A Software Architecture for Extreme-ScaLe
Big-Data AnalyticS in Fog CompuTIng Ecosystems

D1.1 Use case requirement specification and definition

Version 1.0

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Change Log

Version	Author	Description of Change
V 0.1	Author	Initial Draft
V 0.2	THALIT	Document set up
V 0.3	THALIT	Draft of the document
V 0.4	THALIT	First version of the document for THALIT
V 0.5	GEST	Slight update of GEST- related parts
V 0.6	THALIT	Final version for THALIT with FLO and GEST contribution
V 0.7	BSC	OpenFog RA Description
V 0.8	THALIT	More contribution added
V 0.9	ISEP	FIWARE description
V 0.10	THALIT	Integration of new general requirements and revision
V 0.15	THALIT	Final integration of several contributions
V 0.16	ISEP	Reviewer's comments
V 0.17	THALIT	Applied last changes to address the comments from reviewer (ISEP)
V 1.0	BSC	Ready to be submitted to the EC
		(Final Change Log entries reserved for releases to the EC)

Table of contents

Executive Summary

This document covers the work done during the first phase of the project within WP1. The deliverable spans 6 months of work and handles the work done in Task 1.1 "*Smart mobility use case requirement specification and definition*" to reach milestone MS1.

Concretely, this document presents the use case requirement specification and definition for the three use cases implemented in the Tramway network of the City of Florence. It collects all the principal functional and non-functional requirements associated with the initially envisaged use cases: *positioning and obstacle detection*, *predictive maintenance*, and *interaction between the public and the private transport*.

This document represents the basis upon which the ELASTIC software architecture will be developed, tested and evaluated. Based on the advances of the project, the information included in this document may be subject to modification to better asses the benefits of the ELASTIC technology.

The first milestone of Task 1.1 has been carried out successfully and all objectives of MS1 have been reached and documented in this deliverable.

1 Introduction

1.1 Motivation

In the Florence metropolitan area there are about 720 cars per 1.000 inhabitants (recently slightly increasing) – far above the EU average; within the city of Florence there are about 510 cars per 1.000 inhabitants.

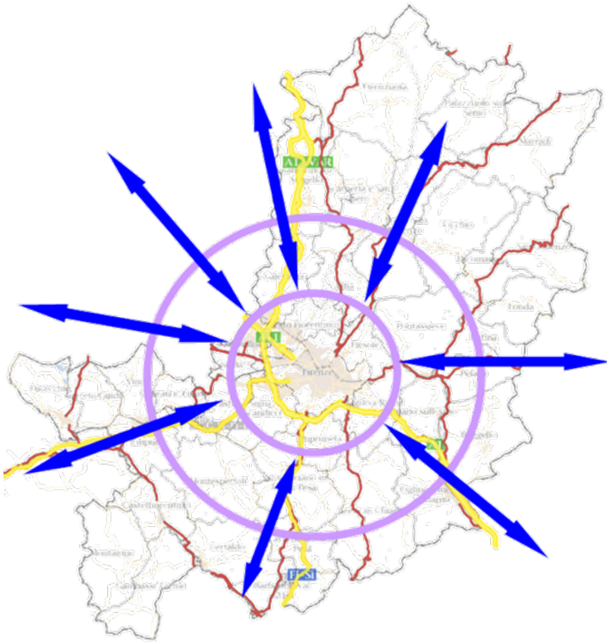


Figure 1: The city of Florence has a central position in the metropolitan area, thus playing a central role in mobility in the area

Due to geographical, infrastructural and socio-economic factors, the city of Florence plays a central role in the mobility scenario of the area, with about 80.000 and 70.000 cars moving respectively to and from Florence every day, accounting for severe traffic congestions and affecting quality of life.

To face these issues, the local governments (municipal, metropolitan and regional) have started a thorough transformation of the public transportation network, which includes the construction of new light rail lines, a complete redesign of the bus service and a widespread use of ICT solutions.

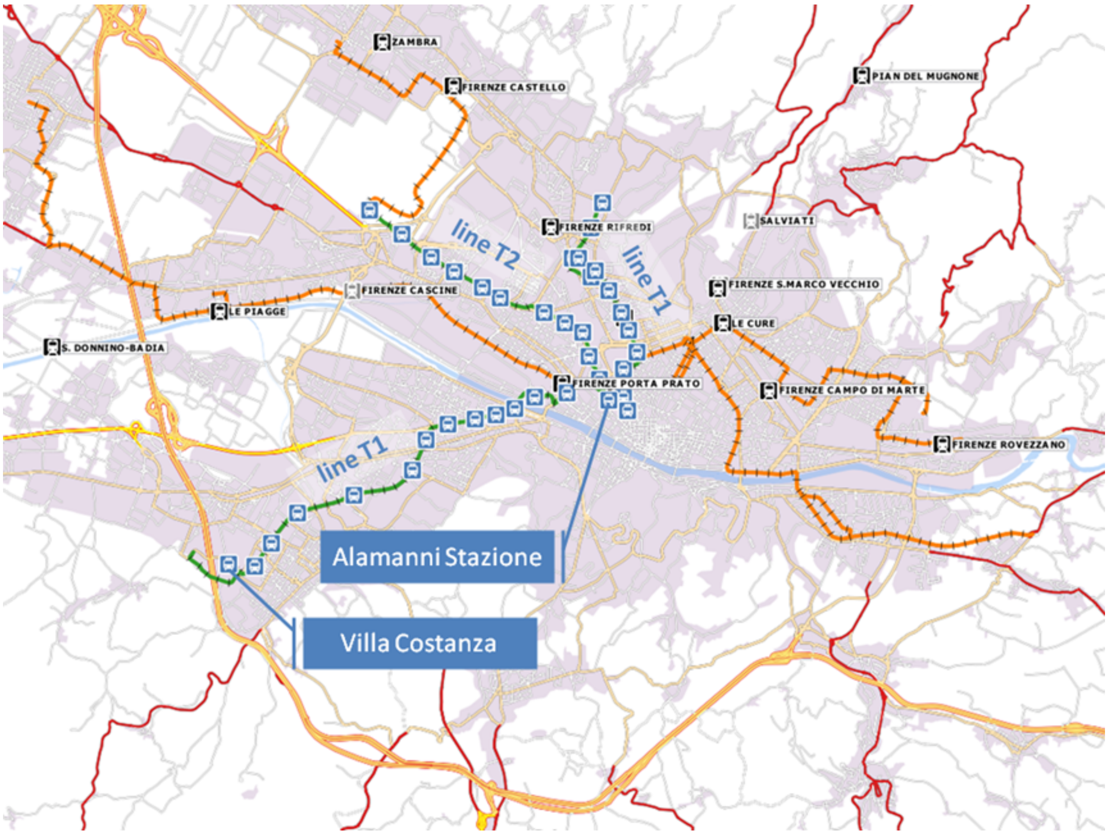


Figure 2: Tramway network in Florence: active lines (green) and planned lines (orange)

The tramway receives 14 million passengers each year on its trams (Data 2017). The reasons that lead to the choice of the tramway are comfort, safety, economic convenience and certainty of travel times. The 87% of passengers are overall satisfied with the service and consider it good and excellent.

However, given the structure of the city and of its surrounding territory, private transport can be reduced, but not eliminated; hence, strategies should be devised and enforced in order to achieve high quality public transport service levels, without compromising security and functionality of private transport.

1.2 The T1 Tramway Line

The ELASTIC project takes as a reference infrastructure for the use cases the T1 line "*Leonardo*" that extends for 11.5 km and has 26 stops: it starts from "*Villa Costanza*" in Scandicci to finish its run at the "*Careggi - Ospedale*" stop in Florence (see Figure 3). From Villa Costanza to Careggi Hospital the tram takes about 40 minutes. (From Villa Costanza to Alamanni about 23 minutes) The service is carried out with a fleet of 23 trams, each with a maximum capacity of 272 people.

Several intersections along the T1 line are suited to host the specific use case related to the interaction between public and private transport, as they feature various interaction patterns between public and private transport (e.g. Leopolda, Batoni, etc.). Moreover, the segment spanning from Villa Costanza to Alamanni-Stazione also provides an access and backbone network that might be exploited for implementation of this use case. The exact intersection will be chosen once technical analysis and design will have been refined.

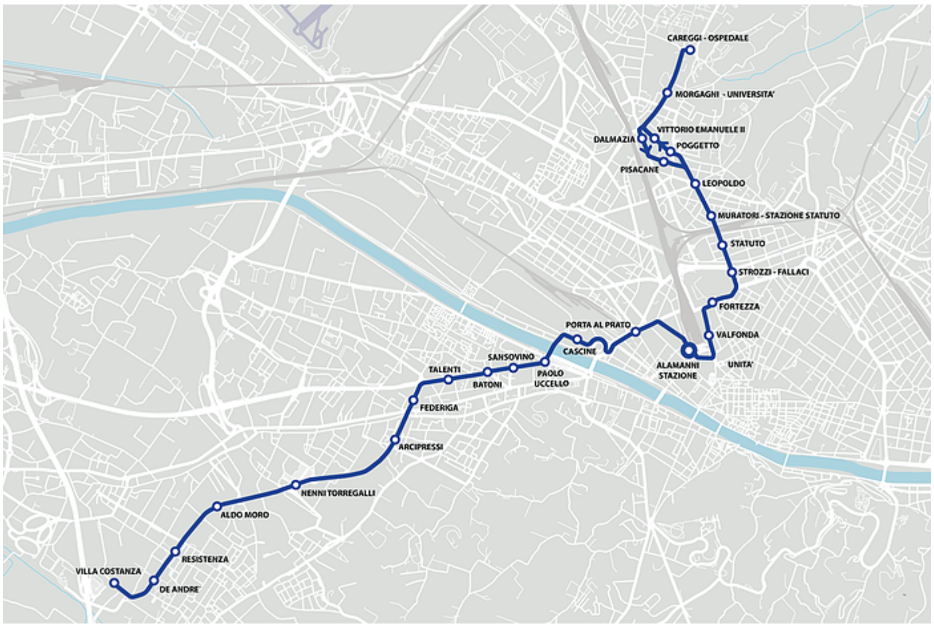


Figure 3: Line T1 "Leonardo" of Florence Tramway.

As anticipated above, the target for the ELASTIC use case applications possible deployment must be the Florence Tram Rail Line T1, which is also the most technologically advanced, and thus the most representative one for future evolution/enhancement of the other lines.

1.2.1 Overview of the Communication infrastructure

In what concerns the electronic data transmission, the Tram Rail Line T1 leverages on an Optical Fiber line connected to the Florence Tramway central station (basically corresponding to the Operational Control Centre). Such Optical Fiber line is active, and assures the switching/routing/priority of the various transmitted data. The Optical Fiber line is compliant with all applicable norms, comprising the ITU-T (Telecommunication Standardization Sector of the International Telecommunications Union) ones.

Currently, this Optical Fiber line is utilized, from the Florence Tramway central station, for collecting/transferring:

- information from/to each tram rail stop: e.g. videos, telephone voice (through VoIP), tram rail stop monitoring data, messages to passengers; and
- data from/to a few Electric Sub-Stations, distributed along the rail track, which are also Telecommunication connected to each respective nearest tram stop (with at least 100 Mbit\s data rate).

Such Optical Fiber line is utilized through TCP-IP protocol, and globally acts as Multi-Service Redundant Gigabit Ethernet Network, which is intended for providing a well-organized telecommunication infrastructure that covers the current key objectives of the Florence T1 line transport service. As reflected in Figure 4 below (applicable to both T1, T2, and T3 Tram Lines), the rail tramway line data transmission capitalizes on a ring-based, redundant double physical optical line (along both right and left rail tracks), thus assuring higher reliability in case of accidental interrupt of either of the two (exploiting the ITU G.8032 Ethernet Protection Ring switching): this architecture, upon accidental interrupt or other failures, assures a re-configuration time not exceeding 100 ms. Therefore, security and safety features are already considered.

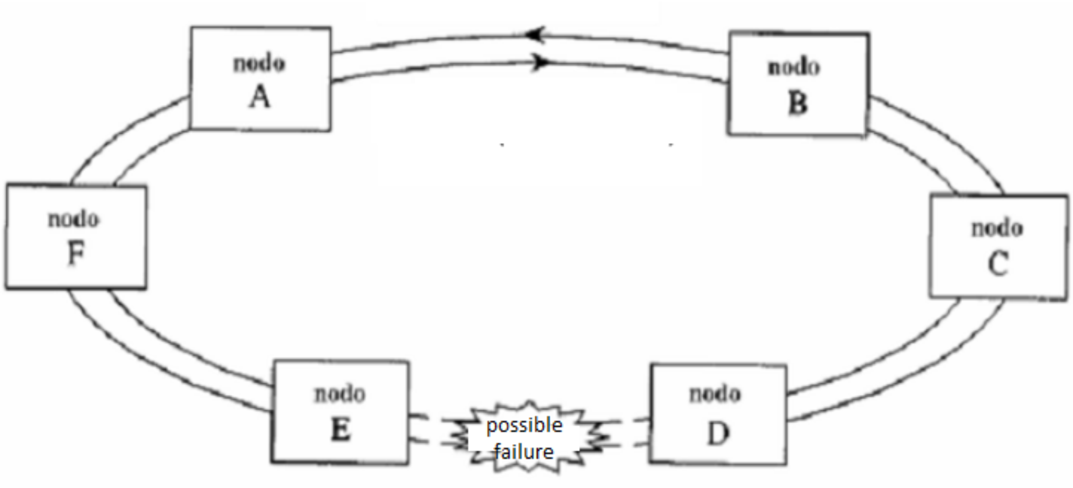


Figure 4: Outline of the 2 rings of the Data Transmission network.

Through the Data Transmission network, an Operator, at Florence Tramway Central Station, can transmit key information to (waiting) passengers at each tram stop. For instance:

- Waiting time for next Tram arrival, and related arrival announcement
- Destination of next arriving Tram
- Successive Trams' coincidences
- Possible inconveniences, delays, evacuation warnings, etc.
- Any other possible information serving the city of Florence (e.g. culture or sport events)

All this information can either be video-displayed and/or voice-announced, through corresponding loudspeaker/video devices (these latter exploiting led matrix technology) connected, through Registered Jack 45 (RJ45) connectors, to the line itself. Note that not only live Operator voice messages, or chosen by the Operator, are transmitted, but also possible ones automatically generated from the tram positioning system. The related priority and order are managed by the Central

Station SCADA (Supervisory Control and Data Acquisition), being the Operator authorized to take the highest priority.

For the recovery against possible transmission network anomalies, the available ZLS (Zero Loss Services) configuration will assure that the Central Station might activate alternative line routes (exploiting the ring architecture).

The aforementioned automatically-generated messages are produced by the Central Station SCADA, upon collecting tram position data from the Automatic Vehicle Location System (AVLS), and then transmitted to the corresponding tram stops. These are generically called "*automatic messages*".

Optical Fiber lines leverage on Layer 3 Ethernet Switches located at the Florence Tramway central station and at each rail stop. The latter assure the required switching/routing/priorities of the various transmitted data. The line uses Omniswitch Alcatel-lucent 6860 switches.

1.2.2 The Tram Vehicles

Moreover, for actually supervising the tram vehicles, their position is also collected, either continuously along the tram track or upon crossing specific positions. This position tracking leverages on specific communication loops installed along the tram track, which transfer the related data to the closest Ethernet switch, to be transmitted to the central station. However, in order to assure a higher continuity of positioning tracking, the tram vehicle odometer-based data are transmitted with higher frequency, using radio-communication. Such radio communication is based on the TETRA (TErrestrial Trunked Radio) European standard that has been conceived for serving multiple public services.

This radio-based communication also assures the feasibility and accuracy of the periodic transfer respectively to remote control system of the estimated tram arrival time at each successive tram stop, and to traffic light control system of the expected tram arrival at successive traffic light-handled crossroad. In this respect, such an expected arrival time allows assigning a higher precedence to tram vehicles when approaching said crossroad.

The positioning and obstacle detection applications have the aim to improve the benefits of the ELASTIC technology for newly conceived tramways solutions. The positioning system enables the tram vehicles of the tramway of Florence to autonomously localize themselves. Starting from this information, the obstacle detection system will be developed to enhance the security and safety of people in the urban environment.

1.3 ELASTIC Use-Case Overview

With reference to the scenario outlined above, this document will describe the use cases of ELASTIC: *positioning and obstacle detection systems, the predictive maintenance and the energy consumption of the tracks* and *the interaction between the public and private transport.*

1.3.1 Positioning and Obstacle Detection Systems

The existing in-use positioning systems, rely on several basic elements:

- Passive RFID tags to trigger the actions that the on-board system shall perform when the vehicle enters a «critical» area.
- Wi-Fi network to send the appropriate command/message to the Wayside Terminal Unit (WTU).
- Wayside Terminal Unit that dispatch the command/message to the «final» consumer of the message (Interlocking, Traffic Lights Regulator, OCC).

Using along line equipment the system is expensive and provides only discrete information. The new innovative approach will provide:

- A Multi-sensor Integrated solution.
- Rail Track mathematical model.
- Sensors: Inertial Measurement Unit (IMU), GNSS (GPS), Doppler Radar and LIDAR.
- Balise/ Loops / Tag.
- Sensor Fusion Algorithm (SFA): Unscented Kalman filter and Data fusion.

1.3.2 Predictive Maintenance

The relevant on-board set of sensors shall be installed in a set of trams that GEST will provide. As these vehicles are normal on-service trams, the installed equipment must be strictly compliant with relevant regulation of Public Transportation and vehicles homologation. Consequently, installation of relevant sensors is much more complicated than what was initially expected.

1.3.3 Public and Private Transport Interaction

High-level information and warnings delivered to users will contribute to an increased awareness of the network status and potential risks. Also, analysis of data collected along the T1 line and at intersections (tram positions, obstacles, traffic flows, etc.) will provide traffic engineers with insights on interaction between public and private transport, unveiling potential margins for performance optimization.

2 Use cases definition

This chapter introduces and defines the use cases of the ELASTIC project, which are under the responsibility of THALIT, GEST and FLO.

2.1 Current network architecture at the T1 Line

The current network architecture available along the first segment of the T1 tramway line is described hereafter.

2.1.1 Core

The core components of the network are hosted at the control centre (also known as "PCC") operated by GEST, where they are interconnected with the Metropolitan Area Network (MAN) of the City of Florence; interconnection with applications (e.g.

mobility supervisor, urban traffic control systems, etc.) and other networks (e.g. Internet, private cloud at PCC, etc.) that are relevant to the project can be configured at the PCC and/or though the aforementioned MAN, depending on user and/or systems requirements. *Figure 5* shows the rack hosting the core components.

Figure 5: Core components of the public access Wi-Fi network are hosted in a rack at the control centre.

2.1.2 Backbone network

The backbone network relies on a fibre optics ring, connecting the core and switches installed at each stop. The backbone network features a fail-safe configuration and is currently operated at 1 Gbps. The layout of the backbone network is shown below.

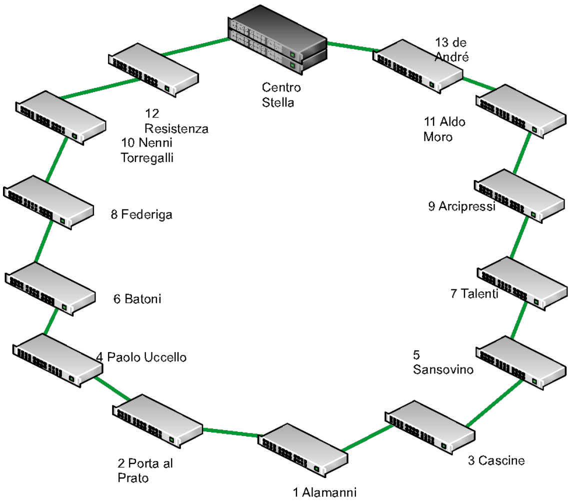


Figure 6: A fibre optics ring connects the control centre and the stops.

2.1.3 Access network

The Wi-Fi access network supports the 802.11a/b/g/n protocols to enable connection of common user devices; to this end, a public SSID is published and users gain access to the Internet through a captive portal. Moreover, hidden SSIDs are configured on the network. A typical configuration of the access network comprises one or more access points connected to the LAN switch installed in the cabinet at the tramway stop. The typical layout of the access network at a single stop is shown below.

