleet operators in challenging road conditions, e.g. areas with occluded visibility. This service is categorized as a “Vehicle Service”, as constitutes part of the CAVs operational system.

The “V2X with Connected (vulnerable) Road Users” service creates value by exhibiting a variety of advantages, which include:

- **Reduced accidents** and **increased awareness** of VRUs due to real-time communication between them and AVs, providing safety alerts and collision avoidance warnings.
- **Improved visibility** in poor conditions because of the capability of V2X systems to transmit information about road conditions and hazards (e.g. fog, heavy rain, black ice).
- **Priority for VRUs**, as the AVs navigation system can prioritize VRUs at intersections and pedestrian crossings, ensuring safer passage and reduced traffic delays.

- **Efficient traffic management** as V2X communication technology allows for optimized signal timing and control, which aims to reduce congestion and travel times for all road users.

3.11.1.1 Use Case

Use Case: Enhancing road safety with V2X with Connected (vulnerable) Road Users service.

Actors:

- *Public Transport Authority:* The organization responsible for managing and operating public transportation services.
- *Equipped vulnerable road user:* A non-motorized road user **with mobile V2X equipment**.

Scenario: The Public Transport Authority implements the "V2X with connected (vulnerable) road users" service. The AV fleet is equipped with sensors and On-Board Units (OBUs) which the latter are capable of transmitting and receiving information. Also, the fleet utilizes local dynamic maps and Data Management Platforms (DMPs), while the road infrastructure incorporates Road-Side Units (RSUs) strategically placed at critical locations like intersections and crossings, or in areas with occluded visibility. Additionally, VRUs are also equipped with V2X-compatible devices, which may include onboard units and sensors, Inertial Measurement Unit (IMU), or even personal smart devices. This equipment allows AVs and VRUs to collect and transmit real-time data that is relevant to each other's algorithmic processes, and thus, they are able to transmit warning notifications and respond rapidly with the suggested action to avoid possible accidents and overall improve their safety.

3.11.2 User Story

As a vehicle, interaction between equipped vehicles and equipped cyclists is required.

3.11.3 Description of Service

The object of this service is to address the problem of the interaction between equipped vehicles and VRUs. It is assumed that the AV and the VRU are equipped with V2X communications and software stack as it is described in ETSI C-ITS standards. The underlying concept here is that both devices function as Intelligent Transport System (ITS) stations, they continuously transmit Cooperative Awareness Messages (CAM). These CAMs not only include position information but also encompass their respective motion dynamics. For vehicles, motion parameters are derived from their sensor systems, while for VRUs (e.g. cyclists), these parameters are obtained from onboard sensors, including the internal IMU and magnetic sensors, following appropriate signal conditioning and filtering processes. By following this approach, both the vehicle and the cyclist not only become aware of each other's presence but also possess all the essential information needed to assess potential risks and respond accordingly. This scenario can be implemented in various road and environmental conditions, especially in challenging situations such as heavy rain, fog, or situations with occluded visibility.

3.11.4 Stakeholders

The main "V2X with connected (vulnerable) road users" stakeholders are described. The **Public Transportation Authority** is responsible for the service implementation and surveillance. **Equipped vulnerable road users** and **Passengers** are the main beneficiaries since the service is applied to protect them from traffic accidents and provide them with increased safety feeling. **Infrastructure** and **Vehicle maintenance teams** are responsible for the overall system's operational equipment and repairs. **Software developers** manage the data collection and management systems. **Local government** agencies, **vehicle manufacturers**, and **technology providers** collaborate on integration and improvements. These stakeholders cooperatively ensure the successful outcome of this service.

3.11.5 State of the art analysis

Improving the safety of interconnected systems that involve equipped VRUs and vehicles has drawn the attention of numerous researchers, as it represents a critical issue in the ongoing development of cutting edge V2X communications [40], [41]. In our area of interest, [15] carries out the performance analysis of the two main messaging protocols for the V2X communication with VRUs. In the first one, VRUs can be detected passively by sensors in both vehicles and roadside units. These sensors then share this information through dedicated messages that contain lists of VRUs and other objects. In the second one, VRUs have the capability to actively transmit messages with the aim of alerting nearby road users to their presence. Simulation results suggest that the combination of sensor data sharing and active VRU transmissions exhibits the best performance. Additionally, [42] introduces an innovative Advanced Driver Assistance Systems (ADAS) system designed to prevent accidents that involve motorcyclists and cyclists by utilizing V2V communications. It integrates them into the vehicular network while considering the distinctive characteristics of each group and adapts to enhance their overall safety. As V2X communication is a fast-growing area, additional work can easily be found.

3.11.6 Functional Requirements

In this section, the functional requirements of the "V2X with connected (vulnerable) road users" service are presented (Table 34). The listed requirements describe the main functionalities of the service, taking the overall ULTIMO architecture into consideration, in order to address the needs of the specific service.

Table 34: V2X with connected (vulnerable) road users functional requirements.

Req_Id	Description
Req_10_001	The AV should collect relevant data from the connected VRUs, the traffic and the road conditions.
Req_10_002	The AV should transmit location, speed, traffic and VRUs data to the ULTIMO Data Management Platform.
Req_10_003	The AV should transmit warning messages.
Req_10_004	The VRU should receive relevant data from the connected AVs, the traffic and the road conditions.
Req_10_005	The VRU should transmit location, speed and relevant data to AVs and the ULTIMO Data Management Platform.
Req_10_006	The VRU should transmit warning messages.
Req_10_007	The RSU should collect connected VRUs, traffic and AVs relevant data.

Req_Id	Description
Req_10_008	The RSU should transmit connected VRUs, traffic, road condition and AVs relevant data to the ULTIMO Data Management Platform.
Req_10_009	The RSU should transmit warning messages.
Req_10_010	The AV shall detect the line of sight connected VRUs using OBUs signal detection and processing.
Req_10_011	The AV shall detect other vehicles using sensors.
Req_10_012	The VRU shall detect connected AVs using V2X-compatible hardware devices.
Req_10_013	The VRU shall detect other vehicles using sensors.
Req_10_014	The RSU could estimate the number of nearby pedestrians and vehicles.
Req_10_015	The operator could know the site's areas with high current traffic, bad road condition and occluded visibility.

3.11.7 Non-Functional Requirements

The following non-functional requirements are crucial for ensuring that the "V2X with connected (vulnerable) road users" service operates effectively, securely, and in compliance with relevant standards and regulations while providing a positive user experience. Considering the aforementioned service is still under development, the main non-functional requirements are as follows:

- **Responsiveness**: The system shall provide AVs and VRUs relevant data and transmit warnings and alerts in real-time to ensure accidents avoidance.
- **Scalability**: The service should scale seamlessly to accommodate larger areas, vehicles and VRUs as the transportation network expands.
- **Reliability**: The system should aim for high performance and continuous operation in high traffic circumstances.
- **Data Reliability**: The system must ensure fast and accurate transmission of AVs and VRUs relevant data to the DMP.
- **Interoperability**: The service should be embeddable with third-party systems, such as transportation management software or emergency services. It should be compatible with various types of public transportation vehicles, irrespective of manufacturer or model.
- **Regulatory Compliance**: The system should comply with industry standards and regulatory requirements to data management.

3.11.8 Technical Requirements

For the seamless integration of this service into the ULTIMO ecosystem, a table of technical requirements is provided. The goal is to incorporate this service to the ULTIMO vehicles as effortlessly as possible, given the restrictions of the fleet equipment. These categorized hardware (Table 35), software (Table 36), and interface (Table 37) requirements are essential for the successful implementation and operation of the "V2X with connected (vulnerable) road users" service, ensuring accurate data collection, and reliable system performance and user satisfaction.

Table 35: Hardware requirements for "V2X with connected (vulnerable) road users" service.

Technical Req_Id	Hardware Requirements	Definition
TReq_10_001	VRU detecting sensors and transmitters.	High quality sensors capable of accurate detection of VRUs at the site of application.

Technical Req_Id	Hardware Requirements	Definition
TReq_10_002	On-board hardware for AVs and VRUs.	Hardware components for on-board installation, such as power supply systems, processing units and connectivity modules.
TReq_10_003	Vehicle integration kits.	Necessary equipment for seamless integration of sensors into the public transport shuttles.
TReq_10_004	Data Transmission equipment.	4G/5G modems and/ or antennas, Wi-Fi routers, etc. for real-time AVs and VRUs data transmission to the ULTIMO DMP.
TReq_10_005	Redundancy mechanisms.	Backup sensors and failover data transmission equipment to ensure system reliability.

Table 36: Software requirements for "V2X with connected (vulnerable) road users" service

Technical Req_Id	Software Requirements	Definition
TReq_10_006	Data processing software.	Software for efficient collection, processing and management of the AVs and VRUs data.
TReq_10_007	Integration APIs.	APIs for seamless integration with third-party systems, such as transportation management software and emergency services.
TReq_10_008	Remote monitoring software.	Software for remote monitoring the system performance, including alerts and notifications for system issues.
TReq_10_009	Data Security software.	Security software to protect system's data, including encryption and access controls.

Table 37: Interface requirements for "V2X with connected (vulnerable) road users" service.

Technical Req_Id	Interface Requirements	Definition
TReq_10_010	Training Materials.	Creation of training materials for operators, maintenance staff, and system administrators to effectively use and maintain the system.
TReq_10_011	Reporting Interfaces.	Interfaces for generating and accessing reports and analytics, allowing transportation planners to make informed decisions.
TReq_10_012	System Status Alerts.	Real-time alerts and notifications interfaces to inform transportation authorities and operators of system status, data transmission issues, and hardware failures.
TReq_10_013	Warning Notifications.	Interfaces for transmitting real-time warning notifications to VRUs through Road Side Units

3.11.9 Data Requirements

The following data requirements (Table 38) are essential for the proper functioning of the "V2X with connected (vulnerable) road users" service, enabling accurate passenger counting, data analysis and service optimization, while also addressing privacy and compliance considerations.

Table 38: Data requirements for "V2X with connected (vulnerable) road users" service.

Data Req_Id	Data Requirements	Definition
DReq_10_001	VRUs data.	Data collected by sensors, relevant to VRUs locations.
DReq_10_002	Vehicle Information.	Data about each AV in the fleet, including vehicle type, and unique identifiers.

Data Req_Id	Data Requirements	Definition
DReq_10_005	Real-time Vehicle Occupancy.	Real-time calculations of vehicle occupancy levels based on passenger count data.
DReq_10_009	System Configuration.	Configuration settings for sensors, data processing and interfaces.
DReq_10_010	Geolocation.	Geographic information, including maps, GPS coordinates, and geofencing data to determine vehicle locations.
DReq_10_011	Security Logs.	Logs of security-related activities, including access attempts, authentication and data encryption status.
DReq_10_012	Emergency Data.	Data related to emergency situations, such as emergency break or steering.
DReq_10_013	Notifications.	Records of notifications sent through road infrastructure.
DReq_10_014	System Performance Metrics.	Metrics related to system performance, including response times, server load and data transmission efficiency.
DReq_10_016	Data Backups.	Copies of data backups, including timestamps and locations of backup files.
DReq_10_017	Retention Policies.	Policies specifying how long different types of data are retained and when they are purged.

3.12 Service: V2X with Non-connected (vulnerable) Road Users

3.12.1 Concept of Service

The “V2X with non-connected (vulnerable) road users” service aims to address the issue of interaction between AVs fleet and Vulnerable Road Users (VRUs) which are not equipped with V2X communications software. Non-equipped VRUs, such as pedestrians and cyclists, exchange messages through Vehicle-to-Infrastructure communications (V2I). The goal is to create a reliable system within AVs transmit and real-time information for the detected VRUs, whereas VRUs receive messages by the Road Infrastructure, including warnings, alerts etc. The target audience is mainly the PTOs, PTA and the VRUs. This service is categorised as a “Vehicle Service”.

The advantages of “V2X with non-connected (vulnerable) road users” include:

- Reliable and continuous real-time interactions between vehicles and pedestrians/cyclists.
- Enhancement of the vehicle awareness through V2I with relevant data about the location of VRUs for in-time proper response (braking, steering etc.).
- Enhancement of pedestrians’ and cyclists’ awareness through warnings/alerts by the proper messages from the Road Infrastructure (i.e. flashing panel).
- Overall contribution to road safety with the utilization of recent technologies and advancements in V2X communications, AI, machine learning etc.

3.12.1.1 Use Case

Use Case: Enhancing road safety with “V2X with non-connected (vulnerable) road users” service.

Actors:

- *Public Transport Authority:* The organization responsible for managing and operating public transportation services.
- *Non-equipped vulnerable road user:* A non-motorized road user with no mobile V2X equipment.

Scenario:

The Public Transport Authority implements the "V2X with non-connected (vulnerable) road users" service. Their AV fleet is equipped with local dynamic maps and Data Management Platforms (DMPs), while the Road Infrastructure is implemented with Road Side Units (RSUs) in key points such as crossings and intersections, which are equipped with proper sensors and AI and DL algorithms, able to transmit warnings and alerts. Through this equipment, vehicles collect real-time data relevant to pedestrians and cyclists, and thus, they are able to respond rapidly with the proper actions to avoid accidents. VRUs are notified on time, through proper messages by the road infrastructure, about incoming vehicles.

With the implementation of the "V2X with non-connected (vulnerable) road users" service, the transportation authority can provide a safer public transport service for pedestrians and cyclists.

3.12.2 User Story

As a vehicle, interaction between equipped vehicles and non-equipped VRUs (pedestrians and cyclists) is required.

3.12.3 Description of service

This service's object is to address the interaction between equipped vehicles and non-equipped VRUs (pedestrians and cyclists). Through V2X C-ITS connectivity between vehicles and road infrastructure (V2I), proper messages are exchanged, enhancing vehicles, and vulnerable users' awareness. The road infrastructure involves Road Side Units (RSUs), equipped with sensors like Camera, LIDAR, RADAR and DMP software, while vehicles possess proper software and communications equipment for data collection and management. Main beneficiaries of the service are VRUs, by increasing their safety feeling and protection. In conventional public transport, the safety of vulnerable road users is limited to traffic signs.

3.12.4 Stakeholders

The main “V2X with non-connected (vulnerable) road users” stakeholders are described. The **Public Transportation Authority** is responsible for the service implementation and surveillance. **Non-equipped vulnerable road users** are the main beneficiaries since the service is applied to protect them from traffic accidents and provide them with increased safety feeling. **Infrastructure and Vehicle maintenance teams** are responsible for the system’s equipment operation and repairs. **Software developers** manage the data collection and management systems. **Local government** agencies, **vehicle manufacturers**, and **technology providers** collaborate on integration and improvements. These stakeholders cooperatively ensure the successful outcome of this service.

3.12.5 State of the art analysis

Safety of non-connected with V2X vulnerable road users has attracted many researchers interest, as an important issue to address for V2X communications in development. In [16] a strategy for VRUs safety is developed considering both centralized and decentralized system architectures. Both cases if equipped VRUs and passive VRUs are simulated within a 3D multi-sensor environment. Authors in [43] present an intersection control strategy taking into consideration the detected non-connected pedestrians by sensors (cameras). A First-Come-First-Serve policy is applied with cooperation of AVs, traffic signs and sensors. Simulations are performed using a microsimulation platform. In [44] a strategy using Collective Perception (i.e., a technology that enables RSUs with information sharing with other V2X system) is applied for AVs to “see” non-line-of-sight pedestrians.

3.12.6 Functional Requirements

In this section, the functional requirements of the “V2X with non-connected (vulnerable) road users” service are presented (Table 39). The listed requirements describe the main functionalities of the service, taking the overall ULTIMO architecture into consideration, in order to address the needs of the specific service.

Table 39: V2X with non-connected (vulnerable) road users functional requirements.

Req_Id	Description
Req_11_001	The vehicle should collect non-connected VRUs and traffic relevant data.
Req_11_002	The vehicle should transmit location, speed, traffic and VRUs data to the ULTIMO Data Management Platform.
Req_11_003	The vehicle should transmit warning messages.
Req_11_004	The RSU should collect non-connected VRUs, traffic and AVs relevant data.
Req_11_005	The RSU should detect vehicles and pedestrians through cameras and active sensors.
Req_11_006	The RSU should transmit warning messages.
Req_11_007	The RSU should transmit non-connected VRUs, traffic and AVs relevant data to the ULTIMO Data Management Platform.
Req_11_008	The vehicle shall detect the line of sight VRUs using sensors.
Req_11_009	The vehicle shall detect other line of sight vehicles using sensors or V2V if available.
Req_11_010	The operator could know the site’s areas with high current traffic.
Req_11_011	The RSU could estimate the number of nearby pedestrians and vehicles.
Req_11_012	The vehicle shall react on a collision risk detected by the infrastructure.

3.12.7 Non-Functional Requirements

The following non-functional requirements are crucial for ensuring that the “V2X with non-connected (vulnerable) road users” service operates effectively, securely, and in compliance with relevant standards and regulations while providing a positive user experience. Taking into account that the aforementioned service is still under development, the main non-functional requirements are as follows:

- **Responsiveness**: The system shall provide VRUs with relevant data and transmit warnings and alerts in real-time to ensure accidents avoidance.
- **Scalability**: The service should scale seamlessly to accommodate larger areas, vehicles and VRUs as the transportation network expands.

- **Reliability**: The system should aim for high performance and continuous operation in high traffic circumstances.
- **Data Reliability**: The system must ensure fast and accurate VRUs relevant data to the DMP.
- **Interoperability**: The service should be embeddable with third-party systems, such as transportation management software or emergency services. It should be compatible with various types of public transportation vehicles, irrespective of manufacturer or model.
- **Regulatory Compliance**: The system should comply with industry standards and regulatory requirements to data management.

3.12.8 Technical Requirements

For the seamless integration of this service into the ULTIMO ecosystem, a table of technical requirements is provided. The goal is to incorporate this service to the ULTIMO vehicles as effortlessly as possible, given the restrictions of the fleet equipment. These categorized hardware (Table 40), software (Table 41), and interface (Table 42) requirements are essential for the successful implementation and operation of the "V2X with non-connected (vulnerable) road users" service, ensuring accurate data collection, and reliable system performance and user satisfaction.

Table 40: Hardware requirements for "V2X with non-connected (vulnerable) road users" service.

Technical Req_Id	Hardware Requirements	Definition
TReq_11_001	VRU detecting sensors.	High quality sensors capable of accurate detection of VRUs at the site of application.
TReq_11_002	On-board hardware.	Hardware components for on-board installation, such as power supply systems, processing units and connectivity modules.
TReq_11_003	Vehicle integration kits.	Necessary equipment for seamless integration of sensors into the public transport shuttles.
TReq_11_004	Data Transmission equipment.	5G modems and/ or antennas, Wi-Fi routers, etc. for real-time AVs and VRUs data transmission to the ULTIMO DMP.
TReq_11_005	Redundancy mechanisms.	Backup sensors and failover data transmission equipment to ensure system reliability.

Table 41: Software requirements for "V2X with non-connected (vulnerable) road users" service

Technical Req_Id	Software Requirements	Definition
TReq_11_006	Data processing software.	Software for efficient collection, processing and management of the Avs, Infrastructure and non-connected VRU related data.
TReq_11_007	Integration APIs.	APIs for seamless integration with third-party systems, such as transportation management software and emergency services.
TReq_11_008	Remote monitoring software.	Software for remote monitoring the system performance, including alerts and notifications for system issues.
TReq_11_009	Data Security software.	Security software to protect system's data, including encryption and access controls.

Table 42: Interface requirements for “V2X with non-connected (vulnerable) road users” service.

Technical Req_Id	Interface Requirements	Definition
TReq_11_010	Training Materials.	Creation of training materials for operators, maintenance staff, and system administrators to effectively use and maintain the system.
TReq_11_011	Reporting Interfaces.	Interfaces for generating and accessing reports and analytics, allowing transportation planners to make informed decisions.
TReq_11_012	System Status Alerts.	Real-time alerts and notifications interfaces to inform transportation authorities and operators of system status, data transmission issues, and hardware failures.
TReq_11_013	Warning Notifications.	Interfaces for transmitting real-time warning notifications to VRUs through Road Side Units

3.12.9 Data Requirements

The following data requirements (Table 43) are essential for the proper functioning of the "V2X with non-connected (vulnerable) road users" service, enabling accurate passenger counting, data analysis and service optimization, while also addressing privacy and compliance considerations.

Table 43: Data requirements for “V2X with non-connected (vulnerable) road users” service.

Data Req_Id	Data Requirements	Definition
DReq_11_001	VRUs data.	Data collected by sensors, relevant to VRUs locations.
DReq_11_002	Vehicle Information.	Data about each vehicle in the fleet, including vehicle type, and unique identifiers.
DReq_11_003	Real-time Vehicle Occupancy.	Real-time calculations of vehicle occupancy levels based on passenger count data.
DReq_11_004	System Configuration.	Configuration settings for sensors, data processing and interfaces.
DReq_11_005	Geolocation.	Geographic information, including maps, GPS coordinates, and geofencing data to determine vehicle locations.
DReq_11_006	Security Logs.	Logs of security-related activities, including access attempts, authentication and data encryption status.
DReq_11_007	Emergency Data.	Data related to emergency situations, such as emergency break or steering.
DReq_11_008	Notifications.	Records of notifications sent through road infrastructure.
DReq_11_009	System Performance Metrics.	Metrics related to system performance, including response times, server load and data transmission efficiency.
DReq_11_010	Data Backups.	Copies of data backups, including timestamps and locations of backup files.
DReq_11_011	Retention Policies.	Policies specifying how long different types of data are retained and when they are purged.

3.13 Service: Predictive Maintenance

3.13.1 Concept of Service

The purpose of the "Predictive Maintenance" service, which is categorized as a “Vehicle Service”, is to enhance the performance and longevity of vehicles. It achieves this by utilizing data, from sensors and employing advanced software algorithms. The main goal is to anticipate issues like battery failures, mechanical wear, or other critical maintenance requirements before they result in vehicle breakdowns. By monitoring and analysing real time sensor data, this service provides insights for vehicle owners, fleet managers and maintenance teams. It enables them to make well-informed maintenance decisions ensuring that vehicles remain in working order. The "Predictive Maintenance" service is a tool for vehicles as it prioritizes reliability while also considering cost effective maintenance strategies. Its benefits extend to stakeholders such, as vehicle manufacturers, fleet operators and individual vehicle owners ultimately contributing to a more dependable and efficient transportation system.

The “Predictive Maintenance” service creates value by exhibiting a variety of advantages, which include:

- Enhance vehicle reliability and reduced downtime, resulting in improved operational efficiency.
- Proactive identification of potential maintenance issues before they cause vehicle breakdowns.
- Cost savings through optimized maintenance schedules and resource allocation.
- Prolonged vehicle lifespan, minimizing the need for premature replacements.
- Enhanced overall fleet management, leading to better resource allocation and route optimization,
- Improved safety for passengers and drivers by preventing unexpected mechanical failures.

3.13.1.1 Use Case

Use Case: Optimizing Public Transportation with Automated Passenger Presence.

Actors:

- *Public Transportation Authority:* The organization responsible for managing and operating public transportation services.
- *Passengers:* Commuters who use public transportation services.

Scenario:

The Public Transportation Authority implements the "Automated Passenger Presence" service, equipping their buses and trains with an array of sophisticated sensors and monitoring devices that continually collect data on various vital components like engines, brakes, batteries, and more. The real-time data streaming from these sensors feeds into a cutting-edge predictive maintenance platform. This platform employs complex algorithms to scrutinize the data, searching for patterns, anomalies, and early warning signs. Whenever the system identifies a potential issue, it immediately triggers predictive maintenance alerts. These alerts are thoughtfully directed to the maintenance team, fleet managers, and even the individual vehicle owner if applicable. With these invaluable alerts in hand, maintenance teams can take proactive action. They schedule maintenance or repairs pre-emptively, warding off breakdowns before they can occur. This might involve replacing a battery displaying early signs of degradation or addressing an emerging engine problem.

By utilising the "Predictive Maintenance" service, this smart vehicle manufacturer ensures a fleet that is not only more reliable but also more cost-effective. They provide enhanced value to both their customers and their own operations.

3.13.2 User Story

As a fleet manager, I often find myself worrying about unexpected breakdowns and the inconvenience it causes to both my team and our passengers. I wish for a solution that can be like an early warning system for our vehicles. Imagine the relief if I could receive timely alerts about potential maintenance issues, allowing me to schedule repairs before a breakdown occurs.

3.13.3 Description of Service

The "Predictive Maintenance" service addresses the evolving needs of vehicle operators and owners in the smart transportation area. It employs advanced technology to predict potential maintenance issues, preventing breakdowns and ensuring reliable vehicle performance. This proactive approach minimizes operational disruptions, reduces downtime, and results in significant cost savings. Passengers benefit from a smoother and more dependable commuting experience. It is a transformative solution that keeps vehicles in peak condition, enhancing the efficiency and reliability of modern transportation.

3.13.4 Stakeholders

The "Predictive Maintenance" service involves a diverse range of stakeholders. **Fleet operators** and **maintenance teams** play central roles in implementing and utilizing the service, ensuring the reliability and longevity of their vehicles. **Vehicle owners**, including both private individuals and commercial entities, benefit directly from the service's proactive approach to vehicle care. **Technology providers** and software developers supply the essential tools and software needed for effective predictive maintenance. **Data analysts** interpret the collected data, extracting valuable insights to inform maintenance decisions. **Vehicle manufacturers** may integrate predictive maintenance systems into their vehicles, while government agencies may promote its use for improved road safety and environmental benefits. **Insurance companies** also take an interest in its impact on policies and premiums. Ultimately, **passengers** experience the indirect advantages of the service through fewer disruptions and delays, contributing to a smoother and more reliable transportation experience. These stakeholders collectively shape the success and efficiency of predictive maintenance in the realm of vehicle maintenance and transportation.

3.13.5 State of the art analysis

Several studies have been carried out that tackle the issue of predictive maintenance. Ameeth Kanawaday, Aditya Sane et al. [45] demonstrated the application of AutoRegressive Integrated Moving Average (ARIMA) forecasting using time series data from sensors on a Slitting Machine in manufacturing. By harnessing Industrial Internet of Things (IIoT) technology, it predicts potential failures and quality defects, enhancing manufacturing processes. This utilization of Machine Learning in IoT offers cost-effective maintenance, quality management, and improved manufacturing outcomes. The authors of [46] explored cutting-edge tools, technologies, and infrastructure, including AI, that facilitate the transition from traditional production scheduling and time-based maintenance to intelligent scheduling and predictive maintenance, thereby enabling the evolution towards smart manufacturing. In [13]

Alessandro Massaro et al., presented a smart Electronic Control Unit (ECU) for bus fleet monitoring, utilizing IoT and AI with an MLP-ANN model to predict maintenance based on driver behavior. Key performance Indicators (KPIs) are established using data mining, correlating driver actions with engine stress. The model demonstrates impressive performance with a low Mean Square Error (MSE) of approximately 10^-3. Finally, in [14] James C.Chen et al. utilized Long Short-Term Memory (LSTM) networks combined with empirical mode decomposition to predict battery faults. Their experimental findings proved that State of Health (SOH) and Remaining Use of LIFE (RUL) of lithium batteries can be accurately predicted with the proposed hybrid method.

3.13.6 Functional Requirements

In this section, the functional requirements of the “Predictive Maintenance” service are presented (Table 44). The listed requirements describe the main functionalities of the service, taking the overall ULTIMO architecture into consideration, to address the needs of the specific service.

Table 44: Predictive Maintenance functional requirements.

Req_Id	Description
Req_12_001	The vehicle must gather real-time data from various vehicle sensors and systems, including engine performance, tire pressure, brake health, battery health and more
Req_12_002	The vehicle should employ advanced data analysis techniques and algorithms to process and interpret the collected data, identifying patterns and anomalies.
Req_12_003	The vehicle should provide timely alerts and notifications to maintenance teams, fleet operators when potential issues are detected.
Req_12_004	The vehicle should utilise predictive models to forecast when specific components or systems may require maintenance.
Req_12_005	The operator shall have secure access to generated maintenance insights, enabling them to make informed decisions about fleet maintenance.
Req_12_006	The operator must be able to communicate with the predictive maintenance system, allowing for efficient scheduling of maintenance tasks and resources.

3.13.7 Non-Functional Requirements

The following non-functional requirements are crucial for ensuring that the "Predictive Maintenance" service operates effectively, securely, and in compliance with relevant standards and regulations while providing a positive user experience. Considering that the service is still under development, the main non-functional requirements are as follows:

- **Responsiveness**: The system shall provide real-time passenger occupancy data with minimal latency, ensuring passengers receive timely information.
- **Scalability**: The service should scale seamlessly to accommodate an increasing number of passengers, vehicles, and routes as the transportation network expands.
- **Reliability**: The system should aim for high availability, with minimal downtime, especially during peak commuting hours. Redundancy mechanisms should be in place for critical components to ensure continuous operation even in the event of hardware or software failures.
- **Privacy**: Passenger data should be anonymized to protect individual privacy while still providing aggregated occupancy Information. The service must adhere to data privacy regulations, such as GDPR, and maintain compliance with industry-specific standards.

- **User-Friendly**: User interfaces should be intuitive and accessible to passengers, transportation authorities and operators, while promoting ease of use.
- **Accessibility**: The system should comply with accessibility standards to ensure it is usable by individuals with disabilities.
- **Data Reliability**: The system must maintain the integrity of passenger count data, ensuring it is accurate and consistent. Regular data backups and a robust data recovery plan should be in place to prevent data loss.
- **Interoperability**: The service should be able to integrate seamlessly with third-party systems, such as transportation management software or emergency services. It should be compatible with various types of public transportation vehicles, irrespective of manufacturer or model.
- **Data Scalability**: The database system should scale to handle the growing volume of passenger data efficiently.
- **Regulatory Compliance**: The system should comply with industry standards and regulatory requirements related to passenger counting and data management.

3.13.8 Technical Requirements

For the seamless integration of this service into the ULTIMO ecosystem, a table of technical requirements is provided. The goal is to incorporate this service to the ULTIMO vehicles as effortlessly as possible, given the restrictions of the fleet equipment. These categorized hardware (Table 45), software (Table 46), and interface (Table 47) requirements are essential for the successful implementation and operation of the "Predictive Maintenance" service, ensuring accurate data collection, and reliable system performance and user satisfaction.

