OMICRON

Intelligent Road Asset Management Platform

OMICRON
Demonstrators Definition

Deliverable D1.2

Date: 29th January 2022

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Executive Summary

The main objective of this deliverable is the definition of OMICRON's Use Cases testing and demonstration activities, so as to develop a first framework for the development of technologies and the activities to be carried out in WP6 *"Intelligent Platform Monitoring, Demonstration and Evaluation".*

The report takes into account and describes:

- The definition of the data, information and tasks to be implemented in the final demonstrator.
- The formal definition of the testing and demonstration process in OMICRON.
- The testing timeline, authorization, and different demonstrators' boundary conditions.

In that respect, the document also summarises the main definition activities around the final demonstrator, performed in Task 1.3 *"Process modelling and historical data collection for the final demonstrator",* to provide an interoperable solution for OMICRON technologies in a specific real scenario. These main activities are:

a. The identification of infrastructure manager maintenance processes.
b. The definition of the involved actors and stakeholders.
c. The collection of available data sources and the identification of decisional steps and workflow.
d. The identification of main strategies, constraints and relevant indicators.
e. The definition of potential new functionalities for data analytics and decision support, related to the final demonstrator.
f. The design of innovative maintenance process building blocks and their interactions and integration with the existing procedures.

The demonstration will be performed in three stages, as follows:

- **Stage 1.** Preliminary testing of technologies at TRL 4 to 5 to ensure a smooth transition towards TRL 7.
- **Stage 2.** Technical demonstration of technologies in a virtual demonstration coordinated by TDU and ARI and in three real pilots in Spain (TRL7), led by IND (A-2 Spain), EIF (A-92, Seville, Spain) and PAV (A-7, Valencia, Spain). These demonstrators will present specific technologies providing information to the final demonstrator.
- **Stage 3.** Final demonstration at TRL 7 to be held by SDP at the A24 in Italy, where the Intelligent Platform will be tested, including the Digital Twin (DT), the Decision Support Tool (DST), the inspection technologies and virtualisation tools, and the robotic technologies.

The demonstration methodology presented in this report is based on the general guidelines provided in OMICRON's Description of Actions (DoA) and uses the information included in Deliverable D1.1 *"Functional and technical requirements of OMICRON technologies".*

This report is structured as follows:

Chapter 1 - "Introduction" states the main objectives of this document and the activities carried out.

Chapter 2 - "Final demonstrator characterisation" reports the main outcomes of Task 1.3, namely the detailed analysis of the maintenance framework of the infrastructure manager (SDP) that will host the final demonstration, together with the potential area of improvement after the application of the OMICRON technologies.

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Chapter 3 - “Demonstration Methodology” includes the relevant information related to the deployment of the Use Cases for each technical demonstrator. In addition, the authorization required for the demo implementation, the boundary conditions, the stakeholders to be involved and any relevant info that can be useful to address the execution of the Use Cases are included.

Chapter 4 - “Workshop Feedback” describes a report of the OMICRON demonstrator workshop held in Malaga (14-15.12.2021), considering the main outcomes that came out after that brainstorming session related to the identification of the activities and main constraints related to the above mentioned three stages of demonstration activities.

Chapter 5 - “Conclusion” presents a summary of the results in this document.

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Acronyms and Abbreviations

Table 1. Acronyms and abbreviations

Acronym or Abbreviation	Description
AI	Artificial Intelligence
AR	Augmented Reality
AUTL	Asphalt Ultra-Thin Layers
BC	Business Case
BPMN	Business Process Model and Notation
BS	British Standards
BVLOS	Beyond Visual Line of Sight
CNN	Convolutional Neural Networks
C-ITS	Cooperative Intelligent Transport Systems
C-UC	Cluster Use Case (following IEC PAS 62559-2)
DoA	Description of Action
DT	Digital Twin
DST	Decision Support Tool
D-UC	Detailed Use Case (following IEC PAS 62559-2)
EASA	European Union Aviation Safety Agency
EN	European Standards
ENAC	Italian Civil Aviation Authority
ENAV	Italian air traffic management (ATM) system responsible
EUROCAE	European Organization for Civil Aviation Equipment