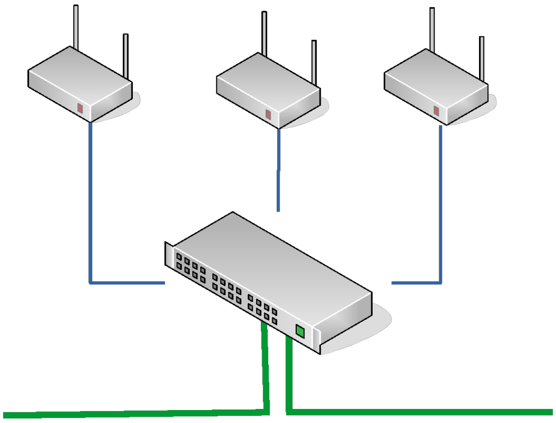


Figure 7: Wi-Fi access points are connected to the LAN switch at each stop.

The following pictures show the different possible locations for edge and/or fog devices, such as cabinets next to traffic lights (figure (a)), lighting poles (figure (b)) and cabinets at stops (figure (c)).

Figure 8: (a) Cabinet hosting devices next to the traffic lights; (b) a lighting pole hosting a Wi-Fi access point and a video camera; (c) cabinet at a stop.

Access points feature a 1 Gbps copper LAN port with PoE output, enabling connection of further devices (e.g. sensors, cameras, etc.) – this could ease the installation of additional devices required for the implementation of the ELASTIC use cases.

2.1.4 Additional components

While some components supporting the implementation of the use cases are already available at the site, some other edge and fog devices have to be added to enable all required functionalities. Hence, the existing network architecture along the first segment of the T1 light-rail line in Florence will be updated with a significant number of components and network devices.

In order to implement the use cases, this network architecture shall be extended to support integration of different components (e.g. sensors, edge/fog computation and/or storage hardware, communication devices, etc.). The set of requirements and additional constraints set by the environment may result in a variety of physical setups for the deployment of field components. The actual setup will be defined better during design and implementation, taking different requirements and constraints into account. Nonetheless, it is already possible to envisage some possible setups, which are illustrated in the pictures below.

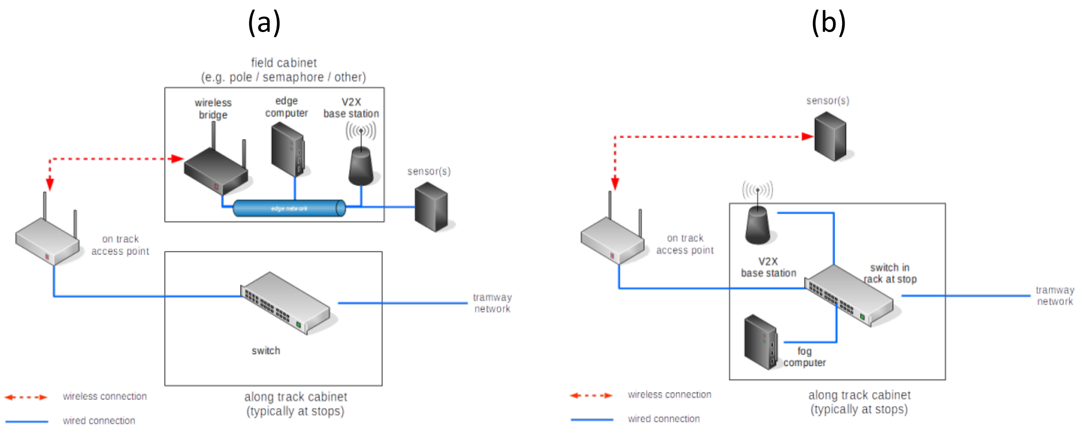


Figure 9: Possible setups of the network architecture along the tramway line, with devices hosted a) in a remote cabinet (e.g. next traffic lights), or b) in a cabinet at the stop.

Connection of edge devices (sensors and/or edge computing devices) relies on the wireless access network, upon which a (hidden) SSID dedicated to the ELASTIC system could be configured and linked to project-specific VLAN on the access network.

Under some conditions, a set of devices might be connected to a local "edge network", which is then connected to the access network through a wireless bridge (e.g. this might be the cases for devices hosted in/nearby a cabinet next to a traffic light); otherwise, single devices (e.g. a camera or a sensor on a light pole) could be connected directly to the wireless access network and others directly to the wired backbone network (e.g. a V2X base station and/or a fog computer, hosted in a cabinet at the stop).

2.1.5 Networks between the fog nodes and the cloud platform

The diagram below shows the interconnections between the tramway network and other relevant networks and or systems/components. As described above, the core of the network deployed along the first segment of the T1 tramway line is located at the control centre (PCC).

Along with the core network components, the PCC datacentre hosts the different systems required by the tramway infrastructure, including the Urban Traffic Control (UTC) system in charge of controlling the traffic lights at intersections with the T1 and T2 tramway lines.

The PCC datacentre is interconnected to FLO's datacenter through a fiber optics metropolitan area network (MAN), which enables interoperability between the UTC and the mobility supervisor, and, consequently, with other Inteligent Transportation Systems (ITS) components that interoperate with the supervisor.

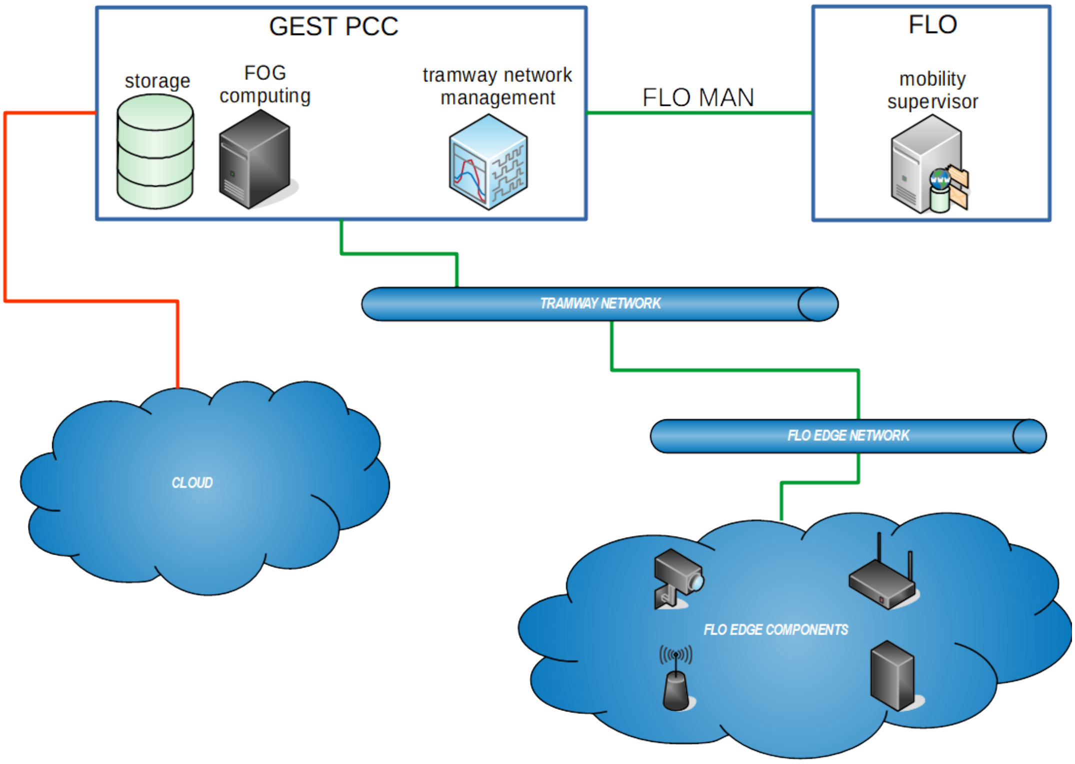


Figure 10: FLO, GEST, tramway, edge and cloud networks interconnections scheme.

2.1.6 Additional components

The use cases may take advantage of computing and storage facilities which are expected to be deployed within the ELASTIC project as part of the implementation of the fog/cloud architecture and will use Internet connection to access cloud services

2.2 Positioning and obstacle detection (NGAP and ADAS)

2.2.1 Next Generation Autonomous Positioning (NGAP)

The precise as well as reliable detection of the tram position and its safe communication, plays a key role for the train and tram operation control system. In recent years, it is possible to observe a tendency to shift more and more positioning equipment functionality, for safety-critical applications, from the track-side to the vehicle on-board-side. Tram-borne positioning systems enable a cost-effective operation technology for LRT (Light Rail Transit) lines with a more flexible operation than track-side positioning systems can offer. In Europe, the train position is traditionally processed with the help of equipment on tracks. The typical equipment is a track circuit, i.e. a simple electrical device used to detect the presence of a train on rail tracks. This equipment is thus not devoted to locating the train specifically but to locating it indirectly on a track portion. The location can also be determined with the help of detectors placed along the track, on which the tram protection relies. These sensors can be transponders (inductive loops and RFID tags), which communicate with the train on-board equipment when the train passes over them. In a standard tramway application, the system composed of a loop and an odometer computes the position of the train. After positioning calculation, the train location is usually sent by the train on-board computer to the ground and in particular to the OCC (Operational Control Center). All information, including signalling and tram positioning, is exchanged between the on-board system and the OCC system through mobile networks.

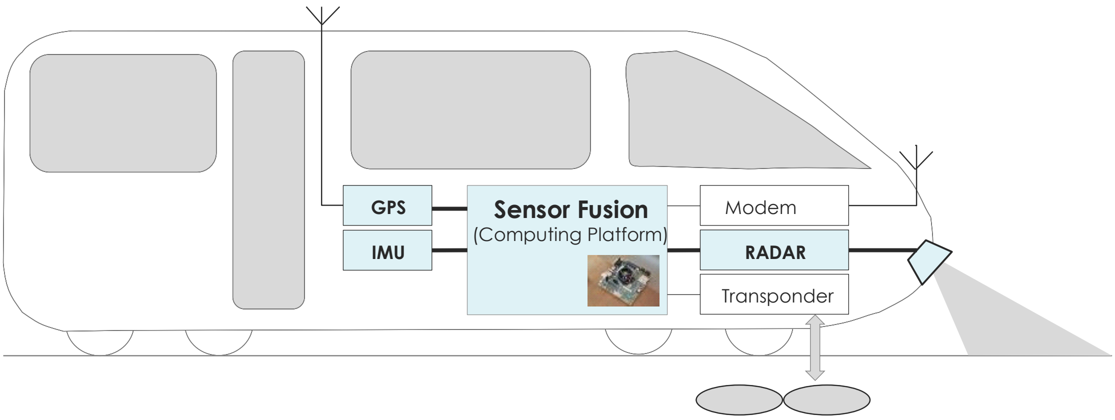


Figure 11: Architecture of the on-board NGAP system.

For the design of a train positioning algorithm using track constraints, it is assumed that the primary motion sensors available comprise: (i) a low-cost, Micro-Electro-Mechanical System (MEMS) Inertial Measurement Unit (IMU); one, or more, sensors (such as radars, tachometers, etc) providing odometry measurements; and (iii) one, or more, sensors providing absolute position measurements.

The NGAP solution is designed and developed using state-of-the-art algorithm techniques: the algorithm is based upon a navigation filter that processes incoming asynchronous sensor data in order to maintain an estimate of the navigation state (position, velocity attitude, etc.).

In terms of sensors, the Global Navigation Satellite System (GNSS) is increasingly useful for positioning moving objects and it streamlines many intelligent transportation systems like trams. The movement patterns of these vehicles varies, including both open spaces and narrow streets. The latter are difficult areas from a GNSS positioning standpoint, e.g. narrow streets bordered by high buildings in the centre of old towns. The GNSS signal can be lost in these spaces or the number of reachable GNSS satellites is decreased. If the number of reachable satellites decreases below four, an ordinary GNSS receiver is not able to calculate its position. Because of this insufficiency, the GNSS has not yet been applicable for tracking trams although tram positioning, as well as train positioning, has one advantage compared to regular vehicles: tram movement is limited by the tracks. Therefore, the navigation accuracy of a train positioning system can be improved significantly by using a priori knowledge of the railway track layout as a constraint on the navigation solution. Such a constraint can improve the observability of errors in both the tram's navigation solution and the errors in the sensor measurements used to compute that solution.

The core system at the basis of the NGAP use case is a Sensor Fusion Algorithm (SFA), which is based upon a non-Euclidean mathematical approach and an innovative unscented filter, rather than the less general Euclidean vector spaces typically used in conventional filtering algorithms, such as the ubiquitous Extended Kalman Filter (EKF). Time evolution of the navigation state uses the IMU data as the control input. The constraint is provided in the form of an a priori track-constraint function that gives the Earth-Centred Earth-Fixed (ECEF) location of a point on the track parameterised by arc-length.

The NGAP system shall retrieve the position of the tram with a maximum error of 2 m every 15 km travelled under the following environment conditions: normal condition, strong wind, fog and rain.

except in case of snow that will not guarantee a correct function of the GPS antenna and the radar odometer.

2.2.2 Advanced Driver Assistance System (ADAS)

Within this use case, THALIT will develop a vehicle mounted obstacle detection and collision avoidance assistance system in order to support the driver in taking decisions (ADAS, Advanced Driver Assistance System) for trams and light rail vehicles, enhancing safety for passengers, service operators and other traffic participants.

The complexity of city traffic requires cognitive capabilities to improve vehicle reactivity and perception of near- and long-range obstacles. The development of this technology and its impact in Florence LRT will result in improved safety of daily operations. We aim to translate this effort into the operational context and its operation will simplify the number of scenarios, representing an excellent context for demonstrating and testing sensor and reactiveness capability of THALIT technology.

In the automotive sector, driver assistance systems have already proven their worth, avoiding collisions and reducing the risk of accidents. Trams and other light rail vehicles, however, place much higher demands upon such systems. Based on a preceding research projects and self-funded internal tasks, THALIT, the provider of this use case, will develop a solution equipped with multiple sensors (scan cameras, radars, lidars), advanced computer vision algorithms as well as innovative data fusion and a vehicle position tracking system.

The system developed for this use case will have the capability to detect any obstacle in the front and the lateral parts of the trams at different depth levels. It will assist drivers in critical situations by detecting and tracking obstacles in real-time – thereby compensating for driver errors. In contrast to existing mono-sensor type radar-based or camera-based solutions, the ELASTIC's embedded ADAS can detect any object regardless of size, shape or material. Notably, this includes people, cars and other vehicles entering the monitoring zone, which contributes greatly to the safety of all traffic participants.

Although technology cannot replace human drivers, it can complement human perception and decision making – often deciding between life and death. Indeed, the system will be able to significantly reduce the number of rear-end collisions involving tram vehicles and, as a result, help to avoid high follow-up costs. The ADAS proof of concept will be implemented in a stand-alone shadow mode, well separated from the revenue service system, capturing and processing data.

The design will consider a variety of optical and radio-based sensors mounted to the front of the train to detect and recognize obstacles. The architecture includes optical sensors capable of identifying objects at distances up to 100m in a variety of lighting conditions, as well as radio-based systems capable of detecting obstacles within the line of sight up to 200m. The data from these sensors will be processed separately on-board and recorded to a data logger, along with GPS positioning and other data. This can then be processed by THALIT software to recognize the obstacle type and identify distance to obstacles, providing awareness to a driver awareness system in various locations on the vehicle and the capability to integrate directly to the on-board computer (OBU – On-Board Unit). For the scope of work of the project, no interface towards the braking system will be provided.

The proposed architecture foresees the storage of the data coll rs and results of the on-board computation. These data will be d cloud components in accordance to the ELASTIC architecture identified in WP3 and WP5.

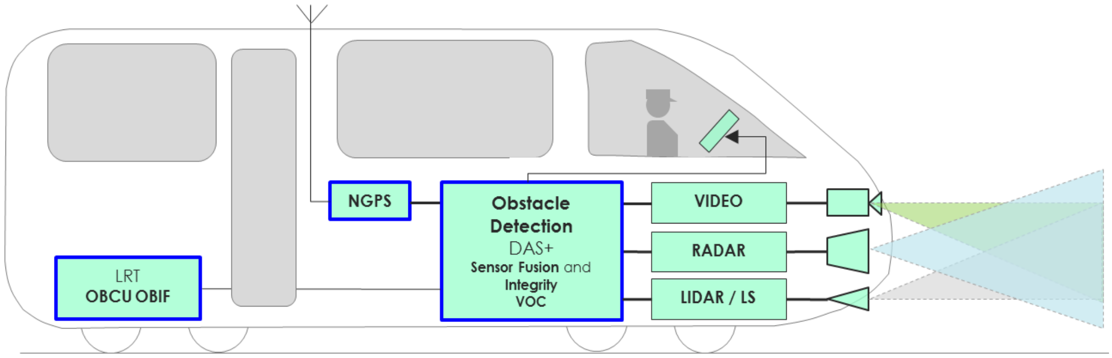


Figure 12: Architecture of the on-board ADAS system.

Starting naturally from the feasibility stage the partners will take a systems approach to its design process, recognizing the need to consider the entire tramway line, its environment, neighbours, stakeholders and processes.

THALIT will continue to recognize the problem space throughout its design process with GEST and this will be reflected in its system representation. THALIT will use COTS technology where possible to ensure both best value and access to the latest technology in a rapidly developing area. Besides THALIT will use hazard identification techniques through its design process to ensure delivery of a proof of concept that is safe by design.

To balance the formality of design with the need to progress to a rapid demonstrator, ELASTIC's partners will follow an approach to software development that is intended to make quick progress utilizing agile development through sprints.

Furthermore, the partners involved in WP1 will review the standards identified in the project deliverables and demonstrate compliance with them. From similar work conducted in other tramway scenarios, THALIT recognizes that primary concerns for a PoC (Proof of Concept) include gauge, mechanical fixing, fire, EMC, space and ease of installation/removal with minimal impact on the train and operations.

The tramway system meets various scenarios according to the different obstacles, weather, lighting and environment conditions. An outline of the scenarios in which the train can occur is represented in Figure 14. According to the different weather and visibility conditions, the train can start its route, it can reduce its speed (thanks to the braking system) and it can proceed along the track with constant speed. For each of the above-cited different behaviour, its operating environment can be the depot, the station and the line. At the train stops and along the train tracks, there are crosswalks and crossroads. Consequently, vehicles and people can result possible obstacles for the ADAS system and it is very important to classify the targets.

	Gait phase	Location	Area	Curve	Straight line	Junction
Different weather/visibility conditions	Departure	Depot	Manoeuvring area	x		x
			Shelter			x
		Station	Platforms surroundings	x	x	x
			Crosswalk	x	x	
		Line	Line sides	x	x	x
			Crosswalk	x	x	x
			Crossroad	x	x	x
	Braking	Depot	Manoeuvring area	x		x
			Shelter			x
		Station	Platforms surroundings	x	x	x
			Crosswalk	x	x	
		Line	Line sides	x	x	x
			Crosswalk	x	x	x
			Crossroad	x	x	x
	Route (Constant speed)	Depot	Manoeuvring area	x	x	x
			Shelter			
		Station	Platforms surroundings	x	x	x
			Crosswalk	x	x	
		Line	Line sides	x	x	x
			Crosswalk	x	x	x
			Crossroad	x	x	x

Table 1 Different scenarios for the ADAS system.

2.2.2.1 Obstacles

We consider an obstacle any possible object (including things, animals, human beings) which can collide with tram because they stand between the rails or because they stand nearby and their shape is suitable with a collision.

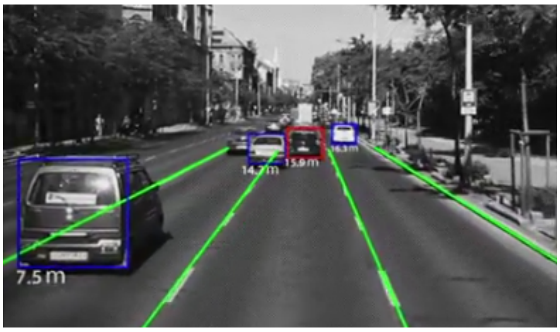
Figure 13 Examples of obstacles.