Table 45: Hardware requirements for "Predictive Maintenance" service.

Technical Req_Id	Hardware Requirements	Definition
TReq_12_001	Sensors.	High quality sensors capable of capturing data from various vehicle components, such as engines, brakes, batteries, and temperature sensors.
TReq_12_002	Data Storage.	Data storage hardware, including servers or cloud-based solutions, is necessary to store and manage the vast amount of data generated by sensors.
TReq_12_003	Computing Power.	Sufficient computing power, such as servers or edge computing devices, is required to process and analyse data in real-time.
TReq_12_004	Environmental Sensors.	Environmental sensors may be required to monitor conditions that could affect vehicle components, such as temperature and humidity sensors.
TReq_12_005	Diagnostic Tools.	Diagnostic tools and equipment for assessing the physical condition of vehicle components.

Table 46: Software requirements for "Predictive Maintenance" service.

Technical Req_Id	Software Requirements	Definition
TReq_12_006	Data processing software.	Software for efficient collection, processing and management of the sensor data.
TReq_12_007	Model Evaluation and Performance Monitoring.	Implement software for the evaluation of AI models and monitoring their accuracy over time.

Technical Req_Id	Software Requirements	Definition
TReq_12_008	AI Algorithms.	Integrate machine learning and AI libraries to build predictive models that can identify maintenance patterns and anomalies in the data.
TReq_12_009	Alert and Notification System.	Create an alerting software that generates timely notifications for maintenance teams and operators when potential issues are detected by the AI models.
TReq_12_010	Visualization and Reporting.	Develop software for creating interactive dashboards and reports that allow users to visualize predictive maintenance insights and historical data.
TReq_12_011	Predictive Maintenance Scheduler.	Design a scheduling software module that can recommend, and schedule maintenance tasks based on AI predictions and maintenance priorities.
TReq_12_012	Data Security software.	Security software to protect passenger data and ensure compliance with privacy regulations, including encryption and access controls.

Table 47: Interface requirements for "Predictive Maintenance" service.

Technical Req_Id	Interface Requirements	Definition
TReq_12_013	User Interfaces.	User-friendly interfaces to interact with the system, including web-based dashboards, mobile app interfaces and operator consoles.
TReq_12_014	API Documentation.	Comprehensive documentation for APIs integration to facilitate third-party system integration.
TReq_12_015	Accessibility Features.	Incorporation of accessibility features in user interfaces to ensure compliance with accessibility standards and regulations.
TReq_12_017	Reporting and Alert Interfaces.	Provide real-time updates and notifications on the dashboard to alert operators to maintenance predictions and issues as they occur.
TReq_12_018	Maintenance Scheduler.	Implement an intuitive scheduling interface that enables users to view, modify and schedule maintenance tasks based on predictive insights.
TReq_12_019	Interactive Visualizations.	Include interactive data visualizations, such as charts and graphs, to help users interpret maintenance data and trends easily.

3.13.9 Data Requirements

The following data requirements (Table 48) are essential for the proper functioning of the "Predictive Maintenance" service, enabling accurate passenger counting, data analysis and service optimization, while also addressing privacy and compliance considerations.

Table 48: Data requirements for "Predictive Maintenance" service.

Data Req_Id	Data Requirements	Definition
DReq_12_001	Sensor Data.	Collect real-time data from various vehicle sensors, such as temperature, pressure, vibration, and component health sensors, to monitor the condition of critical vehicle components.

Data Req_Id	Data Requirements	Definition
DReq_12_002	Historical Maintenance Data.	Gather historical maintenance records, including repair and replacement history.
DReq_12_003	Failure and Anomaly Data.	Record instances of component failures and anomalies, including root causes and impact.
DReq_12_004	Operational Data.	Capture operational data, such as vehicle usage patterns, mileage, and load conditions.
DReq_12_005	Sensor Calibration Data.	Include data related to sensor calibration and accuracy.
DReq_12_006	Environmental Data.	Collect environmental data, such as temperature, humidity, and atmospheric conditions.
DReq_12_007	Maintenance Task Data.	Record details of maintenance tasks performed, including the type of maintenance, time taken, and associated costs.
DReq_12_008	Diagnostic Data.	Gather diagnostic data generated by on-board diagnostic systems and diagnostic trouble codes.
DReq_12_009	Sensor Health Data.	Monitor the health and status of sensors themselves, including sensor calibration data and sensor failure logs
DReq_12_010	Maintenance Actions Data.	Document actions taken in response to maintenance predictions, including scheduling, execution, and outcomes.
DReq_12_011	Time-Stamped Data.	Ensure all data is time-stamped accurately to track data changes and create time series data for analysis
DReq_12_012	Data Integration.	Integrate data from various sources into a unified data repository to support AI model training and analysis
DReq_12_013	Annotated Data.	Annotate data with labels indicating the presence or absence of maintenance events
DReq_12_016	Data Backups.	Copies of data backups, including timestamps and locations of backup files.

3.14 Service: Optimizing Battery Health

3.14.1 Concept of Service

Possessing a battery that endures for multiple years renders the vehicle a more environmentally friendly and sustainable option. Lithium-Ion batteries, which are prevalent in most electric vehicles, exhibit extended longevity when maintained within a specified charge range, ideally between 30% and 80%. The objective of the “Optimizing Battery Health” service, which is categorized as a “Vehicle Service”, is for the vehicle to strike the perfect balance between distance covered and battery wear. When connected to a power source for extended periods, the battery will charge up to 80%, and then, as the time of use approaches, it will top up to 100%. This approach minimizes the duration the battery remains fully charged, while simultaneously maximizing the distance covered. Additionally, it prevents the battery charge from plummeting below 30%.

3.14.1.1 Use Case

Use Case: Optimizing Battery Health with Automated Battery Monitoring.

Actors:

- *Electric Vehicle Fleet Management:* The organization responsible for managing and maintaining a fleet of electric vehicles.
- *Electric Vehicle Drivers:* Individuals who operate the electric vehicles within the fleet.

Scenario:

The Electric Vehicle Fleet Management introduces the "Optimizing Battery Health" service, outfitting their vehicles with advanced battery health sensors to gather real-time battery performance and health data. Electric Vehicle Drivers can view this data through onboard displays, mobile apps, or the management's portal, allowing them to make informed decisions about charging and usage. The management uses the data to optimize charging schedules, predict maintenance needs, and allocate resources efficiently. It produces reports and historical data for long-term planning and can extend the service to new vehicle models and emerging battery technologies, ensuring a prolonged and optimal battery lifespan.

By implementing the "Optimizing Battery Health" service, the fleet management can offer a more efficient and driver-friendly electric vehicle experience while optimizing their operations based on real-time battery health data.

3.14.2 User Story

An electric vehicle should be equipped with a battery that endures for multiple years before necessitating a replacement.

3.14.3 Description of Service

“Optimizing Battery Health” service presents an all-encompassing strategy for enhancing battery health. This service combines state-of-the-art monitoring and diagnostic measures, ideal charging procedures, temperature control, best practice guidelines, software enhancements, energy-saving frameworks, and the advantages of machine learning. Its primary objective is to furnish users with valuable insights, actionable recommendations, and timely alerts, all geared towards prolonging the life and boosting the efficiency of their vehicle's battery.

3.14.4 Stakeholders

The “Optimizing Battery Health” Optimization service for electric vehicle fleet management involves a broad spectrum of stakeholders, each with their specific goals. Owners and investors of **logistics companies** are focused on cost-effectiveness and increased profits. In contrast, **fleet managers** and **operational staff** prioritize streamlined fleet operations and minimizing halts. **Maintenance teams** and **vehicle technicians** appreciate fewer maintenance duties, and **electric vehicle drivers** expect dependable vehicles with optimal charge. **Environmental enthusiasts**, **regulatory bodies**, and **charging infrastructure entities** emphasize green practices and effective infrastructure use. **Battery producers**, **data specialists**, and **scholars** see the potential in battery performance data and research opportunities. While **customers** and **end-users** enjoy enhanced services indirectly, **governmental agencies** emphasize energy conservation and reduced emissions. Together, these stakeholders influence the service's widespread acceptance, each driven by their distinct aspirations related to fleet green practices, cost savings, environmental considerations, and adhering to regulations.

3.14.5 State of the art analysis

Optimizing Battery Health incorporates machine learning to predict and improve battery performance, distinguishing it from traditional methods. The incorporation of instantaneous diagnostics, proactive maintenance, and customized battery usage patterns epitomizes the cutting edge in battery health optimization. Various studies have addressed different aspects of Electric Vehicle (EV) sustainability.

Schoch J., Gaerttner J. et al. [47] introduced a continuous quadratic programming model to derive battery life optimal charging (OPT) and found that the OPT strategy could more than double the expected battery life compared to simple recharging activities. Another research conducted by Wei, Y., Yao, Y. et al. [48] involved a multi-year cycle study of commercial 24 Ah case batteries with Li(NiMnCo)O2 (NCM) cathode. This study established a non-linear degradation model with calendar and cyclic aging to evaluate the battery aging cost under different unmanaged charging (V0G) and vehicle-to-grid (V2G) scenarios. Han, K., Nguyen, T. et al. [49] proposed a computationally tractable model prediction control (MPC) for real-time implementation in autonomous electric vehicles and confirmed its effectiveness in various driving conditions. A study conducted by Kosuru, V. S. R., and Kavasseri Venkitaraman, A. [50] suggested a deep learning-based system for battery data detection and classification of faulty battery sensor and transmission information, which showed superior performance compared to traditional approaches.

Within the context of the AVENUE H2020 project, a five-week energy data collection was conducted to examine and interpret the patterns and trends in battery levels of autonomous vehicles (AVs). The collected data encompassed various parameters such as the timestamp of recording, geographical location, battery status, current battery level, details of the route, speed of the AV, distance covered, and navigation mode. Moreover, the researchers observed that multiple external factors, including the passenger count, potential inclines along the route, and the use of air conditioning, could influence the energy consumption of an AV. Finally, the study displayed the results and assessment criteria of energy consumption prediction using the XGBoost forecasting model, demonstrating that the model nearly succeeded in mirroring the actual battery level patterns.

3.14.6 Functional Requirements

In this section, the functional requirements of the “Optimizing Battery Health” service are presented (Table 49). The listed requirements describe the main functionalities of the service, taking the overall ULTIMO architecture into consideration, in order to address the needs of the specific service.

Table 49: Optimizing Battery Health functional requirements.

Req_Id	Description
Req_13_001	The vehicle shall collect the number of passengers at any given time.
Req_13_002	The vehicle shall monitor the parameters of battery in real time.
Req_13_003	The vehicle shall monitor the thermal parameters of battery in real time.
Req_13_004	The vehicle shall provide alerts for battery status.
Req_13_005	The vehicle shall monitor the time duration it operates.

Req_Id	Description
Req_13_006	The vehicle shall monitor the total weight at any given time.
Req_13_007	The vehicle shall monitor the distance covered.
Req_13_008	The vehicle shall monitor the speed of the AV in real time.

3.14.7 Non-Functional Requirements

The following non-functional requirements are crucial for ensuring that the "Optimizing Battery Health" service operates effectively, securely, and in compliance with relevant standards and regulations while providing a positive user experience. Taking into account that the aforementioned service is still under development, the main non-functional requirements are as follows.

- **Multi-Sensor Data Processing**: The system shall be capable of processing and storing data from multiple sensors simultaneously.
- **Data Encryption**: The system shall ensure that all data collected and transmitted is encrypted.
- **Access Authentication**: The system shall have authentication mechanisms to prevent unauthorized access.
- **Alerts**: The system shall provide clear and understandable alerts to the operator.
- **Diagnostics & Logging**: The system shall provide logs and diagnostics for troubleshooting and maintenance.
- **Environmental Resilience**: The system shall operate effectively under various environmental conditions such as temperature, humidity, and vibration.

3.14.8 Technical Requirements

In this section, the technical requirements of the “Optimizing Battery Health” service are presented (Table 50, Table 51, and Table 52). The listed requirements describe the sensors that must be available for the needs of the specific service.

Table 50: Hardware requirements for "Optimizing Battery Health” service.

Technical Req_Id	Hardware Requirements	Definition
TReq_13_001	Battery health sensors.	High-quality sensors capable of accurate detection and monitoring of battery parameters such as voltage, current, SOC, and SOH.
TReq_13_002	On-board hardware.	Hardware components for on-board installation, such as power supply systems, processing units, and connectivity modules for battery monitoring.
TReq_13_003	Thermal monitoring kits.	Equipment for seamless integration of thermal sensors to monitor battery temperature.
TReq_13_004	Data Transmission equipment.	5G modems and/or antennas, Wi-Fi routers, etc., for real-time battery data transmission.
TReq_13_005	Weight measurement equipment.	High precision weight sensors for accurate vehicle weight measurement.
TReq_13_006	GPS system.	Advanced GPS system for accurate tracking of vehicle location and distance travelled.
TReq_13_007	Passenger counting	Sensors to detect and record the number of passengers

Technical Req_Id	Hardware Requirements	Definition
	system.	entering and exiting the vehicle in real time.
TReq_13_008	Speedometer.	Device to continuously record the speed of the vehicle.

Table 51: Software requirements for "Optimizing Battery Health" service.

Technical Req_Id	Software Requirements	Definition
TReq_13_009	Battery data processing software.	Software for efficient collection, processing, and management of battery health data.
TReq_13_010	User Interfaces.	User-friendly software interface for drivers and fleet managers to access real-time battery health, historical data, and system status.
TReq_13_011	Mobile Applications.	Development of mobile apps for drivers to check battery health and status on smartphones or tablets.
TReq_13_012	Data analytics tools.	Data analytics software for fleet managers and analysts to derive insights from battery data and predict maintenance needs.
TReq_13_013	Integration APIs.	APIs for seamless integration with third-party systems, such as fleet management software and maintenance services.
TReq_13_014	Remote monitoring software.	Software for remote monitoring of battery health, including alerts and notifications for potential issues.
TReq_13_015	Data Security software.	Security software to protect battery data and ensure compliance with privacy regulations, including encryption and access controls.

Table 52: Interface requirements for "Optimizing Battery Health" service.

Technical Req_Id	Interface Requirements	Definition
TReq_13_16	User Interfaces.	User-friendly interfaces to interact with the battery monitoring system, including web-based dashboards, mobile app interfaces, and fleet manager consoles.
TReq_13_17	API Documentation.	Comprehensive documentation for APIs integration to facilitate third-party system integration.
TReq_13_18	Accessibility Features.	Interfaces for generating and accessing reports and analytics, allowing fleet managers to make informed decisions regarding battery health.
TReq_13_19	Training Materials.	Creation of training materials for drivers, maintenance staff, and system administrators to effectively use and maintain the battery monitoring system.
TReq_13_20	Reporting Interfaces.	Interfaces for generating and accessing reports and analytics, allowing fleet managers to make informed decisions regarding battery health.
TReq_13_21	System Status Alerts.	Real-time alerts and notifications interfaces to inform fleet managers and drivers of battery health, potential issues, and maintenance needs.
TReq_13_22	Passenger Notifications.	Interfaces for sending real-time battery health notifications to drivers through mobile apps, electronic signs, or other communication channels.

3.14.9 Data Requirements

In this section, the data requirements of the “Optimizing Battery Health” service are presented (Table 53). The listed requirements describe the data that must be available for the needs of the specific service.

Table 53: Optimizing Battery Health data requirements.

Data Req_Id	Description
DReq_13_001	Passenger count data.
DReq_13_002	Real-time data on battery voltage, current, state of charge (SOC), and state of health (SOH).
DReq_13_003	Real-time data on battery temperature.
DReq_13_004	Data on predefined criteria for battery alerts such as low SOC, high temperature, etc.
DReq_13_005	Data on vehicle operation start and end times.
DReq_13_006	Real-time data on vehicle weight.
DReq_13_007	Real-time data on distance traveled.
DReq_13_008	Real-time data on vehicle speed.

3.15 Service: Manage Incident Resolution

3.15.1 Concept of Service

The “Manage Incident Resolution” service is categorized as an “Operator Service” and aims to create an advanced system for public transportation that uses software to automatically detect, recognise and visualise the incidence of abnormal events regarding the autonomous vehicle operation. It provides real-time notification to intervention teams, supporting the transportation centre to identify and respond to emergencies faster and efficiently. The target audience is mainly the fleet operators and the passengers that use Public Transport methods.

The “Manage Incident Resolution” service creates value by exhibiting a variety of advantages, which include:

- Real-time, accurate, and continuous incident identification and categorization.
- Visualisation of the position of the incident.
- Assign an intervention team regarding the categorised event.

3.15.1.1 Use Case

Use Case: Supporting public transportation safety by identifying unexpected incidents, visualising the incident position and assigning the corresponding intervention team.

Actors:

- *Public Transportation Authority:* The organisation responsible for managing the restoration of normal vehicle operation and the assignment of the suitable team.
- *Intervention Team:* Professionals that restore abnormal incidents such as telecommunications technicians for telecommunications disruptions or law enforcement agents in case of dangerous behaviour.

Scenario:

The incident resolution software identifies an event that is regarded as an outlier compared to what is considered to be normal operation. The software recognises the outlier and provides visualisation of the position of the incident. The Public Transportation Authority assigns the suitable team to intervene. It generates reports and historical data for long-term planning and can expand the service to new routes and emerging transportation technologies, ensuring an improved and adaptive public transportation experience.

3.15.2 User Story

As an operator, I wish to be aware of the unexpected, minor or major, incidents that take place in order for the passengers to be able to experience safe travel.

3.15.3 Description of Service

The target of this service is to address the fundamental need for safe and undisrupted autonomous vehicle operation and passenger commute. The operation of autonomous vehicles is realised in a less than perfect environment with human involvement. Thus, disruptions of services as well as unexpected events are bound to take place. When this happens, on a small scale or larger, it should be identified so that the correct intervention can be applied with the utmost respect to passenger safety as well as to the vehicle operation.

3.15.4 Stakeholders

The "Automated Passenger Presence" service involves a diverse range of stakeholders. The primary actor is the **Public Transportation Authority**, responsible for implementing and overseeing the service. **Intervention teams** are supported in their work through receiving valuable information on the occurrence of incidents. **Data analysts** derive insights, and software developers manage the data systems. Local government agencies, **vehicle manufacturers,** and **technology providers** collaborate on integration and improvements. These stakeholders collectively shape the success and efficiency of this service in the field of public transportation.

3.15.5 State of the art analysis

Regarding the context of incident resolution, it is of vital importance that the system will be able to identify any divergence from, what is considered to be, normal operation and to pinpoint this information on a map so as to convey this information with the help of visualisation.

The basis of incident resolution is incident identification. An incident can be characterised as an event that disrupts normality, an outlier in terms of statistics. An outlier is an observation that is numerically distant from the rest of the data. Grubbs defined an outlier as [51]: An outlying observation, or outlier, is one that appears to deviate markedly from other members of the sample in which it occurs. Hawkins in [52] suggested that an outlier is an observation which deviates considerably from the other observations and is possible to have been generated by a different process. Outliers can occur by chance in any distribution, but they are often indicative either of measurement error or that the population has a heavy-tailed distribution.

There have been significant advancements in the field of outlier detection. Distance based techniques compare Mahalanobis distances, in order to categorise clean data and outliers. To detect outliers in multivariate data, it is common practice to estimate the location and scatter of the data by means of robust estimators. Well-known high-breakdown and affine equivariant estimators of location and scatter are the MCD-estimator [11] and the Stahel-Donoho estimator [12], [53]. Their high-breakdown property implies that the estimators can resist up to 50% of outliers. The Minimum Covariance Determinant scatter estimator, MCD, is a highly Robust estimator for the dispersion matrix of a multivariate elliptically symmetric distribution. Stahel Donoho Estimator [54], [55] measures the distance of each observation from the median of the dataset and weighs the observations with reference to the median value of those distances. Least Trimmed Euclidean Distances algorithm [55] also applies iterative algorithms. However, those algorithms are very efficient when the clean data follow the Gaussian Distribution.

The bibliography for outlier detection and covariance estimation is extended and dynamically evolving [58]. The usual practice for outlier detection is to make use of MLE Estimators and to estimate the Mahalanobis distance of every observation from the rest and to subsequently remove any data point whose Mahalanonis distance di is di ≥ X0.95. However, as we already analysed, this approach is not efficient as outliers have contaminated the sample and they have caused a considerable distortion to these estimations. Consequently, the resulting estimations fall far from the real values since MLE Estimators can estimate the requested parameters based only on a healthy set of observations. The next research step was taken toward the use of modified Mahalanobis distances. The first attempt was to choose the squares of the Mahalanobis distances in order to restrict the influence of the outliers on the log-likelihood function. Under this category fall Huber functions and Turkey biweight functions [59]. This class of estimators is called M -estimators. The S-Estimator originate in generalised Likelihood functions and are based on the scale of the data. MM and GM estimators have also widely been used. The problems with these estimators lie on computational complexity as well as restrictions on the number of data features.

For univariate data, the most common approach is to the median as the location estimate and the median of the absolute deviations as the estimation for the standard deviation. For multivariate data, the equivariance property is sacrificed for speed and we base our estimations on pair variances. The most effectively evolved method among them may be the bivariate winsorization of Khan et al. [60] which improves the univariate winsorization method of Huber by taking into account the directions of the data. Methods that used pair calculations are expected to reduce the complexity. Unfortunately though, the result in a non-positive definite covariance matrix without the equivariance property. This fact has negative impact in reality as, for example, in stock market analysis, it can be falsely translated into negative investment risk. One quite different approach for Robust Estimation is that of Ledoit and Wolf [61]. This approach basically diminishes the MLE estimator toward the direction of certain known matrices, such as the unitary matrix for example, aiming for the minimization of the distance from the real covariance matrix. This approach is appealing for applications where the number n of the observations does not differ significantly from the number of parameters to be estimated, m(m+1).

Distance based techniques compare distances , Euclidean at the beginning and in the Robust version of PJ Rousseeuw and K Van Driessen Mahalanobis distances, in order to categorise clean data and outliers. The Minimum Covariance Determinant scatter estimator (MCD) is a highly Robust estimator for the dispersion matrix of a multivariate elliptically symmetric distribution. It is very efficient when the clean data follow the Gaussian Distribution. As for a profile it usually is a vector of numbers that together capture important aspects of the user's behaviour. Profiles are learned from the data, thereby eliminating the need for defining 'normal' behaviour. By comparing profiles we can find points with unusual behaviour. The model-based processes are somewhat similar with the exception that they focus on learning abnormalities in the sense of semi-supervised learning, and not focusing on normal patterns. These both methods tend to require a fairly large training data set. The above methods in most of the cases assume gaussian distributions for the majority of the data i.e. the clean data, thus trying to detect outliers using scatter matrices or fitting measures to gaussian distributions or other known distributions such as Cauchy or Laplace which are widely used in Telecommunications. However, not every data is produced according to the Gaussian distribution or not every healthy data distribution is known. Our proposition is that for more robust and accurate measurements, we should use the actual density of the data. One way to do this is through Kernel Density Probability Estimates. After the distribution of the whole of the data is estimated, trying to emphasise healthy data and penalise possible noisy data, the data points with the larger probabilities are chosen as more possible to belong to the healthy data set and those with reduced probabilities according to the estimated model are considered to be the outliers.

Based on the widely known kernel density estimator of the probability function, in this project, we will exploit a recently proposed algorithm in order to detect outliers and to provide a robust estimation of location and scatter. With the help of the Gaussian Transform, a robust weighted kernel estimation of the density probability function will be calculated, referring to the whole of the data, including the outliers. In the next step, the data points having the smallest values according to the robust pdf will be removed as the least probable to belong to the clean data. The program based on this algorithm is more accurate even on greatly correlated outliers with the data, and even with outliers with small Euclidean distance from the data. In case the data have many variables, we can use Principal Component algorithm by P.Filzmoser with the same efficiency in the detection of outliers.

3.15.6 Functional Requirements

In this section, the functional requirements of the "Manage Incident Resolution" service are presented (Table 54). The listed requirements describe the main functionalities of the service, taking the overall ULTIMO architecture into consideration, in order to address the needs of the specific service.

Table 54: Manage Incident Resolution functional requirements.

Req_Id	**Description**
Req_14_001	The management centre should verify smooth operation at any given time.
Req_14_002	The management should be aware of the occurrence of any abnormal event.
Req_14_003	The management centre should be aware of the palace and time of the abnormal occurrence.
Req_14_004	The abnormal event should be identified accurately.
Req_14_005	The abnormal event should be categorised accurately.
Req_14_006	The management centre should be able to notify the corresponding intervention team.
Req_14_007	There should be a respective intervention team regarding any outlying process, from

Req_Id	Description
	telecommunications disruption to unlawful behaviour.
Req_14_008	The abnormal events should be verified and recorded.
Req_14_009	The intervention team should be able to provide appropriate services to the passengers, the vehicles, the personnel as well as the infrastructure.
Req_14_010	The intervention team should be able to provide suggestions and guide passengers to safety away from unexpected situations.

3.15.7 Non-functional Requirements

The following non-functional requirements are crucial for ensuring that the "Manage Incident Resolution" service operates effectively, securely, and in compliance with relevant standards and regulations while providing a safe user experience. Taking into account that the aforementioned service is still under development, the main non-functional requirements are as follows:

- **Responsiveness**: The system shall perform real-time incidence identification. The intervention teams should be well prepared and ready to offer their services round the clock supported by efficient scheduling.
- **Scalability**: The service should serve without disruption a fluctuating number of abnormalities with varying time span.
- **Reliability**: The system should aim for high accuracy and availability to ensure continuous operation even in the event of hardware or software failures.
- **Accessibility**: The system should be able to operate in unprecedented conditions such as power failure during which the minimum alarm should be issued.
- **Data Reliability**: The system must maintain the integrity of historical data, ensuring it is accurate and consistent. Regular data backups and a robust data recovery plan should be in place to prevent data loss.
- **Interoperability**: The service should be able to integrate seamlessly with third-party systems, such as transportation management software or emergency services. It should be compatible with various types of public transportation vehicles, irrespective of manufacturer or model.
- **Data Scalability**: The database system should scale to handle the growing volume of data and data inference efficiently.
- **Regulatory Compliance**: The system should comply with industry standards and regulatory requirements related to intervention and law enforcement.

3.15.8 Technical requirements

For the seamless integration of this service into the ULTIMO ecosystem, a table of technical requirements is provided. The goal is to incorporate this service to the ULTIMO vehicles as effortlessly as possible, given the restrictions of the fleet equipment. These categorised hardware (Table 55), software (Table 56), and interface (Table 57) requirements are essential for the successful implementation and operation of the "Manage Incident Resolution" service, ensuring accurate data collection, and reliable system performance and user protection.

Table 55: Hardware requirements for "Manage incident resolution" service.

Technical Req_Id	Hardware Requirements	Definition
TReq_14_001	Telecommunication antennas.	High quality antennas capable of accurate recording of signals.
TReq_14_002	Cameras.	Installed cameras ensuring no blind spots with constant power supply.
TReq_14_003	Acoustic signal antennas	Acoustic antenna systems transmitting and recording acoustic signals.
TReq_14_004	Data Transmission equipment.	5G modems and/ or antennas, Wi-Fi routers, etc. for real-time passenger count/presence transmission to the ULTIMO DMP.
TReq_14_005	Redundancy mechanisms.	Backup sensors and failover data transmission equipment to ensure system reliability.

Table 56: Software requirements for "Manage Incident Resolution" service.

Technical Req_Id	Software Requirements	Definition
TReq_14_006	Data processing software.	Software for efficient collection, processing and management of the passenger data.
TReq_14_007	User Interfaces.	User-friendly software interface for commuters, operators and local authorities, to access real-time occupancy, historical data and system status.
TReq_14_008	Mobile Applications.	Development of mobile apps for passengers to check vehicle occupancy status on smartphones or tablets.
TReq_14_009	Outlier detection tools.	Identification and recognition of abnormalities and disruptions in any operation.
TReq_14_010	Integration APIs.	APIs for seamless integration with third-party systems, such as transportation management software and emergency services.
TReq_14_011	Remote monitoring software.	Software for remote monitoring the system performance, including alerts and notifications for system issues.

Table 57: Interface requirements for "Manage Incident Resolution" service.

Technical Req_Id	Interface Requirements	Definition
TReq_14_013	User Interfaces.	User-friendly interfaces to interact with the system, including web-based dashboards, mobile app interfaces and operator consoles.
TReq_14_014	API Documentation.	Comprehensive documentation for APIs integration to facilitate third-party system integration.
TReq_14_015	Accessibility Features.	Incorporation of accessibility features in user interfaces to ensure compliance with accessibility standards and regulations.
TReq_14_016	Training Materials.	Creation of training materials for operators, maintenance staff, and system administrators to effectively use and maintain the system.
TReq_14_017	Reporting Interfaces.	Interfaces for generating and accessing reports and analytics, allowing transportation planners to make informed decisions.
TReq_14_018	System Status Alerts.	Real-time alerts and notifications interfaces to inform transportation authorities and operators of system status,

Technical Req_Id	Interface Requirements	Definition
		data transmission issues, and hardware failures.
TReq_14_019	Passenger Notifications.	Interfaces for sending real-time occupancy notifications to passengers through mobile apps, electronic signs, or other communication channels.

3.15.9 Data Requirements

The following data requirements (Table 58) are essential for the proper functioning of the "Manage Incident Resolution" service, enabling accurate incident identification, data analysis and proper intervention, while also addressing privacy and compliance considerations.

Table 58: Data requirements for "Manage Incident Resolution" service.