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EVLOS	Extended Visual Line of Sight
GCS	Ground Control Station
GDPR	General Data Protection Regulation
GRA	Grande Raccordo Anulare (Rome's Ring Road)
GRC	Ground Risk Class
GUTMA	Global UTM Association
HL-UC	High Level Use Case (following IEC PAS 62559-2)
IRI	International Roughness Index
ISO	International Organization of Standardization
KML	Keyhole Markup Language
KPI	Key Performance Indicator
LMS	Laboratory for Manufacturing Systems and Automation
MDP	Mean Profile Depth
OSO	Operational Safety Objectives
RAP	Recycled Asphalt Pavement
RSU	Road Side Units
RGB-D	Red Green Blue and Depth images
ROS	Robot Operating System
SCRIM	Sideway-force Coefficient Routine Investigation Machine
SDP	Strada dei Parchi (Project Partner)
SFC	Sideway Force Coefficient
TD	Technical Demonstrator

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UAV	Unmanned Aerial Vehicle
UC	Use Case
V2X	Vehicle-to-everything
VE	Virtual Environment
VLOS	Visual Line of Sight
VR	Virtual Reality
WP	Work Package

1 Introduction

1.1 Objective and activities

The document aims to provide a complete overview of the definition of testing activities foreseen in each demonstrator, defining the duration and the external factors that may impact the implementation. It is essential to highlight that this information may change when the Use Cases are implemented in real scenarios, so it is highly recommended to consider this document as a starting point. The included information must be reconsidered and (eventually) updated when the activities are planned and implemented.

In Deliverable D1.1, the main findings of Task 1.1 and Task 1.2 were presented: a preliminary but fully detailed analysis of all Use Cases has been deployed, together with a full review of legislation, standards and regulatory framework that may have an impact on the deployment of the different technologies for each technical demonstrator, expected in WP6.