2.2.2.2 Basic scenarios

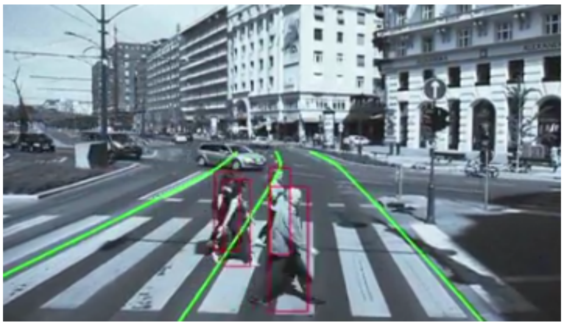
A list of basic scenarios of the tramway system for the obstacle detection application is presented below.

1) Static obstacle between the rails: the height of the object is lower than the height of the lower part of the tram.
2) Static obstacle between the rails: the height of the object is higher than the height of the lower part of the tram.
3) Static harmful obstacle on the track rails. A rock, a bicycle, a car, a person, a fallen branch of a tree, a bunch of snow, could be such obstacles.
4) Static harmless obstacle on the track rails. Newspapers, leaves, empty plastic bags, a snow thin layer, shallow pool of water, could be such obstacles.
5) Obstacle moving along the rail. Its size is sufficient for impacting with tram.
6) Obstacle moving along the rail. Even if size is not sufficient for impacting with tram, its trajectory is too close and dangerous.
7) Obstacle moving at a distance from the tram, but its trajectory and vehicles-speed is compatible with a future collision.

8) Possible obstacle recognition, among categories such as: adult human being, children, dogs, bicycles, motorbikes, cars, trams, buses, lorries, horses, horse-drawn carriages.
9) Tram moving in a city area, crowded with people in the surrounding of tram.
10) Tram moving in a city area with different typologies of vehicles in the tram surrounding.
11) Tram approaching to platform with people standing and walking in the surroundings.
12) Tram moving along a straight section of track.
13) Tram moving along an on-bend section of track.
14) Tram moving near street crossings with traffic lights and vehicles.
15) Tram moving near a pedestrian crossing.
16) Tram moving along a street with cars parked on the street sides and people walking on pavements.
17) Tram moving near other motionless tram.
18) Tram moving near other tram moving in the opposite direction.



(a) Forward Collision Warning (FCW)


(c) Pedestrian&Cyclist Collision Warning (PCW)

(b) Headway Monitoring Warning (HMW)


(d) Signal Detection System (SDS)

Figure 14 Examples of scenarios.

2.2.2.3 Lighting conditions

The obstacle detection system has to work during the operating hours of the tramway system (from 5 a.m. to 2 a.m.). Therefore, it has to detect objects according to variable lighting conditions from the light of the morning to the darkness of the night. The different lighting conditions are:

1) morning time lighting;
2) midday time lighting;
3) twilight time lighting;
4) night-time lighting;
5) presence of reflexes in the surroundings (shop windows, windows, doors, cars...).

2.2.2.4 Weather conditions

The tramway system is in an open environment. It has to work according to the different weather conditions, providing the same functionality. In particular, the measurements related to the presence/absence of the obstacles cannot be affected by the reflection of the electromagnetic waves transmitted by the radar in the water drop and by the low visibility of the camera during a rainy or foggy day. The ADAS system shall works in the following weather conditions:

1) sunny day;
2) rainy day (light raining);
3) rainy day (heavy raining);
4) fog day (thin fog);
5) rainy day (thick fog);
6) snowy day.

2.2.2.5 Environment conditions

Possible environment conditions of the ADAS system are:

1) scenario crowded by pedestrians;
2) scenario crowded by vehicles;
3) the speed-range of vehicles (around 0-60 km/h) and other moving objects is compatible with reasonable urban activities;
4) moving objects to consider are objects moving on the ground and not flying objects.

2.2.3 Data Transmission

The NGAP and ADAS systems shall transmit data to the cloud using two different media channel: LTE for immediately transmit light information that other use case applications need and Wi-Fi for transmitting large amount of data that do not need immediate processing and analytics.

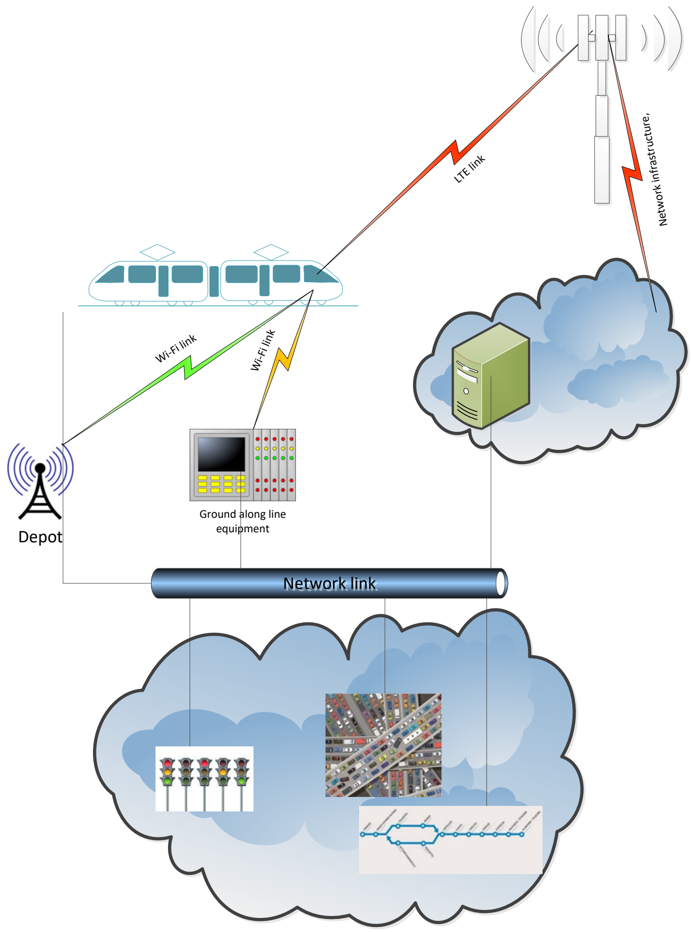


Figure 15 Transmission from/to onboard systems.

2.3 Predictive maintenance and energy consumption

As known, defective assets on the rail track represent a significant cause of hold-ups on most rail and tram networks, causing one third of delays and sometimes rail trams' suspensions, thus impacting citizens' expectations and the normal operation of cities. Therefore, it is fundamental to early collect symptoms associated to possible rail track wears, and thus to identify in advance what sort of intervention might be needed.

The predictive maintenance application will monitor and record in real-time the rail track status and profile. Moreover, possibly exploiting cloud connections, these data can be enriched by spatially associating them to the detected obstacles during the previous tram runs on the same rail track positions, as ADAS-provided. In fact, such link might reveal a correlation between unexpected detected obstacles and rail track damages, as unexpected obstacles might have led to tram vehicle abrupt brakes and these latter representing a possible origin of the consumed rail track portions. These correlations have to be performed with ADAS-provided data collected after the last performed rail track maintenance activity and for a number of tram runs preceding the rail track status monitoring run.

Equally, and always under the predictive maintenance objective, it is important to monitor the tram vehicle electric power consumption profile, in order to potentially minimize consumption. In fact, newly conceived rail track portions might also be catenary-free. This will have an environmental positive impact on city and citizens, and thus the electricity power saving is even more important for assuring longer operational continuity of battery-supported rail tram.

2.3.1 Basic scenarios

The basic scenario is simply represented by a tram vehicle moving along the rail track. No specific restrictions on the Predictive Maintenance use case. While the rail track status monitoring might also be performed by a specific maintenance/monitoring vehicle (not the ordinary tram), moving at lower speed and thus enhancing the data collection and quality, the measured electric power consumption profile has necessarily to be performed on a true tram vehicle in service.

2.3.2 Lighting conditions

The predictive maintenance system, relying on autonomous lighting devices, can work at any lighting conditions (day light or night).

2.3.3 Weather conditions

The used sensors (either laser- or radar-based) can work irrespective of weather conditions. The only true constraint is avoiding performing rail track status monitoring upon or after strong rain or snow conditions, as accumulated rainwater or snow along the rail track might alter the laser- or radar-returned echoes, and thus lead to possible inaccurate rail track status monitoring. However, in case of sudden and not forecasted rain or snow during the rail tracks' monitoring, any signalling of possible rail track damages can be visually verified (sensor data are associated to rail track videos) and associated to rainwater and/or snow or waste material, and thus ignored, requiring successive and repeated rail track monitoring.

2.4 Interaction between the public and the private transport

While some interactions between public and private transport happen by design (e.g. modal shift), some others are not part of the design but happen anyway. A few sample interactions are listed and shortly explained below with reference to real situations.

2.4.1 Scenarios of interactions between public and private transport

In order to provide conditions for high capacity and high frequency of public transport, the trams of the Florence light rail network have granted high priority at intersections. This might result in aperiodic cycles of traffic lights, affecting the (perceived) performance of private transport.

Figure 16 The hard priority granted to trams by the UTC system limits effectiveness of green wave corridors and countdowns at intersections.

In some cases, modal shift from tramway to train and/or bus requires people to walk a short distance; this might include crossing streets. Although traffic lights are present, sometimes people might ignore red lights because they do not want to miss the connection with the bus/train (which is in line of sight); this behaviour is dangerous both for pedestrians as well as for car and/or bus drivers and/or passengers.

Figure 17 In order to catch the bus/train, people cross the street while traffic light is red for pedestrian.

Due to limited visibility of the signs, a misleading layout of the intersection and/or inaccurate information used by navigation software, drivers might perform wrong manoeuvres, which might result in collisions with the trams.

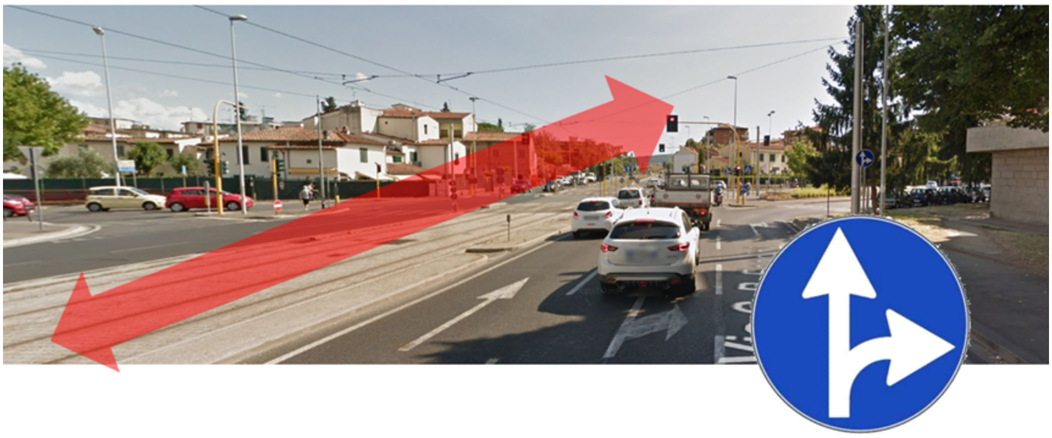


Figure 18 Sometimes cars turn left (traffic light is green for both tramway and cars!).

Figure 19 Sometimes the red phase lasts too long and drivers try to cross the intersection anyway, not seeing if a tram is approaching.

2.4.2 Motivation and objective

The above samples of unintended negative interactions between public and private transport evidence negative effects that such interactions may have on both safety and network performance: ignoring traffic signs or performing incorrect manoeuvres at intersections can be the cause of serious accidents, with injured people and degraded network performance.

Figure 20 Collisions between cars and trams can be harmful for people and a long time might be required for a full recovery of the service.

Consequently, this use case aims to investigate the interaction between the public and the private transport, from two perspectives, namely:

- Safety, i.e., hazards for pedestrians, drivers, tram passengers;
- network performance, including service levels for public transport and service levels for private transport.

Potential users involved in the use case include: car and tram drivers; vulnerable road users (VRUs – pedestrians, cyclists); and traffic engineers.

2.4.3 Scenarios

The system shall collect and process data from different sources, in order to provide a comprehensive representation of the transportation network dynamics. In the online scenario, the system shall provide users (pedestrians, car drivers, tram drivers) with information on relevant situations and/or with alerts on potential hazards.

In the offline scenario, the system shall provide users (traffic engineers) with data useful to assess the transportation network performance so as to enable further optimization.

To this end, the system shall rely on a number of inputs, including:

- UTC plans (rules) to control traffic lights;
- traffic light status/transitions, through an API published by the UTC;
- traffic flows (both measured and estimated), through an API published by the mobility supervisor (which already acts as a data collector for traffic data acquired by different sub-systems). Some dedicated traffic sensors might also be installed at the pilot site(s);
- traffic events (code, description, position), through an API published by the mobility supervisor;
- video cameras, to be installed at the pilot site(s);

- tram position, as an output of the NGAP sub-system to be developed within the ELASTIC project;
- obstacle detection events, as an output of the ADAS sub-system to be developed within the ELASTIC project;
- bus positions and arrival times at bus stops (scheduled and/or effective), through an API published by the mobility supervisor.

The system shall perform some low-level data processing to extract semantically relevant information. This includes processing of:

- live video streams recorded by the cameras, in order to detect higher-level events, as presence of people (i.e. crowds in specific areas) and some behaviours (i.e. pedestrians crossing the street);
- tram position, in order to detect higher-level events as approaching/occupying/leaving an intersection or stop.

It is worth pointing out that state-of-the art solutions for event detection are sufficient to implement the use case. Yet, the flexibility of an ad hoc (even approximate) solution would probably better fit the requirements for the deployment on the continuum of the ELASTIC architecture, from the edge to the cloud. Investigating this aspect appears as an opportunity/challenge for the ELASTIC project consortium: video analytics involves high data volumes, thus it is best performed at the edge if network bandwidth is low; whereas, processing in the cloud could benefit from more computation power. Although event detection is expected to be performed online, it could be useful to store pre-processed video streams (i.e. not raw video, but instead the output of image/video segmentation algorithms, etc.) in the cloud for further analysis and/or processing.

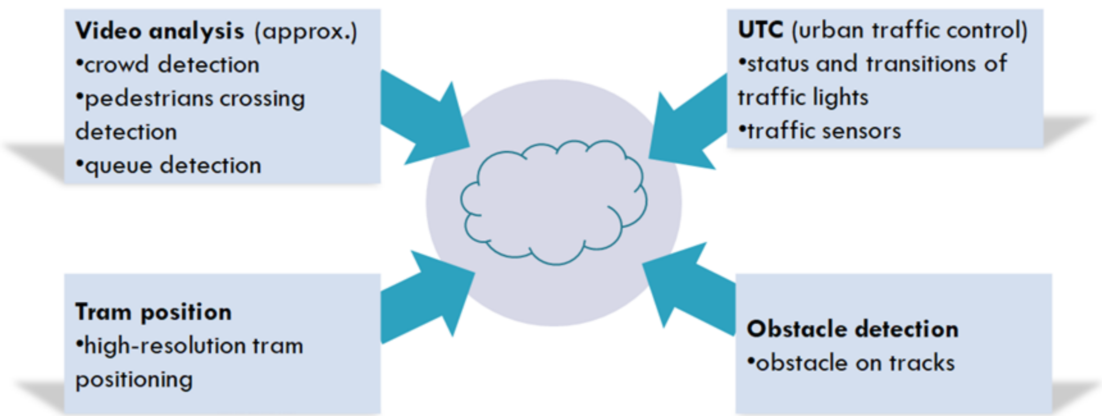


Figure 21 Data fed to the system to implement the mobility optimization use case.

In the online scenario, the system shall close the control loop by delivering information and alerts to users, also with the support of devices and protocols enabling vehicle-to-infrastructure and/or vehicle-to-vehicle communication (e.g. IEEE 802.11p and/or C-V2X, ETSI SPAT/MAP, ETSI DEN, etc.).

Figure 22 V2X interoperability enabling communication among vehicles and infrastructures.

In some cases the control loop might be implemented also locally at the intersection (e.g. warning car drivers about pedestrians crossing the street, warning tram drivers about crowds at the stop, etc.), whereas in some other cases it might be only distributed (e.g. warning car drivers about a tram approaching, warning car drivers about a traffic light going to change its state, etc.).

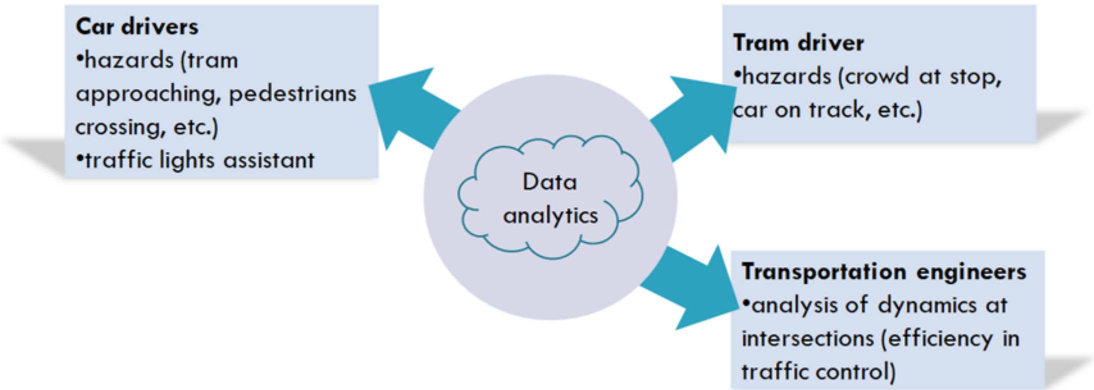


Figure 23 Possible outputs by the system for the implementation of the mobility optimization use case.

Timing related aspects could be framed as follows:

- car travelling at 50 km/h
  - reaction : ~ 15 m / 1 s
  - braking: ~ 25 m / ≤ 2 s
  - overall: ~ 40 m / ≤ 3 s
- tram
  - deceleration 2.2 m/s^2
  - reaction: ~ 15 m / 1 s
  - braking: 50 m / 8 s

Hence, assuming that tasks for detecting an event and providing the user with a warning are executed in the range 1 ms ≤ t ≤ 1 s, additional 15 m / 1 s would be added to the above.

In the offline scenario, the system shall perform big data analysis to reveal recurrent patterns in transportation network dynamics, as well as to support traffic engineers in the evaluation of KPIs useful to assess performance of the overall transportation network, from different perspectives.

Concerning safety related issues, no direct control actions on any safety critical system are envisaged for the above listed scenarios. For the sake of completeness, it has to be noticed that warnings are issued to users: if no solution is available to guarantee trust and/or authenticity, false warnings could be published by hackers and distract drivers and/or affect the transportation network performance (e.g. by declaring false accidents or congestions, etc.). However, and although security concerns are reflected in the ELASTIC architecture, these issues do not fall within the scope of the use case being addressed in this project.

Similarly, concerning security issues, the use case does not require any personal data to be stored (or even processed). Moreover, as stated above, no direct control actions are required on any safety critical system. Physical access to devices depends on the cabinet characteristics. Hence, practices and solutions can be adopted that are common in similar situations as challenging the state of the art on this topic falls also beyond the scope of this project.

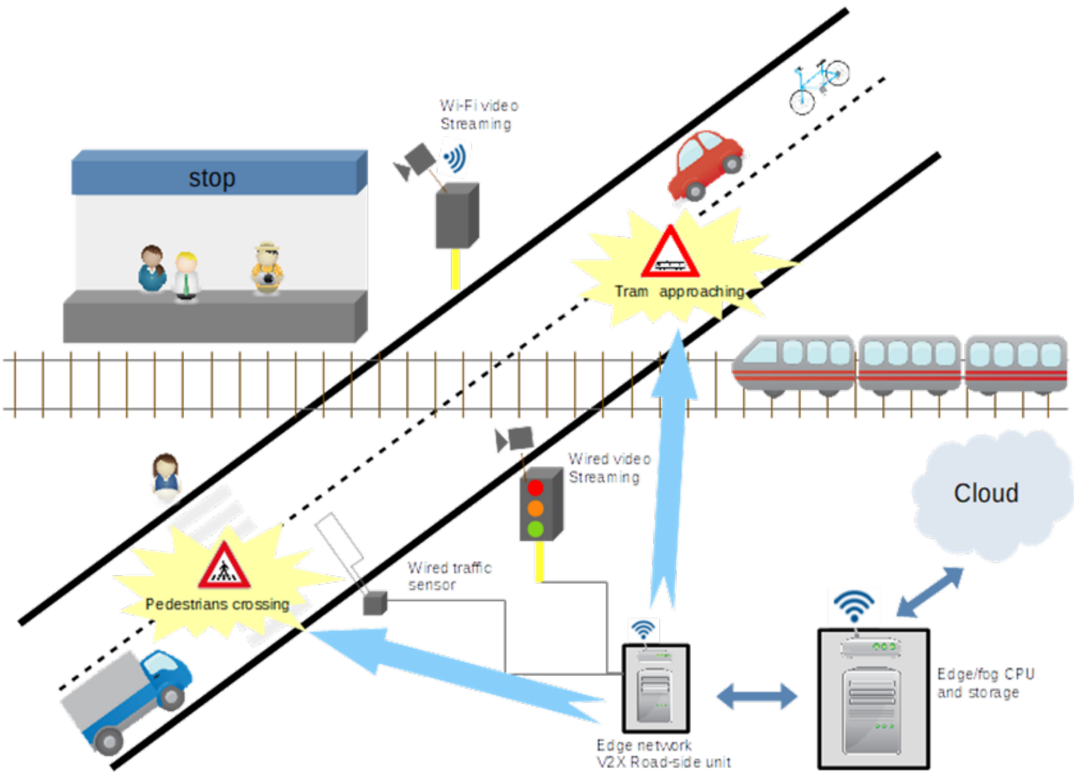


Figure 24 Putting pieces together: envisioned setup of the system for the implementation of the city performance optimization use case.