Data Req_Id	Data Requirements	Definition
DReq_14_001	Telecommunications inter-connectivity data.	Raw data collected by telecommunication antennas to ensure that they communicate seamlessly.
DReq_14_002	Vehicle Information.	Data about each vehicle operation such as fuel availability, stability.
DReq_14_003	Passenger Information.	Anonymized passenger behaviour data.
DReq_14_004	Route and Scheduling.	Information on routes, schedules and stops, including geospatial data to verify anticipated behaviour.
DReq_14_009	System Configuration.	Configuration settings for sensors, data processing and user interfaces.
DReq_14_010	Geolocation.	Geographic information, including maps, GPS coordinates, and geofencing data to determine vehicle locations.
DReq_14_011	Security Logs.	Logs of security-related activities, including access attempts, authentication and data encryption status.
DReq_14_012	Emergency Data.	Data related to emergencies, such as emergency stops or requests for assistance from passengers.
DReq_14_013	Notifications.	Records of notifications sent to intervention teams, including the content and delivery status.
DReq_14_014	System Performance Metrics.	Metrics related to system performance, including response times, server load and data transmission efficiency.
DReq_14_015	Accessibility Data.	Data related to the accessibility of user interfaces and services, including compliance with accessibility standards.
DReq_14_016	Data Backups.	Copies of data backups, including timestamps and locations of backup files.
DReq_14_017	Retention Policies.	Policies specifying how long different types of data are retained and when they are purged.

3.16 Service: Anti-jamming defense mechanism

3.16.1 Concept of Service

The “Anti-jamming defence mechanism” service is categorized as a “Vehicle Service” and aims to protect public transportation from jamming attacks thus ensuring safe telecommunications between personnel, passengers but also between electronic devices. Such a mechanism protects the normal operational status of the autonomous transportation network as numerous messages regarding the state of the devices and the passengers as well as operational messages are exchanged every moment.

The “Anti-jamming defence mechanism” service creates value by exhibiting a variety of advantages, which include:

- Real-time, accurate, and continuous jammer localization.
- Estimation and prediction of jamming levels.
- Jamming mitigation which provides safe passage for the message to be transmitted.

3.16.1.1 Use case

Use Case: Identifying jamming incidence, localising the jammers and applying the anti-jamming mechanism to route the message along lower jamming levels.

Actors:

- *Public Transportation Authority:* The organisation responsible for managing the operation of the anti-jamming mechanisms.
- *Intervention Team:* Telecommunications professionals who operate the jammer localisation software and control the antenna network thus guiding the signals.

Scenario:

The anti-jamming defence system detects jamming attacks. It localises the jammers and forms an estimated map of their positions. It routes the message through lower levels of interference through manipulating the equilibrium state of the antenna network. Consequently, the transportation telecommunications are routed along lower noise paths.

3.16.2 User story

As an operator, I wish to be part of a network that is supported via a seamless telecommunications connection of electronic devices that ensure the normal and efficient operation of the vehicles and a safe environment for the exchange of passenger and personnel information and needs.

3.16.3 Description of Service

The target of this service is to address the fundamental need for safe and undisrupted exchange of telecommunication messages, primarily between electronic devices but also between personnel and passengers. The operation of autonomous vehicles is based on the constant exchange of information between these devices. Moreover, the operators of these devices and of the vehicles and people who benefit from telecommunications should be in a position to safely transmit and receive messages. Thus, disruptions of services through jamming attacks where interference distorts transmitted signals must be dealt with real-time and effectively.

3.16.4 Stakeholders

The "Anti-Jamming Defence mechanism" service involves a targeted group of stakeholders. The primary actor is the **Public Transportation Authority**, responsible for implementing and overseeing the service. **Telecommunication operators** form an estimated map of the network of the jammers and route the information transmitted along low interference paths. These stakeholders collectively shape the success and efficiency of this service in the field of public transportation.

3.16.5 State of the art analysis – New algorithm proposal

Regarding the context of anti-jamming defence, it is of vital importance that the system will be able to identify any jamming attack. The purpose is for the system to be able to estimate an accurate map of the location of the jammers and, most importantly, to be able to defend its telecommunications and to protect the sage transmission of telecommunications signals between any device guiding it along low interference paths.

3.16.5.1 Jammer Localisation

In wireless sensor networks (WSNs), due to the shared nature and the open access to the wireless medium, an adversary can easily launch jamming attacks to paralyse the whole network [63]. Jamming attacks affect the network either by preventing the transmitters from sending messages due to the busy medium, or by dramatically decreasing the signal-noise ratio, SNR, at receivers to cause a large number of packet collisions. Although some existing countermeasures against jamming attacks, such as channel surfing [64], frequency hopping [17], demonstrate a certain degree of resistance to jamming attacks, advanced devices and complex protocols are required. Furthermore, to keep working under the existence of the jammer, the power consumption of the whole WSN could be unacceptable.

There are several algorithms proposed to cope with jamming attacks in wireless sensor networks. Noubir and Lin [17] combined error-correction codes and cryptographically strong interleavers to increase the likelihood of decoding corrupted packets. Xu et al. [18] presented two strategies, channel surfing and spatial retreats, to increase the resistance to jamming attacks by avoiding the interference as much as possible in the transmission frequency or physical location.

In this work, we suggest the application of a new Robust Location Estimate [64] that has proven to be accurate for symmetric as well as asymmetric data. We intend to use a recently proposed ε-insensitive median [64], ε-med, which is suitable both for data that are normally distributed and for data that display skewness. This formulation is a modification of the ε insensitive loss function suggested by Vapnick and has been proven suitable both for symmetrically distributed as well as skewed data [65].

3.16.5.2 Robust Centroid Jammer Localisation

Centroid Localization, CL, [67] is derived from the idea of centroid, which is the geometric centre in geometry. CL uses location information of all neighbouring nodes, which are nodes located within the transmission range of the target node. In case of jammer localization, the target node is the jammer, and the neighbouring nodes of the jammer are jammed nodes. CL collects all coordinates of jammed nodes, and averages over their coordinates as the estimated position of the jammer. Assuming that there are N jammed nodes (X1, Y1), (X2, Y2), · · · , (XN , YN), the position of the jammer can be estimated by:

$$(X_{jammer}, Y_{jammer}) = (\frac{\sum X_N}{N}, \frac{\sum Y_N}{N})$$

In our work, instead of the median, which is the most efficient estimator for symmetrically distributed data, we will apply the ε-insensitive median [64], the ε-med. Figure 2 depicts all the aforementioned.

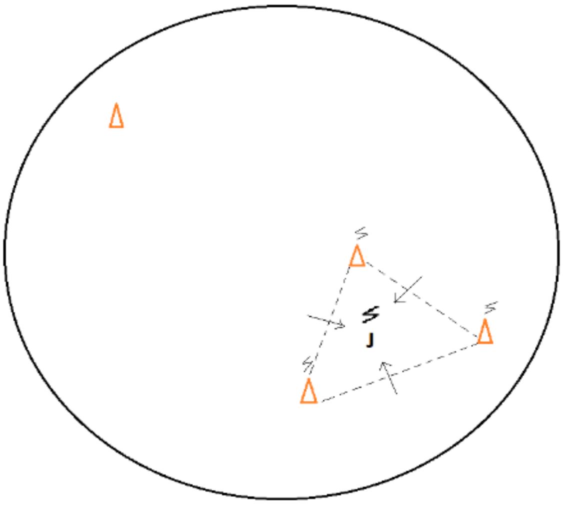


Figure 2: On the upper left, we notice an unjammed node. Due to its increased distance from the Jammer, the Jammer location is estimated as the mean location of the jammed nodes within its range.

3.16.5.3 Jamming Mitigation through Markov Equilibrium Manipulation

Autonomous vehicles (AVs) have emerged as a transportation solution that provides increased levels of automation as well as efficiency without human input. Wireless communications are fundamental for the purposes of safely exchanging messages with the operation centre but also for accurately navigating along the trajectory. However, AVs communication interruptions (Figure 3) can introduce significant danger especially in public transportation, where passenger safety is critical. Malicious interference could deteriorate not only communication, but also the navigation of the vehicles.

Jamming attacks include the heavy interference as well as the obstruction of telecommunication with the intention of distorting or overall disrupting the wireless communication of the message transmitted. Jammers can be placed steadily in specific positions, or they can be moving such as on drones and any other moving vehicle. Moreover, the jammers can act in a single form or in a network constellation.

Evading jammers [68] has been approached through various strategies. Game Theory and specifically Differential Games [69] are amongst the most analytically developed solutions, where the solution is based on the capability of the telecommunications network to maintain a secure communication in the presence of jammers. Other popular perspectives include geometric approaches to control theory [70] and optimal trajectories on specific surfaces.

Among the first pursuit-evasion games, which were presented in [71][72], the pursuer tries to capture the evader in some sense, specifically in this case to jam and interfere with their communications, while the evader tries to avoid and prevent it. Initially, the pursuit- evasion games, regarding jamming, focused on the performance of the network in relation to the agility and energy of the agents, [73][74][75] and [76]. In [68], the basic goal was to preserve the communication of the network.

Figure 3: The Jammer node interferes with the shuttle antenna node and the (above-the-ground) transceiver antenna nodes. An underground sensor node is added in order to manipulate the Jammer Transition matrix and therefore its Equilibrium State Distribution. The underground node is not affected by the jammer and can be connected underground with whichever supporting transceiver antennas that we choose.

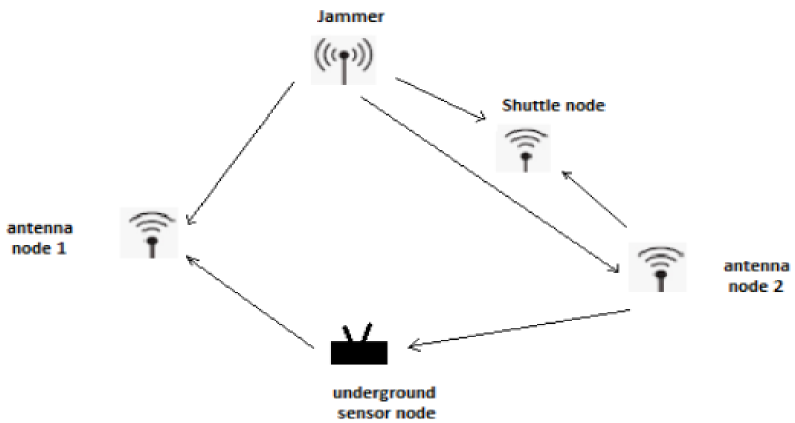


Figure 4: The Jammer node, the shuttle Antenna node, the transceiver Antenna nodes and an underground sensor node form the total graph.

While, up to now, research has been focusing on the signal and the signal circulation itself, trying to protect, support and strengthen it, this work follows a different path. We focus on the Graph along which noise circulates. Regarding this graph Figure 4, we try to find its weak points in order to exploit them and pass our signal as safely as possible. Specifically, a novel technique for countering AVs jamming attacks based on graph theory and equilibrium state distribution is introduced. Practical solutions are proposed of how to form aperiodic and irreducible graphs to circulate the interference signals so that we can manipulate their transition matrices and equilibrium distribution as well as the states of the jamming. In the following Section, we briefly describe Transitions in Markov graphs and basic elements on equilibrium state distribution. Next, the experimental design and evaluation of our contribution is developed. Examples of network designs for jammers and jammed nodes as well as desirable modifications are presented in order to result in graphs that not only have equilibrium state distributions but in order to influence the equilibrium to our advantage for the safe-passing of the signal in the next steps. In this way, it is possible to prepare desirable circulation and levels for the interference amongst the network nodes so that, in the step after that, the transmission is routed on a path of lower jamming state values. The counter jamming mechanisms of the AVs infrastructure could be enhanced by adopting the proposed method.

3.16.6 Functional Requirements

In this section, the functional requirements of the "Anti-jamming defence mechanism" service are presented (Table 59). The listed requirements describe the main functionalities of the service, taking the overall ULTIMO architecture into consideration, in order to address the needs of the specific service.

Table 59: Anti-jamming defence mechanism functional requirements.

Req_Id	Description
Req_15_001	The management centre should verify smooth exchange of telecommunications at any given time.
Req_15_002	The management should be aware of the occurrence of any jamming attack over a given threshold of interference.
Req_15_003	The telecommunications professionals should be able to estimate the map of the active jammer positions at the given time.
Req_15_004	The telecommunications professionals should be able to take advantage of the equilibrium state of the antenna network in order to route the transmitted telecommunications messages along low interference paths.

3.16.7 Non-Functional Requirements

The following non-functional requirements are crucial for ensuring that the "Anti-jamming defence mechanism" service operates effectively, securely, and in compliance with relevant standards and regulations while providing a safe user experience. Taking into account that the aforementioned service is still under development, the main non-functional requirements are as follows:

- **Responsiveness**: The system shall anticipate jamming attacks any moment. The telecommunications teams should be well prepared and ready to offer their services round the clock.
- **Scalability**: The service should serve without disruption a fluctuating number of jamming attacks and jamming levels with varying time span.
- **Reliability**: The system should aim for high accuracy and availability to ensure continuous operation even in the event of hardware or software failures.

- **Accessibility**: The system should be able to operate in unprecedented conditions such as power failure during which the minimum alarm should be issued.
- **Data Reliability**: The system must maintain the integrity of historical data, ensuring it is accurate and consistent. Regular data backups and a robust data recovery plan should be in place to prevent data loss.
- **Interoperability**: The service should be able to integrate seamlessly with third-party systems, such as transportation management software or emergency services. It should be compatible with various types of public transportation vehicles, irrespective of manufacturer or model.
- **Data Scalability**: The database system should scale to handle the growing volume of data and data inference efficiently.
- **Regulatory Compliance**: The system should comply with industry standards and regulatory requirements related to intervention and law enforcement.

3.16.8 Technical Requirements

For the seamless integration of this service into the ULTIMO ecosystem, a table of technical requirements is provided. The goal is to incorporate this service to the ULTIMO vehicles as effortlessly as possible, given the restrictions of the fleet equipment. These categorised hardware (Table 60), software (Table 61), and interface (Table 62) requirements are essential for the successful implementation and operation of the "Anti-jamming defence mechanism" service, ensuring accurate data collection, and reliable system performance and user protection.

Table 60: Hardware requirements for "Anti-jamming defence mechanism" service.

Technical Req_Id	Hardware Requirements	Definition
TReq_15_001	Telecommunication antennas.	High quality antennas distributed in the field of operations desirably with overlapping operability.
TReq_15_002	Data Transmission equipment.	5G modems and/ or antennas, Wi-Fi routers, etc. for real-time passenger count/presence transmission to the ULTIMO DMP.
TReq_15_003	Redundancy mechanisms.	Backup sensors and failover data transmission equipment to ensure system reliability.

Table 61: Software requirements for "Anti-jamming defence mechanism" service.

Technical Req_Id	Software Requirements	Definition
TReq_15_004	Data processing software.	Software for efficient collection, processing and management of transmitted signals as well as interference.
TReq_15_005	User Interfaces.	User friendly software interface for telecommunications specialists, to access real-time jammer network information.
TReq_15_006	Remote monitoring software.	Software for remote monitoring the system performance, including alerts and notifications for system issues.

Table 62: Interface requirements for "Anti-jamming defence mechanism" service.

Technical Req_Id	Interface Requirements	Definition
TReq_15_007	User Interfaces.	User-friendly interfaces to interact with the system, including web-based dashboards, mobile app interfaces and operator

Technical Req_Id	Interface Requirements	Definition
		consoles.
TReq_15_008	Accessibility Features.	Incorporation of accessibility features in user interfaces to ensure compliance with accessibility standards and regulations.
TReq_15_009	Reporting Interfaces.	Interfaces for generating and accessing reports and analytics, allowing transportation planners to make informed decisions.

3.16.9 Data Requirements

The following data requirements (Table 63) are essential for the proper functioning of the "Anti-jamming defence mechanism" service, enabling accurate incident identification, data analysis and proper intervention, while also addressing privacy and compliance considerations.

Table 63: Data requirements for "Anti-jamming defence mechanism" service.

Data Req_Id	Data Requirements	Definition
DReq_15_001	Telecommunications inter-connectivity data.	Raw data collected by telecommunication antennas to ensure that they communicate seamlessly and deliver un-distorted messages.
DReq_15_002	Signal Routing.	Information on routes of the signal to be transmitted along specific antennas.
DReq_15_003	Security Logs.	Logs of security-related activities, including access attempts, authentication and data encryption status.
DReq_15_004	Emergency Data.	Data related to emergency situations, such as emergency stops or requests for assistance from passengers.
DReq_15_005	Notifications.	Records of notifications sent to intervention teams, including the content and delivery status.
DReq_15_006	System Performance Metrics.	Metrics related to system performance, including response times, server load and data transmission efficiency.
DReq_15_007	Accessibility Data.	Data related to the accessibility of user interfaces and services, including compliance with accessibility standards.

3.17 Service: Anticipate and mitigate the security incidents

3.17.1 Concept of Service

The “Anticipate and mitigate the security incidents” service is categorized as an “Operator Service” and aims to create an advanced system for public transportation that predicts emergency situations and unexpected events before they occur and that manages the response teams so that security is ensured. The target audience is mainly the fleet operators and the passengers that use Public Transport methods.

The “Anticipate and mitigate the security incidents” service creates value by exhibiting a variety of advantages, which include:

- Real-time, accurate, and continuous incident prediction.
- Visualisation of the position of the incident and prediction of its severity.
- Assignment of an intervention team regarding the event and synchronisation of services to achieve the mitigation of the incident.

3.17.2 Use Case

Use Case: Supporting public transportation safety and operability of electronic devices as by predicting and anticipating unexpected events before they occur or at an early stage and subsequently by deciding on the appropriate intervention team to be dispatched.

Actors:

- *Public Transportation Authority:* The organisation responsible for managing the unexpected event prediction and anticipation software and for authorising and verifying the dispatch of the appropriate team.
- *Intervention Team:* Professionals that restore abnormal incidents that have been predicted by offering their services to the area where the problem or disruption is anticipated.

Scenario:

The incident prediction software anticipates that a certain disruption is about to take place regarding a specific operation and notifies the management centre while also suggests the intervention of the suitable team. The Public Transportation Authority assigns the team to intervene so that the disruption is avoided by providing any supporting information. Reports and historical data are generated for long-term planning ensuring an improved efficiency of the system.

3.17.3 User Story

As an operator, I wish to be aware of the unexpected, minor or major, incidents before it happens so that it can be avoided, and the transportation system can be safe from problems that may evolve and lead to unforeseen situations.

3.17.4 Description of Service

The target of this service is to address the fundamental need for safe and undisrupted autonomous vehicle operation and passenger commute. The operation of autonomous vehicles is expected to confront problems in many areas such as its devices operations or its fleet dysfunction for example. Based on historical data, it is important that the system can predict the occurrence of any disruption before it happens so that the appropriate restoration can take place and the event will be avoided.

3.17.5 Stakeholders

The "**Anticipate and mitigate the security incidents**" service involves a diverse range of stakeholders. The primary actor is the **Public Transportation Authority**, responsible for implementing and overseeing the service. **Intervention teams** are supported in their work through receiving valuable information on the occurrence of incidents. **Data analysts** derive insights, and **software developers** manage the data systems. **Local government** agencies, **vehicle manufacturers**, and **technology providers** collaborate on integration and improvements. These stakeholders collectively shape the success and efficiency of this service in the field of public transportation.

3.17.6 State of the art analysis

Regarding the context of incident resolution, it is of vital importance that the system will be able to predict, real-time, any divergence from, what is considered to be, normal operation and to suggest the dispatch of the suitable team to prevent the event from happening.

Event prediction in statistics is primarily based on machine learning and specifically regression analysis. Regression analysis applies the minimization of errors in order to estimate a linear or non-linear relationship between past and future data. Currently, regression analysis is realised either through Neural Network algorithms or by using Support Vector Machines algorithms as it is researched in [84] and [85]. Neural Network Theory includes high efficiency algorithms and can be applied to a variety of data. The restriction is that in order for the coefficients of the model to be estimated the process needs a large volume of historical data. Moreover, because of this volume, should there happen any change in the data of any operation, the model should gather not just a little but a considerable amount of data and to be re-trained on them so that it can present accurate predictions. This fact can lead to unexpected delays and to loss of accuracy. Support Vector analysis is based on mathematical programming optimization and is bound to require far less data in order to be trained. Thus, the predictions can be provided real-time. Modern algorithms have evolved so that they include modifications that render the models robust to outliers. We suggest the use of a recent robust Support Vector Regression algorithm for the prediction of unexpected events in Autonomous Vehicles Transportation.

Regression Analysis assumes that the distribution of the data is the Gaussian, mostly based on the Central Limit Theorem. However, in reality, that is not the case. In practice, most of the data demonstrate, at least, some level of asymmetry, or else called skewness.

In [87], a novel e-Insensitive Support Vector Regression method was presented that was suitable both for symmetrically distributed as well as skewed data, S-eSVR. The new regression formula was the following:

$$Minimize\ (wTw) + (b)\sigma + \sum \xi i$$

Subject to:

$$yi - < wxi > -b \leq \epsilon + \xi i$$

$$< wxi > +b - yi \leq \epsilon + \xi i$$

$$\xi i \geq \epsilon$$

$$\xi i, \epsilon, \mathrm{w}, \mathrm{b} \geq 0$$

where ξi are the residuals of the regression and ϵ is the margin adjustment The novelty of this e-insensitive Support Vector Regression, SVR, algorithm is the third constraint. In this case, ϵ becomes a decision variable, which means that it is optimised in the same process and at the same time as the rest of the decision variables which results in reducing the computational cost but also it prevents error input to the formula due to a-priori estimations of the ϵ, which is currently the standard practice. Equally important is the effect of this new constraint on the model. Specifically, this constraint forces the model not to take into any consideration the regression errors that are smaller than ϵ by setting them equal to ϵ and at the same time it reduces the effect of errors the rest of the observations by ϵ.

Through setting a threshold to the small regression residuals, the attention of the model is directed away from the observations whose residuals are significantly small thus giving the opportunity the true nature of the data, skewness, to manifest itself and to control the decision variables while, at the same time, forcing for the optimum residuals and regression variables. In case of symmetry, ϵ is regulated from the model and is set close to zero which results in the classical ϵ-insensitive SVR formula. Figure 5 depicts the aforementioned model.

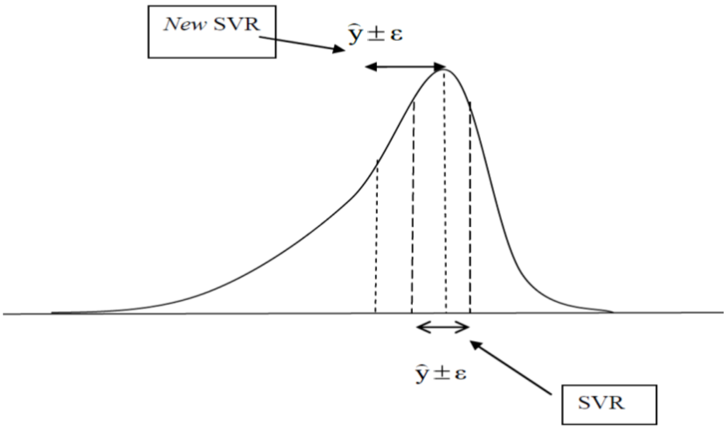


Figure 5: The new model drives the attention of the regression model towards the direction of skewness.

3.17.7 Functional Requirements

In this section, the functional requirements of the "Anticipate and mitigate the security incidents" service are presented (Table 64). The listed requirements describe the main functionalities of the service, taking the overall ULTIMO architecture into consideration, in order to address the needs of the specific service.

Table 64: Anticipate and mitigate the security incidents functional requirements.

Req_Id	Description
Req_16_001	The management centre should monitor time series data of the operations at any given time.
Req_16_002	The prediction software will notify for the anticipation of an unexpected event in the near future.
Req_16_003	The software will suggest the appropriate team to be dispatched.
Req_16_004	The management centre will verify the suitability of the team and will invite the team to intervene.
Req_16_005	The abnormal events should be verified and recorded for future use from the software.
Req_16_006	The intervention team should be able to provide appropriate services to the passengers, the vehicles, the personnel as well as the infrastructure.

Req_Id	Description
Req_16_007	The intervention team should be able to provide suggestions and guide passengers to safety away from unexpected situations.

3.17.8 Non-Functional Requirements

The following non-functional requirements are crucial for ensuring that the "Anticipate and mitigate the security incidents" service operates effectively, securely, and in compliance with relevant standards and regulations while providing a safe user experience. Taking into account that the aforementioned service is still under development, the main non-functional requirements are as follows:

- **Responsiveness**: The system shall perform real-time incidence prediction. The intervention teams should be well prepared and ready to offer their services round the clock.
- **Scalability**: The service should serve without disruption a fluctuating number of abnormalities with varying time span.
- **Reliability**: The system should aim for high accuracy and availability to ensure continuous operation even in the event of hardware or software failures.
- **Accessibility**: The system should be able to operate in unprecedented conditions such as power failure during which the minimum alarm should be issued.
- **Data Reliability**: The system must maintain the integrity of historical data, ensuring it is accurate and consistent. Regular data backups and a robust data recovery plan should be in place to prevent data loss.
- **Interoperability**: The service should be able to integrate seamlessly with third-party systems, such as transportation management software or emergency services. It should be compatible with various types of public transportation vehicles, irrespective of manufacturer or model.
- **Data Scalability**: The database system should scale to handle the growing volume of data and data inference efficiently.
- **Regulatory Compliance**: The system should comply with industry standards and regulatory requirements related to intervention and law enforcement.

3.17.9 Technical Requirements

For the seamless integration of this service into the ULTIMO ecosystem, a table of technical requirements is provided. The goal is to incorporate this service to the ULTIMO vehicles as effortlessly as possible, given the restrictions of the fleet equipment. These categorised hardware (Table 65), software (Table 66), and interface (Table 67) requirements are essential for the successful implementation and operation of the "Anticipate and mitigate the security incidents" service, ensuring accurate data collection, reliable system performance and user protection.

Table 65: Hardware requirements for "Anticipate and mitigate the security incidents" service.

Technical Req_Id	Hardware Requirements	Definition
TReq_16_001	Data Transmission equipment.	5G modems and/ or antennas, Wi-Fi routers, etc. for real-time passenger count/presence transmission to the ULTIMO DMP.
TReq_16_002	Redundancy	Backup sensors and failover data transmission equipment

Technical Req_Id	Hardware Requirements	Definition
	mechanisms.	to ensure system reliability.

Table 66: Software requirements for "Anticipate and mitigate the security incidents" service.

Technical Req_Id	Software Requirements	Definition
TReq_16_006	Data processing software.	Software for efficient collection, processing and management of the system data.
TReq_16_007	User Interfaces.	User-friendly software interface for commuters, operators and local authorities, to access real-time occupancy, historical data and system status.
TReq_16_008	Regression tools.	Identification and recognition of abnormalities and disruptions in any operation.
TReq_16_009	Remote monitoring software.	Software for remote monitoring the system performance, including alerts and notifications for system issues.

Table 67: Interface requirements for "Anticipate and mitigate the security incidents" service.

Technical Req_Id	Interface Requirements	Definition
TReq_16_010	User Interfaces.	User-friendly interfaces to interact with the system, including web-based dashboards, mobile app interfaces and operator consoles.
TReq_16_011	Training Materials.	Creation of training materials for operators, maintenance staff, and system administrators to effectively use and maintain the system.
TReq_16_012	Reporting Interfaces.	Interfaces for generating and accessing reports and analytics, allowing transportation planners to make informed decisions.
TReq_16_013	System Status Alerts.	Real-time alerts and notifications interfaces to inform transportation authorities and operators of system status, data transmission issues, and hardware failures.

3.17.10 Data Requirements

The following data requirements (Table 68) are essential for the proper functioning of the "Anticipate and mitigate the security incidents" service, enabling accurate incident identification, data analysis and proper intervention, while also addressing privacy and compliance considerations.

Table 68: Data requirements for "Anticipate and mitigate the security incidents" service.

Data Req_Id	Data Requirements	Definition
DReq_16_001	Data stored regarding any operation of the Transportation system.	Raw data collected that regard any aspect of the system such as telecommunications or fleet functionality.
DReq_16_002	Security Logs.	Logs of security-related activities, including access attempts, authentication and data encryption status.
DReq_16_003	Emergency Data.	Data related to emergency situations, such as emergency stops or requests for assistance from passengers.
DReq_16_004	Notifications.	Records of notifications sent to intervention teams, including the content and delivery status.

Data Req_Id	Data Requirements	Definition
DReq_16_005	System Performance Metrics.	Metrics related to system performance, including response times, server load and data transmission efficiency.
DReq_16_006	Accessibility Data.	Data related to the accessibility of user interfaces and services, including compliance with accessibility standards.
DReq_16_007	Data Backups.	Copies of data backups, including timestamps and locations of backup files.
DReq_16_008	Retention Policies.	Policies specifying how long different types of data are retained and when they are purged.

3.18 Intervention services

As described in the Grant Agreement of the project [22] and as mentioned in Section 3.2, specific intervention services will be implemented throughout the project, particularly during real-life demonstrations, which are the following:

- **Manage the incident response interventions**: The actors of this service are the intervention teams and the main goal is to follow/monitor on incidents in near real time.
- **Ensure public health**: The interventions teams are the actors of this service and their aim is to ensure public health in all vehicles.
- **Manage accidents**: In accordance to the previous services, the main actors are the intervention teams aiming at following/monitoring on accidents in near real time.

These services rely on the same set of software algorithms, sensors, and systems for detecting abnormal behaviour, suspicious objects, and health-related issues, among other functionalities. In addition, the supervision dashboard (described in the next Chapter 4) can assist the operators and their intervention teams to gather near real-time information and make informed decisions. Consequently, there is no need to establish new functional, non-functional, technical, and data requirements. Nevertheless, in the next version of this deliverable, and as part of the pilot operations of AVs, a more comprehensive analysis will be provided on how these services will be handled from the responsible PTO of each pilot city.

4 Passenger Safety Dashboard

The overall intention of this system is to provide a comprehensive solution for monitoring and managing alerts in vehicles. The system is designed to categorize different types of events and trigger alerts based on predefined settings and contexts. By providing supervisors with timely and relevant information about events occurring in the vehicle, they can take appropriate actions to address any potential issues.

The system also allows for the configuration of different alert settings and priorities, creating a hierarchy to ensure that the most critical events are addressed first. Overall, the system is intended to improve the safety and efficiency of vehicle operations by providing real-time alerts and actionable insights to supervisors.