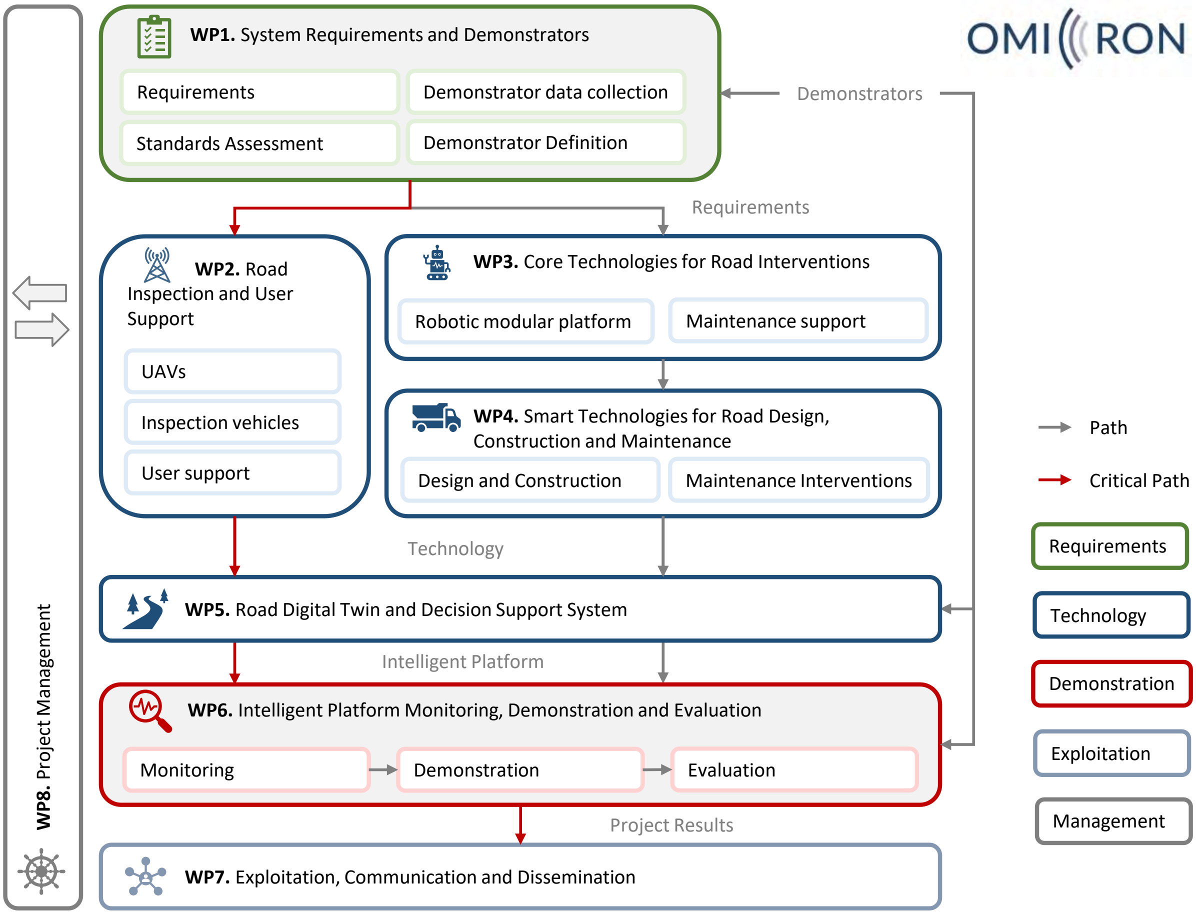

Figure 1. The connection between WP1 and WP6 (highlighted in grey)

The functional and technical requirements are closely connected with the information included in this document, particularly in Chapter 3 “Demonstration Methodology”. The intention is to take into account the work done in Deliverable D1.1 and try to better detail the information, trying to identify some specific activities or peculiarities that can characterise the deployment of the technologies on each technical demonstrator.

The document includes Task 1.3 outcomes collected in close cooperation with all partners involved (SDP, AIS, CEM) with the leadership of UNIGE. Task 1.3 is a detailed review of the current process

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related to maintenance procedures and stakeholders involved, including relevant information related to the main asset data (pavements and structures) and the rules for the inspection and quality assurance of the elements.

Also, a detailed analysis was carried out to determine the potential area of improvement using OMICRON technologies, mainly related to the use of AI and decision support for the infrastructure manager decision-making procedures.

Moreover, the outcomes of Task 1.4 are integrated into this document. The definition of the OMICRON testing and demonstration activities is detailed, considering the three different stages of the testing phase and each technical demonstrator, following the different environments and peculiarities that may impact the implementation of the Use Cases.

Finally, a workshop was organised to discuss further and refine the requirements and details that can be addressed at this stage. These fruitful discussion results are considered in a specific chapter of this document.

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2 Final demonstrator characterisation

2.1 Introduction

As already mentioned, the final demonstrator will be performed at the A24 motorway and the connection to Rome's ring road, part of the Scandinavian-Mediterranean CEF corridor in Italy, managed by Strada dei Parchi SpA (SDP).

The demonstrator site will provide the opportunity to test roads and specific assets, such as tunnels and viaducts, in natural conditions.

As depicted in Figure 2, A24 is a highway connecting Rome to the Adriatic sea, crossing the GRA (Rome's ring road). It combines the two East and West sides of the Italian peninsula. It is a suitable location for testing OMICRON's results as it includes all the sites to demonstrate the construction, inspection, maintenance, upgrade and digitalization tools developed within the project.