3 Requirements

3.1 Positioning and obstacle detection (NGAP and ADAS)

This section describes the general requirements for the NGAP and the ADAS systems in the tramway environment of the city of Florence (Italy). The technical and specific requirements of the NGAP and ADAS systems are presented in the Annex A document [25].

3.1.1 General requirements

PUID: **[SYS-ELA-GEN-REQ-001]**
NGAP system **shall** be integrated in the ELASTIC architecture.
IE Rationale:
IE Functionality: Functional
IE Req Category: Architecture
IE Test Method Expected: Demonstration

PUID: **[SYS-ELA-GEN-REQ-002]**
ADAS system **shall** be integrated in the ELASTIC architecture.
IE Rationale:
IE Functionality: Functional
IE Req Category: Architecture
IE Test Method Expected: Demonstration

PUID: **[SYS-ELA-GEN-REQ-003]**
NGAP and ADAS systems **shall** collect data from relevant sensors.
IE Rationale: IMU, Radar, Cameras, LiDAR, GNSS.
IE Functionality: Functional
IE Req Category: Architecture
IE Test Method Expected: Demonstration

PUID: **[SYS-ELA-GEN-REQ-004]**
NGAP and ADAS systems **shall** process data from sensors on board, so the outputs of these systems do not need cloud processing.
IE Rationale: This is a typical FOG computation scenario. Hence, large amount of data must not be transferred over the network.
IE Functionality: Non-Functional
IE Req Category: Data
IE Test Method Expected: Demonstration

PUID: **[SYS-ELA-GEN-REQ-005]**
NGAP system output data **shall** be relevant information on the position of tram along the rail track.
IE Rationale:
IE Functionality: Non-Functional
IE Req Category: Data

IE Test Method Expected: Demonstration

PUID: **[SYS-ELA-GEN-REQ-006]**
NGAP system **shall** make its output data as soon as they are available in order to let other system to use them.
IE Rationale:
IE Functionality: Non-Functional
IE Req Category: Availability
IE Test Method Expected: Demonstration

PUID: **[SYS-ELA-GEN-REQ-007]**
NGAP system **shall** deliver its output data on a channel that can work in every position along the configured rail track.
IE Rationale:
IE Functionality: Non-Functional
IE Req Category: Performance
IE Test Method Expected: Demonstration

PUID: **[SYS-ELA-GEN-REQ-008]**
NGAP system **shall** store sensor input/output data on-board for no longer than one day.
IE Rationale:
IE Functionality: Non-Functional
IE Req Category: Performance
IE Test Method Expected: Demonstration

PUID: **[SYS-ELA-GEN-REQ-009]**
NGAP system **shall** upload sensor output data stored when the tram is parked in the depot.
IE Rationale: THALIT expects that the relevant infrastructure managed by GEST and FLO is compliant with this scenario.
IE Functionality: Non-Functional
IE Req Category: Performance
IE Test Method Expected: Demonstration

PUID: **[SYS-ELA-GEN-REQ-010]**
A cloud application **shall** use positioning information from NGAP system to show train position along the configured rail track.
IE Rationale:
IE Functionality: Functional
IE Req Category: Performance
IE Test Method Expected: Demonstration

PUID: **[SYS-ELA-GEN-REQ-011]**
NGAP system output data **shall** be linked to the date and time they refer to.
IE Rationale:
IE Functionality: Functional
IE Req Category: Schedule
IE Test Method Expected: Demonstration

PUID: **[SYS-ELA-GEN-REQ-012]**
ADAS system output data **shall** be relevant information about detected obstacles or possible ones.
IE Rationale: Information detected by the ADAS system are immediately useful on-board, to provide warnings and alarms to the driver. Nevertheless, the same information, grouped in relevant typologies, is useful for statistics understanding of dangerous or critical areas and for driveability management.
IE Functionality: Non-Functional
IE Req Category: Data
IE Test Method Expected: Demonstration

PUID: **[SYS-ELA-GEN-REQ-013]**
ADAS system output data **shall** include relevant information about the state of the track: free or obstructed and other relevant states. We call them DETECTED OBSTACLES.
IE Rationale:
IE Functionality: Non-Functional
IE Req Category: Data
IE Test Method Expected: Demonstration

PUID: **[SYS-ELA-GEN-REQ-014]**
DETECTED OBSTACLES **shall** not include videos, even if ADAS system provides information in the form of videos to the driver.
IE Rationale: Information in the video format will be available only on-board and they are not delivered outside.
IE Functionality: Non-Functional
IE Req Category: Data
IE Test Method Expected: Demonstration

PUID: **[SYS-ELA-GEN-REQ-015]**
ADAS system **shall** provide its output data as soon as they are available, in order to let other systems to use them.
IE Rationale:
IE Functionality: Non-Functional
IE Req Category: Availability
IE Test Method Expected: Demonstration

PUID: **[SYS-ELA-GEN-REQ-016]**
ADAS system **shall** deliver its output data on a channel that can work in every position along the rail track.
IE Rationale:
IE Functionality: Functional
IE Req Category: Performance
IE Test Method Expected: Demonstration

PUID: **[SYS-ELA-GEN-REQ-017]**
ADAS system **shall** store sensor output data for a configurable time.
IE Rationale: ADAS does not need to store sensor data for a time longer than that one required by the processing of on board activities. Nevertheless, it will store sensor data output for a configurable amount of time. This is useful for saving sample video or video associated to special events.
IE Functionality: Non-Functional
IE Req Category: Performance
IE Test Method Expected: Demonstration

PUID: **[SYS-ELA-GEN-REQ-018]**
A cloud application **shall** use information from ADAS system to implement statistical analytics about relevant events along the line.
IE Rationale:
IE Functionality: Functional
IE Req Category: Performance
IE Test Method Expected: Demonstration

PUID: **[SYS-ELA-GEN-REQ-019]**
ADAS system **shall** store its output data from the time it leaves the depot to the time it is parked again in the depot.
IE Rationale:
IE Functionality: Non-Functional
IE Req Category: Performance
IE Test Method Expected: Demonstration

PUID: **[SYS-ELA-GEN-REQ-020]**
NGAP system **shall** transmit output data to cloud application as soon as data are available on board of tram.
IE Rationale:
IE Functionality: Non-Functional
IE Req Category: Data
IE Test Method Expected: Demonstration

PUID: **[SYS-ELA-GEN-REQ-021]**

NGAP system **shall** transmit output data to cloud application regardless of the tram position along the rail track when tram is on service.
IE Rationale:
IE Functionality: Non-Functional
IE Req Category: Data
IE Test Method Expected: Demonstration

PUID: **[SYS-ELA-GEN-REQ-022]**
All ADAS system output data **shall** be transmitted to the cloud except videos.
IE Rationale:
IE Functionality: Non-Functional
IE Req Category: Data
IE Test Method Expected: Demonstration

PUID: **[SYS-ELA-GEN-REQ-023]**
ADAS system **shall** transmit output data to cloud application as soon as data are available on board of tram.
IE Rationale:
IE Functionality: Non-Functional
IE Req Category: Data
IE Test Method Expected: Demonstration

PUID: **[SYS-ELA-GEN-REQ-024]**
ADAS system **shall** transmit output data to cloud application regardless of the tram position along the rail track when tram is on service.
IE Rationale:
IE Functionality: Non-Functional
IE Req Category: Data
IE Test Method Expected: Demonstration

PUID: **[SYS-ELA-GEN-REQ-025]**
NGAP system **shall** retrieve date/time synchronization data from NTP system.
IE Rationale:
IE Functionality: Functional
IE Req Category: Architecture
IE Test Method Expected: Demonstration

PUID: **[SYS-ELA-GEN-REQ-026]**
ADAS system **shall** retrieve date/time synchronization data from NTP system.
IE Rationale:
IE Functionality: Functional
IE Req Category: Architecture
IE Test Method Expected: Demonstration

PUID: **[SYS-ELA-GEN-REQ-027]**

NGAP system **shall** receive NTP synchronization data from the cloud.
IE Rationale:
IE Functionality: Functional
IE Req Category: Schedule
IE Test Method Expected: Demonstration

PUID: **[SYS-ELA-GEN-REQ-028]**
ADAS system **shall** receive NTP synchronization data from the cloud.
IE Rationale:
IE Functionality: Functional
IE Req Category: Schedule
IE Test Method Expected: Demonstration

PUID: **[SYS-ELA-GEN-REQ-029]**
NGAP system **shall** transmit its input sensors data (that it collects and uses) to the cloud using wireless link when it is in service along the rail track and/or when it is in the depot.
IE Rationale:
IE Functionality: Functional
IE Req Category: Data
IE Test Method Expected: Demonstration

PUID: **[SYS-ELA-GEN-REQ-030]**
ADAS system **shall** transmit its input sensors data (that it collects and uses) to the cloud using wireless link when it is in service along the rail track and/or when it is in the depot.
IE Rationale:
IE Functionality: Functional
IE Req Category: Data
IE Test Method Expected: Demonstration

PUID: **[SYS-ELA-GEN-REQ-031]**
ADAS system **shall** store sensor input/output data on-board for no longer than one day.
IE Rationale:
IE Functionality: Non-Functional
IE Req Category: Data
IE Test Method Expected: Demonstration

PUID: **[SYS-ELA-GEN-REQ-032]**
NGAP data stored during the daily service, which have not been uploaded to the cloud, **shall** be uploaded before the beginning of a new day service.
IE Rationale:
IE Functionality: Functional

IE Req Category: Data
IE Test Method Expected: Demonstration

PUID: **[SYS-ELA-GEN-REQ-033]**
ADAS data stored during the daily service, which have not been uploaded to the cloud, **shall** be uploaded before the beginning of a new day service.
IE Rationale:
IE Functionality: Functional
IE Req Category: Data
IE Test Method Expected: Demonstration

PUID: **[SYS-ELA-GEN-REQ-034]**
NGAP data related to the days before the new service day **shall** be deleted from the on-board systems.
IE Rationale:
IE Functionality: Functional
IE Req Category: Data
IE Test Method Expected: Demonstration

PUID: **[SYS-ELA-GEN-REQ-035]**
ADAS data related to the days before the new service day **shall** be deleted from the on-board systems.
IE Rationale:
IE Functionality: Functional
IE Req Category: Data
IE Test Method Expected: Demonstration

PUID: **[SYS-ELA-GEN-REQ-036]**
NGAP historical output **shall** be stored in the cloud.
IE Rationale:
IE Functionality: Functional
IE Req Category: Data
IE Test Method Expected: Demonstration

PUID: **[SYS-ELA-GEN-REQ-037]**
ADAS historical output **shall** be stored in the cloud.
IE Rationale:
IE Functionality: Functional
IE Req Category: Data
IE Test Method Expected: Demonstration

PUID: **[SYS-ELA-GEN-REQ-038]**
ADAS output video **shall** not be transmitted to the cloud.

IE Rationale:
IE Functionality: Functional
IE Req Category: Architecture
IE Test Method Expected: Demonstration

PUID: **[SYS-ELA-GEN-REQ-039]**
ADAS raw input data from sensors (included relevant videos) **shall** be temporary stored in on-board systems and transmitted to the cloud. In particular, video raw data **shall** be necessary for the training of models.
IE Rationale:
IE Functionality: Functional
IE Req Category: Performance
IE Test Method Expected: Demonstration

PUID: **[SYS-ELA-GEN-REQ-040]**
Videos, that ADAS uses for models training, **shall** be stored in a dedicated repository and their confidentiality of data guaranteed within the ELASTIC FRAMEWORK.
IE Rationale:
IE Functionality: Non-Functional
IE Req Category: Performance
IE Test Method Expected: Demonstration

3.2 Predictive maintenance and energy consumption

3.2.1 General requirements

PUID: **[SYS-PredMaint-001]**
Both Rail Track Status and Electric Energy consumption systems **shall** process data from on board sensors, so the outputs of these systems do not necessarily need cloud processing.
IE Rationale: This is a typical FOG computation scenario. Hence, large amount of data must not be transferred over the network.
IE Functionality: Non-Functional
IE Req Category: Data
IE Test Method Expected: Demonstration

3.2.2 Predictive maintenance

PUID: **[SYS-PredMaint-RailTrack-10]**
The PredMaint-RailTrack system (later simply called "system") **shall** be capable of measuring profiles and geometrical parameters of rail tracks, in order to derive the overall track profile geometry and thus identify possible anomalies requiring maintenance.
IE Rationale: The system might be installed on-board of a tram vehicle, or also on a specific rail track monitoring trolleys.
IE Functionality: Functional

IE Req Category: Operational Objective
IE Test Method Expected: Demonstration
IE Real-time or Latent: Real-time

PUID: **[SYS-PredMaint-RailTrack-20]**
Namely, the system **shall** compute the following track profile geometric parameters: horizontal/vertical misalignment, rail track curve radius, rail track surface profile with highlight of possible wears (either lateral, vertical or at 45°).
IE Rationale: It shall rely on two lasers, as part of the system.
IE Functionality: Functional
IE Req Category: Functional
IE Test Method Expected: Demonstration
IE Real-time or Latent: Real-time

PUID: **[SYS-PredMaint-RailTrack-30]**
The system **shall** associate the formerly cited track profile geometric parameters with the measured vertical and transversal acceleration of both wheel and vehicle, vehicle speed, GPS position (according to WGS84), and kilometric chainage, all gathered by locally, physically connected devices.
IE Rationale: The ultimate rail track status has to be accurately time/space correlated with said additional parameters.
IE Functionality: Non-Functional
IE Req Category: Data
IE Test Method Expected: Test
IE Real-time or Latent: Real-time

PUID: **[SYS-PredMaint-RailTrack-40]**
The above cited vertical and transversal acceleration of both wheel and vehicle, and vehicle speed, GPS position (according to WGS84), and kilometric chainage, will be collected at minimum at 10 Hz frequency, and then accordingly saved on permanent local system memory.
IE Rationale: Minimal spatio/temporal granularity of measures associated to rail track geometric parameters.
IE Functionality: Non-Functional
IE Req Category: Performance
IE Test Method Expected: Test
IE Real-time or Latent: Real-time

PUID: **[SYS-PredMaint-RailTrack-45]**
The tram position measurements (both GPS data and kilometric chainage), as possibly shared with NGAP system, **shall** not be affected by weather conditions (rain, snow, ice, fog).
IE Rationale:
IE Functionality: Non-Functional
IE Req Status: In negotiation

IE Req Category: Performance
IE Test Method Expected: Demonstration

PUID: **[SYS-PredMaint-RailTrack-50]**
Moreover, the system **shall** also associate the formerly cited track profile geometric parameters with videos of both the tramway track (panorama) and actually monitored rail track portion (both left and right side).
IE Rationale: It shall rely on rail vehicle video cameras, as part of the system.
IE Functionality: Non-Functional
IE Req Category: Data
IE Test Method Expected: Test
IE Real-time or Latent: Real-time

PUID: **[SYS-PredMaint-RailTrack-60]**
The system **shall** be capable of gathering and storing up to 5k laser measurements per second.
IE Rationale: Related to the lasers expected behaviour.
IE Functionality: Non-Functional
IE Req Category: Performance
IE Test Method Expected: Test
IE Real-time or Latent: Real-time

PUID: **[SYS-PredMaint-RailTrack-70]**
The above cited collected and saved data are transferred from the specific devices to the system local permanent memory storage through physical networks.
IE Rationale: Self-contained system with no wireless communication.
IE Functionality: Non-Functional
IE Req Category: Architecture
IE Test Method Expected: Inspection
IE Real-time or Latent: Real-time

PUID: **[SYS-PredMaint-RailTrack-72]**
The system **shall** be able to communicate with the cloud through either wireless or wired network communications.
IE Req Status: Accepted
IE Rationale:
IE Functionality: Non-Functional
IE Req Category: Delivery
IE Test Method Expected: Demonstration

PUID: **[SYS- PredMaint-RailTrack-74]**
The data **might** be sent to the cloud to record possibly estimated, excessive rail track consumed status, and thus accordingly associate them (correlated through tram position) with formerly ADAS-recorded obstacles detections, during previous tram runs on the same track. This will possibly associate the consumed rail track status

with their possible cause due to frequent, unexpected heavy brakes of tram vehicle itself in the corresponding tram position, in turn due to said detected obstacles.
IE Req Status: Analysis
IE Rationale: Only for elastic
IE Functionality: Functional
IE Req Category: Delivery
IE Test Method Expected: Demonstration

PUID: **[SYS-PredMaint-RailTrack-80]**
The system **shall** have an expandable storage capacity.
IE Rationale: Open to possible augmentation of sensors' collected data (volume and/or frequency).
IE Functionality: Non-Functional
IE Req Category: Architecture
IE Test Method Expected: Inspection
IE Real-time or Latent: N.A.

PUID: **[SYS-PredMaint-RailTrack-90]**
Upon termination of tram route, the system **shall** accurately (time/space) synchronize the collected data in order to let them be displayed as overlaid to a route map, as associated to the progressive registered positions of the tram vehicle.
IE Rationale: Necessary to monitor the rail track status, as detected along the path run by the tram vehicle.
IE Functionality: Functional
IE Req Category: Data
IE Test Method Expected: Analysis
IE Real-time or Latent: N.A.