4.1 The personae

A persona is a fictional individual who represents a target group. When constructing a persona, this fictional person is assigned a set of attributes that enrich their profile to better express the characteristics of the target group. Through these attributes, teams (Table 69, Table 70, Table 71, Table 72, Table 73, Table 74) create usage scenarios for a product or service, define a positioning, promotion, or distribution strategy.

The objectives are:

- Develop a deep understanding of user needs and expectations.
- Identify key characteristics and motivations of different types of users.
- Create detailed profiles of each persona to guide user-centered product design and development.

Supervisor

Table 69: Supervisor team

Photo	Bio
	The supervisor is a person responsible for ensuring the safety of passengers. They play a crucial role in managing alerts and taking appropriate actions when necessary.
Pains	Gains
• **High Responsibility**: The supervisor carries the weight of ensuring passenger safety, which can be stressful and demanding. • **Alert Overload**: Dealing with numerous alerts and alarms can be overwhelming, leading to potential oversight. • **Time Pressure**: Responding to alerts promptly is crucial, and time pressure can be a constant challenge. • **Complex Decision-Making**: They often need to make complex decisions quickly, which can be mentally taxing.	• **Passenger Safety**: The satisfaction of ensuring passengers reach their destination safely. • **Professionalism**: Recognition for their competence and professionalism in handling emergencies. • **Efficiency**: Finding ways to streamline alert response processes can lead to increased efficiency.
See	Listen to:
• The supervisor sees a control room with multiple screens displaying various data related to the transportation system. • They observe the actions taken by the intervention team. • They see a constant flow of alerts and information that requires their attention.	The supervisor listens to alert sounds.
Says and Does	Think and Feel
• **Says:** The supervisor communicates with the intervention team through radio or phone calls to coordinate responses to alerts. • **Does:** They take swift and decisive actions when faced with emergencies, such as rerouting transportation, deploying maintenance teams, or alerting security personnel.	• **Thinks:** The supervisor is constantly evaluating the severity of alerts, considering potential consequences, and devising strategies to mitigate risks. • **Feels:** They may feel a mix of stress, responsibility, and satisfaction in successfully managing passenger safety.

Site Manager

Table 70: Site Manager team

Photo	Bio
	The site manager is responsible for configuring the alerts' dashboard. They play a crucial role in ensuring that the system operates smoothly and efficiently.
Pains	Gains
• **Technical Challenges:** Dealing with the complexities of configuring and maintaining the alert dashboard and system can be demanding. • **User Training:** Ensuring that system operators and staff are adequately trained to use the dashboard effectively.	• **System Efficiency:** A well-configured system can lead to improved operational efficiency. • **Data Insights:** Access to valuable data and insights for making informed decisions. • **Recognition:** Being recognized for successfully configuring and maintaining a reliable alert system. • **Problem-Solving:** Opportunities to apply problem-solving skills to optimize the alert dashboard and system.
See	Listen to:
• The site manager observes the Supervisor responding to alerts and taking actions. • They view analytics generated by the system.	The site manager may listen to feedback from the Supervisor regarding any issues or challenges they encounter while using the dashboard.
Says and Does	Think and Feel
• **Says:** The site manager communicates with the Supervisor to understand their needs and challenges. • **Does:** They configure and maintain the alert dashboard and make adjustments to the system as needed.	• **Thinks:** The site manager is constantly thinking about ways to improve system configuration for better performance and user experience. • **Feels:** They may feel a sense of accomplishment when they successfully configure the system to meet operational needs, but also experience frustration when dealing with technical challenges or system issues.

Super Admin

Table 71: Super Admin team

Photo	Bio
	The Super Admin holds a critical role in overseeing the entire system and its configuration. They are responsible for ensuring the system functions smoothly, configuring user access, managing events, and overseeing various aspects of the system.
Pains	Gains
• **Complex Configuration:** Managing a system with numerous components and configurations can be technically challenging. • **Security Concerns:** Maintaining system security and protecting against data breaches and cyber threats is a constant concern. • **User Management:** Handling user accounts, permissions, and access rights can be time-consuming. • **System Scalability:** Ensuring the system can scale to accommodate growth or changes in the organization.	• **System Reliability:** The satisfaction of ensuring the system operates smoothly and reliably. • **Data Control:** Access to critical data and insights for decision-making. • **Problem-Solving:** Opportunities to apply problem-solving skills to optimize system performance.
See	Listen to:
• The Super Admin sees the system's central control panel, which provides an overview of the system's health, status, and user activity. • They observe user accounts, system logs, and configuration settings. • They may also review reports and analytics related to system performance.	• The Super Admin may listen to feedback and requests from Supervisors and Site Manager regarding system functionality and issues. • They may engage in discussions with technical experts and security personnel to stay updated on potential threats. • They might also communicate with other administrators and managers within the organization.
Says and Does	Think and Feel
• **Says:** The Super Admin communicates with other administrators, Supervisors, and Site Manager to gather information and make decisions. • **Does:** They configure user accounts, set access permissions, monitor system performance, and implement security measures. They may also oversee system upgrades and troubleshoot issues.	• **Thinks:** The Super Admin is always thinking about system optimization, security, and scalability. They contemplate ways to improve user experience and data management. • **Feels:** They may experience a sense of responsibility for the system's smooth operation and may feel pressure to keep the system secure and efficient.

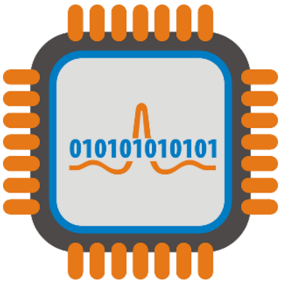
Intervention Team

Table 72: Intervention team

Photo	Bio
	The intervention team leader is a key figure responsible for managing and leading a team of experts who respond to critical incidents and emergencies within the transportation system. They play a pivotal role in coordinating the team's actions to mitigate risks and ensure passenger safety.
Pains	Gains
• **High-Stress Situations:** Dealing with emergencies and critical incidents can be highly stressful and emotionally taxing. • **Time Sensitivity:** The team leader must make rapid decisions and coordinate actions under time constraints. • **Resource Management:** Ensuring that the team has the necessary resources, equipment, and personnel available during emergencies. • **Interagency Collaboration:** Collaborating with various agencies and departments during complex incidents can be challenging.	• **Passenger Safety:** The satisfaction of successfully responding to incidents and safeguarding passengers. • **Leadership Skills:** Opportunities for leadership development and honing crisis management abilities. • **Team Collaboration:** Building a cohesive and well-trained intervention team. • **Continuous Improvement**: Identifying areas for improvement in response protocols and equipment.
See	Listen to:
The intervention team leader sees the transportation system's operations center, where they monitor incident reports and real-time data.	• The intervention team leader listens to radio communications from team members and other relevant personnel during incidents. • They pay attention to updates and reports from team members in the field. • They may also engage in discussions with other incident response agencies and authorities.
Says and Does	Think and Feel
• **Says:** The intervention team leader communicates with team members, relaying critical information, and providing guidance and support. • **Does:** They make quick decisions, allocate resources, and coordinate the team's response during emergencies. They may also conduct post-incident debriefings to assess performance and identify areas for improvement.	• **Thinks:** The intervention team leader is constantly assessing the situation, anticipating potential challenges, and formulating response strategies. • **Feels:** They may experience a mix of stress, responsibility, and satisfaction when successfully managing critical incidents and ensuring passenger safety.

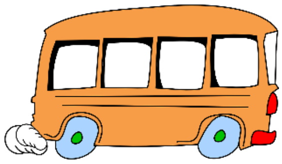
On Board Unit (OBU)

Table 73: In-Vehicle OBU

Photo	Bio
	The OBU is the electronic brain of the transportation vehicle, responsible for monitoring various aspects of the vehicle's operation, detecting events, and transmitting event data to the central system for analysis and response.
Pains	Gains
• **Technical Challenges:** Dealing with the complexities of event monitoring and data transmission can be technically challenging. • **Reliability:** Ensuring that the OBU functions reliably, especially in harsh environmental conditions and high-stress situations. • **Data Accuracy:** Striving to provide accurate event data to the central system for informed decision-making.	• **Enhanced Safety:** The satisfaction of contributing to passenger safety and the smooth operation of the transportation system. • **Efficiency:** The ability to streamline event monitoring and data transmission processes, improving overall system efficiency. • **Data Insights:** Access to valuable data insights generated by the central system for continuous improvement. • **Reliability Recognition:** Being recognized for providing reliable event data to the central monitoring system.
See	Listen to:
• The OBU with recognition capabilities "sees" the interior of the vehicle through onboard cameras. • It observes passenger behavior and events, such as vandalism or fights, and can analyze these visually.	• In addition to visual data, the OBU may "listen" to audio within the vehicle, further enhancing its ability to detect events like fights based on sound cues. • It pays attention to specific audio patterns, such as raised voices or aggressive sounds.
Says and Does	Think and Feel
• **Says:** The OBU communicates through data transmission, sending event reports with visual, audio, and other data to the central system. • **Does:** It continuously monitors the interior of the vehicle for specific events, using image and audio recognition algorithms to identify events like fights. When an event is detected, it transmits relevant data to the central system for analysis and response.	• **Thinks:** The OBU with recognition capabilities processes both visual and audio data in real-time, making decisions based on recognition algorithms and predefined criteria. • **Feels:** Similar to the standard OBU, it lacks emotions but operates with precision and efficiency to ensure passenger safety and security within the transportation system.

Vehicle fleet manager

Table 74: Vehicle fleet manager

Photo	Bio
	The Vehicle Fleet Manager is responsible for overseeing and managing a fleet of vehicles within a transportation system. They play a crucial role in ensuring the vehicles are well-maintained, operate efficiently, and comply with safety and operational standards.
Pains	Gains
• **Vehicle Maintenance:** Managing vehicle maintenance schedules and ensuring all vehicles are in optimal condition can be challenging. • **Data Overload:** Handling a large volume of data from various vehicles and systems, including event data, can be overwhelming. • **Operational Efficiency:** Striving to maximize vehicle efficiency and minimize downtime. • **Coordination with PTO:** Ensuring that vehicle operational efficiency efforts to achieve overall goals.	• **Fleet Optimization:** The satisfaction of achieving optimal fleet performance through effective management. • **Data Insights:** Access to valuable data for making informed decisions about maintenance and operations. • **Safety:** Contributing to passenger safety by monitoring and responding to vehicle events. • **Coordination Success:** Successfully coordinating with PTO to resolve incidents and minimize disruptions.
See	Listen to:
• The Vehicle Fleet Manager sees the entire fleet of vehicles, including their current locations, statuses, and maintenance schedules. • They observe real-time data, such as vehicle speed, door status, and other event-related information.	• The Vehicle Fleet Manager listens to reports and alerts generated by the vehicles' onboard systems, such as speed violations, engine faults, or door status changes. • They may engage in discussions with PTO personnel regarding incidents that require coordination and resolution.
Says and Does	Think and Feel
• **Says:** The Vehicle Fleet Manager communicates with vehicle operators and maintenance teams to coordinate maintenance schedules and respond to operational issues. • **Does:** They use fleet management software to monitor vehicle events in real-time and analyze historical data for trends. They also coordinate with PTOs to resolve incidents like vehicle immobilization.	• **Thinks:** The Vehicle Fleet Manager constantly evaluates vehicle performance, maintenance needs, and incident data to make informed decisions that optimize fleet operations. • **Feels:** They may experience a mix of responsibility and satisfaction in ensuring the fleet's smooth operation and safety while dealing with the challenges of maintenance and incident coordination.

4.2 The Experience Map

This map (Figure 6) is not about actions in the monitoring dashboard but how real life works for users (the actions they do). Only some of the actions are then done using the dashboard. With experience mapping, you define the steps a user takes in the context of the big picture in which they will use your platform. Normally you start from the user's final goal or need and decompose all the possible steps to reach the goal or fulfil the need. This is not yet the specific user journey inside your own platform, but a way for the whole team to understand how your platform intervenes in the larger context of the persona using it. The experience mapping can include steps outside your platform and how your platform integrates with the real world. It helps to build empathy with the users and understand their motivations, pain points and needs. The mapping in a multi-user experience also depicts how the different personas interact.

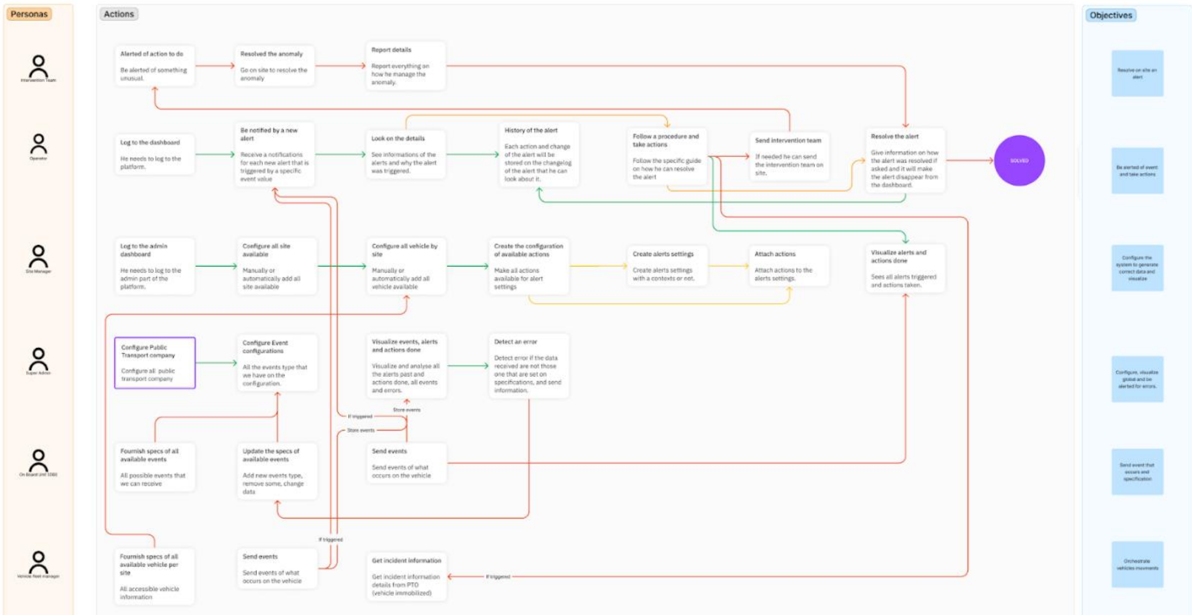


Figure 6: The experience map

4.3 The Database

Here is a presentation (Figure 7) of the current database version of the Passenger Safety Dashboard. All the separate parts are described in the following module descriptions. A PDF (vectorial) version is available for a cleaner visualization.

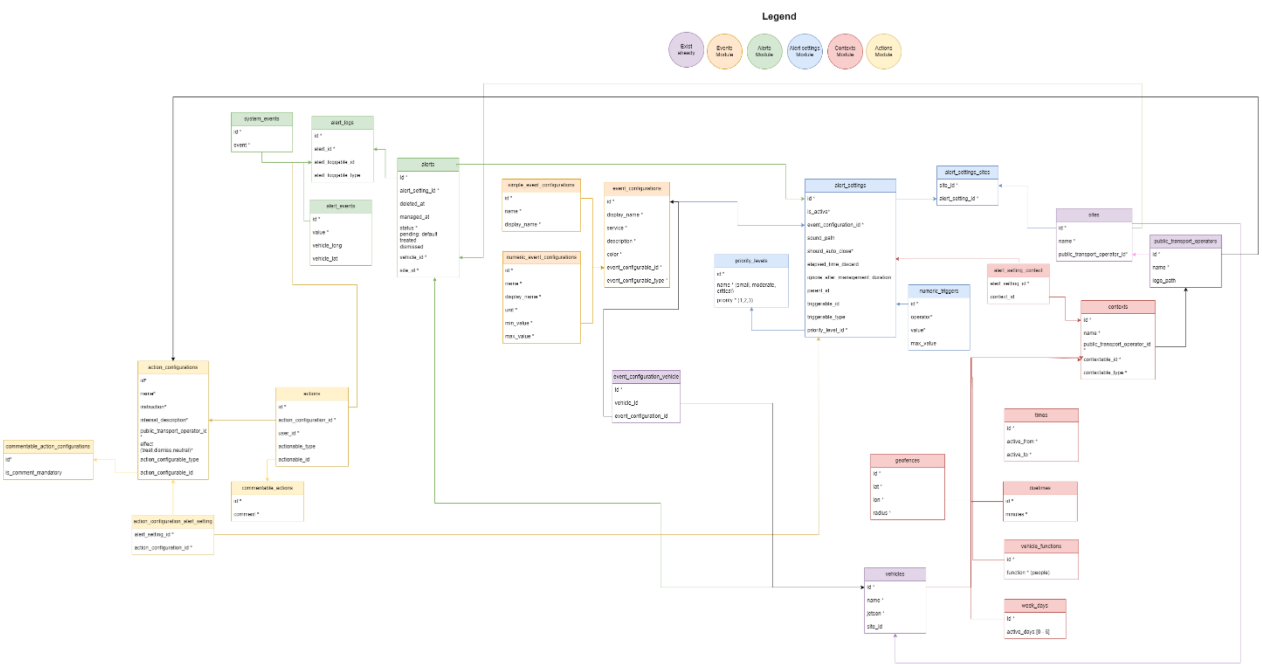


Figure 7: Database version of the Passenger Safety Dashboard

4.4 The 5 Modules

The Passenger Safety Dashboard was initiated in the H2020 AVENUE Project and brought as a contribution to the HEU ULTIMO Project by MobileThinking. The objective here is to industrialize the platform and add many features that will help PTO's to remotely monitor what's happening in the vehicles.

We divided the development of the Passenger Safety Dashboard into 5 modules, with each being described in the following subsections.

- **Event configurations module**
    - An event configuration is the type of event that is happening in the vehicle. There are multiple types of events available, and each event reported by the vehicle will be categorized using the available Event configurations.
- **Alerts module**
    - The purpose of an alert is to inform the supervisor about an event occurring in a vehicle and can be managed by the supervisor.
    - An alert is triggered by an Alert Setting.
- **Alerts settings module**
    - An alert setting allows you to configure when an alert should be triggered.
    - It's possible to create multiple alert settings with different triggers and different levels of priority for the same Event configuration, to create a priority hierarchy for the same event configuration.

- **Contexts module**
    - Contexts are variables like weekdays, time range, vehicle positions etc. used to define in an alert setting, in addition to the triggers, in which context an alert should be triggered.

- **Actions module**
    - Actions are used to define what a supervisor can do to treat an alert.
    - They are linked to an alert setting, and all alerts triggered by this alert setting will be manageable using the linked actions.

4.4.1 Events Configuration Module

4.4.1.1 Objective

The objective of an Event Configuration is to be able to categorize the events coming from the vehicle. This will allow the creation of alert settings for an event that will match some specific configured conditions. We use the Event to define the possible configurations.

4.4.1.2 Users involved

Super Admin:
- Manage (create, update, Archive)
- Analyze logs

4.4.1.3 Golden Path

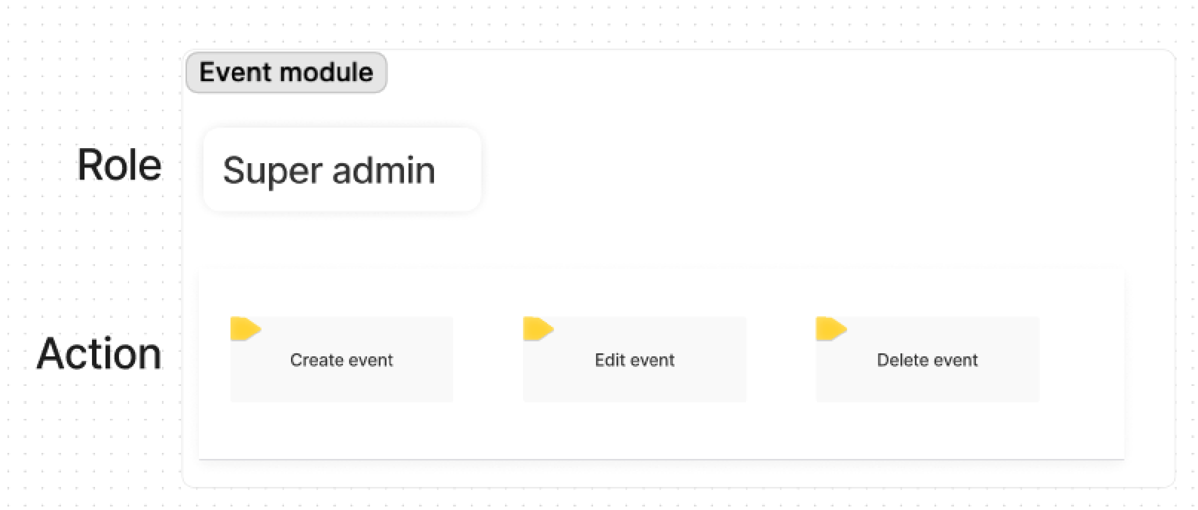


Figure 8: Golden Path of events configuration module

4.4.1.4 User Stories

Table 75: User stories of events configuration module

Feature	As	I want to	Version
Create an event configuration	Super Admin	Add a new event to fit the events sent by the vehicle.	v1 Implemented

Edit an event configuration	Super Admin	Edit an event if the vehicle changes the event structure.	v1 Implemented
Archive an event configuration	Super Admin	Archive an event if the vehicle is no longer sending this type of event.	v1 Implemented
Edit some field of an event configuration	Super Admin	Edit the color, description and service without archiving the old version of the configuration.	v1.1 Implemented
Configure the accepted event's frequency	Super Admin	Configure the frequency of the event.	V3 Planning
Regulate the frequency of an event.	System		Planning
Assign event configuration to vehicles (capabilities)	Super Admin		Planning

4.4.1.5 Use Cases

Table 76: Use cases of events configuration module: Create an event

Use Case		Create an event
Primary Actor		Super Admin
Scope		Settings for the alert dashboard
Brief		A Super Admin should be able to create a new event
Stakeholders		Every person using the system since events are the heart of the alert dashboard
Postconditions	**Minimal Guarantees**	The Super Admin can create a new event
	Success Guarantees	• The Super Admin can create a new event • The event can be used in alert settings • The event corresponds to a real event sent by a vehicle
Preconditions		• An event with the same name and same service does not exist.
Triggers		• A new event type is added on the specification and the Super Admin invokes a create request for the new event
Basic flow		• The Super Admin opens the admin dashboard. • The Super Admin navigates to the event section. • The Super Admin opens the creation form. • The Super Admin fills all the fields for the event until the event fits the vehicle event he wants to match. • The Super Admin submits the form. • The system confirms the creation to the Super Admin.

Table 77: Use cases of events configuration module: Edit an event configuration

Use Case		Edit an event configuration
Primary Actor		Super Admin
Scope		Settings for the alert dashboard
Brief		A Super Admin should be able to edit an existing event configuration
Stakeholders		Every person using the system since events are the heart of the alert dashboard
Postconditions	**Minimal Guarantees**	The Super Admin can edit an event configuration
	Success Guarantees	• The Super Admin can edit an event configuration • The current event configuration will be archived • A new event configuration with data updated will be saved
Preconditions		• An event configuration exists
Triggers		• A new event type is updated on the specification and the Super Admin invokes a create request for the new event
Basic flow		• The Super Admin opens the admin dashboard. • The Super Admin navigates to the event section. • The Super Admin changes all the fields for the event that he wants to change until the event fits the vehicle event he wants to match. • The Super Admin submits the form. • The system updates the event configuration • The system confirms the update to the Super Admin.

Table 78: Use cases of events configuration module: Archive an event

Use Case		Archive an event
Primary Actor		Super Admin
Scope		Settings for the alert dashboard
Brief		A Super Admin should be able to Archive an event
Stakeholders		Every person using the system since events are the heart of the alert dashboard
Postconditions	**Minimal Guarantees**	The Super Admin can Archive an event
	Success Guarantees	• The Super Admin can Archive an event

		• All the alerts settings using this event are soft-Archived • The event is no longer selectable when creating an alert setting
Preconditions		• An event exists
Triggers		• A new event type is deprecated on the specification and the Super Admin invokes an archive request for the event
Basic flow		• The Super Admin opens the admin dashboard. • The Super Admin navigates to the event section. • The Super Admin asks for the deletion of an event. • The Super Admin confirms his action. • The system Archives the event and all the alert settings related to this event.

Table 79: Use cases of events configuration module: Edit some field of an event configuration

Use Case	Edit some field of an event configuration
Primary Actor	Super Admin
Scope	Edition of an event configuration
Brief	Edit the color, description and service without archiving the old version of the configuration.
Stakeholders	Super Admin
Preconditions	• An event configurations exists
Triggers	• Upgrade from Edit of event configuration
Basic flow	• Description and color editable, the rest

4.4.1.6 Wireframes

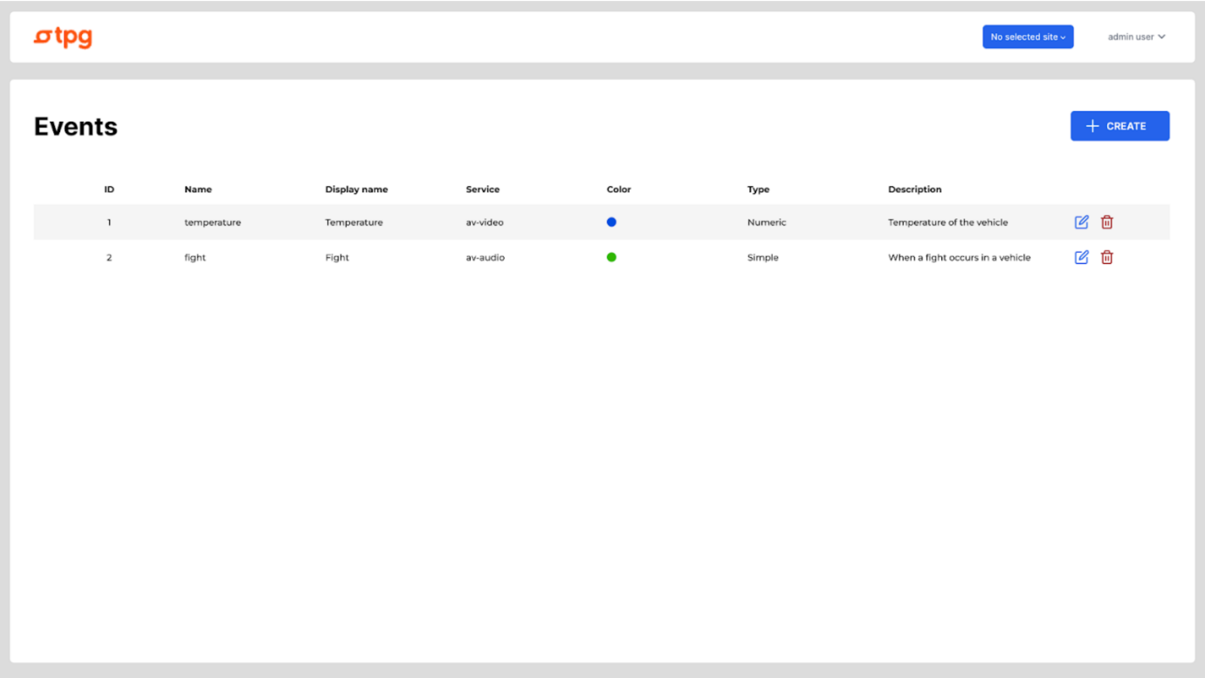


Figure 9: Wireframes of the events configuration module: List of the events available on the system.