The highway (with a length of more than 500 km) includes 116 km of viaducts (21% of total highway length) and 70 km of tunnels (13% of total length). The following assets are highlighted:

- **GRAN SASSO TUNNEL** is the longest twin-tube tunnel in Europe, with a length of about 10 km. The tunnel goes through the homonymous mountain located in the Appenins; each tube has two one-way lanes. In the middle of the tunnel (in the direction to Rome), the National Institute of Nuclear Physics laboratories is located. Access to laboratories is only possible through the tunnel.
- **VALLE MURA VIADUCT** is a monolitic structure of reinforced concrete. A span constitutes the structural scheme on conically shaped piers with polygonal directrix and very subtle thickness. The viaduct has a total length of 272 m, the deck's width is 22.6 m, and the average height is 21 m.
- **URBAN CONNECTION TO ROME** is the road section that connects the toll motorway with the centre of Rome. Its peculiarity is due to the significant traffic volume, with a high percentage of heavy vehicles and its strategic function and increased impact from the environmental and social point of view.

The following macro-sections will also be considered:

- A24 road section from East Rome motorway exit to East Tangenziale crossing Rome's ring road (GRA) is characterised by heavy traffic conditions, high traffic flow (no-toll motorway), and a travel time tracking system flat urban connection to Rome.
- A24 toll road section from East Rome motorway exit to Carsoli, with a heavy traffic condition, as a hilly extra-urban road section.
- A25 road section from Torano to Pescina, a light traffic section on the Fucino Plateau.

Furthermore, other shorter segments could be identified and used in the OMICRON project's test and study: the assets mentioned above are considered the most relevant ones from a technical point of view and the OMICRON solutions that will be tested there.

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Figure 2. Strada dei Parchi Highway location

The final demonstrator will include the deployment of the following technologies:

- The UAV inspection technologies from WP2.
- The inspection vehicle technologies in WP2.
- Demonstration of the V2X communications.
- The multipurpose robotic platform, following T4.2, T4.3, T4.7 and other related tasks.
- The VR-AR technologies from WP3 and WP4.
- The Digital Twin (DT) and the Decision Support Tool (DST).

The main expectation is to test the OMICRON technologies with a particular focus on ordinary road maintenance, solving management problems and achieving high safety standards.

The following benefits are expected:

- Improve damages assessment through inspections, performed using drones, evaluating the state of viaducts or other assets.
- Improve procedures for positioning and removing temporary road signs via automated technologies.
- Improve visual inspection procedures related to assets (bridges and viaducts) with automated technologies, such as drones, to save time and increase workers safety.
- Improve procedures for positioning roadside traffic barriers by applying automated technologies.

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- Improve procedures for erasing road marking (to be confirmed in the following stages of the project).

2.2 Analysis and modelling of current maintenance process

2.2.1 Current maintenance strategies and procedures

The analysis of current maintenance strategies and procedures is performed to characterise the final demonstrator. It was defined with Strada dei Parchi (infrastructure concessionaire) within Task 1.3 focusing on the following aspects:

- Identification of asset types and their peculiarity from the maintenance procedure point of view.
- Identification of relevant Italian regulations and internal standards.
- Definition of current inspection and maintenance procedures.
- Identification of possible improvements.

The outcomes of the analysis are reported in Table 2.

Table 2. Analysis of current maintenance process

Considered asset type
Two types of assets are distinguished: road pavement and structures, i.e. viaducts/tunnels. Regarding **road pavement**, the following aspects should be considered: • Road pavement is an asset with a high impact on infrastructure status and road network availability. • The relevant standards for inspection and maintenance procedures are defined by the infrastructure manager contract named “Concessione Unica”. • A consolidated historical dataset is available from 2013. • The same European and National regulation has been in force for many years, while viaducts and tunnels present a more complex regulatory framework that has been subject to modifications over time. The following peculiarities are highlighted for **viaducts and tunnels**: • Viaducts and tunnels are critical assets with a strategic function within the road network. • A new regulatory framework is under definition by the MIMS (Italian Ministry of Sustainable Infrastructures and Mobility). • According to the new regulatory framework, Strada dei Parchi standards for inspection and maintenance procedures are currently under revision. • The available historical dataset is not in line with the new legislation. However, new data will be collected within the project.