3.2.3 Energy consumption

PUID: **[SYS-PredMaint-EnergyConsumpt-10]**
The PredMaint-EnergyConsumption system (later simply called "system"), by accessing a specific on board electric power meter, **shall** be capable of measuring in real-time the current electric energy consumption (kilowatt) of the tram vehicle.
IE Rationale: Being a system installed on-board of the rail vehicle, it results efficient and effective than simply periodically (e.g. monthly) gathering the overall consumed electricity on the catenary that feeds the trams'. Moreover, this will result quite important as some newly conceived rail track portions might be catenary-free, having an environmental positive impact on city and citizens, and thus the electricity power saving is even more important for assuring longer operational continuity of battery-supported rail trams.
IE Functionality: Functional
IE Req Category: Operational Objective
IE Test Method Expected: Demonstration
IE Real-time or Latent: Real-time

PUID: **[SYS-PredMaint-EnergyConsumpt-20]**
The system **shall** display the currently measured electricity power consumption (kilowatt) to the rail tram driver.
IE Rationale: This will let the tram driver associate such real-time kilowatt measures with possible unique, local driving peculiarities (rail track curve, current acceleration, downhill or uphill rail track, etc.).
IE Functionality: Functional
IE Req Category: Ergonomics (MMI)
IE Test Method Expected: Demonstration
IE Real-time or Latent: Real-time

PUID: **[SYS-PredMaint-EnergyConsumpt-30]**
The system **shall** associate the formerly cited electricity power consumption with vehicle speed, acceleration, GPS position (according to WGS84), and kilometric chainage, all gathered by locally, physically connected devices, as shared with NGAP-provided ones.
IE Rationale: It shall rely on appropriate additional on-board devices, as part of the system.
IE Functionality: Non-Functional
IE Req Category: Functional
IE Test Method Expected: Test
IE Real-time or Latent: Real-time

PUID: **[SYS-PredMaint-EnergyConsumpt-40]**
The above cited vehicle speed, GPS position (according to WGS84), and kilometric chainage, will be collected at minimum at 10 Hz frequency, and then accordingly saved on permanent local system memory.
IE Rationale: Minimal spatio/temporal granularity of such measures as associated to power consumption ones.
IE Functionality: Non-Functional
IE Req Category: Performance
IE Test Method Expected: Test
IE Real-time or Latent: Real-time

PUID: **[SYS-PredMaint-EnergyConsumpt-50]**
Moreover, the system **shall** also associate the formerly cited electricity power consumption with current tram vehicle weight (due to number of passengers and related luggage), again gathered by a locally, physically connected device acting as a weight scale.
IE Rationale:
IE Functionality: Non-Functional
IE Req Category: Data
IE Test Method Expected: Test

IE Real-time or Latent: Real-time

PUID: **[SYS-PredMaint-EnergyConsumpt-60]**
The system **shall** be capable of gathering and storing up to 10 electric power measurements per second.
IE Rationale: It is related to the electric power meter devices' expected behaviour.
IE Functionality: Non-Functional
IE Req Category: Performance
IE Test Method Expected: Test
IE Real-time or Latent: Real-time

PUID: **[SYS-PredMaint-EnergyConsumpt-70]**
The above cited collected and saved data are transferred from the specific devices to the system local permanent memory storage through physical networks.
IE Rationale: Self-contained system with no wireless communication.
IE Functionality: Non-Functional
IE Req Category: Architecture
IE Test Method Expected: Inspection
IE Real-time or Latent: Real-time

PUID: **[SYS- PredMaint-EnergyConsumpt-72]**
The system shall be able to communicate with the cloud through either wireless or wired network communications.
IE Req Status: Accepted
IE Rationale:
IE Functionality: Non-Functional
IE Req Category: Delivery
IE Test Method Expected: Demonstration

PUID: **[SYS- PredMaint-EnergyConsumpt-74]**
The data **might** be sent to the cloud to associate them to successive rail track status monitoring, thus associating possible electric power energy peaks (in turn due to large tram weight, acceleration, speed, etc.) with next resulting rail track consumed status. In fact, such correlation might help determining a possible source cause of such rail track consumed status.
IE Req Status: Analysis
IE Rationale: Only for elastic
IE Functionality: Functional
IE Req Category: Delivery
IE Test Method Expected: Demonstration

PUID: **[SYS-PredMaint-EnergyConsumpt-80]**
The system **shall** have an expandable storage capacity.
IE Rationale: Open to possible augmentation of sensors' collected data (volume and/or frequency).

IE Functionality: Non-Functional
IE Req Category: Architecture
IE Test Method Expected: Inspection
IE Real-time or Latent: N.A.

PUID: **[SYS-PredMaint-EnergyConsumpt-90]**
Upon termination of tram route, the system **shall** accurately (time/space) synchronize the collected data in order to let them be displayed as overlaid to a route map, as associated to the progressive registered positions of the tram vehicle.
IE Rationale: Necessary to monitor the power consumption profile, as detected along the path run by the tram vehicle.
IE Functionality: Functional
IE Req Category: Data
IE Test Method Expected: Analysis
IE Real-time or Latent: N.A.

3.3 Interaction between the public and the private transport

PUID: **[SYS-ELA-FLO-REQ-001]**
Infrastructure **shall** provide power supply for sensors, computers, network devices and any other appliance to be installed along the line and in nearby locations.
IE Rational:
IE Functionality: Non-Functional
IE Req Category: Availability
IE Test Method Expected: Inspection
IE Real-time or Latent: N.A.

PUID: **[SYS-ELA-FLO-REQ-002]**
System **shall** use field equipment along the line. Equipment **shall** be placed in cabinets or fastened to poles, depending on their typology.
IE Rationale:
IE Functionality: Non-Functional
IE Req Category: Availability
IE Test Method Expected: Inspection
IE Real-time or Latent: N.A.

PUID: **[SYS-ELA-FLO-REQ-003]**
Existing cabinets **shall** be able to host relevant field equipment.
IE Rationale:
IE Functionality: Non-Functional
IE Req Category: Availability
IE Test Method Expected: Inspection
IE Real-time or Latent: N.A.

PUID: **[SYS-ELA-FLO-REQ-004]**
Existing poles **shall** be used when available and suited for the purpose.
IE Rationale:
IE Functionality: Non-Functional
IE Req Category: Availability
IE Test Method Expected: Inspection
IE Real-time or Latent: N.A.

PUID: **[SYS-ELA-FLO-REQ-005]**
Existing racks at the control center **shall** be able to host devices for network interconnections, buffer storage, etc.
IE Rationale:
IE Functionality: Non-Functional
IE Req Category: Availability
IE Test Method Expected: Inspection
IE Real-time or Latent: N.A.

PUID: **[SYS-ELA-FLO-REQ-006]**
Existing backbone and access network infrastructure **shall** provide connectivity to field equipment.
IE Rationale:
IE Functionality: Non-Functional
IE Req Category: Availability
IE Test Method Expected: Inspection
IE Real-time or Latent: Real-time

PUID: **[SYS-ELA-FLO-REQ-007]**
Additional network devices to be installed on the edge **shall** extend the existing LAN/WLAN access network in order to support the pilot implementation.
IE Rationale:
IE Functionality: Non-Functional
IE Req Category: Installation
IE Test Method Expected: Inspection
IE Real-time or Latent: Real-time

PUID: **[SYS-ELA-FLO-REQ-008]**
Existing MAN/Internet connectivity **shall** support data exchange with other ITS subsystems in the area (e.g. mobility supervisor, etc.).
IE Rationale:
IE Functionality: Non-Functional
IE Req Category: Availability
IE Test Method Expected: Inspection
IE Real-time or Latent: N.A.

PUID: **[SYS-ELA-FLO-REQ-009]**
Additional Internet connectivity and network devices at the control centre **shall** provide high capacity access to the cloud.
IE Rationale:
IE Functionality: Non-Functional
IE Req Category: Installation
IE Test Method Expected: Inspection
IE Real-time or Latent: N.A.

PUID: **[SYS-ELA-FLO-REQ-010]**
Traffic sensors **shall** be installed in the pilot area(s) to provide traffic measures specific for the area(s) of interest.
IE Rationale:
IE Functionality: Non-Functional
IE Req Category: Installation
IE Test Method Expected: Inspection
IE Real-time or Latent: Real-time

PUID: **[SYS-ELA-FLO-REQ-011]**
Measures recorded by traffic sensors in the pilot area(s) **shall** enrich the traffic data set of the mobility supervisor.
IE Rationale:
IE Functionality: Non-Functional
IE Req Category: Architecture
IE Test Method Expected: Test
IE Real-time or Latent: Real-time

PUID: **[SYS-ELA-FLO-REQ-012]**
Video cameras **shall** be installed in the pilot area(s) to capture live video streams of the area(s)
IE Rationale:
IE Functionality: Non-Functional
IE Req Category: Installation
IE Test Method Expected: Inspection
IE Real-time or Latent: Real-time

PUID: **[SYS-ELA-FLO-REQ-013]**
Video cameras to be installed in the pilot area(s) **shall** support standard communication and video protocols.
IE Rationale:
IE Functionality: Non-Functional
IE Req Category: Architecture
IE Test Method Expected: Inspection
IE Real-time or Latent: Real-time

PUID: **[SYS-ELA-FLO-REQ-014]**
System **shall** feature edge computing appliances to enable local data processing at the pilot area(s).
IE Rationale:
IE Functionality: Non-Functional
IE Req Category: Architecture
IE Test Method Expected: Inspection
IE Real-time or Latent: Real-time

PUID: **[SYS-ELA-FLO-REQ-015]**
Edge computing appliances **shall** process local sensor data, data coming from other subsystems (e.g. tram position, obstacle detection) and or from the cloud to implement control loops on the edge, implementation of I2V communication protocols (e.g. translate data from the cloud into messages compliant with I2V standards), send locally detected events to the cloud.
IE Rationale:
IE Functionality: Non-Functional
IE Req Category: Architecture
IE Test Method Expected: Inspection
IE Real-time or Latent: Real-time

PUID: **[SYS-ELA-FLO-REQ-016]**
System **shall** perform video analysis of live video feeds to detect relevant events (e.g. crowds, pedestrians crossing the street, etc.).
IE Rationale:
IE Functionality: Functional
IE Req Category: Architecture
IE Test Method Expected: Demonstration
IE Real-time or Latent: Real-time

PUID: **[SYS-ELA-FLO-REQ-017]**
System **shall** feature storage at the edge for temporary storage of big volume data (e.g. video streams with "blobs" representing the output of segmentation resulting from video analysis).
IE Rationale:
IE Functionality: Non-Functional
IE Req Category: Architecture
IE Test Method Expected: Inspection
IE Real-time or Latent: Real-time

PUID: **[SYS-ELA-FLO-REQ-018]**
System **shall** feature buffer storage at the control center for temporary storage of big volume data to be sent to the cloud.

IE Rationale:
IE Functionality: Non-Functional
IE Req Category: Architecture
IE Test Method Expected: Inspection
IE Real-time or Latent: N.A.

PUID: **[SYS-ELA-FLO-REQ-019]**
System **shall** provide long-term storage services for big data.
IE Rationale:
IE Functionality: Non-Functional
IE Req Category: Architecture
IE Test Method Expected: Inspection
IE Real-time or Latent: N.A.

PUID: **[SYS-ELA-FLO-REQ-020]**
System **shall** acquire traffic data from sensors and other subsystems.
IE Rationale:
IE Functionality: Functional
IE Req Category: Data
IE Test Method Expected: Demonstration
IE Real-time or Latent: Real-time

PUID: **[SYS-ELA-FLO-REQ-021]**
System **shall** acquire tram position data from NGAP sub-system.
IE Rationale:
IE Functionality: Functional
IE Req Category: Data
IE Test Method Expected: Demonstration
IE Real-time or Latent: Real-time

PUID: **[SYS-ELA-FLO-REQ-022]**
Systems **shall** acquire data related to presence of obstacles on the tramway line from ADAS sub-system.
IE Rationale:
IE Functionality: Functional
IE Req Category: Data
IE Test Method Expected: Demonstration
IE Real-time or Latent: Real-time

PUID: **[SYS-ELA-FLO-REQ-023]**
System **shall** manage data about presence/behavior of people (pedestrians crossing the street, crowd at tram stop).
IE Rationale:
IE Functionality: Functional

IE Req Category: Data
IE Test Method Expected: Demonstration
IE Real-time or Latent: Real-time

PUID: **[SYS-ELA-FLO-REQ-024]**
System **shall** acquire data about state/state transitions of traffic lights controlled by the urban traffic control system.
IE Rationale:
IE Functionality: Functional
IE Req Category: Data
IE Test Method Expected: Demonstration
IE Real-time or Latent: Real-time

PUID: **[SYS-ELA-FLO-REQ-025]**
System **shall** feature devices enabling I2V communication based on the 802.11p protocol.
IE Rationale:
IE Functionality: Non-Functional
IE Req Category: Architecture
IE Test Method Expected: Inspection
IE Real-time or Latent: Real-time

PUID: **[SYS-ELA-FLO-REQ-026]**
System shall produce information/alerts on traffic events to provide road users and operation with (nearly) real-time info and alerts.
IE Rationale:
IE Functionality: Functional
IE Req Category: Operational Objective
IE Test Method Expected: Demonstration
IE Real-time or Latent: Real-time

PUID: **[SYS-ELA-FLO-REQ-027]**
System **shall** deliver information/alerts to car drivers to provide them with information/alerts on road conditions.
IE Rationale:
IE Functionality: Functional
IE Req Category: Operational Scenario
IE Test Method Expected: Demonstration
IE Real-time or Latent: Real-time

PUID: **[SYS-ELA-FLO-REQ-028]**
System **shall** deliver information/alerts to vulnerable road users (VRUs - e.g. pedestrians, cyclists) to provide them with information/alerts on hazards.
IE Rationale:

IE Functionality: Functional
IE Req Category: Operational Scenario
IE Test Method Expected: Demonstration
IE Real-time or Latent: Real-time

PUID: **[SYS-ELA-FLO-REQ-029]**
System **shall** deliver information/alerts to tram drivers to provide them with information/alerts on conditions around the tramway line.
IE Rationale:
IE Functionality: Functional
IE Req Category: Operational Scenario
IE Test Method Expected: Demonstration
IE Real-time or Latent: Real-time

PUID: **[SYS-ELA-FLO-REQ-030]**
System **shall** distribute information/alerts to other systems (e.g. mobility supervisor).
IE Rationale:
IE Functionality: Functional
IE Req Category: Operational Scenario
IE Test Method Expected: Demonstration
IE Real-time or Latent: Real-time

PUID: **[SYS-ELA-FLO-REQ-031]**
System **shall** support traffic optimization.
IE Rationale:
IE Functionality: Functional
IE Req Category: Operational Objective
IE Test Method Expected: Demonstration
IE Real-time or Latent: Latent

PUID: **[SYS-ELA-FLO-REQ-032]**
System **shall** provide traffic engineers with KPIs on transportation network performance.
IE Rationale:
IE Functionality: Functional
IE Req Category: Operational Scenario
IE Test Method Expected: Demonstration
IE Real-time or Latent: Latent

PUID: **[SYS-ELA-FLO-REQ-033]**
System **shall** provide traffic engineers with KPIs on interactions between public transport (tramway), private transport (cars) and other factors (pedestrians).
IE Rationale:
IE Functionality: Functional

IE Req Category: Operational Scenario
IE Test Method Expected: Demonstration
IE Real-time or Latent: Latent

PUID: **[SYS-ELA-FLO-REQ-034]**
System **shall** deliver information/alerts to users in simple, effective and safe manner.
IE Rationale:
IE Functionality: Non-Functional
IE Req Category: Ergonomics (MMI)
IE Test Method Expected: Demonstration
IE Real-time or Latent: Real-time

PUID: **[SYS-ELA-FLO-REQ-035]**
System **shall** provide a clear and understandable representation of analytic data to traffic engineers.
IE Rationale:
IE Functionality: Non-Functional
IE Req Category: Ergonomics (MMI)
IE Test Method Expected: Demonstration
IE Real-time or Latent: N.A.

PUID: **[SYS-ELA-FLO-REQ-036]**
System **shall** operate with adequate performance, guaranteeing the fulfilment of (near) real-time requirements where needed.
IE Rationale:
IE Functionality: Non-Functional
IE Req Category: Performance
IE Test Method Expected: Analysis
IE Real-time or Latent: N.A.

PUID: **[SYS-ELA-FLO-REQ-037]**
System **shall** feature adequate scalability with respect to performance, ensuring that the performance can be guaranteed also when scaling up beyond the pilot implementation.
IE Rationale:
IE Functionality: Non-Functional
IE Req Category: Performance
IE Test Method Expected: Analysis
IE Real-time or Latent: N.A.

PUID: **[SYS-ELA-FLO-REQ-038]**

System **shall** prevent unauthorized access to systems, network and data - per se, as well as to allow fulfilment of safety requirement.
IE Rationale:
IE Functionality: Non-Functional
IE Req Category: Security
IE Test Method Expected: Analysis
IE Real-time or Latent: N.A.

PUID: **[SYS-ELA-FLO-REQ-039]**
System **shall** prevent delivery of fake information/false alerts to avoid injuries to people, as well as failures and/or low performances of the transportation network.
IE Rationale:
IE Functionality: Non-Functional
IE Req Category: Safety
IE Test Method Expected: Analysis
IE Real-time or Latent: N.A.

PUID: **[SYS-ELA-FLO-REQ-040]**
System **shall** be economically sustainable - i.e. ensure that the solution is economically sustainable also when scaling up beyond the pilot implementation.
IE Rationale:
IE Functionality: Non-Functional
IE Req Category: Cost
IE Test Method Expected: Analysis
IE Real-time or Latent: N.A.

PUID: **[SYS-ELA-FLO-REQ-041]**
System **shall** monitor availability and functionality of devices and components it relies on.
IE Rationale:
IE Functionality: Non-Functional
IE Req Category: Maintainability
IE Test Method Expected: Inspection
IE Real-time or Latent: Latent

4 Architecture outline

4.1 Positioning and obstacle detection (NGAP and ADAS)

This subsection provides an initial draft of the on-board system architecture of the ELASTIC project, concerning the train position and the obstacles detection/avoidance on the track of the tramway system in the city of Florence. The NGAP application enables the tram vehicles of the tramway system to autonomously localize themselves and provide this information to another device connected on the cloud that shows relevant data and position. The ADAS application concerns the obstacle detection and the collision avoidance techniques, in order to give a visual and an acoustic alarm to the driver in case of obstacles presence. Each subsystem application includes different sensors as shown in Figure 25.

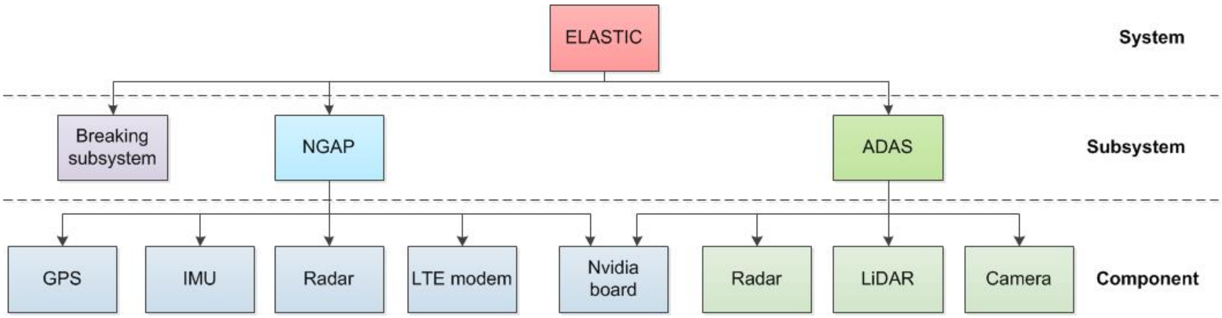


Figure 25 System overview.

The data are collected from each sensor; then they are transformed, processed and analysed through a range of hardware and software stages conforming the compute continuum from the physical world sensors (close to the source of data) to the analytics back-bone. Finally, the data are sent to the cloud server, where they are stored and examined for future system improvements. Both the NGAP and the ADAS applications involve several steps towards full autonomous systems, which will improve the overall tramway public transportation service and so will enhance the quality of life of citizenship in terms of sustainability and safe mobility. Concretely, the NGAP and ADAS application will inform to the driver about potential risks of the journey, enhancing the safety of passengers.

4.1.1 NGAP system

The system overview for the NGAP application is represented in Figure 26. The radar must be oriented towards the asphalt with an incline between 35° and 45° respect to the vertical, in order to measure the speed of the tramway from the signal reflections of the rails.

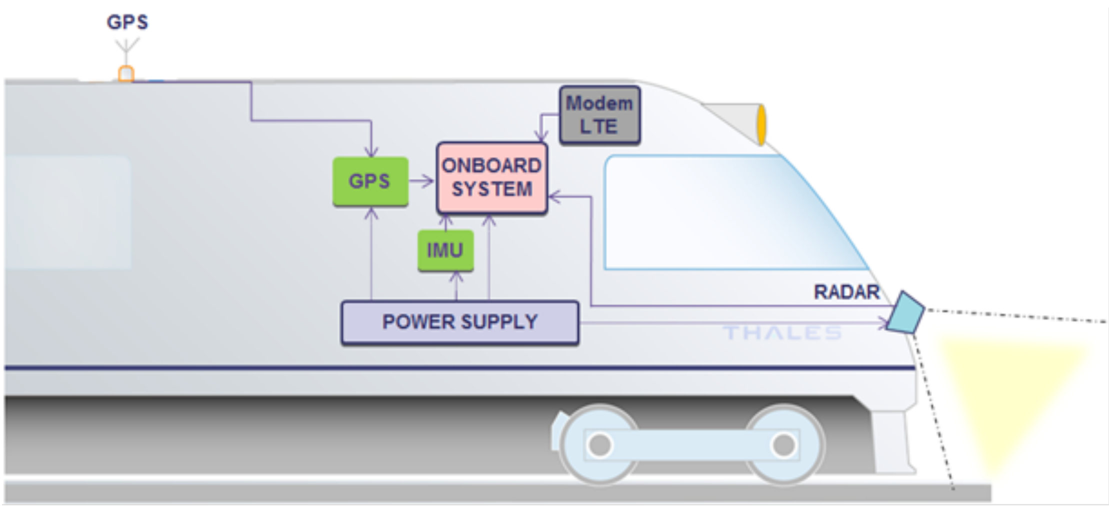


Figure 26 Proposal of the NGAP architecture and devices installation.