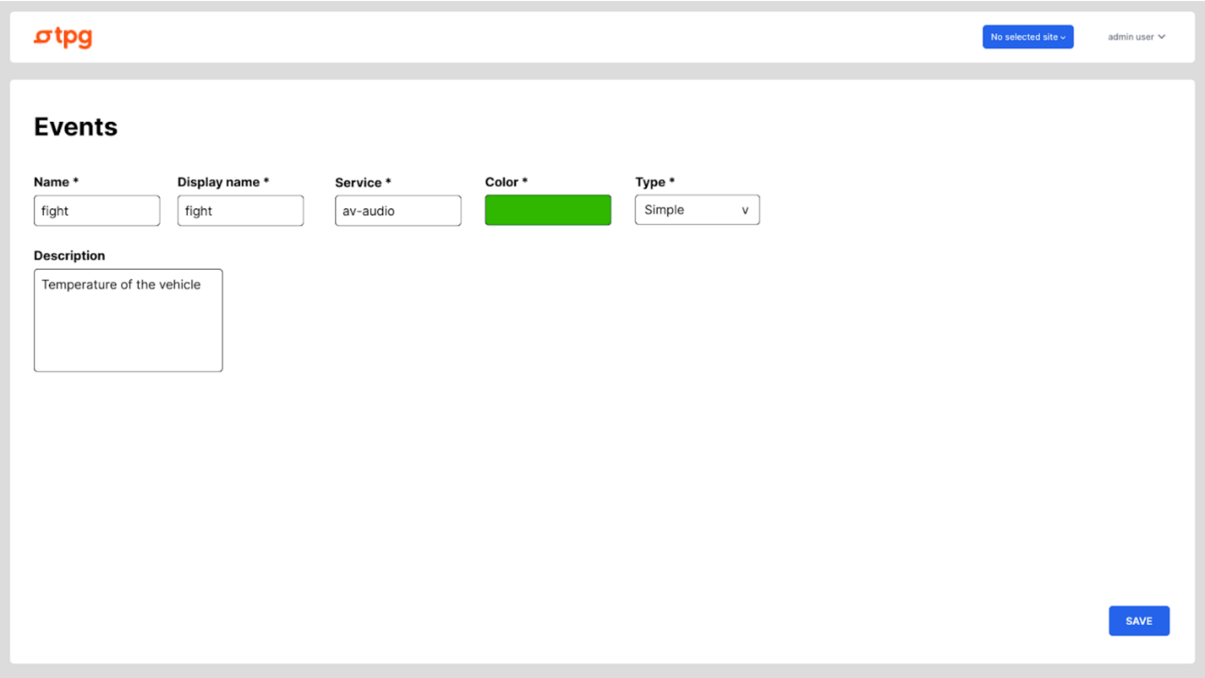


Figure 10: Wireframes of the events configuration module: Form to create/update an event of type Simple

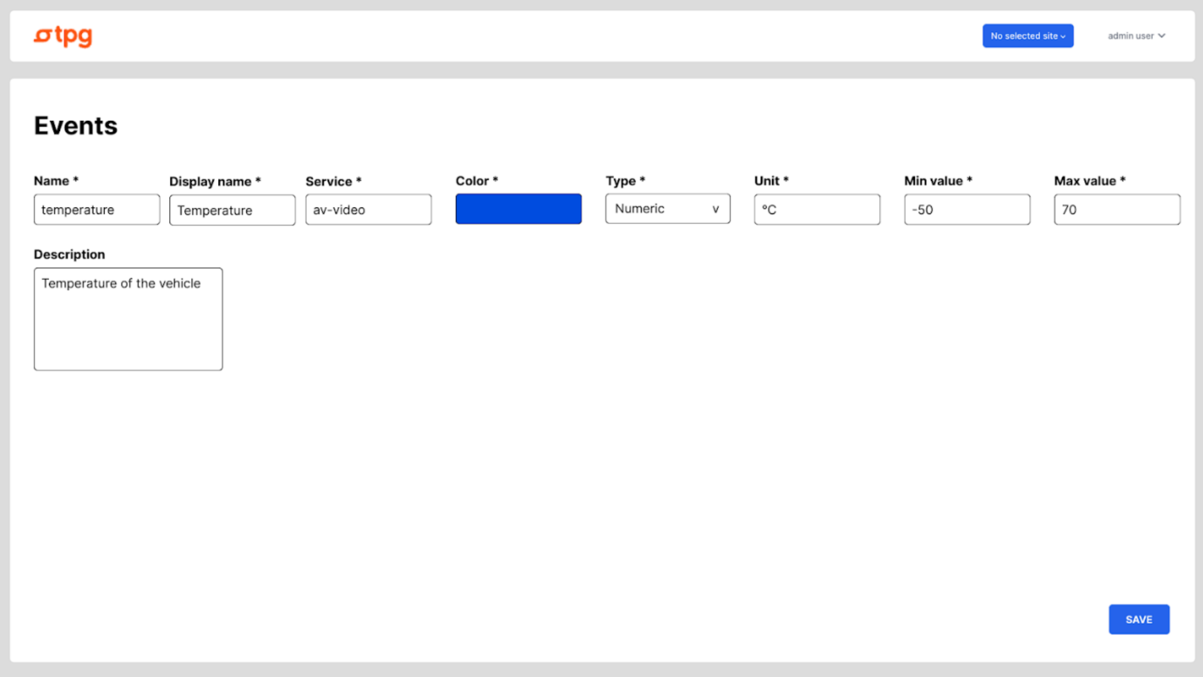


Figure 11: Wireframes of the events configuration module: Form to create/update an event of type Numeric. Numeric types of events have more fields than the simple event like Type, Unit, Min Value, Max value.

4.4.1.7 Technical Specifications

4.4.1.7.1 Database

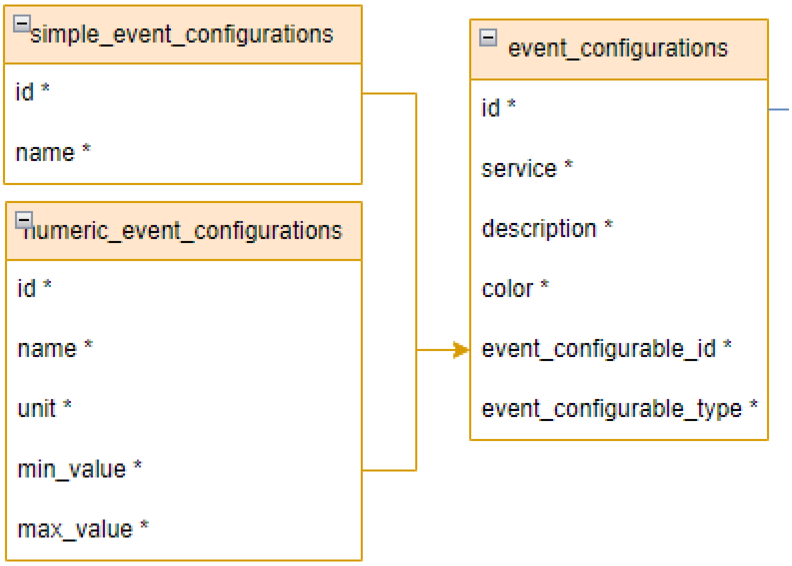


Figure 12: Database of events configuration module - Full database schema available in chapter 4.3

4.4.1.7.2 Data structures

- Name * (vandalism, humid, fight..)
- Type * (simple/numeric)
- Service * (av-environmental, av-video…)
- Description *

- Color * (The color used to identify the event)
- Unit (°C, %...) only available when Type is Numeric
- Min value
- Max value

Simple Event (**Table 80*****)***

Events that cannot be measured using numeric value.

Example: Fight. When there is a fight in the vehicle the event received will be of type boolean since it only indicates that a fight is occurring.

Table 80: Simple event example

Event type	Service	Description
bag_snatch	av-video	Bag Snatch
falling_down	av-video	Fall down
fight	av-video	Fighting
vandalism	av-video	Vandalism
fight	av-audio	Fighting
scream	av-audio	Scream
smoke	av-environmental	Smoke
safe_distance	av-counting	Safe distance
abandoned_luggage	av-abandoned-luggage	Abandoned Luggage
thumbs_up ??	av-handgesture	Thumbs up
thumbs_down ??	av-handgesture	Thumbs down

Thumbs : -1 (No gesture), 0 (Thumbs down), 1 (Thumbs up)

Numeric Event (**Table 81*****)***

Events that are measured using numeric value.

Example: Temperature. The event received will indicate the temperature using numeric value.

Table 81: Numeric event example

Name	Service	Description	Unit	Value range (min/max)
passengers	av-counting	Number of passengers detected in the shuttle	peoples	0 to 200
temp_forecast	av-environmental	Predicted temperature forecast for the next 5 minutes	Celsius (°C)	-30 to 100
aq_index	av-environmental	Air quality index	AQI	0 to 100

temp	av-environmental	Current temperature	Celsius (°C)	-30 to 100
humid	av-environmental	Current humidity	Percentage (%)	0 to 100
co2	av-environmental	Current Carbon Dioxide (CO2) level	Parts per million (ppm)	400 to 5000
voc	av-environmental	Current Volatile Organic Compounds (VOCs) level	Parts per million (ppm)	0 to 60
pm25	av-environmental	Current Particulates (PM2.5) level	Micrograms per cubic meter (µg/m3)	0 to 1000

4.4.2 Alerts module

4.4.2.1 Objective

The objective of an Alert is to inform a supervisor that an event occurs in a vehicle. The creation of an alert is triggered by an Alert Setting when an event received from a vehicle is matching the conditions configured in the Alert Setting.

4.4.2.2 Users involved

Supervisor:

- Consult the alerts dashboard
- Manage the alerts (dismiss, treat...)

Manager:

- Analyze alerts logs

4.4.2.3 Golden Path

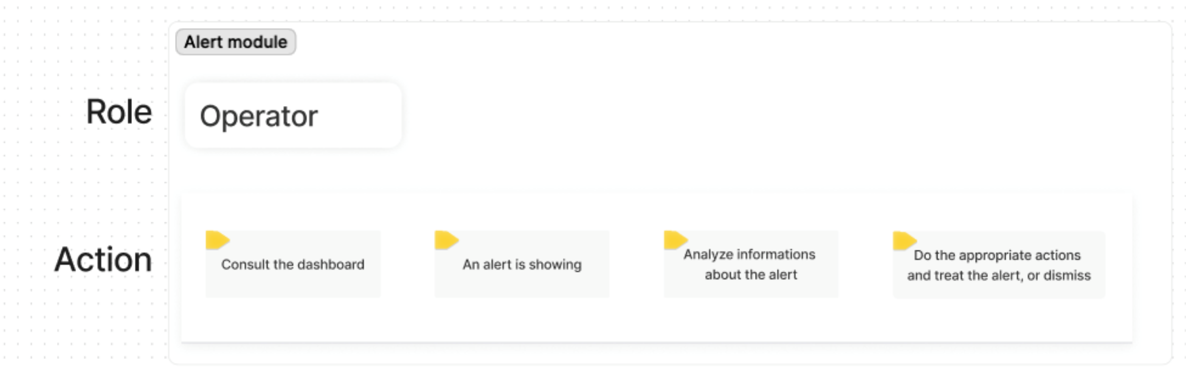


Figure 13: Golden Path of Operator in alert module

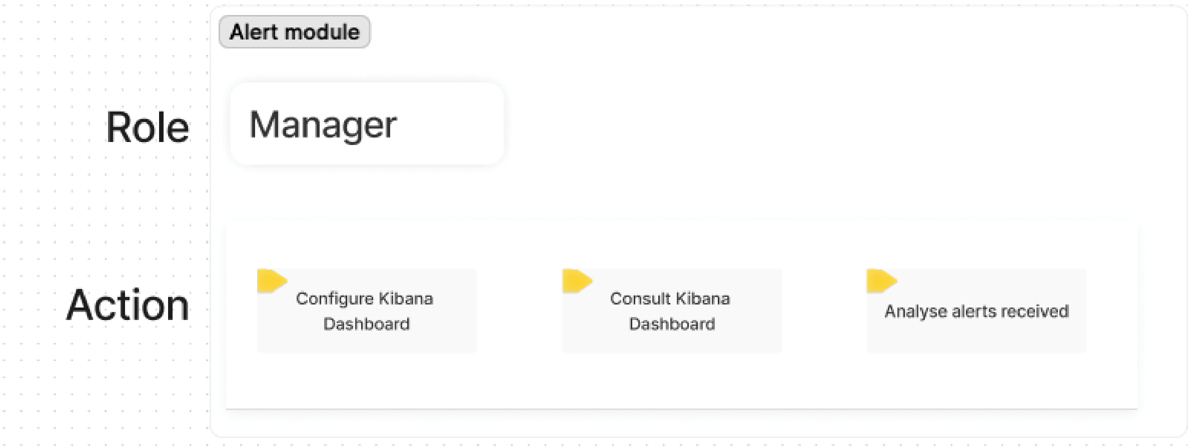


Figure 14: Golden Path of Manager in alerts module

4.4.2.4 User Stories

Table 82: User stories of alerts module

Feature	As	I want to	Version
Show alert in dashboard	supervisor	Receive real-time alerts and be notified on the dashboard.	v1 implemented
Show alert information	supervisor	See all the information about an alert such as type, location, criticality level etc.	v1 implemented
Alert changelog	supervisor	View the changelog of an alert to understand the evolution and the actions that are already done.	v1 implemented
Enhanced alert changelog	System	Add in the changelog all the elements that determined the triggering of the alert (alert setting, event, context, etc).	v1.1
Alert changelog event given an alert setting update	System	create a system event (loggable) if the linked pending alert is linked to an updated alert setting (including any of its parameters like the triggerable, context, actions or anything else).	v1.1
Status	supervisor	Change the status of an alert by selecting actions (ex. Choose an action that threatens the alert). The system can also change the status.	v1.2
Kibana dashboard configuration	Manager	Configure my own dashboard with graphs and useful data.	v2
Kibana analyzes	Manager	Consult and analyzes the graphs in the Kibana dashboard	v2
Auto-close	supervisor	See the alert auto-close	v2

4.4.2.5 Use Cases

Table 83: Use cases of alerts module: Show alerts in dashboard

Use Case	Show alerts in dashboard

Primary Actor		supervisor
Scope		Use of alerts dashboard
Brief		a supervisor should receive real-time alerts and be notified on the dashboard.
Stakeholders		supervisor
Postconditions	**Minimal Guarantees**	The supervisor can see alerts
	Success Guarantees	• supervisor will be notified of a new alert in real-time
Preconditions		• The supervisor has the dashboard open. • An alert settings should have been triggered to create an alert
Triggers		• Reception of an event triggers an alert settings
Basic flow		• The supervisor opens the dashboard. • An event from the vehicle is received and matches alert settings conditions, an alert is created. • The supervisor is notified by a new alert.

Table 84: Use cases of alerts module: Dismiss

Use Case		Dismiss
Primary Actor		supervisor
Scope		Management of alerts
Brief		a supervisor should be able to dismiss an existing alert
Stakeholders		supervisor
Postconditions	**Minimal Guarantees**	The supervisor can dismiss an alert
	Success Guarantees	• The supervisor can dismiss an alert • The supervisor can add a comment.
Preconditions		• A pending alert exists
Triggers		• The supervisor invokes a dismiss request for an existing alert
Basic flow		• The supervisor opens the alert dashboard. • The supervisor receives a new alert on the dashboard. • The supervisor consults the alert and analyzes the information.

	• It's a low criticality level and no actions are needed, so the supervisor dismisses the alert. • The system confirms to the supervisor that the alert has been dismissed. • The alert is no longer visible on the dashboard.

Table 85: Use cases of alerts module: Actions

Use Case		Actions
Primary Actor		supervisor
Scope		Management of alerts
Brief		a supervisor should be able to do actions related to an alert.
Stakeholders		supervisor
Postconditions	**Minimal Guarantees**	The supervisor can do an action for an alert
	Success Guarantees	• The supervisor can do multiple actions for an alert • All the actions done will be noted in the alert changelog
Preconditions		• The alert setting that triggers the alert should have at least one action available
Triggers		• The supervisor invokes a request to do an action on an alert
Basic flow		• The supervisor opens the dashboard. • An alert is received. • The supervisor opens the alert, consults the information and views the possible actions. • The supervisor clicks on an action that he wants to do and it shows the steps to achieve it. • Actions are put on the changelog • The action is selected and clickable and has been added to the alert changelog.

Table 86: Use cases of alerts module: Show alert information

Use Case	Show alert information
Primary Actor	supervisor
Scope	Management of alerts
Brief	a supervisor should be able to see information about an alert

Stakeholders		supervisor
Postconditions	**Minimal Guarantees**	The supervisor can see basic information (level, vehicle, site, name, value, related alerts, if auto close)
	Success Guarantees	• The supervisor can see more information (the basic information, trigger activated, geolocation and actions available)
Preconditions		• A pending alert exists
Triggers		• The supervisor requests to see more information that he cannot see just by looking at the alert.
Basic flow		• The supervisor opens the alert dashboard. • The supervisor receives a new alert on the dashboard. • The supervisor sees basic information on the alert without opening it. • The supervisor consults the alert to see more information about the alert.

Table 87: Use cases of alerts module: Alert changelog

Use Case		Alert changelog
Primary Actor		supervisor
Scope		Management of alerts
Brief		a supervisor should be able to understand the evolution of an alert and what action(s) has already been done and by who.
Stakeholders		supervisor
Postconditions	**Minimal Guarantees**	The supervisor can see the changelog of an alert
	Success Guarantees	• The supervisor can see the changelog of an alert • The supervisor can view the day and the time of each event modification or action • The supervisor can see the position of the vehicle at the time of the event for each event
Preconditions		• The alert have a previous state or an action has been done
Triggers		• The supervisor invokes a request to see the changelog of an alert
Basic flow		• The supervisor opens the dashboard. • An alert is received but is not managed immediately. • The vehicle sends the same event with different values. • The supervisor opens the alert changelog and sees all the previous states of the alert and actions done.

Table 88: Use cases of alerts module: Treat

Use Case		Treat
Primary Actor		supervisor
Scope		Management of alerts
Brief		a supervisor should be able to treat an alert when the issue has been solved
Stakeholders		supervisor
Postconditions	**Minimal Guarantees**	The supervisor can treat an alert
	Success Guarantees	• The supervisor can add a comment to the treatment with the actions he has done.
Preconditions		• A pending alert exists
Triggers		• The supervisor requests to treat the alert
Basic flow		• The supervisor opens the alert dashboard. • The supervisor receives a new alert on the dashboard. • The supervisor opens the alert, selects some actions and can write a comment. • The supervisor treats the alert. • The alert disappeared from the dashboard.

4.4.2.6 Wireframes

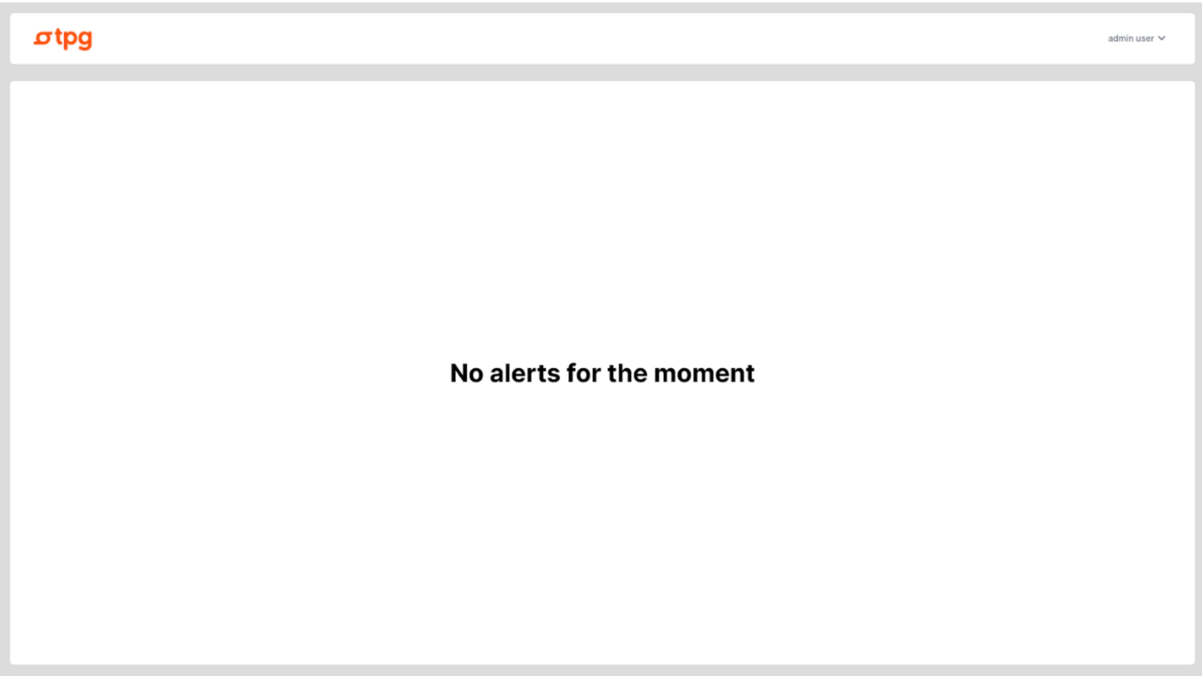


Figure 15: Wireframes of alerts module: Initial dashboard state when there is no alert.

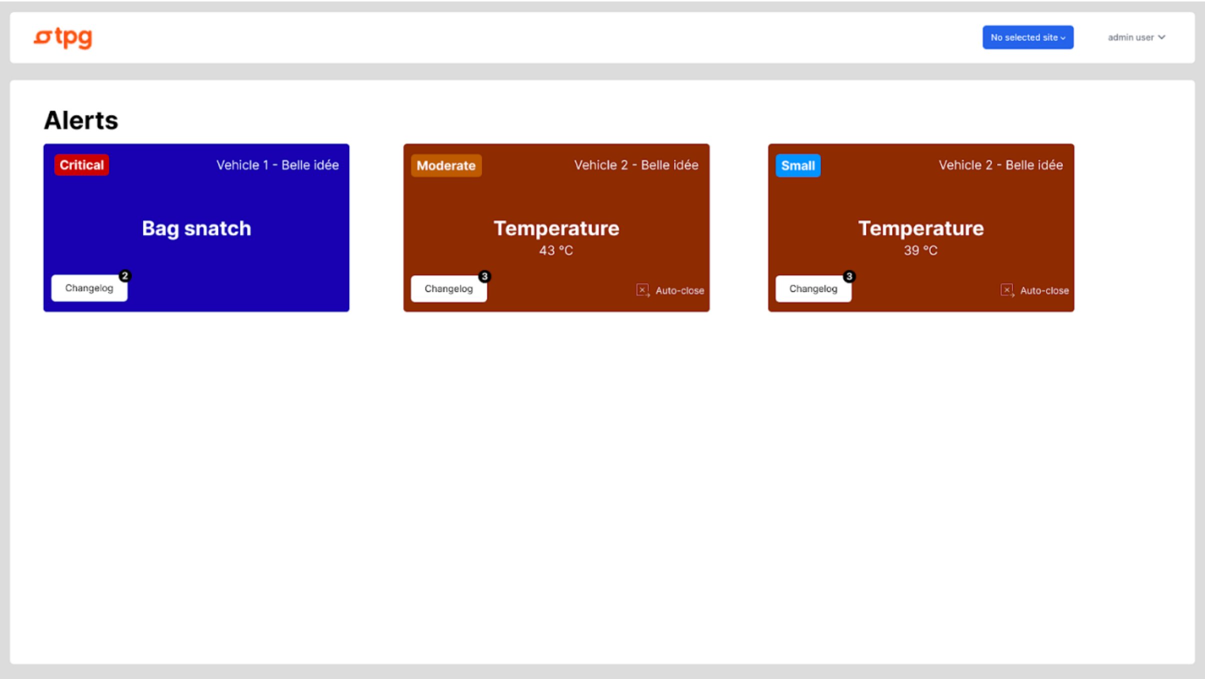


Figure 16: Wireframes of alerts module: Preview of alerts on the dashboard, indicating essential information: Event with his value if type Numeric, Criticality, Vehicle, Site, How many times the vehicle sent the same alert (changelog), if the alert can be auto-closed.

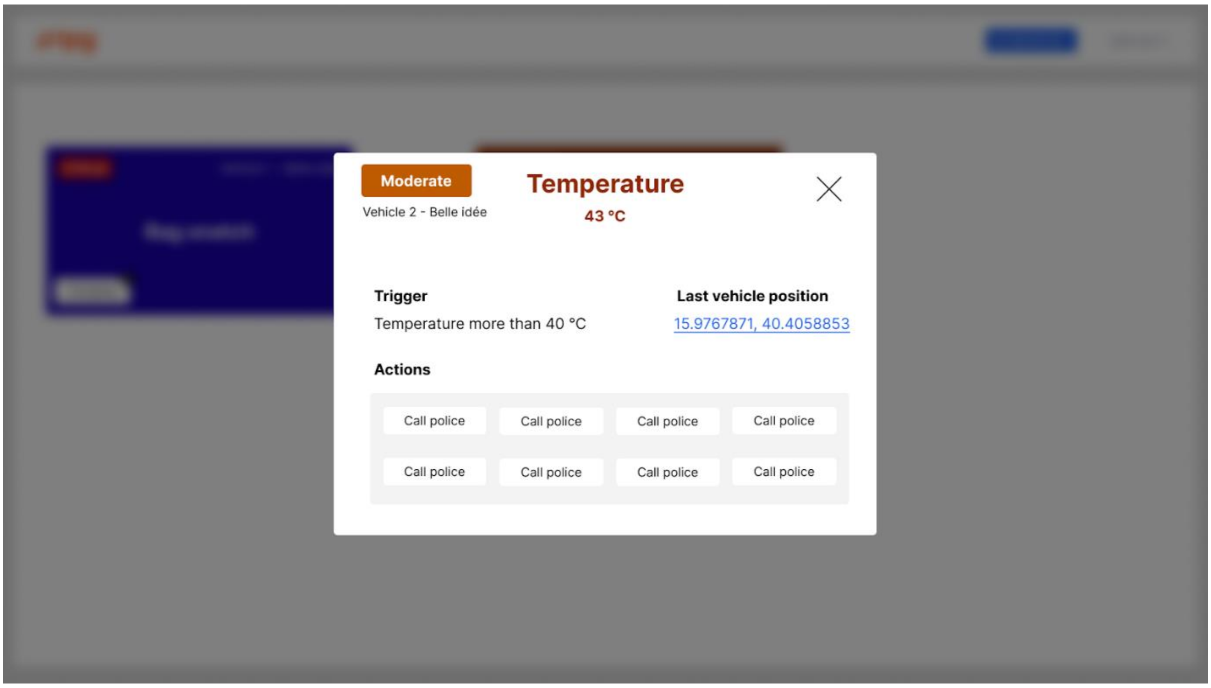


Figure 17: Wireframes of alerts module: By opening an alert we can see more information about it such as trigger, last vehicle position, actions available and options to dismiss or treat an alert with a comment.

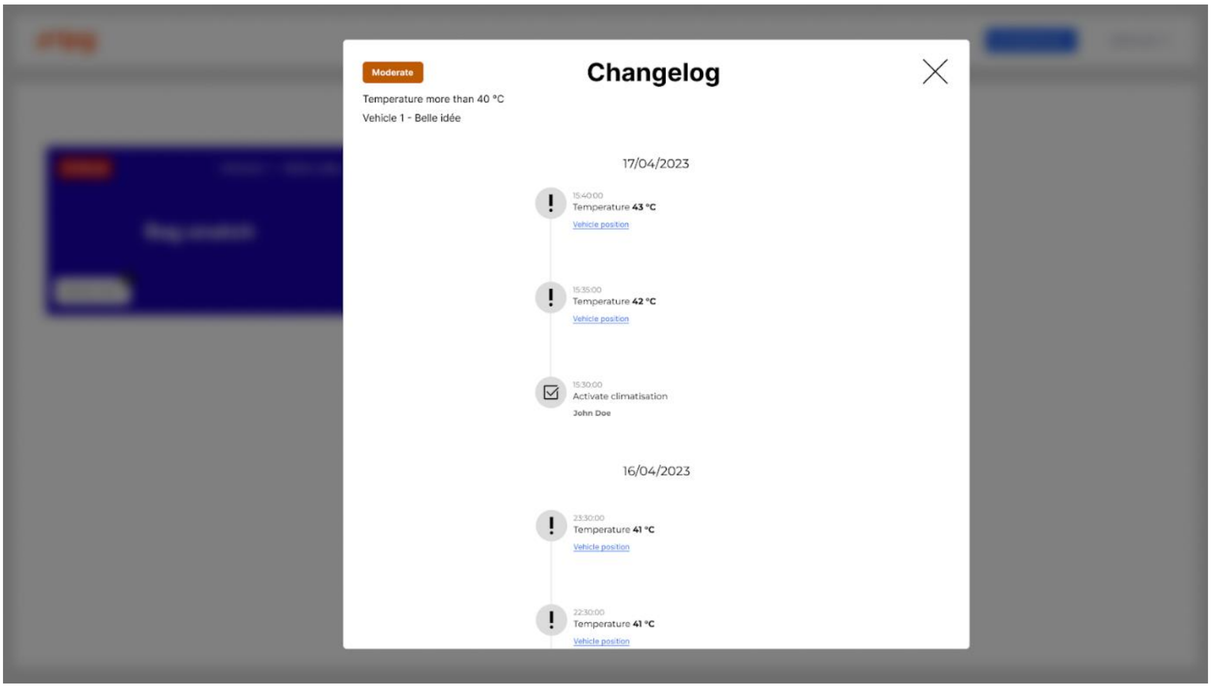


Figure 18: Wireframes of alerts module: The changelog shows all the previous states of the alert and all actions done at a time and date.