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Main regulations and standards

The regulations and standards to be considered within the final demonstrator are identified regarding the different types of assets.

The general regulations that Strada dei Parchi must apply are:

- The infrastructure manager's contract 'Concessione Unica'. This document is the base for managing the highway according to specific standards and conditions. It also includes specific references to standards and parameters to calculate tolling tariffs.
- The instructions from MIMS (Ministero delle Infrastrutture e della Mobilità Sostenibili). As the grantor of the concession, the Ministry of sustainable Infrastructure and mobility can add new technical instructions regarding every aspect of the infrastructure management, promoting improvement at every level of detail.

SDP defined internal procedures called "Zero Defect Manual" considering road pavement. This document describes a specific internal method for communicating observed defects from Operational Centres through a particular ROAR of APP.

Concerning viaducts and tunnels, the following regulations are applied:

- "Linee Guida ponti esistenti 2020". The guidelines will be subject to an experimental application concerning the monitoring system, even dynamic, of bridges and viaducts. Following the outcome of this experimentation, the policies will provide an advanced, unique and uniform tool for all operators on the national territory.
  This tool will determine a "class of attention" for risk management and the safety check of infrastructures through a general, multi-level, multi-criteria and multi-objective approach.
- "Manuale ispezione gallerie 2020". This manual aims to ensure risk classification and management homogeneity, safety assessment, and monitoring of existing tunnels along the entire road and motorway network. These specific guidelines are defined with the Higher Council of Public Works' opinion and in agreement with the Regions, Provinces and Municipalities for the tunnels owned by these bodies.

Current inspection procedures

Current SDP inspection procedures are analysed according to the asset type.

Regarding the **pavement**, the following type of surveys are performed:

- "High Performance" survey is executed once a year along with the entire network, using diagnostic vehicles to evaluate road pavement parameters (CAT and IRI) on the whole infrastructure and road marking reflectivity.
- Test of mechanical properties: it is executed on selected road sections, with a variable frequency. SDP tests mechanical properties (FWD) for evaluating the expected remaining service life of pavements.
- Daily inspections and periodical reports: these inspections are performed according to the internal procedures "Zero Defect Manual" by the staff of CSA (Centro Sicurezza Autostradale) to detect pavements defects. In particular, the procedure establishes that:
  - Minor defects are immediately corrected.
  - Significant defects are included in the maintenance plan according to the inspection report.

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The CSA works every day 24 hours travelling along the network, checking the infrastructure status. The observed defects are communicated through the Application ROAR, assigning each photo of the pavement defect, the exact location, and a specific defect code.

Regarding the **viaduct** inspection procedure, SDP carries out regular periodic inspections conducted visually every six months, requiring the compilation of reports for each structural element.

All defects are photographed with adequate resolution and with metric references. The photographs are identified and transferred to the Bridge Management Systems (BMS) linked to the reports.

Drones and robotic vehicles support visual inspections, with optic equipment in the visible and infrared fields or RGB scanners. Scanned images of the inspected elements are geo-located and geo-referenced, and the extent of the defects is measured. To facilitate the identification of the structural elements, they present a plate with QR or bar code. The inspections also concern the surrounding environment to detect anomalous situations such as floods and landslides. Ordinary inspections aim to attribute a numerical/quantitative value representative of the state of condition for each investigated element and the entire structure. This attribution can be performed automatically by the algorithms integrated into the BMS.

Extraordinary inspections acquire useful information to understand the degradation phenomena and the condition of the structures when ordinary inspections have found obvious criticalities. Exceptional inspections must be accompanied by in situ tests and can also be accompanied by static load tests and dynamic measurements.

At the end of the inspection process, it is decided whether to carry out specific safety checks that provide for the structural modelling of the viaduct.

Regarding **tunnels**, the purpose of the inspections is to identify the present defects, including:

- Water interaction.
- Soil degradation.
- Concrete tunnel lining degradation.
- Degradation or lack of sealing system.
- Degradation or lack of draining system.

Visual inspections can also be accompanied by laser scanners, geo-radars or thermographic surveys.