Studying the system from a wide perspective, the system architecture for the NGAP application is represented in Figure 27.

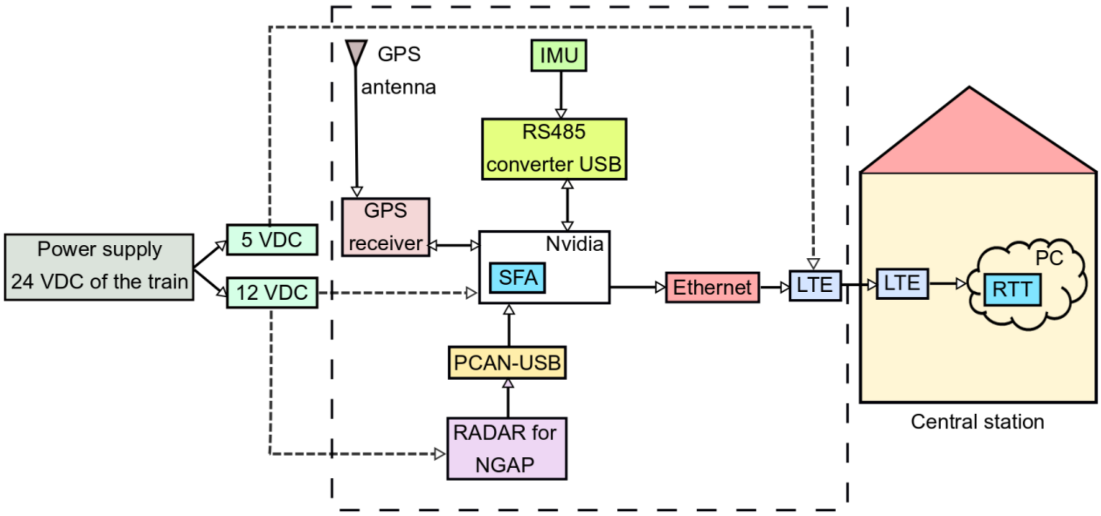


Figure 27 NGAP subsystem architecture.

The GPS receiver gets the position information from the GPS antenna, through pseudorange measurement. The IMU measures the acceleration and the angular speed through the accelerometer and the gyroscope sensors along the three x, y and z axes. The RS485 converter USB allows the communication between the IMU and the on-board computer (based on a NVIDIA TX2 board). The radar has only one communication interface with the CAN bus, in which the information speed is 500 kbit/s. The CAN-USB converter allows sending registered CAN messages from the radar to the on-board computer. The radar works in the near range for the NGAP application, due to its orientation and to the maximum tramway speed of 50 km/h in the urban path. The architecture core is the SFA for the NGAP application, implemented in the CPU of the NVIDIA board. The Sensor Fusion Algorithm combines the data obtained from the different sensors (IMU, radars and GPS), in order to achieve an accurate position. ELASTIC NGAP architecture will be defined in two phases:

- First phase: the SFA is installed on the NVIDIA board, so the data sent to the cloud is the sensor information (IMU, GPS, odometer speed) and the output information (position, speed, etc…) of the SFA;
- Second phase: the SFA installed on the PC connected to the cloud (placed by GEST), receives sensors information and calculates SFA outputs by itself.

The Rail Track Tool (RTT) shows the position of the tram along the “Florence Line” for both phases and also the following relevant data:

- IMU acceleration in x, y, z coordinates over time;
- IMU angular velocity in x, y, z coordinates over time;
- number of GPS satellites;
- output position of the SFA respect to travelled space (with the ground truth position if present);

- speed value of the SFA respect to travelled space;
- speed provided by the radar odometer;
- variances of the output position and speed value of the SFA;
- performance parameters of the system.

For more information regarding the data received and transmitted by the NGAP system, please refer to the NGAP Interface Control Document [18].

The SFA output is saved inside the NVIDIA board and then it is sent to the central station through a modem LTE, where the user can acquire and process the information.

The tramway system uses also loops: passive devices that receive information from the tram. They are static elements positioned on the tramway line. When the tramway passes above a loop, it sends the route request (via a radio communication system) to a ground communication device, which will forward this information to the interlocking system, to control signals and traffic lights. In order to ameliorate the accuracy of the position measurement, a ground truth system using an RTK GPS is implemented outside the NGAP subsystem. The RTK GPS accomplishes code differential GNSS positioning and integrates a radio modem with a 450 MHz wide band receiver/transmitter.

The NGAP main functions are:

- to acquire the sensors (IMU, GPS and radar) raw data and to send them to the on-board system (for more information regarding the communication of these sensors with the NGAP system refer to [17]);
- to filter the raw data at the sensors outputs;
- to organize and interpolate the raw data as a function of the epoch. If the epoch of a data in the queue is wrong, the value is cancelled;
- to send the data at the input of the SFA and to provide the accurate position of the tramway at the output;
- the information is stored in a 32 GByte SD card;
- to send the information to the base station, thanks to an LTE modem, where they are analysed.

In conclusion, the output of the NGAP system is the estimation of the tramway position and speed together with the variance, in order to know the error between the real location and the evaluated one. For more information about the detailed description of the Sensor Fusion Algorithm used in the NGAP system, please refer to [19].

4.1.2 ADAS system

The ADAS system overview is presented in Figure 28. The radar shall be installed in front of the tram, looking forward to the path, in order to cover the entire field of view. Moreover, the LiDAR (Light Detection And Ranging) must be mounted on the upper part of the train, to scan the surrounding tramway environment.

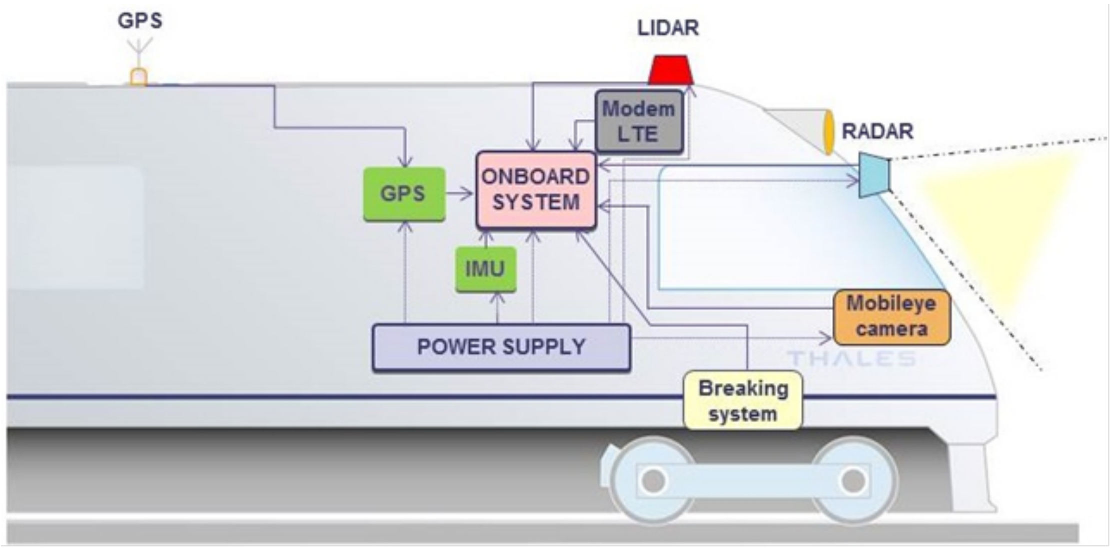


Figure 28 Proposal of the ADAS architecture and devices installation.

The system architecture for the ADAS application is represented in Figure 29.

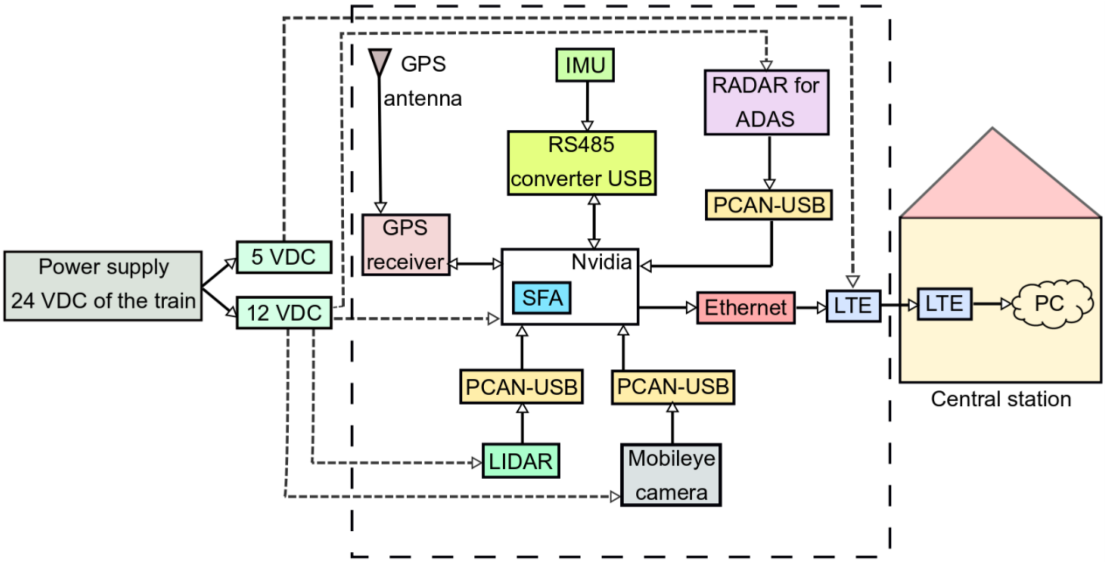


Figure 29 ADAS subsystem architecture.

The radar sends the CAN message of the received signal to the NVIDIA GPU, in which a SFA for the ADAS application is implemented. Each CAN message includes the target information on: object ID, lateral and longitudinal coordinates of the target, relative velocity in longitudinal and lateral direction and RCS (Radar Cross Section). Considering that the radar for the ADAS application is the same of the NGAP one, the communication network is a CAN bus as specified in ISO 11898-2 with a transmission rate of 500 kbits/s. All sensors must detect objects up to 100 m, but the LiDAR and the camera has a better resolution in the narrow environment of the tramway [17]. All these sensors communicate with the NIVIDIA board through a PCAN-USB converter. The algorithm combines the raw data obtained from the radar, the LiDAR and the camera and it gives as the output the obstacle position and its velocity. These data are sent to the central station through an LTE modem, where they are analysed and stored in a PC.

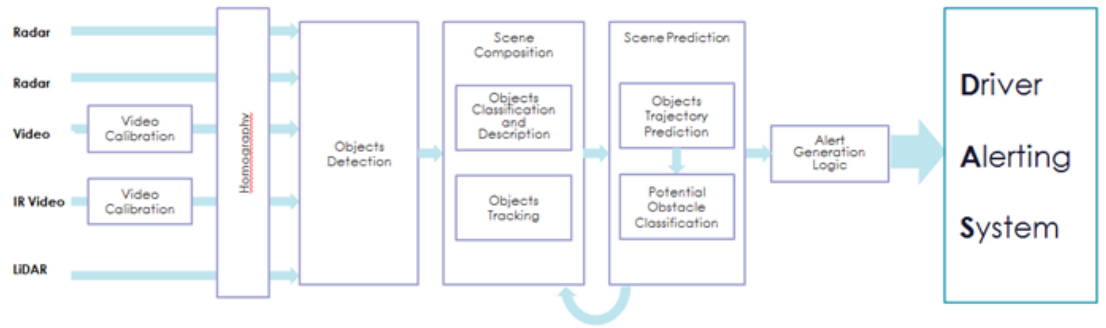


Figure 30 ADAS sequential functions.

The ADAS main functions are:

- to acquire the sensors (radar, LiDAR, camera) raw data and to send them to the on-board system;
- to filter the raw data at the sensors' outputs;
- to process the raw data with the help of the SFA for the ADAS application, including camera calibration and homography;
- to track the detected obstacles in front of the train;
- to give a visual and sound alarm, to notice the obstacles presence;
- to activate the braking system, to avoid the obstacles;
- to send the outputs of the SFA through an LTE modem to the central station, where they are analysed and stored.

The LiDAR sensor and the camera ameliorate the resolution and the visibility in the surrounding environment of the tramway.

It is particularly interesting to distinguish various intervals, in order to implement difference alarm solutions, to avoid any collisions with any type of obstacles [8]. When an obstacle is detected in the High risk of collision region, a high alarm rings and a red LED turns on. Instead if an object is detected in the Low risk of collision region, a lower volume alarm sounds and a yellow LED switches on. It is very important to implement a redundant safety system in a future product realization, in order to minimize the probability of failure of the emergency breaking and of the ADAS subsystems.

In conclusion the ADAS subsystem detects if any obstacle is on the tramway path. In case of obstacle presence, its position and velocity are known at the output of the SFA, in order to avoid it. In addition, the alarm can be visualized on the Rail Track Tool, knowing the position of the tram on the Florence Line thanks to the NGAP outputs.

4.2 Predictive maintenance and energy consumption

The system overview for the Predictive Maintenance system is represented in Figure 31. The camera for panoramic videos must be placed closer to vehicle head, in order to better monitor the nearby and incoming rail track portions.

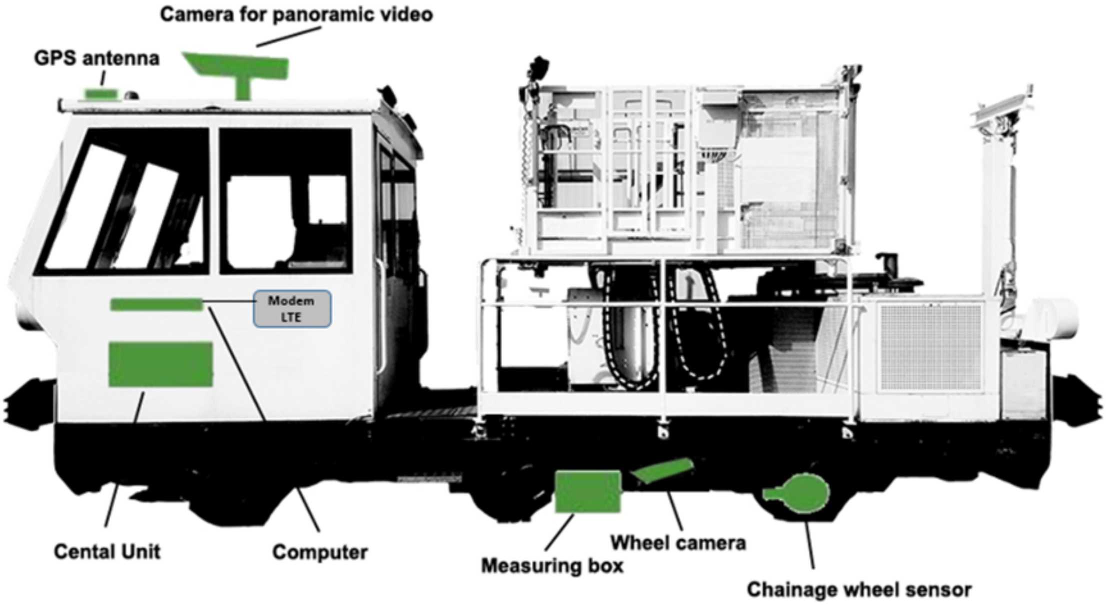


Figure 31 Predictive Maintenance architecture and devices installation.

For the purpose of this document, the above outline is sufficient. Inner details concerning possible HW/SW architecture will be refined successively.

4.3 Interaction between the public and the private transport

4.3.1 ITS assets

FLO owns or has access to a variety of intelligent transportation systems (ITS), including:

- mobility supervisor, acting both as a collector for data acquired or produced by other systems and as an orchestrator of traffic control strategies;
- several traffic sensor subsystems, covering both the area of Florence and main roads leading to it;
- urban traffic control (UTC) systems, controlling the traffic lights in Florence;
- variable message signs (VMS) in the area of Florence and on main roads around it;
- automatic vehicle monitoring (AVM) system of the public transport bus fleet serving the area of Florence.

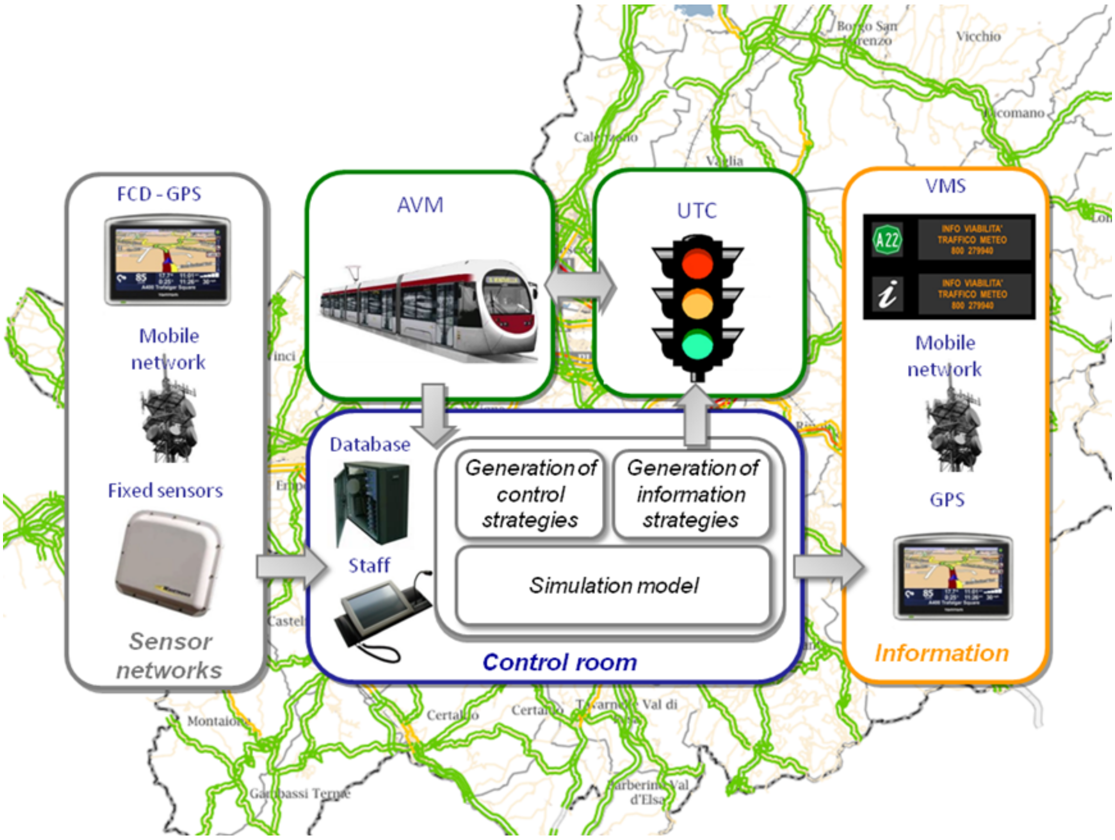


Figure 32 Intelligent Transportation Systems deployed in the Florence metropolitan area.

In particular, among many functions and data sets managed by the above listed systems, the following might be of some relevance for the implementation of the ELASTIC use case:

- acquisition, processing and storage of traffic data;
- acquisition, processing, storage and dispatching of traffic events;
- (dynamic) state of traffic lights;
- strategy management.

4.3.2 Network assets

In past years, FLO has deployed a network infrastructure along the first segment of the L1 tramway line, from Villa Costanza to Alamanni-Stazione. This might serve as access and backbone network to connect field equipment to each other as well as to systems located at the control centre or in the cloud.