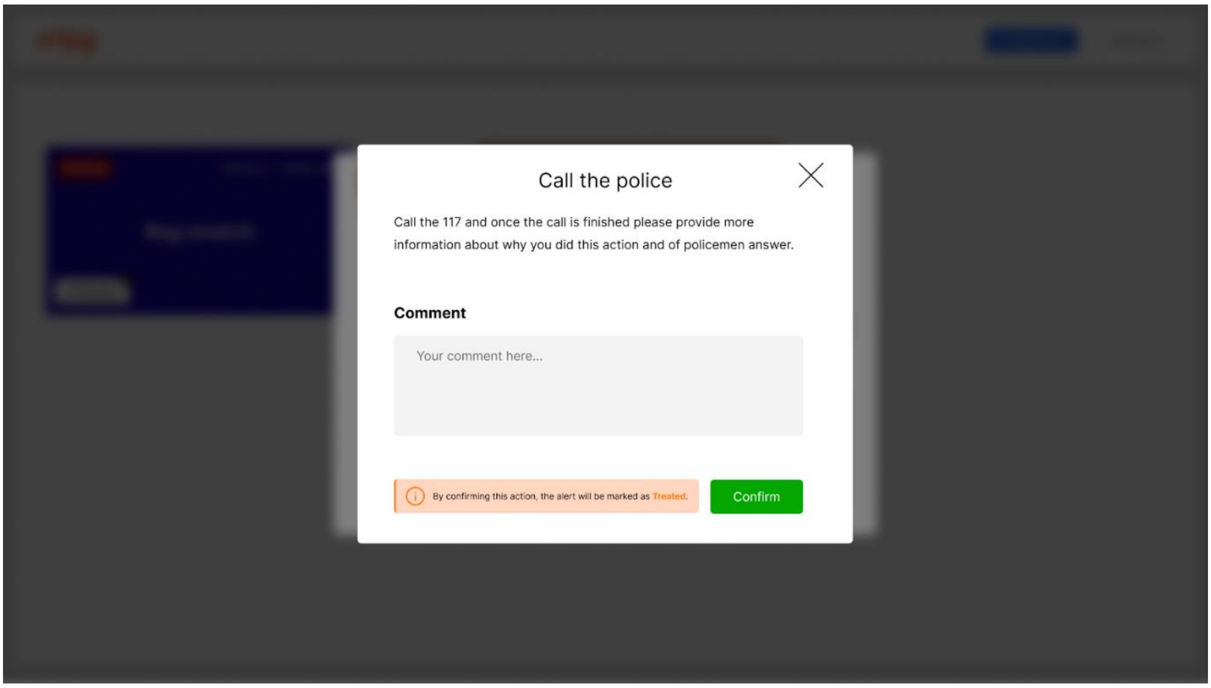


Figure 19: Wireframes of alerts module: Call the police functionality

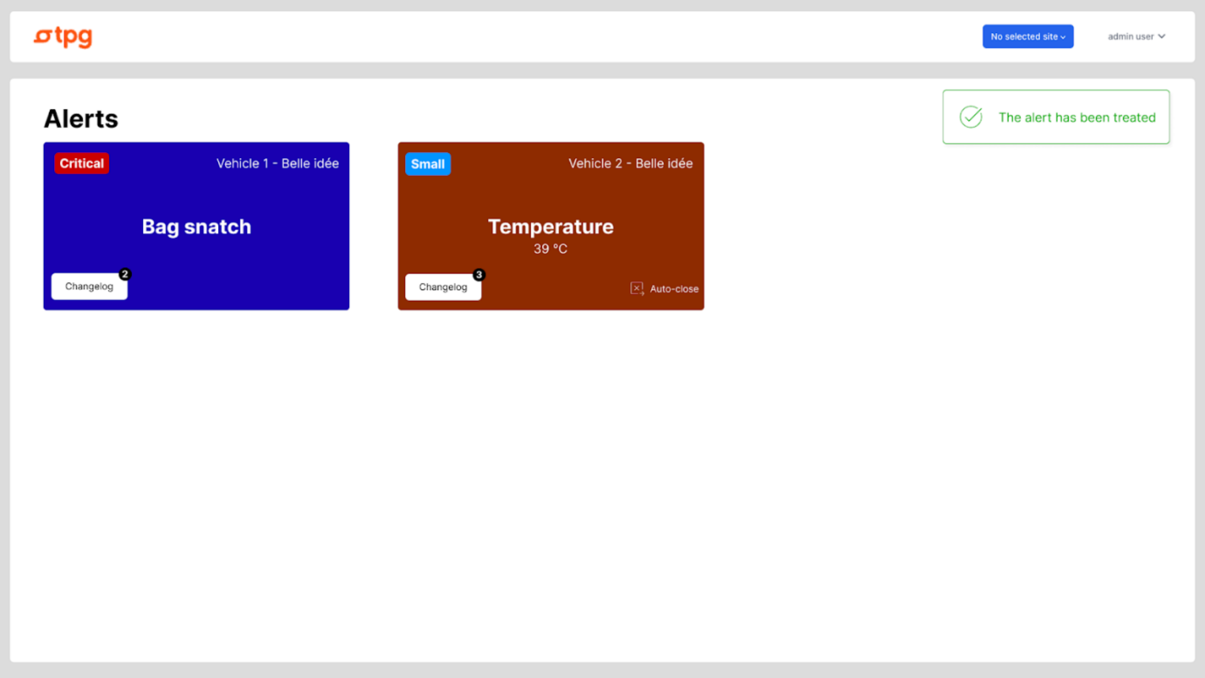


Figure 20: Wireframes of alerts module: Overview of alerts

4.4.2.7 Technical Specifications

4.4.2.7.1 Database

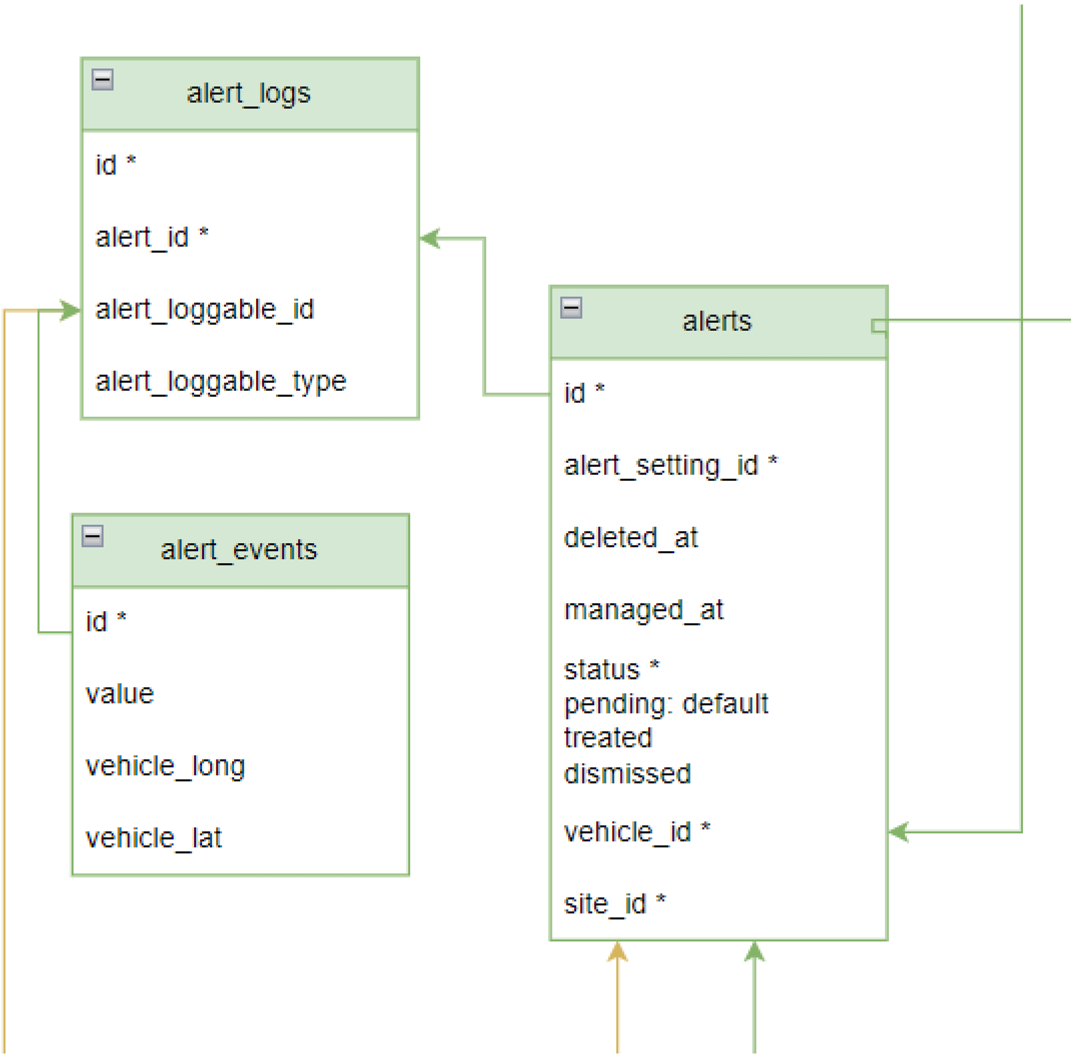


Figure 21: Database of alerts module - Full database schema available in chapter 4.3

4.4.2.7.2 Data structures

Alerts

These represent the high-level alert objects that are created based on specific criteria. Each alert is associated with an Alert Setting, a Vehicle and a Site. Alerts have a status.

Alert Logs

These represent individual occurrences of alerts. Each Alert Log is associated with a specific timestamp and contains information such as the Alert Events that contains location and value of the vehicle at the time the alert was triggered, it will also contain all the actions done for this specific alert.

Alert Events

These represent the specific data of each alert that causes an alert to be created. Each Alert Event is associated with an alert in the Alert logs with a specific timestamp and contains information such as the value of the event and the position of the vehicle when triggered.

Current Alert
The most recent alert based on his timestamp in status pending in this group, is the current alert. Only the current alert will be displayed on the dashboard.

Statuses

- Pending
- Treated
- Auto-closed
- Dismissed

4.4.3 Alert Settings Module

4.4.3.1 Objective

The objective of an Alert setting is to configure when an event received from a vehicle should trigger an alert.

4.4.3.2 Users involved

Manager:

- Manage the alert settings

4.4.3.3 Golden Path

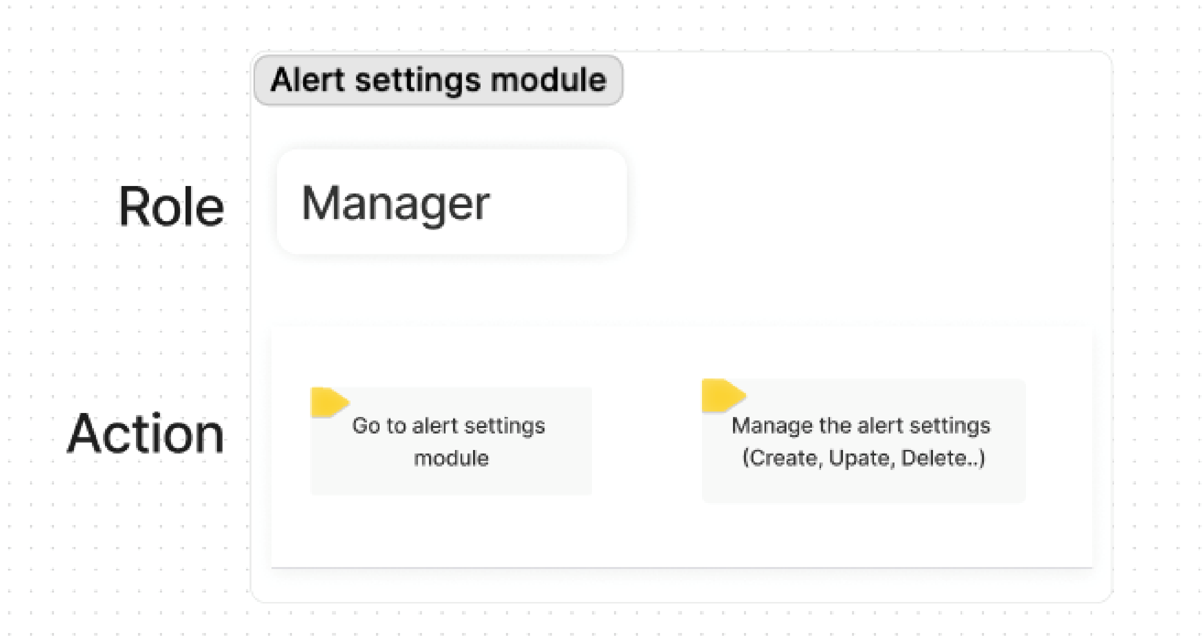


Figure 22: Golden Path of alert settings module

4.4.3.4 User Stories

Table 89: User stories of alert settings module

Feature	As	I want to	Version
Create Alert Setting	Manager	Create a new Alert Setting.	v1 implemented

Update Alert Setting	Manager	Update an existing Alert Setting.	v1 implemented
Archive Alert Setting	Manager	Archive an existing Alert Setting.	v1 implemented
Alert creation	System	Verify if I should create an alert based on the available Alert Settings when a new event arrives.	v1 implemented
Alert update	System	Verify if I should update an alert based on the available Alert Settings and current alerts when a new event arrives.	v1 implemented
Alert creation with context verification	System	Verify if I should create an alert based on the available Alert Settings and their contexts when a new event arrives.	v1.1 planning
Create Alert Setting with actions	Manager	create a new Alert Setting with at least one treat or dismiss action.	v1.1 planning
Archive Alert Setting if context changes	Manager	Archive an Alert Setting when I change the context parameters (attach/detach).	v1.2 planning
Auto-close (time)	Manager	Configure an Alert Setting to auto-close an alert if it is no longer relevant due to a time limit.	V2 planning
Ignore after closure (time)	Manager	Configure an Alert Setting to ignore related events for X minutes after the supervisor closes an alert triggered by the same Alert Setting.	V2 planning
Archive all alert settings	System	archive all the alert settings related to an event configuration that is being archived.	v2 planning
Auto-close (context)	Manager	Configure an Alert Setting to auto-close an alert if it is no longer relevant due to a context change.	V3 planning
Ignore after closure (context)	Manager	Configure an Alert Setting to ignore related events until a given context changes after the supervisor closes an alert triggered by the same Alert Setting.	V3 planning

4.4.3.5 Use Cases

Table 90: Use cases of alert settings module: Create Alert Setting

Use Case	Create Alert Setting
Primary Actor	Manager
Scope	Management of alert settings
Brief	A manager should be able to create a new Alert Setting.
Stakeholders	Manager, supervisor (The alerts that he shows on the dashboard will depend on the alert settings)

Postconditions	**Minimal Guarantees**	The manager can create alert settings with the minimum required fields
	Success Guarantees	• The manager can create alert settings • The manager can precisely configure the alert setting using conditions and contexts
Preconditions		• At least one event configuration exists
Triggers		• The manager invokes a request to create a new alert setting
Basic flow		• The manager goes to the Alert Setting module. • The manager opens the creation form. • The manager fills all the fields of the form to configure his Alert Setting. • The manager submits the form. • The system creates the Alert Setting. • The system confirms that the Alert Setting has been created.

Table 91: Use cases of alert settings module: Update Alert Setting

Use Case		Update Alert Setting
Primary Actor		Manager
Scope		Management of alerts settings
Brief		A manager should be able to update alert settings and archive the old data to keep a trace.
Stakeholders		Manager, supervisor
Postconditions	**Minimal Guarantees**	The manager can update the value of fields in an alert settings
	Success Guarantees	• The manager can update the value of fields in an alert setting • The manager can precisely configure the alert setting using conditions and contexts • The system will archive the alert Settings and create a new one. • The system keeps the link between the alert settings (the new one knows its origin)
Preconditions		• An existing alert setting
Triggers		• The manager wants to update the alerts settings
Basic flow		• The manager goes to the Alert Setting module. • The manager requests to edit an existing alert setting • The manager changes the fields of an alert setting • The manager submits the form • The system archives the old Alert Setting and creates a new one. • The system links the old Alert Setting to the new one

	• The system confirms that the Alert Setting has been updated.

Table 92: Use cases of alert settings module: Archive Alert Setting

Use Case		Archive Alert Setting
Primary Actor		Manager
Scope		Management of Alert Settings
Brief		A manager should be able to Archive an existing Alert Setting.
Stakeholders		Manager, supervisor
Postconditions	**Minimal Guarantees**	The manager can Archive an alert setting.
	Success Guarantees	• The manager can Archive an alert setting.
Preconditions		• An Alert Settings is already created.
Triggers		• The manager invokes a request to Archive an alert setting.
Basic flow		• The manager goes to the Alert Setting module. • The manager requests to Archive an Alert Setting. • The system shows a confirmation modal. • The manager confirms. • The system Archives the alert setting. • The system confirms the soft deletion of the alert setting.

Table 93: : Use cases of alert settings module: Alert creation

Use Case		Alert creation
Primary Actor		System
Scope		Creation of alerts based on Alert Settings
Brief		The system should evaluate if an event originates a new alert given the set of available Alert Settings.
Stakeholders		Manager, supervisor
Postconditions	**Minimal Guarantees**	The system can evaluate if the event rises an alert.
	Success Guarantees	• The system creates an alert. • The system registers the first changelog data for the new alert.

Preconditions	• An Alert Settings is already created.
Triggers	• An event is received.

Basic flow	• The system receives and processes a new event.
	• The system retrieves the Alert Settings concerning the event configuration of the received event.
	• The system verifies if any Alert Setting triggers are true.
	    o If any trigger is true, create an alert
	    o Otherwise do nothing
	• If an alert is created, add the first element in the alert changelog.

Table 94: Use cases of alert settings module: Alert update

Use Case		Alert update
Primary Actor		System
Scope		Creation of alerts based on Alert Settings
Brief		The system should evaluate if an event updates an alert given the set of available Alert Settings and the existing alerts.
Stakeholders		Manager, supervisor
Postconditions	**Minimal Guarantees**	The system can evaluate if the event rises an alert.
	Success Guarantees	• The system updates an alert. • The system registers the changelog data for the existing alert.
Preconditions		• An Alert Settings is already created. • An alert for the same Alert Setting is already active.
Triggers		• An event is received.

Basic flow		• The system receives and processes a new event.
		• The system retrieves the Alert Settings concerning the event configuration of the received event.
		• The system verifies if any Alert Setting triggers are true.
		    o If any trigger is true, continue
		    o Otherwise do nothing
		• The system retrieves the existing open alert for the triggered Alert Setting
		• The system updates the alert by adding the new data in its changelog.

Table 95: Use cases of alert settings module: Attach actions to alert setting

Use Case	Attach actions to alert setting

Primary Actor		Manager
Scope		Attachment of actions to an alert setting
Brief		The manager should be able to indicate for an alert setting which actions are available to do on an alert triggered by this alert setting.
Stakeholders		Manager
Postconditions	**Minimal Guarantees**	The alert setting has minimum one action of type Dismiss or Treat.
	Success Guarantees	• The alert setting can have multiple actions, but still minimum one of type Dismiss or Treat.
Preconditions		• An Alert Settings is already created. • An Action is already created.
Triggers		• The manager request to attach actions to an alert setting.
Basic flow		• The manager goes to the Alert Setting module. • The manager opens the creation form. • The manager fills the “Actions” mandatory multiselect field, with a minimum of one action of type Dismiss or Treat. • The manager submits the form. • The system creates the Alert Setting with the actions attached. • The system confirms that the Alert Setting has been created.

4.4.3.6 Wireframes

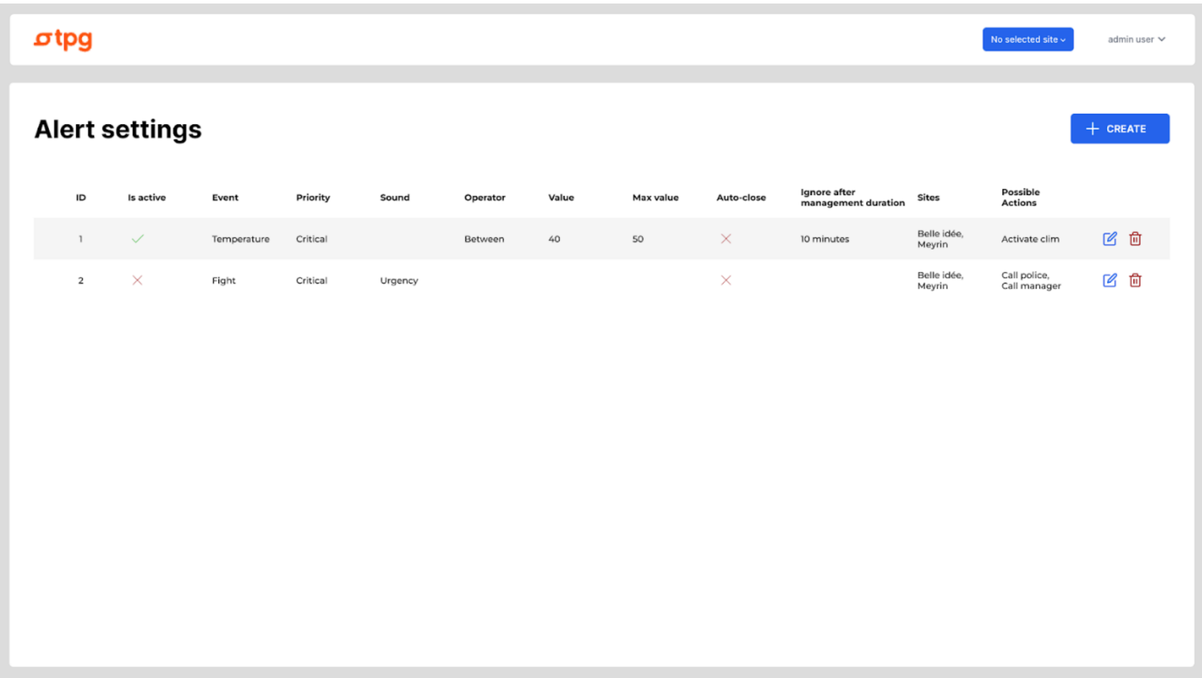


Figure 23: Wireframes of alert settings module: Alerts settings index

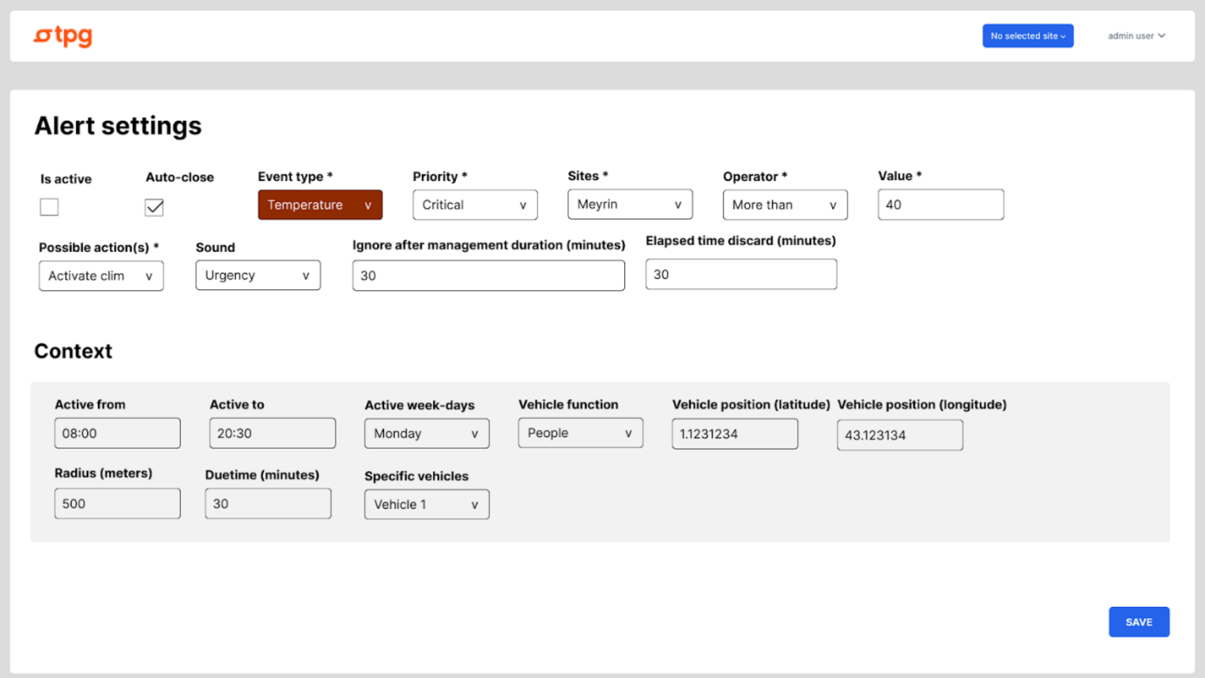


Figure 24: Wireframes of alert settings module: Alerts settings numeric type with auto close checked

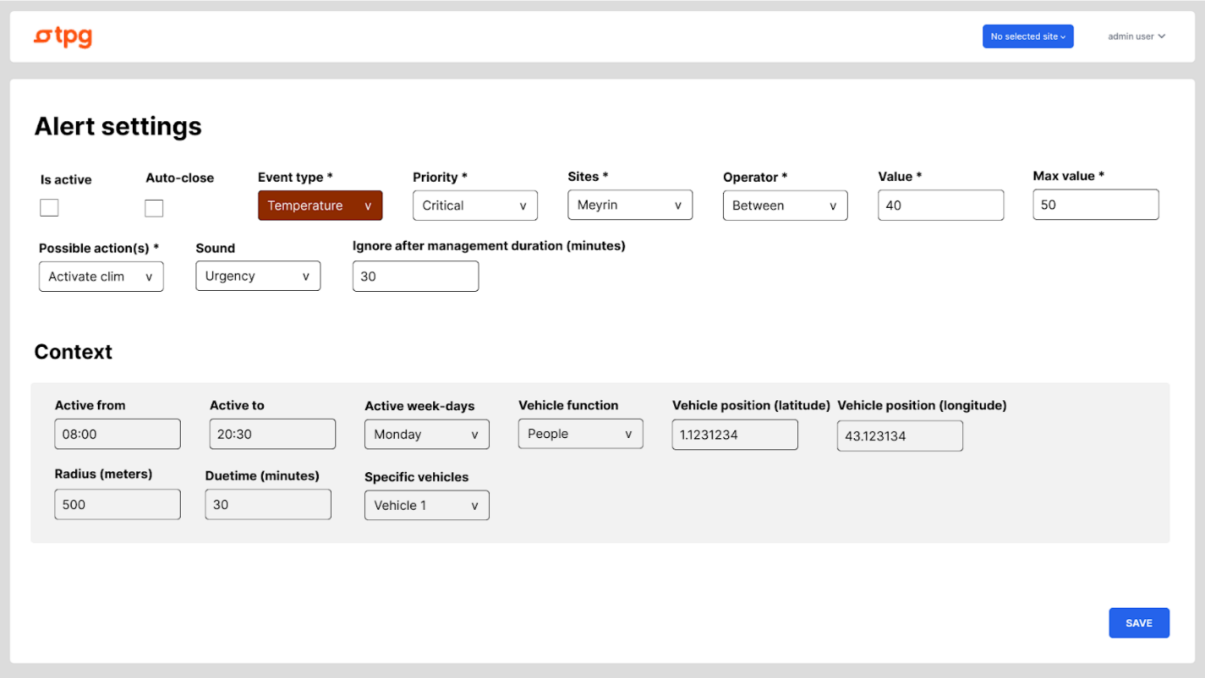


Figure 25: Wireframes of alert settings module: Alert settings with between operator

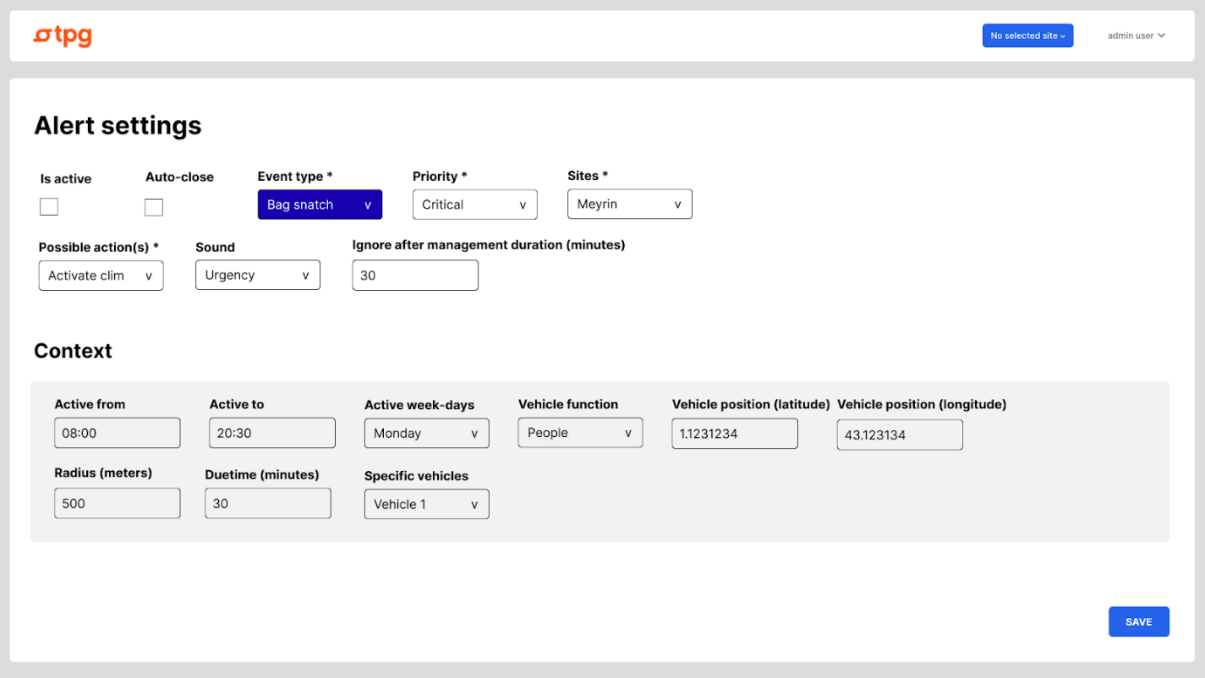


Figure 26: Wireframes of alert settings module: Alert settings simple event

4.4.3.7 Technical Specifications

4.4.3.7.1 Database

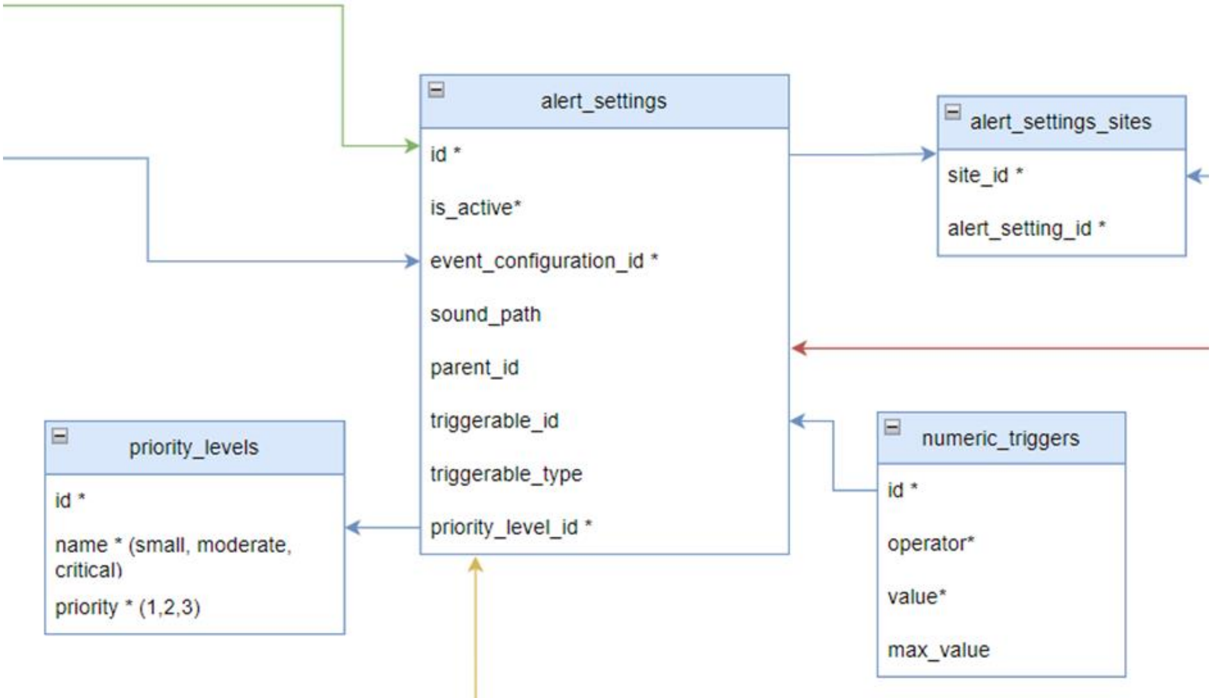


Figure 27: Database of alert settings module - Full database schema available in chapter 4.3

4.4.3.7.2 Data Structures

The fields available to configure the Alert Settings will depend on the Event type selected.