SDP is creating and implementing an asset management platform (Open Maint) that allows inspection management to plan interventions to optimise the inspection activities. The platform has several modules to support the entire management process of individual assets, divided into bridges, viaducts, tunnels, overpasses, underpasses (L >6 m). Each asset is also subdivided into single structural components.

The main features of the system are the following:

- All the structures are geolocated and completed with information (geometry, road section, static scheme and typologies, traffic data).
- Plan and control of inspection activities through immediate notification (automatic emails, notifications on mobile devices, etc.).
- Inspection report for each asset according to the current legislation (e.g." Linee Guida ponti esistenti 2020", "Manuale ispezione gallerie 2020").

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- Create inspection reports for each structure automatically.
- Data export from inspection activities in aggregate form (e.g. types, defects, etc.).

Represent the progress of the inspection activities.

Current maintenance procedures

Regarding current maintenance procedures, a distinction is made according to the asset type. Moreover, the analysis focuses on the applied strategies, planning, and maintenance execution.

Regarding the road pavement, the applied maintenance strategies are:

- Preventive maintenance is usually planned between April and November due to environmental constraints. The maintenance planning is based on the high-performance surveys data and the periodical reports from the CSA personnel.
- Corrective maintenance consists of:
  - Unplanned maintenance operations in particular cases, such as accidents.
  - Correction of minor defects immediately executed.

The maintenance plan is defined according to the results of the high-performance survey. The survey of the entire highway is performed every year and requires two/three days. The raw data are collected automatically, recorded and elaborated. The average trend is estimated to define the maintenance plan. The maintenance activities to be executed during the following year are established, grouping road sections with similar conditions. The maintenance activities already included in the maintenance plan of the current year are removed in the definition of the following maintenance plan.

The maintenance manager makes the planning decision without automated support. Existing tools are usually designed to model the status of urban road infrastructure and are not readily applicable to highways.

Maintenance interventions are executed during summer, characterized by favourable weather conditions but high traffic due to the vacation period. To limit the impact on traffic, the Italian MIMS Instruction establishes that the maintenance activities along highways can be executed only from Monday at 12 to Friday at 14. No activity is allowed during weekends.

The maintenance work is subdivided into sections (usually around 1 km long) and usually completed in 5 days. The duration depends on the involved material (m^3) considering the dimension of the intervention.

The detailed maintenance plan (CRONOPROGRAMMA LAVORI) schedules three different interventions at the same time, one in each of the main highway sections:

- Roma - Torano.
- Torano - Teramo.
- Torano - Pescara.

The detailed maintenance plan is updated every week, considering the weather conditions. Every intervention must be decided one week in advance. It must be communicated to the CRI (CENTRO RADIO INFORMATIVO) to check the compatibility with other works (the distance of at least 2 kilometres must be guaranteed between two construction sites). The impact of unexpected events is limited to 5-6% of the budget.

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Regarding the viaducts and tunnels, the following aspects must be highlighted regarding maintenance strategy, planning and execution: • Preventive and corrective maintenance strategies are applied. • Preventive/corrective maintenance interventions are planned every year at the end of November. The maintenance plan is defined according to the results of the inspections. As mentioned for pavement, bridges and tunnels, the maintenance interventions are executed during summer, characterised by favourable weather conditions but high traffic due to the vacation period. To limit the impact on traffic, the Italian MIMS Instruction establishes that the maintenance activities along highways can be executed only from Monday at 12 to Friday at 14. No activity is allowed during weekends.
The main potential of improvements (in order of priority)
From the analysis of current inspection and maintenance procedures, the following potential improvements and infrastructure manager's goals are identified: • The reduction of the exposure of workers to hazardous situations. • The reduction of traffic disruptions due to inspections and maintenance. • The reduction of maintenance intervention times and costs. • The reduction of the effort for maintenance planning. • The reduction of the effort for infrastructure status evaluation.