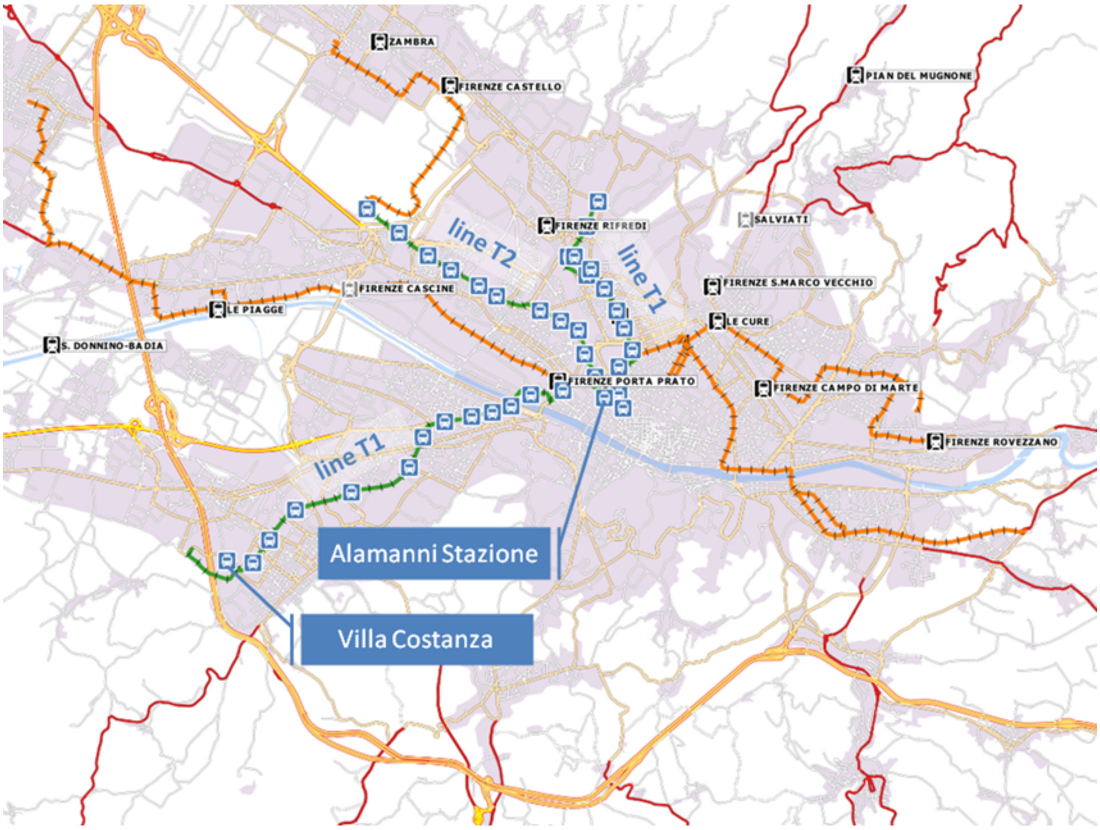


Figure 33 A LAN/WLAN network is available along the 1st segment of the T1 line.

The light rail/tramway infrastructure features a dedicated LAN. Moreover, a second LAN network has been deployed along the first segment of the T1 tramway line to provide users with public access to the Internet through Wi-Fi; this network covers the segment spanning from Villa Costanza (south-east) to Alamanni-Stazione (downtown).

The network architecture comprises the following components:

1. core switch, routers and firewalls;
2. wired backbone network, with LAN switches at each stop;
3. Wi-Fi access points at stops and at some other spots along the line.

Being physically separated from the "production" network serving the tramway infrastructure, as anticipated in the proposal phase, this second network can be used within the use case of ELASTIC.

The network features only very limited computing and storage capabilities at the core level (mostly for control and management purposes) and none at the access level.

4.3.3 Overall architecture

The overall architecture envisaged for the use case is depicted in Figure 34.

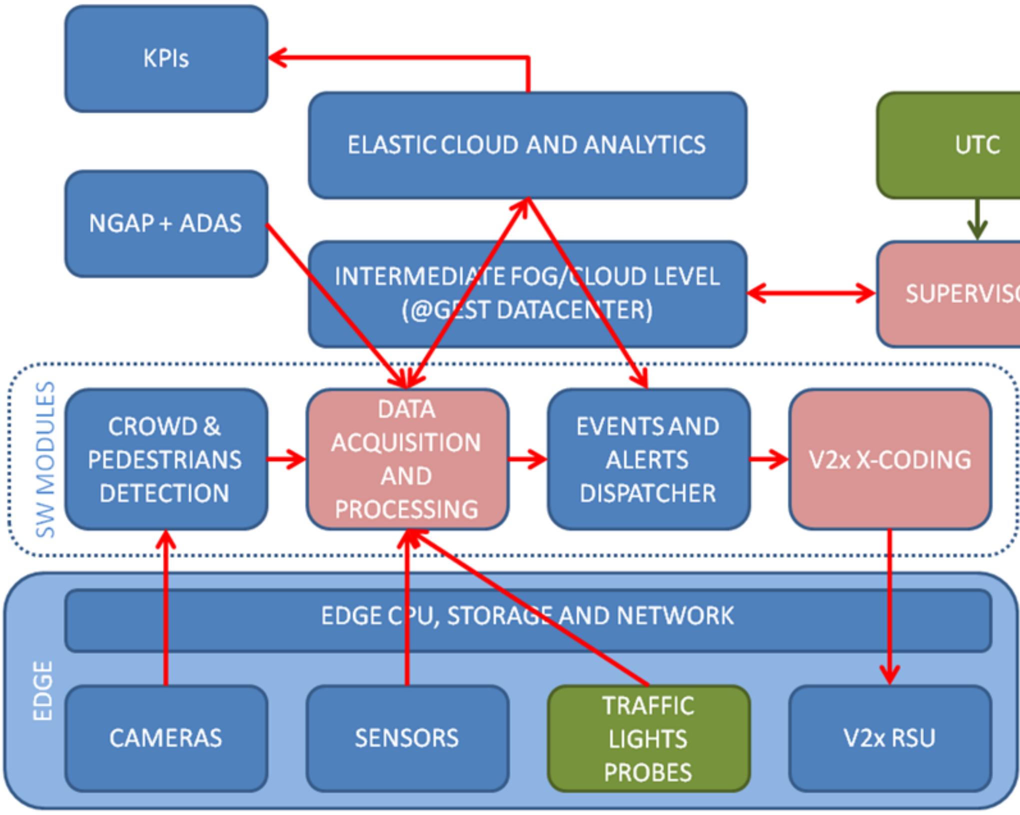


Figure 34 Logical architecture for the use case.

At the edge level:

- cameras provide the video stream to feed the video analysis component;
- other sensors (e.g. traffic sensors), installed at the pilot site, provide additional data;
- local traffic light probes record state (transitions) of traffic lights controlled by the tramway UTC;
- a V2X road-side unit (RSU) delivers alerts/messages to users;
- a CPU executes tasks that can be performed locally.

Software modules that can be deployed on the ELASTIC fog infrastructure perform different tasks, such as the following acquired additional data from NGAP and ADAS:

- train positions;
- events for train arrival at the stop/intersection;
- obstacle detection events.

Software modules that can be deployed on the ELASTIC fog infrastructure perform different tasks, such as:

- analysis video flows to detect relevant events;
- pre-processing raw data from sensors;
- forwarding resulting data for further processing and/or dispatching;
- transcoding/formatting to comply with standards.

External systems involved in the use case include:

- the UTC that controls traffic lights along the tramway line provides the mobility supervisor and other components with:
    - the plans (rules) controlling the behaviour of traffic lights;
    - state transitions of the traffic lights, in (nearly) real-time;
- the mobility supervisor
    - acts as a source for additional collected from other subsystems;
    - monitors road network status;
    - enforces control strategies.

KPIs are evaluated relying on data analytics provided by the cloud level.

5 Applicable standards

5.1 Positioning and obstacle detection (NGAP and ADAS)

In the subsection 5.1 each sensor in the NGAP and ADAS system will be considered, in order to underline the standards satisfied by each device. Finally, a list of other standards, applicable to a future product (but not intended to be enforced in the ELASTIC project) will be analysed. NGAP and ADAS final systems will be on-board systems for Tram, and therefore the product shall be compliant with the EN 50155 standard.

5.1.1 Industrial Automation Security standards

The reference standards are the ISA/IEC 62443, which covers the “Security for Industrial Automation and Control Systems” [26] and is referenced here as a non-normative guideline for the ELASTIC project. It is a commercial and international standard, which has been widely used in both IACS (Industrial Automation Control Systems) and transport systems. Industrial Automation Control Systems (IACS) standards are already employed in the transport field as guidance for the development of transportation systems like railways and tramways. In particular the ISA/IEC 62443-3-3 “Security for industrial automation and control systems Part 3-3: System security requirements and security levels” and the ISA/IEC 62443-4-1 “Secure product development lifecycle requirements” are important guides to implement secure by design coding practices. The recommended SL (Security Level, as per ISA/IEC 62443-3-3) for the ELASTIC project could be determined through a risk analysis process, but as a rule of thumb the SL-2 could be considered as the minimum.

5.1.2 Railway Functional Safety standards

Operational safety is defined as the absence of unacceptable risks, injury or harm to the health of humans, whether direct or indirect, resulting from damage to equipment or the environment. A risk analysis allows for the determination of how operational safety will allow for a guarantee of adequate protection against any risk that may arise. These dangers are therefore treated appropriately during the design phase so that the final system is fault-free.

Safety functions result from electrical, electronic or programmable electronic systems, which are usually complex and make it very difficult to determine breakdowns. The objective is therefore to design a system in such a way as to prevent as many breakdowns as possible and control them when they do occur. Breakdowns may occur for a number of different factors: software errors, human error, environmental intelligence, random breakdown of equipment mechanisms, etc.

Railway standards were created as operational safety therefore depends on the proper operations of a global system or equipment in response to system or equipment entries.

5.1.2.1 IEC 61508 standard and Functional Safety

The standard IEC 61508 (titled *Functional Safety of Electrical/Electronic/Programmable Electronic Safety-related Systems*) [31] includes the necessary and sufficient requirements to minimize the breakdowns described above. All the phases of the equipment and software lifecycle (from the conceptualization through to the design, installation, operations, maintenance and final disposal) are addressed by this specification.

IEC 61508 was approved by CENELEC as a European Standard (ES) and presents a generic approach to all activities related to the lifecycle (from the creation to the disposal of the system) of the electrical-electronic-programmable electronic (E/E/PE) elements that are used to realize safety features.

The SIL (Safety Integrity Level) indicates a level of safety integrity. The SIL notion results directly from the IEC 61508 standard. The SIL may be defined as a measurement of operational safety that determines recommendations related to the integrity of the safety features to be assigned to E/E/PE systems.
There are four SIL levels: SIL4 being the highest level of system security, SIL1 the lowest. This involves an average probability of failure on demand for a period of 10 years.
Thanks to significant expertise in formal calculation and operational safety, Thales Italy Engineering is qualified to conduct projects that require a SIL certification (SIL2, SIL3 or SIL4) pursuant to IEC 61508 standard.

The IEC 61508 standard concerns itself with *functional safety*. This phrase refers to aspects of safety concerning the function of the system. There will typically be safety aspects of a system which do not concern the function of the system directly. These aspects are usually noted by the term non-functional safety.

If it is found during the hazard and risk analysis of the system functions that a particular aspect is too risky (we discuss below how this is determined), then the specific risk must be mitigated or eliminated. One way to do this is to redesign the system such that the specific risky aspect is no longer present. Another way, emphasised by IEC 61508, is to provide additional functions whose purpose is to intervene to mitigate the identified risk so that it becomes acceptable. Such a function is called a safety function in the standard.

The entire assessment of safety in IEC 61508 occurs through risk assessment and risk reduction. In the hazard and risk analysis, hazardous events are identified and the necessary risk reduction for these events determined.

Apart from the definition of “risk” which we have discussed, IEC 61508 says that “[r]isk is a measure of the probability and consequence of a specified hazardous event occurring”

(Part 5, Annex A: Risk and safety integrity - general concepts, Paragraph A5. The definitions explicitly refer to Part 5, Annex A for "discussion", so we may assume this is intended to be definitive). This suggests that the overall risk of using a system is not a concept to which IEC 61508 explicitly gives much credence

5.1.2.2 CENELEC 50126, 50129, 50128

The standards that have been derived from the IEC 61508 include norms for industrial processes (IEC 61511), the nuclear sector (IEC61513), machine safety (IEC 62061 and ISO 13849) or railway industry (EN 50126/EN 50128 /EN 50129).

In the railway/tramway application, the one investigated by ELASTIC, the EN 5012x standards [32-34] are based on system life cycle and were written to fit the requirements of IEC 61508 generic standard constraints in this sector. Compliance with the requirements of the EN 5012x standards is sufficient to ensure compliance with the IEC61508 standard without necessitating any further evaluation.

5.1.2.3 Railway standards and ELASTIC

In the scope of the ELASTIC project, special attention will be given to the analysis of the rules identified in the railway safety standards impacted during the project implementation phases.

In deliverables D1.5 (*Impact on standards and open initiatives – First analysis*) and D1.6 (*Impact on standards and open initiatives – Final analysis)* will be evaluated the link of the ELASTIC technology and the main principles of the railway standards IEC 61508, EN 50126, 50128 and 50129.

Furthermore, in accordance with the objective of Task 1.4 "Impact of ELASTIC on safety standards and open initiatives", if gaps are identified the relevant findings will be communicated to the specific standardization bodies for information and related changes will be proposed.

5.1.3 Ublox EVK-7P GPS

The Ublox EVK-7P GPS is compliant with the essential requirements and other relevant provisions of Radio Equipment Directive (RED) 2014/53/EU and Restriction of the use of certain Hazardous Substances Directive (RoHS) 2011/65/EU (Table 2).

Essential Requirements Radio Equipment Directive 2014/53/EU	**Standards**
Safety & Health(Article 3.1a)	EN 60950-1:2006+AC:2011 +A11:2009+A1:2010+A12:2011+A2:2013
EMC (Article 3.1b)	EN 301 489-1 V2.1.1 EN 301 489-19 V2.1.0
Radio Spectrum Efficiency (Article 3.2)	EN 303 413 V1.1.1
Essential Requirements RoHS Directive 2011/65/EU	**Standards**
Prevention (Article 4.1)	EN 50581:2012

Table 2 Ublox EVK-7P GPS standards [15].

The EVK-7P device must be supplied by an external limited power source in compliance with clause 2.5 of the standard IEC 60950-1. In addition to an external limited power source, only separated or Safety Extra-Low Voltage (SELV) circuits are connected to the evaluation kit, including interfaces and antennas [16].

5.1.4 Inertial Labs OS3D-FG IMU

The IMU has its cable connection IP 67 environment sealed, which means that it is protected from dust and capable of withstanding water immersion between 15 cm and 1 meter for 30 minutes. The IP Code, International Protection Marking (IEC standard 60529), classifies and rates the degree of protection provided against intrusion, dust, accidental contact, and water by mechanical casings and electrical enclosures.

Each OS3D-FG module is individually calibrated in a special non-magnetic laboratory, where reference accelerations, angular rates, and magnetic fields are applied to the device and measured at constant temperature. The magnetometer calibration will be done in the operating environment of the system.

Directive	Standards
Electromagnetic compatibility 2004/108/EC Restriction of the use of certain hazardous substances (RoHS) 2011/65/EU	EMC : EN 60945:2002 RoHS : EN 50581:2012

Table 3 Directives and standards for the OS3D-FG IMU.

5.1.5 NVIDIA Jetson TX2 board

The NVIDIA Jetson TX2 Developer Kit is compliant with the regulations listed in this section, analysing the standards required from each country [14]. The NVIDIA GPU has the "Recognized Component Mark", which is a type of quality mark issued by Underwriters Laboratories. It is placed on components which are intended to be part of a UL listed product, but which cannot bear the full UL logo themselves.

This product is designed and tested to meet the IEC 60950-1 standard (for Safety of Information Technology Equipment) [30]. This also covers the national implementation of IEC 60950-1 based safety standards around the world e.g. UL 60950-1. These standards reduce the risk of injury from the following hazards:

a) electric shock such as hazardous voltage levels contained in parts of the product;
b) fire for overload, temperature, material flammability;
c) mechanical for sharp edges, moving parts, instability;
d) energy like circuits with high energy levels (240 volt amperes) or potential as burn hazards;
e) heat, including accessible parts of the product at high temperatures;
f) chemical like chemical fumes and vapours;
g) radiation such as noise, ionizing, laser, ultrasonic waves.

5.1.5.1 United States

This device complies with part 15 of the FCC Rules. Operation is subject to the following two conditions:

a) this device may not cause harmful interference;
b) this device must accept any interference received, including any interference that may cause undesired operation of the device.

In addition, this equipment complies with FCC RF radiation exposure limits set forth for an uncontrolled environment. This equipment should be installed with a minimum distance of 20 cm between the radiator and your body.

5.1.5.2 Canada

This device complies with Industry Canada's license exempt RSSs of the Industry Canada Rules. Operation is subject to the following two conditions:

a) this device may not cause interference;
b) this device must accept any interference, including interference that may cause undesired operation of the device.

The frequency band 5150÷5250 MHz is only for indoor use, to reduce the potential for harmful interference to co-channel mobile satellite systems.

Jetson Dev Kit has been tested and complies with IC RSS 102 RF radiation exposure limits set forth for an uncontrolled environment when used with the NVIDIA accessories supplied or designated for this product. To satisfy IC exposure requirements, a separation distance of at least 20 cm must be maintained between the antenna of this device and persons during device operation. The use of any other accessories may not ensure compliance with IC RSS 102 RF exposure guidelines.

5.1.5.3 European Union

This device bears the CE mark and class-2 identifier in accordance with Directive 1999/5/EC, Equipment Class: Class B Digital Device - ITE.

This device complies with the following directives:

- R&TTE Directive for radio equipment;
- Low Voltage Directive for electrical safety;
- RoHS Directive for hazardous substances.

5.1.5.4 Australia and New Zealand

This product meets the applicable EMC requirements for Class B ITE equipment and applicable radio equipment requirements. In addition, it meets the applicable EMC requirements for Class B, ITE equipment and applicable radio equipment requirements, recognized by the Australian Communications and Media Authority (RCM).

5.1.5.5 Other countries

The marks of conformance recognized by other countries for the NVidia Jetson TX2 GPU are listed in Table 4.

Country	Marks of conformance & Authority
Japan	Voluntary Control Council for Interference (VCCI) (Radio/ Telecommunications Certification)
South Korea	Radio Research Agency (RRA) Korean Agency for Technology and Standards (KATS)
Taiwan	National Communications Commission
China	State Radio Regulations Committee
Singapore	Info-Communications Development Authority of Singapore for IDA Standards DA00006A

Table 4 Marks of conformance recognised by other countries.

5.1.6 Continental ARS 408-21 Premium Long Range Radar

The radar used in the system is the ARS 408-21 Premium Long Range radar, which has the operating frequency band between 76 GHz and 77 GHz [12].

The ARS 408-21 will be compliant with the applicable frequency regulation standards in the following regions/countries:

- European Union;
- USA;
- Canada;
- Russia;
- South Korea;
- Australia;
- Japan;
- further countries.

In addition, this sensor is compliant to UN/ECE electromagnetic compatibility regulation No.10 [13]. The ARS 408-21 sensor has one CAN interface; the communication network is a CAN bus as specified in ISO 11898-2 with a transmission rate of 500 KBits/s.

Evaluating the influence on human health, the ARS 408-21 radar is compliant with international regulatory requirements (e.g. FCC – Federal Communication Commission, ETSI – European Telecommunications Standards Institute) and accordingly should not be hazardous to human health. In addition studies by independent experts have proven that automotive radars have no negative influence on persons (e.g. Forschungsbericht von der Forschungsgemeinschaft Funk e.V. - Newsletter 4-00').

The operating conditions regulated by the standards are shown in Table 5 [12]. LV 124 is a quality and reliability test standard jointly established by German automotive manufacturers in 2013. LV 124 applies to in-vehicle electric components for the 12 V electrical systems and it includes climatic and mechanical requirements and tests. During the mechanical tests, the profile D is applied, including dynamic load and broadband random vibrations.

The ISO 16750 (Road vehicles — Environmental conditions and electrical testing for electrical and electronic equipment) is an ISO standard, which provides guidance regarding environmental conditions commonly encountered by electrical and electronic systems installed in automobiles. The concept of ISO 16750 series is to assist its user in systematically defining and/or applying a set of internationally accepted environmental conditions, tests and operating requirements, which are based on the anticipated actual environment, in which the equipment will be operated and exposed to during its life cycle. Some environmental factors considered in this standard are: world geography/climate, type of vehicle and mounting location in the vehicle. Indeed the sensor is designed to withstand the test requirements according to ISO 16750-2 for 12 V systems without centralized load dump suppression.