- Is Active (checkbox, default true)
- Event *

- Site(s) *
- Sound (Select between a list of proposed sounds. When selecting, the sound is playing)
- Action(s) * (select all actions for this alert settings)
- Level of priority *
- Should auto-close: If checked, auto-close is enabled.
- Elapsed time discard is used for auto closed
- Ignore after treatment (in minutes): Ignore alerts coming from the same Event Type for X minutes after an alert triggered by this Alert Setting that has been managed.

Event Simple

A simple event does not require specific configuration in alert settings.

Event Numeric

An alert setting with an event type of type Numeric is defined by the possibility of having a numeric value and an operator. For example, we can configure our alert setting to trigger an alert when humidity level is between (operator) 10 (value) and 20 (max value). Or when temperature is going over (operator >) 30°C (value).

Specific fields for alert settings with Value event type:

- Operator *
- Value *
- Max value (used to define the max value. Only visible if operator is BETWEEN)

Operators

Table 96: Data structures of alert settings module: Operator side

Operator	**Value**
More than	>
Less than	<
Equal to	=
Less than or equal to	<=
More than or equal to	>=
Between	BETWEEN value AND max_value

4.4.3.7.2.1 Priority

Low

- Low-level alerts that do not require immediate action.
- Typically related to minor issues that do not impact the good functioning of the vehicle.
- Example: The vehicle is slightly crowded with 12 people and has a space of 13 people.
- It's still acceptable and does not require immediate intervention.

Moderate

- Mid-level alerts that require attention and may require action.

- Usually related to issues that may affect the operation of the vehicle.
- Example: The temperature has reached 35°C.
- It needs to have an action of the supervisor if the temperature is not going down after a certain amount of time.

Critical

- High-level alerts demand immediate action and resolution.
- Typically related to critical issues that impact the safe operation of the vehicle and passenger safety.
- Require urgent response and may involve specialized teams.
- Example: A fight is detected and is during 2 min, the police needs to be sended with an intervention team.

Calculate event duration

1. Since the first event that matches the Alert setting condition, start a timer that will define the duration of the event.
2. Use a 30 second timer to check if the event has been finished. At each event matching the condition received before 30 seconds, this timer is reset.
3. When the 30 seconds timer ends, it means that the event is finished because we no longer receive events that match the Alert Setting condition. Stop the timer.

The id of the parent_id will be kept for the one that is archived when there is an update.

4.4.4 Contexts Module

4.4.4.1 Objective

The objective of the contexts module is to add contextual conditions that will define when an alert setting should trigger the alert or not.

4.4.4.2 Users involved

Manager:

- Manage the alert settings with contexts

4.4.4.3 Golden Path

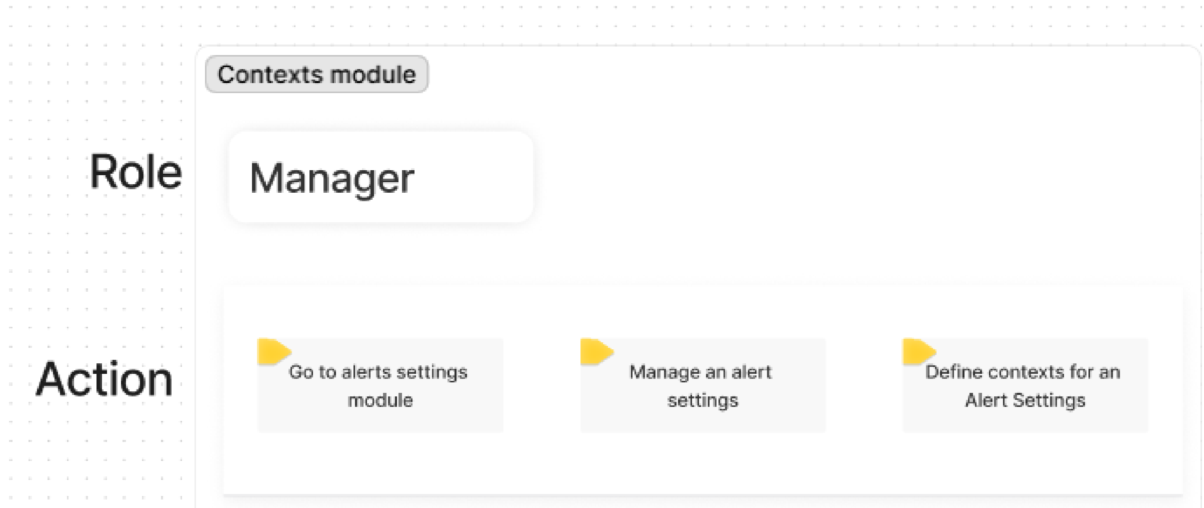


Figure 28: Golden Path of Contexts module

4.4.4.4 User Stories

Table 97: User stories of contexts module

Feature	As	I want to	version
Create context	Manager	Create a new context	v1 implemented
Update context	Manager	Update a context	v1 implemented
Archive context	Manager	Archive a context	v1 implemented
Attach a context to alert setting	Manager	Attach a context to an alert settings	v1 implemented
Detach a context from alert setting	Manager	Detach an existing context from an alert settings	v1 implemented
Check context conditions before triggering an alert	System	Check that the contexts attached to the alert setting are also matching condition before triggering the alert	v1 implemented

4.4.4.5 Use Cases

Table 98: Use cases of contexts module: Create a new context

Use Case	Create a new context
Primary Actor	Manager
Scope	Management of contexts
Brief	A manager should be able to create a new context.

		Available contexts are: • Times • Vehicle(s) • Weekdays
Stakeholders		Manager
Postconditions	**Minimal Guarantees**	The manager can create a context.
	Success Guarantees	• The manager can create multiple contexts
Preconditions		• The name should be unique
Triggers		• The manager fills the form and submits the form.
Basic flow		• The manager goes to the Context module. • The manager opens the creation form. • The manager fills all the fields of the form to configure his context. • The manager submits the form.

Table 99: Use cases of contexts module: Update a context

Use Case		Update a context
Primary Actor		Manager
Scope		Management of contexts
Brief		A manager should be able to update an existing context
Stakeholders		Manager
Postconditions	**Minimal Guarantees**	The context is updated
	Success Guarantees	• The previous context is archived. • A new context is created with fields updated. • The related alert settings are also updated to keep in the history the link between the alert setting and the old context
Preconditions		• A context exists
Triggers		• The manager updates the form and submits the form.
Basic flow		• The manager goes to the Context module. • The manager opens the edit form for the context. • The manager updates the context fields. • The manager submits the form. • The previous context is archived.

	• A new context is created with fields updated. • The related alert settings are also updated to keep in the history the link between the alert setting and the old context • Link the new context with the alert setting

Table 100: Use cases of contexts module: Archive a context

Use Case		Archive a context
Primary Actor		Manager
Scope		Management of contexts
Brief		A manager should be able to archive an existing context
Stakeholders		Manager
Postconditions	**Minimal Guarantees**	The context is soft deleted
	Success Guarantees	• Remove the link between the context and all his alert settings • The context is soft-deleted.
Preconditions		• A context exists
Triggers		• The manager deletes the context.
Basic flow		• The manager goes to the Context module. • The manager requests to archive a context. • A confirmation modal appears • The manager confirms. • Remove the link between the context and all his alert settings • The context is soft-deleted.

Table 101: Use cases of contexts module: Attach a context from alert setting

Use Case		Attach a context from alert setting
Primary Actor		Manager
Scope		Management of alerts settings / contexts
Brief		A manager should be able to attach a context to an alert settings
Stakeholders		Manager
Postconditions	**Minimal Guarantees**	The context is attached to an alert setting
	Success Guarantees	• The contexts is attached to multiple alert settings

Preconditions	• An existing alert setting
Triggers	• The manager wants to update the alerts settings contexts
Basic flow	• The manager goes to the Alert Setting module. • The manager requests to edit existing alert settings. • The manager selects one or multiple contexts. • The manager submits the form. • The system confirms that the Alert Setting has been updated.

Table 102: Use cases of contexts module: Detach a context from alert setting

Use Case		Detach a context from alert setting
Primary Actor		Manager
Scope		Management of Alert Settings / Contexts
Brief		A manager should be able to remove a context from an existing Alert Setting.
Stakeholders		Manager
Postconditions	**Minimal Guarantees**	The manager can remove a context from an alert setting.
	Success Guarantees	• The manager can remove multiple contexts from an alert setting.
Preconditions		• At least one context need to exist in a alert settings
Triggers		• The manager invokes a request to remove a context
Basic flow		• The manager goes to the Alert Setting module. • The manager edits an Alert Setting. • The manager removes the contexts he wants from the Alert Settings. • The manager submits the form. • The system removes the context from the alert setting.

Table 103: Use cases of contexts module: Check context conditions before triggering an alert

Use Case	Check context conditions before triggering an alert
Primary Actor	System
Scope	Management of contexts
Brief	Check that the contexts attached to the alert setting are also matching conditions before triggering the alert.

Stakeholders		Manager
Postconditions	**Minimal Guarantees**	The system can check the condition for one context.
	Success Guarantees	• The system can check the condition for multiple contexts attached to an alert settings.
Preconditions		• A context is attached to an alert settings (or vice versa)
Triggers		• An event with matching alert settings is received
Basic flow		• An event is received. • The system will check the alert setting condition with a potential context attached. • The system will trigger an alert or not.

4.4.4.6 Wireframes

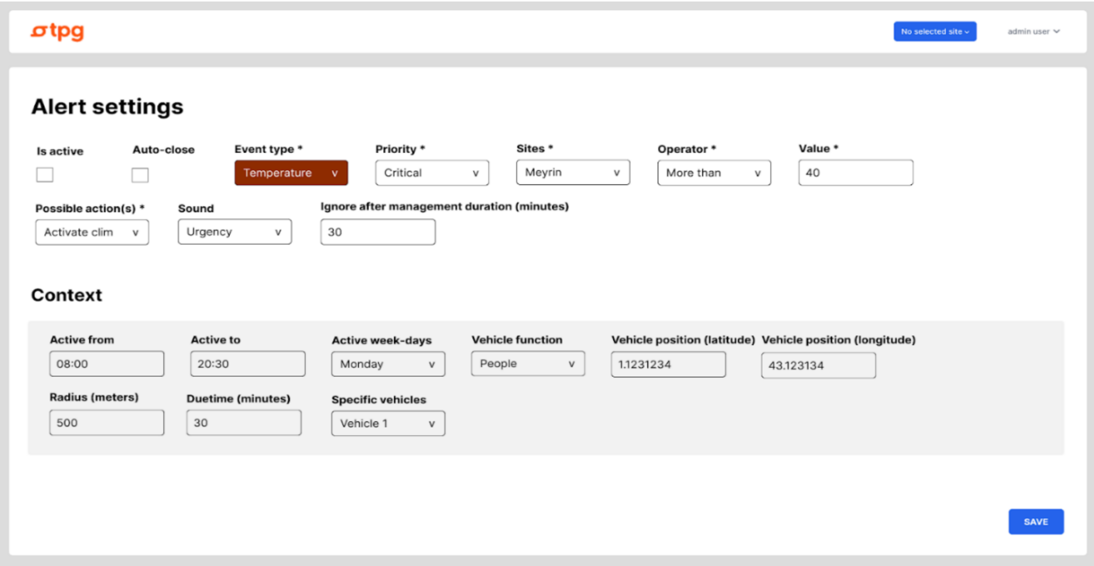


Figure 29: Wireframes of contexts module: Alerts settings numeric type with contexts

4.4.4.7 Technical Specifications

4.4.4.7.1 Database

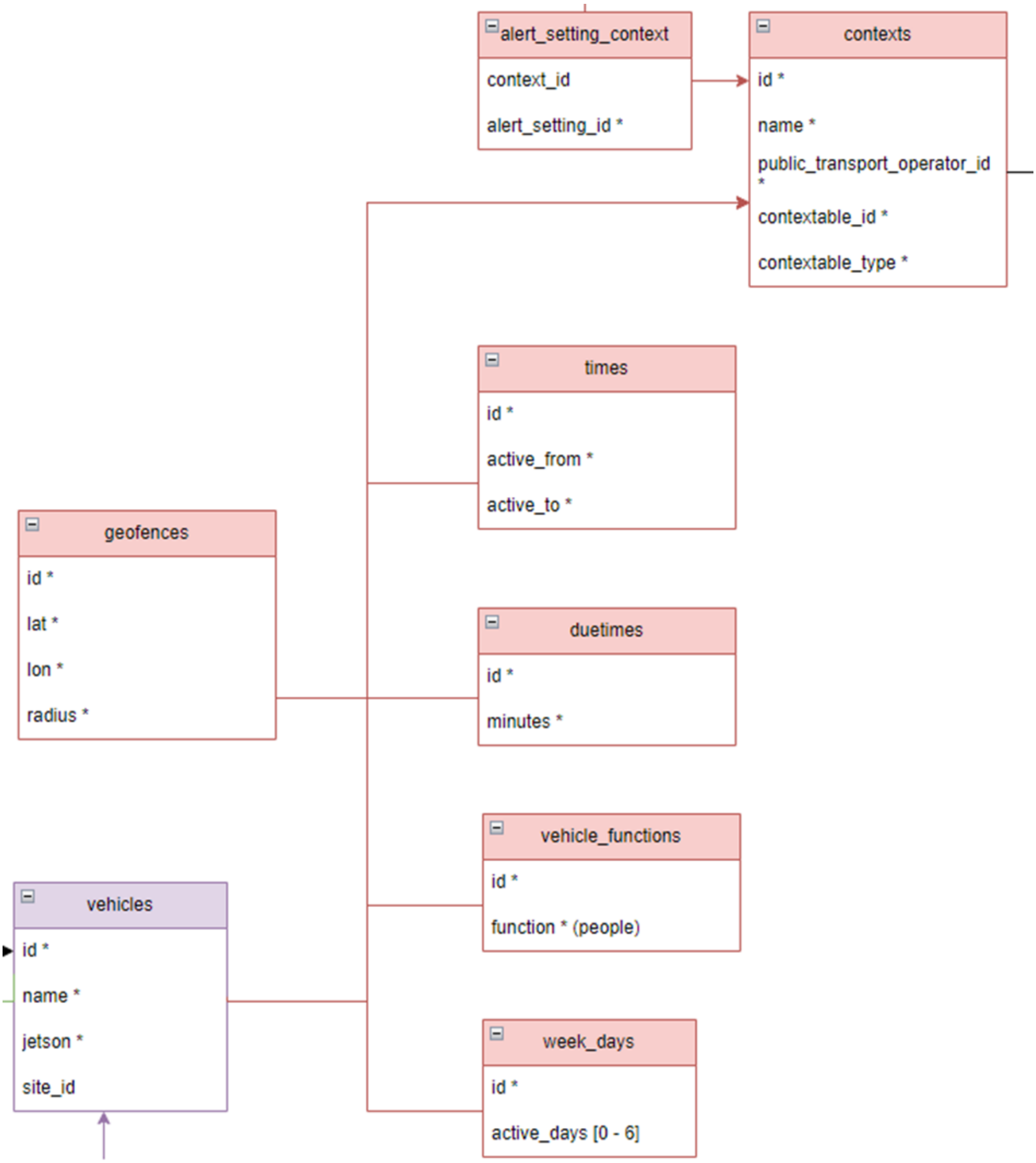


Figure 30: Database of contexts module - Full database schema available in chapter 4.3

4.4.5 Actions Module

4.4.5.1 Objective

The objective of the actions module is to define the available actions that a supervisor can use to treat an alert.

4.4.5.2 Users involved

Manager:

- Will create the available actions and use them in the alert settings

Supervisor

- Choose what actions to use to treat an alert.

4.4.5.3 Golden Path

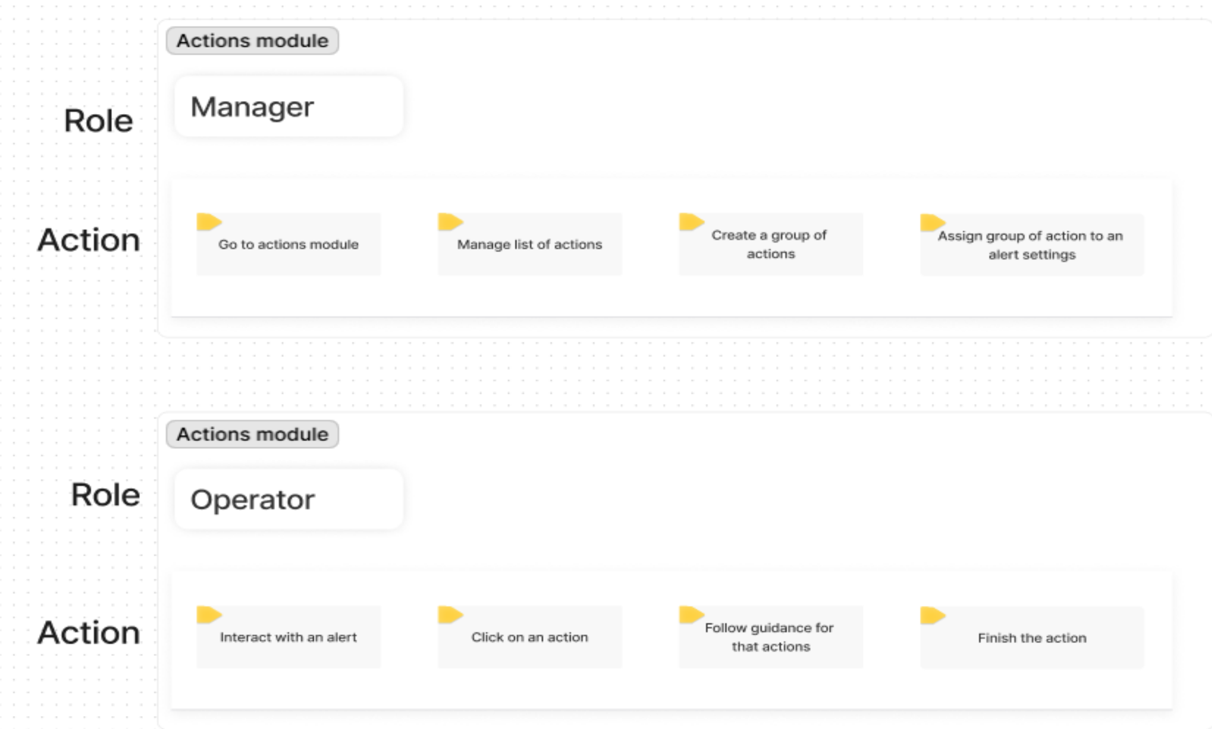


Figure 31: Golden Path of Actions module

4.4.5.4 User Stories

Table 104: User stories of actions modules

Feature	As	I want to	Version
Create action	Manager	Create an action	v1 implemented
Update action	Manager	Update an action	v1 implemented
Archive action	Manager	Archive an action	v1 implemented
Attach action to alert settings	Manager	Assign action to an alert setting	v1 implemented
Detach action from alert settings	Manager	Remove action from an alert setting	v1 implemented
Do actions on alert	supervisor	Do actions that I want to execute to manage the alert	v1 implemented

Group of actions	Manager	Create a group of actions and assign actions to it	v2
Feedback actions	supervisor	Give feedback to the system about the accuracy of an alert	v2

4.4.5.5 Use cases

Table 105: Uses cases of actions module: Create action

Use Case		Create action
Primary Actor		Manager
Scope		Management of action
Brief		A manager should be able to create a new action.
Stakeholders		Manager, supervisor (who will execute the action)
Postconditions	**Minimal Guarantees**	The manager can create an action with the minimum required fields
	Success Guarantees	The manager can create an action.
Preconditions		• A PTO needs to exist. • A manager for that PTO needs to exist.
Triggers		The manager invokes a request to create a new action.
Basic flow		• The manager goes to the Action module. • The manager opens the creation form. • The manager fills in all the fields of the form to configure the action. • The manager submits the form. • The system creates the action. • The system confirms that the action has been created.

Table 106: Uses cases of actions module: Update action

Use Case	Update action
Primary Actor	Manager
Scope	Management of action
Brief	A manager should be able to update an existing action assigned to an Alert Setting.

Stakeholders		Manager, supervisor (who will execute the action)
Postconditions	**Minimal Guarantees**	The manager can update the value of fields in an action.
	Success Guarantees	The manager can update the value of fields in an action.
Preconditions		An existing action.
Triggers		The manager wants to update the action.
Basic flow		• The manager goes to the Action module. • The manager requests to edit an existing action. • The manager changes the fields of action. • The manager submits the form. • The system checks if not used on an alert (action_done) otherwise it will archive and create a new one. • If the system creates a new action, it needs to add the new action on all the AlertSettings in which the old action was used (no need to remove the old action connected with the AlertSetting because archived [sof-delete] actions do not appear as query result). • The system confirms that the action has been updated.

Table 107: Uses cases of actions module: Archive action

Use Case		Archive action
Primary Actor		Manager
Scope		Management of action
Brief		A manager should be able to archive an existing action assigned to an Alert Setting.
Stakeholders		Manager, supervisor (who will execute the action)
Postconditions	**Minimal Guarantees**	The manager can Archive an action.
	Success Guarantees	The manager can Archive multiple actions.
Preconditions		The action exists and it is not archived.
Triggers		The manager wants to Archive the action.
Basic flow		• The manager goes to the Action module. • The manager requests to Archive an action. • The system shows a confirmation modal. • The manager confirms. • The system Archives the action (soft-deletes).

	• The system confirms the archive of the action.

Table 108: Uses cases of actions module: Attach action to alert settings

Use Case		Attach action to alert settings
Primary Actor		Manager
Scope		Management of actions
Brief		A manager should be able to assign actions to an Alert Setting.
Stakeholders		Manager, supervisor
Postconditions	**Minimal Guarantees**	The manager can assign at least one action of type Dismiss or Treat to an Alert Setting.
	Success Guarantees	• The manager can assign multiple actions to an Alert Setting, with a minimum of one action of type Dismiss or Treat.
Preconditions		• At least one Alert Setting and one Action exist.
Triggers		• The manager requests to assign an Action to an Alert Setting.
Basic flow		• The manager opens the index of alert settings • The manager opens the details of an alert setting • The manager in alert settings details scrolls to the actions section • The manager uses the button "attach action" to add an action to the alert setting • The manager selects the action and confirm • The system confirms that the action is attached and refreshes the list of actions

Table 109: Uses cases of actions module: Detach action of alert settings

Use Case		Detach action of alert settings
Primary Actor		Manager
Scope		Management of actions
Brief		A manager should be able to detach actions from an Alert Setting.
Stakeholders		Manager, supervisor
Postconditions	**Minimal Guarantees**	The manager can detach at least one action

	Success Guarantees	• The manager can detach multiple actions of an Alert Setting, and it should still have a minimum of one action of type Dismiss or Treat.
Preconditions		• An Alert Setting has at least two dismiss/treat actions.
Triggers		• The manager requests to assign an Action to an Alert Setting.
Basic flow		• The manager opens the index of alert settings • The manager opens the details of an alert setting • The manager in alert settings details scrolls to the actions section • The manager uses the button "detach action" to remove the action of the alert setting • The manager selects the action and confirm • The system checks if by removing the action (rule) that at least one action of type treat or dismiss remain attached to the alert setting (add the same check in a policy such that Nova even prevents to show the button to detach an action if it is the last action of type treat or dismiss) • If yes, detaches the action, otherwise do nothing • The system confirms that the action is detached and refreshes the list of actions

Table 110: Uses cases of actions module: Do actions on alert

Use Case		Do actions on alert
Primary Actor		supervisor
Scope		Management of alert
Brief		a supervisor should be able to do one or multiple actions.
Stakeholders		supervisor
Postconditions	**Minimal Guarantees**	The supervisor can do an action.
	Success Guarantees	• The supervisor can do multiple actions.
Preconditions		• An action exists for the alert setting that has triggered the alert.
Triggers		• An alert is triggered. • The supervisor wants to do an Action.
Basic flow		• The supervisor goes to the detail of an alert. • The supervisor chooses what action to do • The supervisor does the actions and confirms. • The system saves the action and adds it to the changelog. • The system confirms that the action has been saved. • The system, depending on the effect of the action (Dismiss, Treat) can change the status of the alert.

4.4.5.6 Wireframes

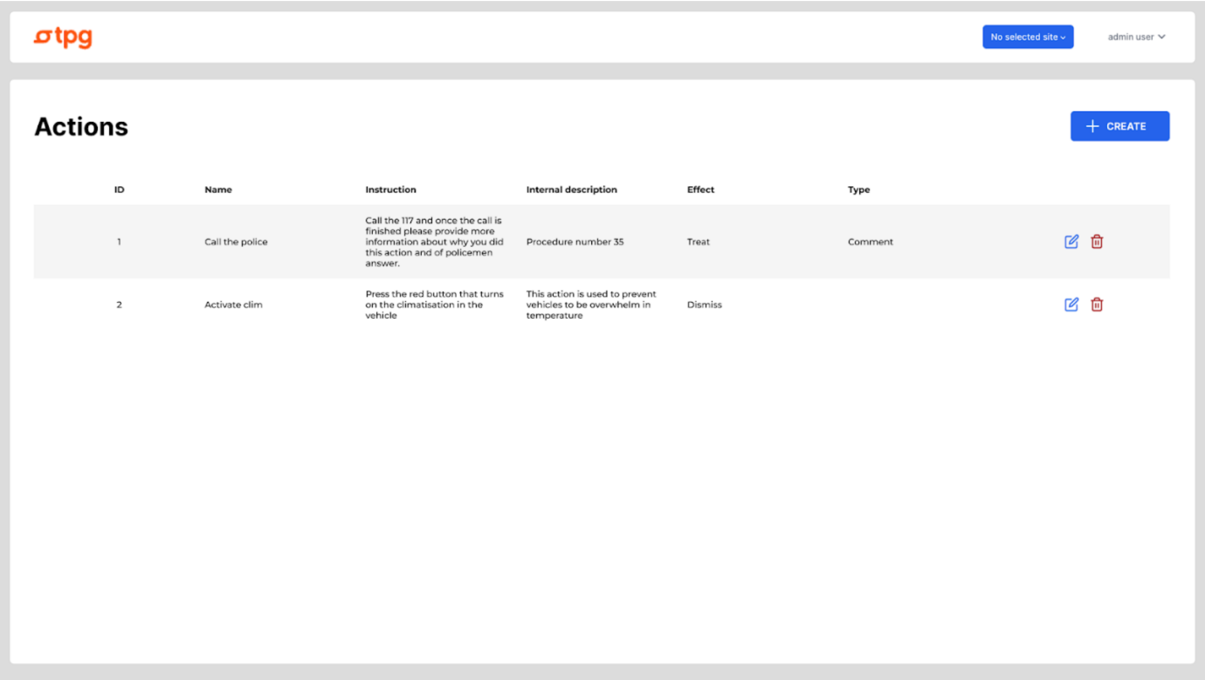


Figure 32: Wireframes of actions module: List of the available actions

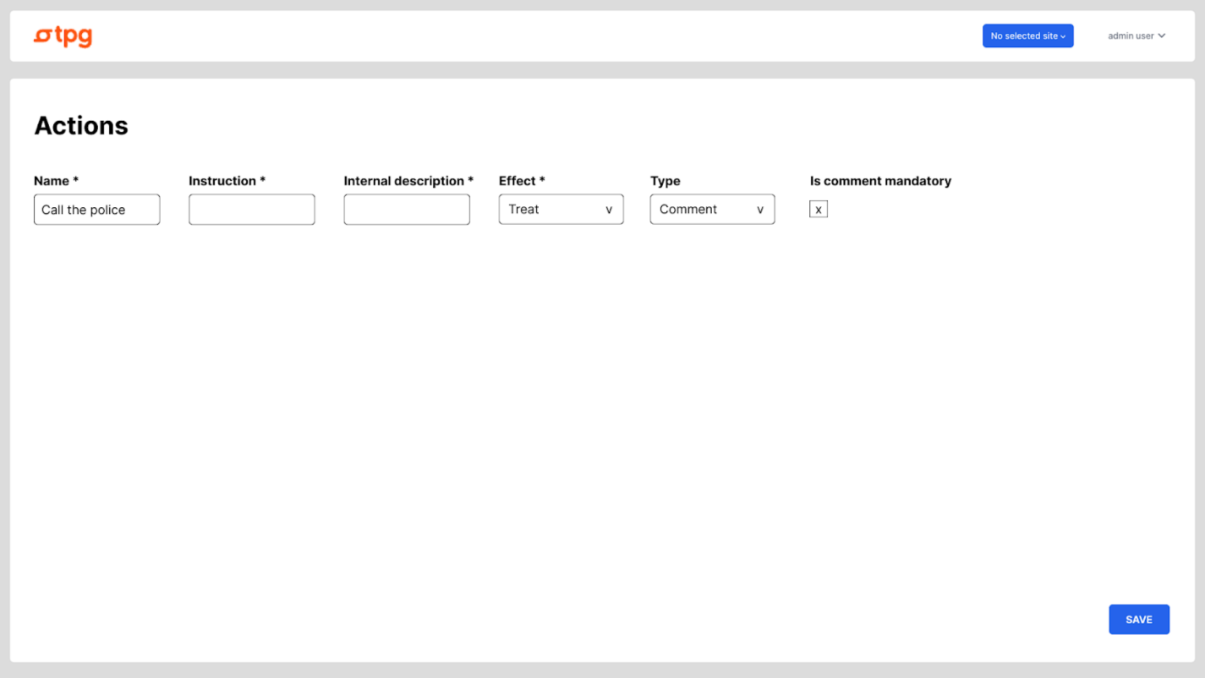


Figure 33: Wireframes of actions module: Forms to create/update an action

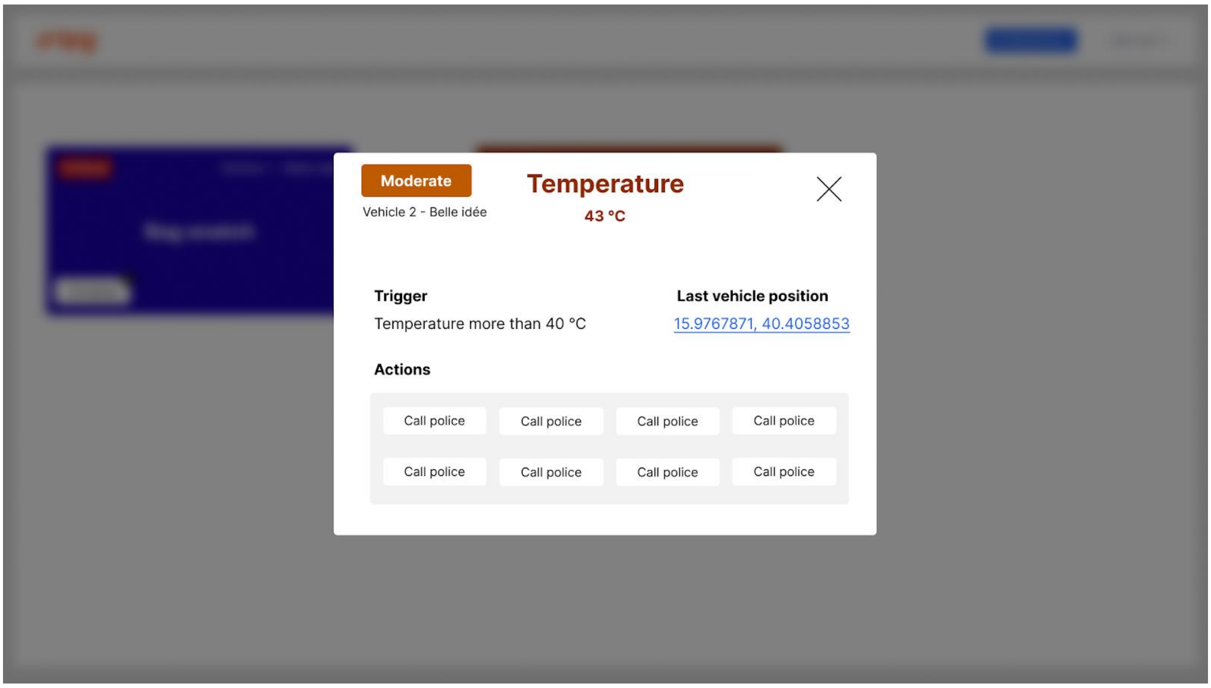


Figure 34: Wireframes of actions module: The actions that can be checked by the supervisor on the detail of an alert