2.2.2 Maintenance planning

According to the planning time horizon and the involved actors, the overall maintenance planning process can be divided into different planning levels, as depicted in Figure 3. The objectives of the various planning levels are reported in Table *3*.

In modelling the SDP maintenance process, as described in the following chapter, two maintenance-planning levels are addressed:

- A long-term planning level, which corresponds to an "annual plan" functionality.
- A short-term planning level, which represents the detailed maintenance plan functionality.

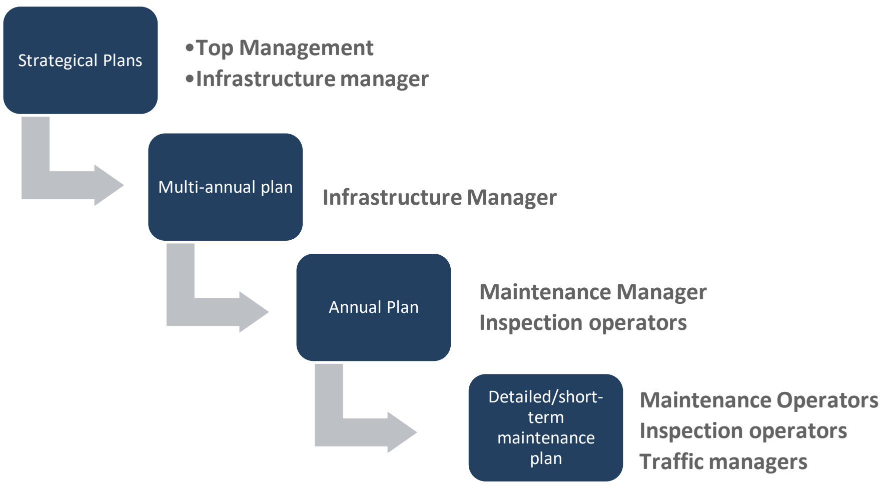

Figure 3. Maintenance planning levels

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Table 3. Maintenance planning levels and involved actors

Planning level	Function	Involved actors
Strategical	Definition of budget allocated to maintenance interventions	Top Management Infrastructure Manager
Multi-annual	Budget subdivision to different maintenance activities/assets, taking into account the total available budget	Infrastructure Manager
Annual	Maintenance activities definition according to survey results.	Maintenance Manager Inspection operators
Detailed/Short-term maintenance plan	It is defined as CRONOPROGRAMMA LAVORI and consists of planning lane reduction and deviation construction sites. This schedule is reviewed monthly and confirmed weekly according to constraints such as compatibility with traffic and other works. Minor variations 5-6% from the predefined budget are acceptable.	Maintenance operators Inspection operators Traffic managers

2.2.3 Current process modelling

Within Task 1.3, the current SDP maintenance process has been analysed and modelled through a Business Process Modelling Notation (BPMN). As mentioned, the analysis is conducted considering two primary planning levels: long-term and short-term planning.

Figure *4* shows the BPMN model of the SDP current process for long-term maintenance planning. Then, a description of each element of the BPMN model is included in Table *4*.