Operating conditions		
Radar operating frequency	band acc. ETSI & FCC	76…77 GHz
Life time	acc. LV124 part 2 - v1.3	10000 h or 10 years (for passenger cars)
Vibration	mechanical, profile D acc.LV124 specification	20 $[(m/s^2)^2/Hz]$@10 Hz / 0,14 $[(m/s^2)^2/Hz]$@1000Hz (peak)
Protection rating	ISO 16750 Classification (Trucks)	IP 6k 9k (dust, high-pressure cleaning) IP 6k7 (10 cm under water), ice-water shock test, salt fog resistant, mixed gas EN 60068-2-60

Table 5 ARS 408-21 Radar operating conditions.

5.1.7 CAN-USB converter

The PCAN-USB converter allows the connection between the sensors CAN interface and the Nvidia USB port. This device is CE certified and it fulfils the requirements of the EU EMC Directive 2014/30/EU. Indeed, it is designed for the Electromagnetic Immunity and Electromagnetic Emission fields of application. In addition, the high-speed CAN bus is ISO 11898-2 certified.

5.1.8 Traco Power DC/DC converter

One of the two DC/DC converters used in the hardware setup is the Traco Power DC/DC converter, which has the CE mark and the UL and CB certifications. The IECEE CB scheme is an international system for mutual acceptance of test reports and certificates, dealing with the safety of electrical and electronic components, equipment and products.

The input filter is used, to reduce the conducted input noise. Thanks to this filter the device meets the EN 55022 and the FCC part 15 categorization as a class A apparatus. Consequently, the Traco Power DC/DC converter would cause RF noise in domestic environments. According to the limits set by the IEC 61000-4 standard, the device follows the class A performance criteria specified in Table 6. The maximum operating temperature is +80 °C (without derating), satisfying the IEC/EN/UL60950-1 standard.

The certificate of conformity sets the input electrical ratings to 24VDC or 9-36 VDC, 48 VDC or 18-75 VDC, according to the low voltage Directive 2006/95/EC.

Input specifications	
ESD	EN 61000-4-2, air ±8 kV, contact ±4 kV, perf. criteria A
Radiated immunity	EN 61000-4-3, 10 V/m, perf. criteria A
Fast transient/surge (with external input capacitor)	EN 61000-4-4, ±2 kV, perf. criteria A EN 61000-4-5, ±2 kV, perf. criteria A
Conducted immunity	EN 61000-4-6, 10 Vrms, perf. criteria A

Table 6 Traco Power DC/DC converter specifications.

5.1.9 DTE60 DC/DC converter

The other DC/DC converter used in the system is the XP Power DTE60 series device. As the Traco Power DC/DC converter, it meets the EN 55022 for the conducted and radiated EMC emission as a class A apparatus and it is CB and UL certified. The EMC Immunity tests and performance criteria are listed in Table 7.

Phenomenon	Standard	Test level	Performance criteria
Immunity	EN55024	---------	---------
ESD Immunity	EN61000-4-2	±4 kV Contact, ±8 kV Air	A
Radiated Immunity	EN61000-4-3	10 V/m	A
EFT/Burst	EN61000-4-4	3	A
Surges	EN61000-4-5	3	A
Conducted Immunity	EN61000-4-2	10 Vm	A
Magnetic Fields	EN61000-4-8	30 A/m	A

Table 7 EMC Immunity of the DTE60 DC/DC converter.

Safety agency	Safety standard
CB	IEC60950-1
UL	UL60950-1

Table 8 Safety approvals for the DTE60 DC/DC converter.

5.1.10 Mikrotik R11e-LTE modem

The R11e-LTE modem is compliant to the relevant harmonized standards under the Directive 2014/53/EU on RED.

5.2 FIWARE standard

The FIWARE platform was created in the scope of the Future Internet Public-Private Partnership (FI-PPP) [27] project of the European Union, and it is supported by a community foundation (FIWARE foundation) [28], an open legal independent body.

The FIWARE platform [29] establishes a set of Application Programming Interfaces (API), which facilitates the development of applications for the Internet of Things (IoT). It is an open source initiative, defining a set of standards for context data management, which facilitate the development of smart applications. Furthermore, the platform provides in public access an open-source reference implementation of each of its components.

These components allow acquiring, aggregating and harmonizing data coming from heterogeneous sensors devices, and publish them in a core component that is able to provide the view of the system's state over time. The typical IoT applications acquire data from multiple and diverse sources types but all related to a specific context, which is then processed and registered, such that applications can answer requests on the working context.

The FIWARE architecture (Figure 35) core component is the Context Broker, which is able to manage context information in a decentralized and scalable manner. The Context Broker exposes an API, the FIWARE NGSI (Next Generation Service Interface) API standard, a simple Restful API that enables updates, queries or subscribing to changes on context information.

Around the Context Broker different components can be plugged in, related to:

- Interfacing with the real world, for sensing and actuation.
- Data management, implementing the expected behaviour of applications.
- Processing, analysis and visualization of context information.

These are supported by a rich set of deployment tools.

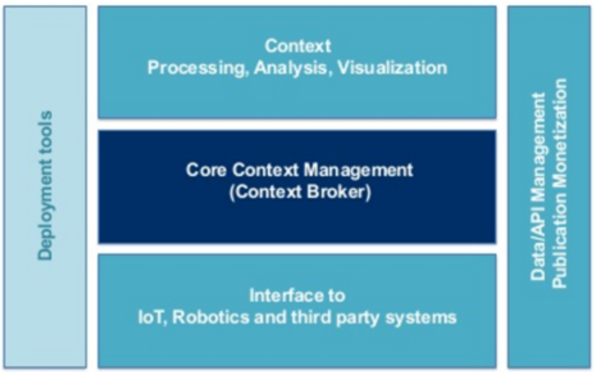


Figure 35 FIWARE Architecture Overview (source FIWARE Foundation).

The FIWARE NGSI API defines a data model for context information, based on a simple information model using the notion of "context entities", a context data interface for exchanging information by means of query, subscription, and update operations, and a context availability interface for exchanging information on how to obtain context information.

Additional functionality can be easily added by creating additional FIWARE-compatible components, using the FIWARE Context Broker. This integration is simplified since all components comply to the FIWARE NGSI standard interface.

5.2.1 FIWARE and ELASTIC

In the scope of the ELASTIC project, special attention will be given to the analysis of the attributes that the FIWARE NGSI standard provides to support the elasticity concept and the non-functional properties quality-of-service attributes.

Furthermore, and although a FIWARE-compatible implementation of the ELASTIC Software Architecture is not foreseen, it will be identified how ELASTIC can use the well-established interfaces of NGSI, to guarantee seamless interoperability among different systems and to ensure efficient data sharing among heterogeneous data providers.

5.3 OpenFog standard

The OpenFog Consortium [17], participated by BSC, is an independently-run open membership ecosystem of industry, end users and universities in charge of the specification of the OpenFog Reference Architecture (RA). The OpenFog RA provides interoperability, messaging, and interface standards to enable fog nodes to cooperate, with the objective of reducing latency, network bandwidth and availability constraints.

Recently, the OpenFog RA for fog computing has been adopted as an official standard by the IEEE Standards Association (IEEE-SA). The new standard, known as IEEE 1934 [18], relies on the RA as a universal technical framework that enables the data-intensive requirements of the Internet of Things (IoT), 5G and artificial intelligence (AI) applications. Figure 36 summarises the eight pillars that an OpenFog RA compliant framework has to accomplish.

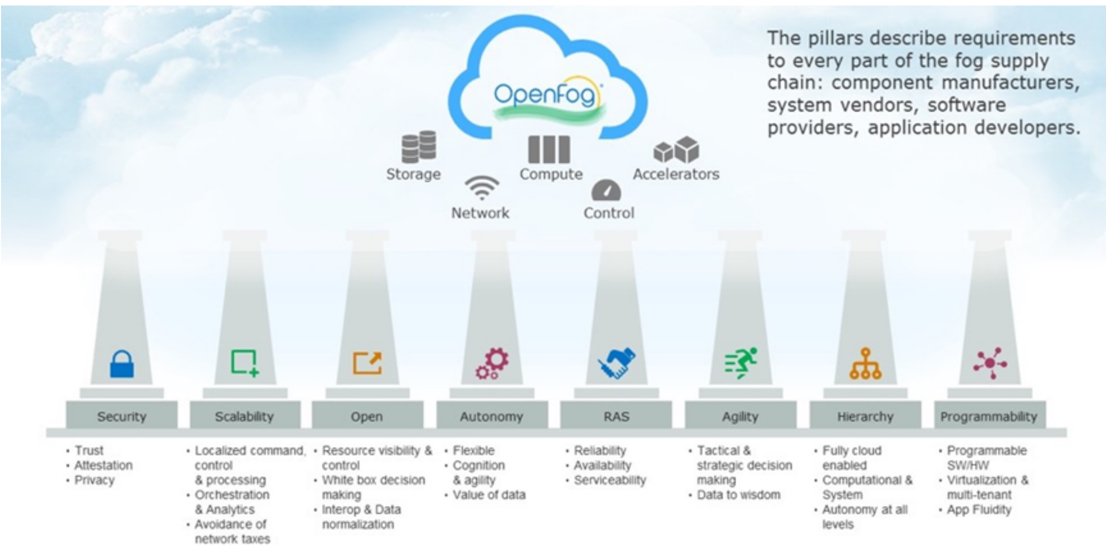


Figure 36 Key pillars of the OpenFog RA (source OpenFog).

5.3.1 Smart City OpenFog Use Cases

The OpenFog Consortium has already identified two smart city use-cases highly related to ELASTIC: connected (and autonomous) vehicles [19] and Traffic Congestion Management [20], upon which fog computing can be applied. Concretely, the eight pillars of the OpenFog RA that smart cities will take benefit are as follows:

1. *Security.* The OpenFog RA specifies the processes by which fog nodes manages the physical interfaces, wireless protocols, and packets and data being transferred, ensuring that the right packet gets to the right location, and so fulfilling the strict security and privacy requirements.
2. *Scalability.* Sophisticated and mission-critical capabilities (e.g., obstacle detection) require strong service quality guarantees. Hence, the system must be continuously monitored and measured to guarantee that the terms of *Service Level Agreements* (SLAs) are measured and met. Fog management and orchestration may ensure that the SLA is maintained. When an anomaly is detected, the orchestrator takes remediation action with minimal or no impact to the system.
3. *Open.* One of the primary drivers for interoperability is open data, including: the header, metadata, payload formatting, data transport/access, interfaces, etc. Proving an open, multi-party ecosystem producing these capabilities to improve the cost, functionality, safety and rate of vehicle manufacturers, city councils, insurance companies or government regulators, is well beyond what would be possible in a single vendor proprietary solution.
4. *Autonomy.* Each fog node is expected to be autonomous with a certain level of processing, storage, and decision-making. Autonomy begins with "self-awareness" and the ability of a fog node to express its own capability, ability and current participation with other nodes and services. Orchestration and service management functions will have the ability to get to real-time and current data about all the participants in events and services without having to talk to a central authority.
5. *Reliability, Availability, and Serviceability/Safety (RASS).* Each fog node includes standards for the meta-data and telemetry necessary to provide input for systems that describe RASS features. This is important because distribution of compute, storage, communication, and control can increase the potential for a problem due to a dropped connection or during a hand off between networks. Because fog nodes are automatically aware of each other and act as a community of nodes, they also have the ability to check on each other, request feedback, and get a health status on local network connections.
6. *Agility.* Each fog node has the ability to evaluate a request and provide services if it has that capability. Fog networking supports dynamic location update schemes (based on the inter-fog node network and community service capabilities). As a result, connected vehicles can react in real-time to location-based traffic patterns or needs.

7. *Hierarchy:* The OpenFog RA supports hierarchical and distributed implementations, e.g., including fixed sensors installed in the city and on-vehicle sensors. These sensors provide data so that the various levels at city, vehicle and cloud level can carry out their given functions.
8. *Programmability*: Programmability is at the heart of the OpenFog ecosystem and provides the ability to develop and customize the fog platform.

5.3.2 The OpenFog RA in ELASTIC

The research within the ELASTIC project will take special attention to the following *Pillars* defined by the OpenFog consortium and described in above:

- *Security.* The ELASTIC software architecture will incorporate mechanisms to avoid undesirable accesses to computing and storage resources, as well as data security in terms of data integrity (see Deliverable D5.1 [21]).
- *Scalability.* The data analytics platform (WP2) to be included in the ELASTIC software architecture will provide an Abstraction Programming Interface (API) to efficiently describe data analytics methods needed to support the ELASTIC use-cases (see Section 2 and Deliverables D2.5 [22] and D3.1 [23]). Moreover, the ELASTIC software architecture will monitor and measure the non-functional requirements imposed by the cyber-physical interactions of the system (see Deliverable D4.2 [24]. This information will be forwarded to the orchestrator component, that will guarantee its fulfilment.
- *Autonomy, agility* and *hierarchy.* The computing nodes included within the tramway vehicles and along the tramway network will have processing, storage, and decision-making capabilities. Moreover, the orchestrator component of the ELASTIC software architecture will have the ability to evaluate which nodes can provide the requested service and distribute the computation accordingly (see Deliverable D3.1 [23]). These features will be fundamental to guarantee the non-functional requirements of the system and so its correct operation, as each computing nodes will have the capability of responding without depending on other nodes.
- *RASS.* The ELASTIC software architecture will incorporate capabilities to constantly monitor the network connection status, to allow the orchestrator to re-distribute the data analytics workloads in case network connections are dropped (see Deliverables D3.1 [23] and D5.1 [21]).
- *Programmability.* Programmability will be one of the key features of the ELASTIC software architecture, already identified as a technical requirement to be fulfilled by the architecture (see Deliverable D3.1 [23]). This will allow the application developer to develop the application independently of the underlying technology implementing the compute continuum.

ELASTIC acknowledges the importance of the *Open* pillar. However, due to the already challenging research envisioned within ELASTIC, this pillar will remain as a future work.

6 Use case added value

All the use cases of the ELASTIC project consist of two different layers:

1) Data acquisition from sensors;
2) Data analytics and exploitation.

Usually the data acquisition alone does not provide much value without analysis. This is not the case in the ELASTIC project since the data acquisition itself is performed on the edge where a first step of computation is carried on to implement the ADAS, NGAP, predictive maintenance, energy consumption and optimization of the city performances.

6.1 Data acquisition

Data acquisition for the use cases is composed of the outputs information presented in Table 9.

Use case	Data
NGAP	Train position on the spline
ADAS	Obstacle position, speed and classification with labels
Predictive maintenance	Rail track status profile
Energy consumption	Electric power consumption profile
Optimization of the city performances	- Information about the status of the transportation/mobility networks and warnings about hazards - KPIs about the performance of the transportation/mobility networks

Table 9 Data of the different use cases.

6.2 Analytics

The possible analytics per use case will in general depend on the quality and performance of the inputs from the data acquisition. Thus, at the time of the deadline of this deliverable it is possible that not all analytics have been identified and accurately described. Once the data acquisition and performance evaluation have been carried on, the missing details and corrections to this initial picture will be finalized.

6.2.1 NGAP

The NGAP system collects internally all the calculations made in order to retrieve the tram position, but only the following information is sent to the cloud:

- variance of the acceleration and angular speed in x, y, z in order to give an indication of the reliability of data;
- number of IMU packets that have not been processed by the Sensor Fusion Algorithm (wrong timestamp, wrong data, etc…);

- number of GPS data that have not been processed by the Sensor Fusion Algorithm (wrong timestamp, too higher variance, etc …);
- number of Radar odometer data that have not been processed by the Sensor Fusion Algorithm (wrong timestamp, too higher variance, etc …);
- variance of the Sensor Fusion Algorithm position;
- variance of the Sensor Fusion Algorithm speed.

6.2.2 ADAS

The ADAS analytics are useful to realize statistical analysis on:

- the number of occurred accidents;
- the occurred false alarms;
- the pedestrians crossing the line;
- the number and type of tracks occlusions;
- the traffic on the crossing path between the tracks and the road.

6.2.3 Predictive maintenance and energy consumption

Both Predictive Maintenance and Energy Consumption systems are composed of two layers: the edge layer and the analytics layer.

For the Predictive Maintenance of rail track status, the edge layer contains and handles the various sensors, i.e. GPS, odometer, lasers, accelerometers, video cameras, and collects said raw data. The analytics will derive the rail track status, and will accordingly time-space correlate such data with GPS and odometers data, which are either own-specific or shared with NGAP ones.

For the Energy Consumption, the edge layer contains and handles its various sensors, i.e. GPS, odometer (as shared with NGAP) vehicle weight and electric power consumption, while the analytics layer simply time-space correlates such power measures with GPS- and odometers-provided data.

6.2.4 Interaction between the public and the private transport

The analytics collected are useful to assess the performances of transportation networks and mobility services in the area from different perspectives: public transport, private transport and safety.

For each perspective, some of the possible elements to enriching knowledge on mobility in the city are listed below:

- public transport:
  - frequency of service (absolute value, regularity);
  - occupation of intersections in terms of *duration*, *frequency* and *pattern* (tram in one direction, two trams in opposite directions, two trams in the same direction);
  - number of outages due to external factors;
  - presence/entity of crowds at tram stops;
- private transport:

  - occupation of intersections in terms of average green phase duration and number of occurrences of pre-emption due to tram priority;
  - pedestrians crossing while traffic light is red;
- safety:
  - accidents in terms of quantity and temporal and spatial distribution.

Evaluating, interpreting and investigating these elements are expected to highlight areas where actions can be enforced to optimize performances.

Acronyms and Abbreviations

Each term should be bulleted with a definition. Below is an initial list that should be adapted to the given deliverable.

- ADAS – Advanced Driving Assistant System
- API – Application Programming Interfaces
- AVM – Automatic Vehicle Monitoring
- BP – Back-Plane
- CE – European Conformity
- CFS – Completely Fair Scheduler
- CPU – Central Processing Unit
- CRC – Cyclic Redundancy Code
- D – Deliverable
- EEA – European Economic Area
- EMC – Electromagnetic Compatibility
- ESD – Electrostatic Discharge
- EVT – Euro NCAP Target Vehicle (see [Ref. 10] Annex A EVT specification)
- FCC – Federal Communications Commission
- FCW – Forward Collision Warning
- FMCW – Frequency Modulated Continuous Wave
- FoV – Field of View
- GB – Gigabye
- GDPR – General Data Protection and Regulation
- GPS – Global Positioning System
- GPU – Graphic Processor Unit
- GUI – Graphical User Interface
- HTTP – Hypertext Transfer Protocol
- ID – Identifier
- IMU – Inertial Measurement Unit
- IoT – Internet of Things
- ITE – Information Technology Equipment
- ITS – Information Technology System
- KPI – Key Performance Indicator
- LTE – Long Term Evolution
- NGAP – Next Generation Autonomous Positioning
- NGSI – Next Generation Service Interface
- NTP – Network Time Protocol

- RED – Radio Equipment Directive
- RCS – Radar Cross-Section
- RoHS – Restriction of Hazardous Substances
- ROS – Robotic Operative System
- RSS – Radio Standard Specification
- RSU – Road Side Unit
- RTT – Rail Track Tool
- SELV – Safety Extra-Low Voltage
- SFA – Sensor Fusion Algorithm
- SLA – Service Level Agreement
- TBLA-25 – Tram-to-Bicyclist Longitudinal Adult 25%
- TBLA-50 – Tram-to-Bicyclist Longitudinal Adult 50%
- TBNA-50 – Tram-to-Bicyclist Nearside Adult 50%
- TCRb – Tram-to-Car Rear Braking
- TCRm – Tram-to-Car Rear Moving
- TCRs – Tram-to-Car Rear Stationary
- TPFA-50 – Tram-to-Pedestrian Far side Adult 50%
- TPLA-25 – Tram-to-Pedestrian Longitudinal Adult 25%
- TPLA-50 – Tram-to-Pedestrian Longitudinal Adult 50%
- TPNA-25 – Tram-to-Pedestrian Nearside Adult 25%
- TPNA-75 – Tram-to-Pedestrian Nearside Adult 75%
- TPNC-50 – Tram-to-Pedestrian Nearside Child 50%
- TTC – Time-to-Collision
- UTC – Urban Traffic Control
- VMS – Variable Message Signs
- VRU – Vulnerable Road Users
- VUT – Vehicle Under Test

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