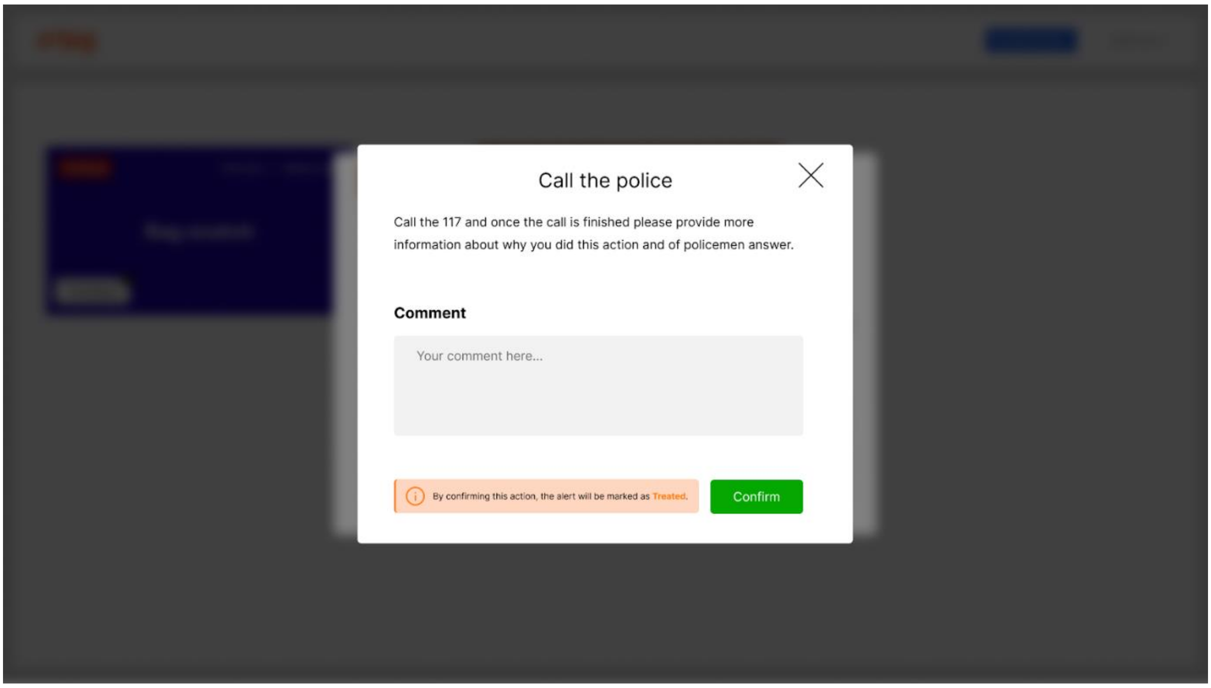


Figure 35: Wireframes of actions module: Additional comment that the supervisor has to fill when checking an action that has the "With comment" field checked.

4.4.5.7 Technical Specifications

4.4.5.7.1 Database

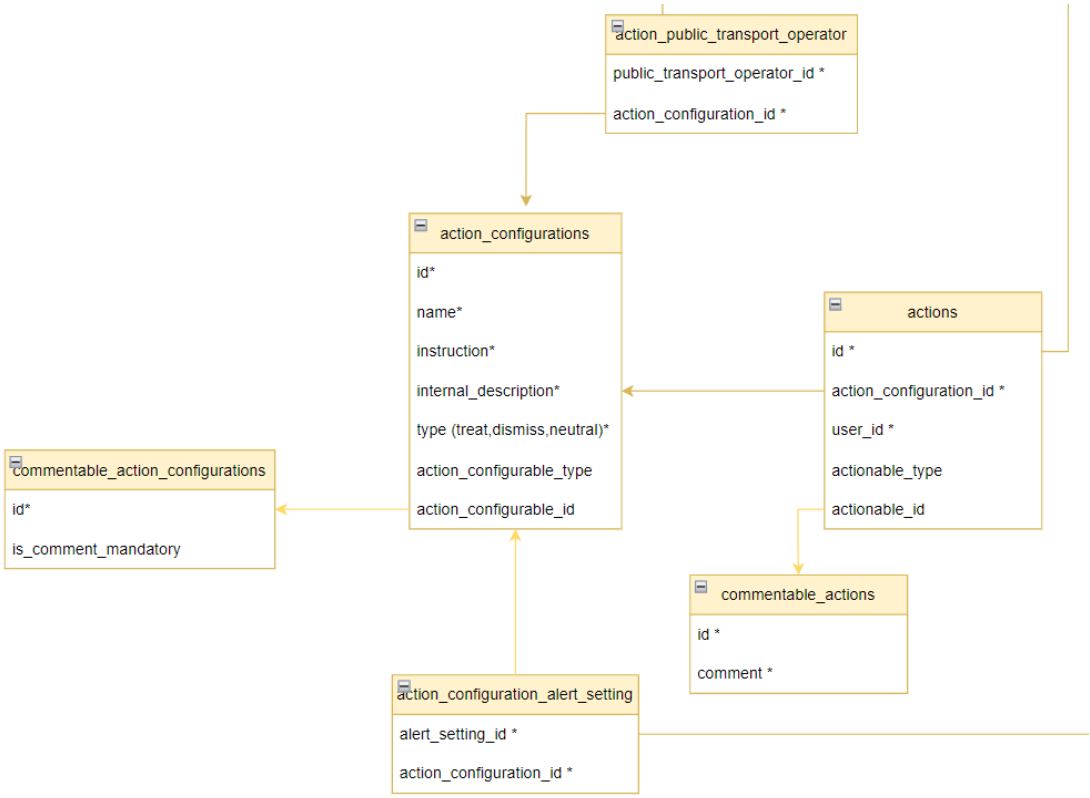
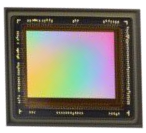
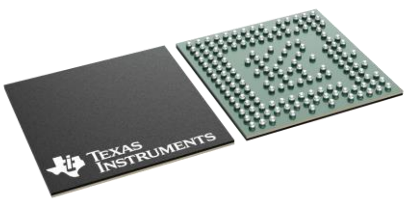


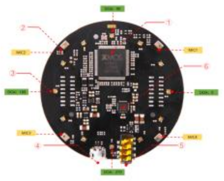
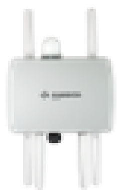
Figure 36: Database of actions module - Full database schema available in chapter 4.3

5 Hardware Infrastructure

The hardware infrastructure serves as an essential element for bringing autonomous transportation systems and services to fruition. This chapter offers an in-depth exploration of the diverse collection of the hardware components, each meticulously chosen to fulfil specific roles and tasks. Ranging from advanced AI processors to specialized sensors, this infrastructure effectively combines various technologies to enable the creation of safe, efficient, and intelligent mobility solutions. Table 111 below presents each hardware component along with their key features.

Table 111: On-board hardware and key features

Component	Features
NVIDIA Jetson Orin 	• Powerful AI computer for energy-efficient autonomous machines. • High performance up to 275 TOPS. • Energy efficient and power configurable between 15W and 60W. • Supports multiple concurrent AI interference pipelines. • High-speed interface support for multiple sensors.
Intel Realsense D435 	• Features RGB and Depth maps. • High resolution and sufficient range for in-vehicle monitoring. • Ideal for low-light and wide field of view.
PROPHESEE Metavision 	• Event-based vision with Artificial Intelligence. • High framerate and dynamic range for extreme lighting conditions. • 0.08 lx low light cut-off for clean image in night. • Very high power efficiency of abound 26mW at sensor level.
VIVOTEK FE9180-H 	• 5-Megapixel Panoramic Fisheye Camera. • Supports real Wide Dynamic Range. • Fisheye lens, high-resolution sensor, distortion correction, PoE support. • IR illuminators and night vision support. • Ideal for placing in a top-down position to cover large areas and avoid occlusion issues.
Texas Instruments AWR6843 	• Single-chip 60-GHz to 64-GHz automotive radar sensor integrating DSP, MCU and radar accelerator • FMCW transceiver • Built-in calibration and self-test • Cryptographic acceleration, Device identity/keys, Secure boot, Secure software update, Software IP protection

ReSpeaker Mic Array v2.0 	• Features integrated algorithms for beamforming and direction of arrival. • Noise suppression. • De-reverberation and acoustic echo cancellation. • Capable of detecting voice up to 5m away even with background noise.
Awair Element 	Environmental sensor capable of detecting PM2.5, VOCs, CO2, temperature and humidity.
Yocto-Light-V3 	A USB ambient light sensor (lux meter) which allows measuring ambient light up to 100'000 lux.
MB1403 HRUSB-MaxSonar-EZ0 	• A very small ultrasonic sensor component module for distance detection. • Offers virtually noise-free distance readings through the use of high-output acoustic power.
OBU V2X YoGoKo 	• New OBU generation with multiple radio technology on board such as ITSG5 or C-V2X &WIFI & 4G. • OBU including Y SMART software platform for V2X communication.
RSU V2X FARECO 	• New RSU generation including ITSG5/C-V2X technology. • WIFI and 4G radio as optional. • RSU including Y SMART software platform for V2X communication. • Opportunity to connect the RSU to an external sensor such as camera, Lidar technology to provide CPM message.

This hardware infrastructure integrates cutting-edge technologies, aligning seamlessly to underpin the evolution of autonomous public transportation systems and services, and enabling the realization of the ULTIMO project's objectives.

6 Communications network

6.1 Challenges in V2X communications and conventional solutions

Fueled by the rapid advancements in wireless communication technology, vehicular communications, often referred to as vehicle-to-everything (V2X) communications, have emerged as a highly promising field. They offer support for cutting-edge applications, including vehicular services and the realization of autonomous driving capabilities. Notably, the 3rd Generation Partnership Project (3GPP) has undertaken the task of standardizing V2X services within long-term evolution (LTE) and fifth-generation (5G) cellular networks [94]. In Release 16 [95], a wide variety of novel use cases and corresponding requirements have been put forth and meticulously examined to enhance 5G V2X capabilities.

Moreover, the field of autonomous and cooperative driving requires the transmission of safety-related messages, including critical information like vehicle position, speed, direction, and more, among nearby vehicles. These exchanges occur through the domain of Vehicle-to-Vehicle (V2V), Vehicle-to-Pedestrian (V2P) and Vehicle-to-Infrastructure (V2I) communications. Notably, this endeavour must prioritize achieving a high level of reliability to enhance the "cooperation awareness" by all vehicles within the immediate local driving environment.

On the contrary, there are numerous challenges in V2X communications that need to be addressed [96][97]:

- **Blockage (or shadowing)**: One of the main challenges in V2X is dealing with the presence of obstacles, such as buildings, trees, and other vehicles, which could block **line-of-sight** communication between vehicles and infrastructure, resulting in weakened signal strength and overall connectivity.
- **Interference**: V2X systems may face signal interference from other wireless devices operating in close frequency bands, such as Wi-Fi or next-gen mobile devices.
- **High-Frequency Utilization:** V2X communications often require the use of high-frequency bands to transmit large amounts of data quickly. However, employing high-frequency bands introduces challenges related to signal strength, as these bands may be more vulnerable to signal attenuation, especially in unfavorable mobile environments and weather conditions (e.g., rain).
- **Doppler Effect:** The phenomenon of “Doppler shift” due to the mobility of high-velocity vehicles can deteriorate the signal quality and also disrupt the operating frequency.
- **Synchronization**: Especially high vehicular user equipment can lead to frequent changes in network topology, potentially resulting in synchronization issues between the vehicle's user equipment and the base station.

Low latency and **high throughput** are essential in V2X communication as they are critical for enabling autonomous driving applications. Nevertheless, as the frequency bands in use continue to expand, maintaining reliable communication for vehicular networks poses a significant challenge. This arises from the fact that shorter wavelength signals, which come with higher frequencies, are more susceptible to obstruction by physical obstacles, leading to reduced range of communication and associated data rates. Furthermore, the high-mobility of vehicles can increase this instability. Hence, in urban environments, particularly central business districts, the presence of contemporary structures and infrastructure significantly affects signal propagation.

To address these challenges, various technologies have been introduced to ensure reliable transmissions, including **active relays, massive MIMO** and **device-to-device (D2D) communication.** These solutions but will also induce numerous challenges to vehicular networks:

- **Relays**: a relay is a wireless device or component that plays an intermediary role in transmitting signals between a source and a destination. The primary purpose of a relay is to extend the coverage area, enhance signal strength, or overcome obstacles that might hinder line-of-sight communication between the source and the destination. Even though this technology can improve the received signal power, it also comes with disadvantages. Commonly, relays either transmit or receive a signal at a time instance, while active relays are not power efficient and enlarge both the signal of interest but also the noise. Additionally, a relay device has the capability of supporting one (vehicle) user at a time.
- **Massive MIMO**: By deploying hundreds or even thousands of antennas at base stations, Massive MIMO delivers substantial improvements in spectral efficiency, effectively meeting the growing demands of next-generation wireless communication networks. Nonetheless, within massive MIMO systems, the crucial necessity for precise channel state information arises as a prominent requirement. This precision is vital to mitigate multi-user interference and attain significant spectral efficiency enhancements. Furthermore, in scenarios with high mobility, the Signal-to-Interference-plus-Noise Ratio (SINR) and achievable data rates are constrained by pilot contamination, a challenge that becomes more pronounced.
- **Device-to-Device (D2D) communications:** D2D communications in the context of V2X refers to the exchange of information between two or more connected vehicles (V2V), without involving a central **road side unit** (RSU). This technique can be an effective way of overcoming the challenges posed by blockage and shadow fading, but on its own can greatly increase the overall system delay and also introduce the risk of information leakage.

6.2 Reconfigurable Intelligent Surfaces: the main component of the Programmable Wireless Environment

In the world of wireless communication, enhancing the connection between base stations and receivers has been a long-standing challenge. Traditionally, this has involved revising the specifications of existing equipment and deploying additional devices to establish Line of Sight connections. However, this approach often grapples with the problem of receivers experiencing reduced energy levels, necessitating an increase in energy consumption to maintain the desired Quality of Service (QoS).

Enter the era of Beyond 5G and 6G networks, where the way we perceive the communication environment is undergoing a fundamental transformation. It is no longer viewed as a stable and uncontrollable entity but rather as a dynamic system that can be actively managed and optimized. This paradigm shift redefines concepts such as fading and scattering, which were once considered inherent phenomena governed solely by stochastic processes. Instead, they are now recognized as parameters that can be strategically controlled and fine-tuned within the communication network.

This evolved perspective of the communication environment is encapsulated in the research literature as the "Programmable Wireless Environment" (PWE) [98]. The PWE represents a comprehensive framework that facilitates software-defined wireless propagation. This framework addresses many of the longstanding challenges in the field and turns what were previously accepted losses into opportunities for optimization and innovation.

Within the context of the PWE, several established tools and technologies take center stage, with Artificial Intelligence and Machine Learning playing pivotal roles. These cutting-edge technologies enable the network to adapt in real-time, learning from past communication patterns, and making intelligent decisions to optimize signal transmission, minimize interference, and enhance overall network efficiency.

The core element of PWE is a class of electromagnetic (EM) structures referred to as Reconfigurable Intelligent Surfaces (RIS). These structures exhibit the remarkable capability to manipulate incident EM waves or transmit EM power with precision in desired far-field directions, as well as concentrate EM power within designated near-field regions. RIS structures can be viewed as a more advanced iteration of common metasurfaces, which are essentially two-dimensional metamaterial structures designed to exert control over incident and transmitted EM fields, typically tailored to serve a specific function [99][100]. Metasurfaces are composed of appropriately designed resonant elements, referred to as unit cells, strategically arranged in either a periodic or non-periodic fashion.

What distinguishes the RIS concept is the incorporation of concentrated voltage-controlled elements within the unit cells of the 2D structure. These elements encompass diodes, tunable capacitors, tunable resistors, oscillators, and similar components, offering the ability to dynamically alter the metasurface's functionality [101][102]. Consequently, the RIS concept empowers the creation of structures featuring programmable metasurface functionalities, as illustrated in Figure 37. These functionalities encompass a wide array of applications, including but not limited to anomalous reflection, beam-forming and beam-steering, electromagnetic field focusing, EM power absorption, polarization control, radar cross-section reduction, and numerous other transformative capabilities. Furthermore, owing to the predominantly passive nature of RIS, it has the capability to operate concurrently across numerous frequency bands, including those designated for V2X communication such as Dedicated Short-Range Communication (DSRC), Long-Term Evolution (LTE), and microwave bands. These characteristics position RIS as a versatile component within the V2X communication ecosystem.

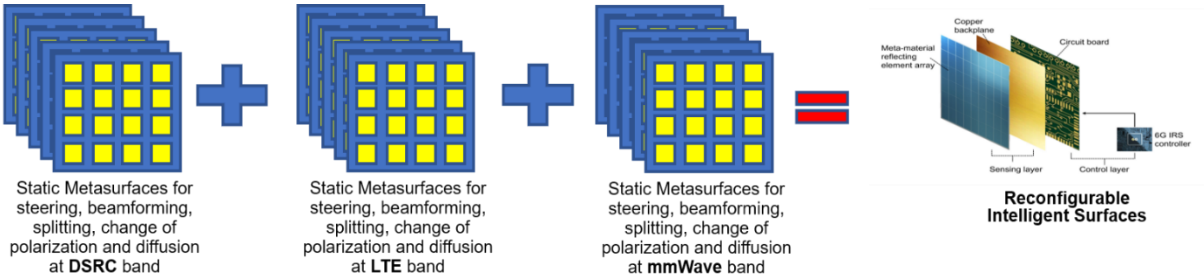


Figure 37: RIS functionalities in V2X networks

6.3 RIS-assisted environment in V2X communication

The RIS concept holds great promise as a transformative technology to effectively address the challenges introduced by rich scattering environments in communication systems, particularly in high-frequency communications, such as those utilized in the Super High Frequency band commonly employed in V2X communications. In contrast to the current Multiple-Input Multiple-Output technology, RIS presents a solution to the issues associated with the utilization of multiple RF chains in MIMO systems, which often result in high energy consumption. The schematic representation of a V2X communication environment enhanced by RIS is provided in Figure 38.

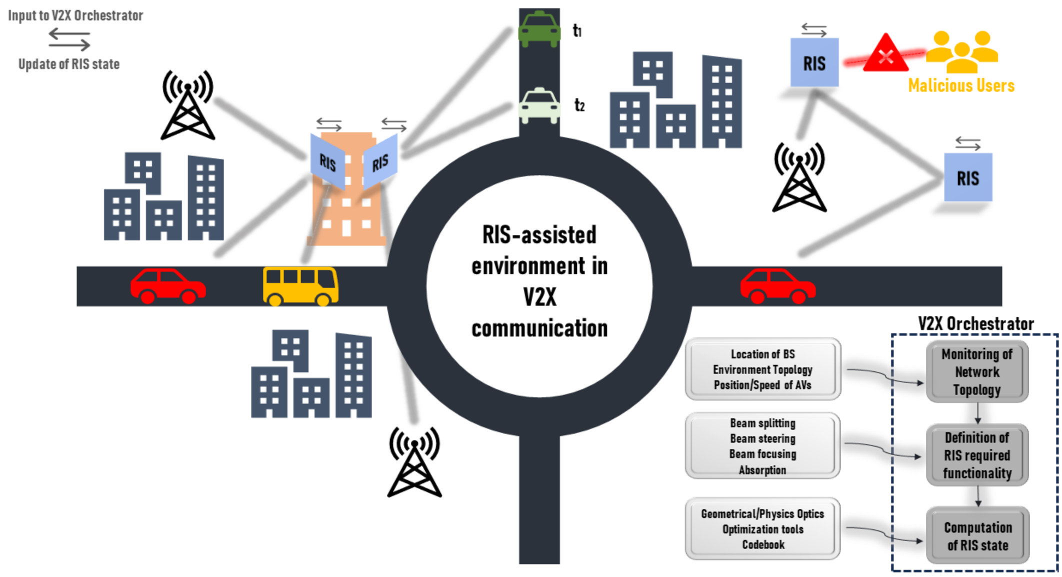


Figure 38: RIS assisted environment in V2X ecosystem

RIS in Rich Scattering Environments: RIS's tunable functionalities prove invaluable in rich scattering environments, efficiently overcoming physical blockages prevalent in urban areas. RIS structures can significantly enhance V2V, V2P, and V2I connectivity. Leveraging their wave manipulation capabilities, RIS units can seamlessly "follow" moving targets by employing anomalous reflection, beam steering, and focusing functionalities. This leads to a reduction in transmitted power in undesired directions. The use of highly directive beams ensures the achievement of high data rates, a critical requirement for real-time transmission of substantial data volumes, including video streaming, images, and event processing data. Such capabilities are crucial for time-critical applications like accident avoidance, warnings, and alerts, facilitating communication from infrastructure to pedestrians and more.

Doppler Effect Reduction: RIS units are instrumental in mitigating signal attenuation caused by the Doppler effect, which becomes pronounced when dealing with high-speed moving vehicles. By incorporating RIS technology, these effects can be significantly reduced, contributing to the robustness of V2X communications [103].

Anti-Jamming Measures: When RIS is deployed as in-vehicle equipment, its beam-forming functionality can be strategically employed to nullify antenna gain in the direction of potential malicious interference. This capability effectively counters the adverse effects of jamming signals while simultaneously enabling continued communication with desired Infrastructure Road Units [104].

The primary entity responsible for managing the reconfigurable components within the V2X network is the Orchestrator specific to the network. The key input for the Orchestrator is the Network Topology. Through the utilization of localization sensors, the Orchestrator gathers information regarding the positioning of AVs, their directional movement, and speed. This information becomes even more critical in scenarios where the base stations are in motion.

By continuously monitoring the Network Topology, the Orchestrator gains the capability to initiate a decision-making process concerning the optimal functionality of each RIS component. Prioritization strategies and optimization tools are employed to macroscopically define the desired network performance based on fundamental communication metrics such as QoS and Signal-to-Noise Ratio (SNR).

The ultimate responsibility of the V2X Orchestrator is to align the macroscopic electromagnetic response of each RIS entity with the corresponding microscopic configuration of each RIS unit cell. The computation of the RIS state can draw upon conventional physics tools like Optical and Physical Optics, as well as Full Electromagnetic Analysis. These tools, in conjunction with various metaheuristic techniques that have been developed, can be leveraged to generate a physics-aware codebook compilation of the electromagnetic response. This compilation can significantly expedite the determination of the RIS state during the operational phase.

6.4 Next steps

Coverage maps, also known as propagation maps, depict the geographical regions served by radiocommunication transmitting stations. They are commonly employed in mobile phone, cellular, and satellite networks. In CERTH/ITI's research, these maps describe network performance in specific locations based on their electromagnetic characteristics. They are valuable for identifying areas requiring improvements in V2X network connectivity. To create these maps, CERTH/ITI gathers essential geospatial and operational data for pilot sites and utilizes appropriate radio propagation software. To facilitate this data collection, completing the Questionnaire in the Annex I is crucial.

CERTH/ITI is developing an innovative RIS electromagnetic response model that incorporates resonant unit cell interactions in a semi-analytical form. This model offers highly accurate results compared to existing state-of-the-art models. With just a few initial simulations, it can predict transmitted, reflected, or absorbed power in any direction with exceptional accuracy and minimal computational cost. This model will enable rapid design optimization of RIS structures for efficient V2X communication networks, meeting radio coverage and the respective data rate requirements.

Furthermore, CERTH/ITI's study investigates the benefits of deploying physics-based EM codebook compilation. It examines the microscopic correlation between the tunable elements of the unit cells and the macroscopic EM RIS behaviour, enabling a focus on the parameters governing the RIS response. This contribution represents a significant step towards creating accurate codebooks for all desired RIS functionalities, minimizing the required computational time. Additionally, the study will evaluate the efficiency of well-known metaheuristic methods to distinguish the most suitable approach for determining the RIS state based on its functionality.

7 Conclusion and next steps

The deliverable objective is to present the first version report on the Vehicle and Infrastructure services that will be implemented in the context of the ULTIMO project. This deliverable introduces the Vehicle and Infrastructure services initial version, while two updates are expected in months 28 and 40 respectively.

With the elimination of in-vehicle operators in autonomous vehicles, ULTIMO and specifically WP4 seeks to replace their functions with a comprehensive array of services. A state-of-the-art analysis of relevant technologies and tools set the ground for understanding the available solutions, and for defining the concept behind each service. In addition, the stakeholders are one of the core components of the services that dictate the technical side with requirements and use case scenarios. By taking into consideration all the aforementioned, various functional and non-functional requirements, along with technical and data requirements, have been defined for each service. These requirements will set the foundation for the testing of the services in the forthcoming months.

The deliverable also included an overview of the infrastructure on the operator's side. It provided details about the dashboard (Chapter 4), which will utilize and further evolve the software developed in the AVENUE project. Additionally, it highlighted the hardware requirements for installation in the vehicles and discussed the essential road infrastructure components.

Regarding the next steps, the development of the services mentioned in this deliverable is an iterative procedure, which is going to be further enhanced during the next period, taking into account the user requirements and needs defined in WP2, the envisioned architecture and PTO services’ requirements from WP3, along with the services development within WP4. All the aforementioned will set the ground for the real-life demonstrations that will occur in each pilot site in the forthcoming months as part of WP5. In addition, the assessment of the communications network within the project, in order to overcome the challenges described in Chapter 6, is a critical step towards ensuring the seamless integration and operation of our systems and services. Finally, various meetings with all the interested partners will be organized to define potential integration/hosting of the developed services or applications to the operators depending on the maturity and development status of each service.

Annex I: Questionnaire about ULTIMO Communication networks

This is a questionnaire that is being circulated among the operating sites of ULTIMO. Its primary objective is to define the communication technologies being utilized in each site, identify the current and future requirements, anticipate potential challenges and issues that may arise, and explore potential solutions. The questionnaire is comprised of 5 parts (Table 112):

- Main properties of the communication network
- The current requirements for data transferring
- Metrics for the evaluation of the communication connection
- Main challenges in your ecosystem
- Future demand prediction and solutions

Table 112: Communications network in ULTIMO

Parts	Question
Part 1: Main properties of the communication network	1. What type of network technology is being utilized? 2. Within which frequency band is data transfer established between the vehicle and other systems? 3. How many antennas are installed in each vehicle, and what is the total number of antennas in your communication system? 4. What is the strategy of their positioning? 5. Please, provide us the accurate GPS location of your antennas and their datasheets, combined with the datasheets of the vehicles' antennas.
Part 2: The current requirements for data transferring	1. What types of data are transmitted between the vehicle and your infrastructure? 2. What is the volume of data being transferred between these systems? 3. What are the requirements of the applications that utilize this data?
Part 3: Metrics for the evaluation of the communication connection	1. What are the primary metrics that you use to assess the quality of your communication connections? 2. Which of the following metrics are you able to measure: signal strength, latency, signal-to-noise ratio (SNR), power consumption and bandwidth? 3. Do you have the capability to associate the metrics with the corresponding timestamp and GPS location? 4. Are you familiar with the concept of a coverage map and its significance in a communication system?

Part 4: Main challenges in your ecosystem	1. What are the primary challenges currently being faced by your organization? 2. Is your operating environment predominantly urban or semi-urban?
Part 5: Future demand prediction and solutions	1. What are your projected data rate requirements for the upcoming years? 2. What potential applications do you anticipate in the future, and what is the predicted data rate demand for these applications? 3. What measures are you planning to take to improve and enhance your communication network?

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