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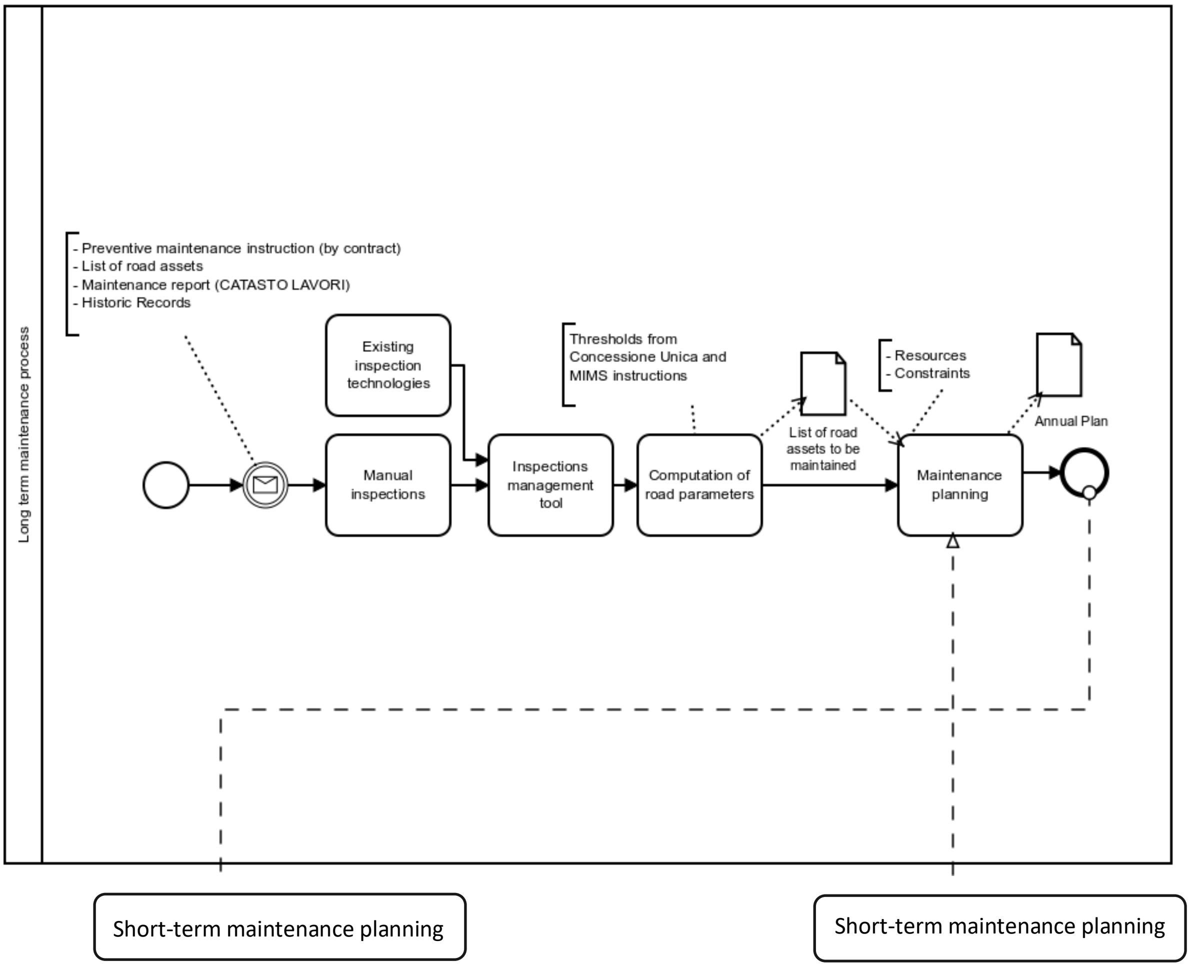

Figure 4. BPMN model of current SDP process for long-term maintenance planning

Table 4. Description of BPMN model of the current process for long-term maintenance planning

Existing inspection technologies	
This block includes all the existing monitoring technologies applied by SDP for collecting information about road infrastructure status.	
Input data	**Output data**
Inspection frequency by Contract	Raw data about road status
Function name	**Function description**
Data collection	Collection of data about road status parameters

Manual inspection
This block represents the visual inspections performed by SDP operators on road assets such as pavement, bridges and tunnels.

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Input data	Output data
Inspection frequency by Contract Instruction from SDP internal regulation	Checklist and images about infrastructure status
Function name	**Function description**
Data collection	Collection of data about road status parameters

Inspection management tool	
This module represents the inspection management tool able to notify and report inspection activities	
Input data	**Output data**
Inspection frequency	Inspection report
Function name	**Function description**
Inspection management	Inspection activities are planned and reported

Computation of road parameters	
This module aims to evaluate specific road parameters starting from the raw data.	
Input data	**Output data**
Raw data collected by existing, manual	Evaluation of road parameters about road infrastructure status
Function name	**Function description**
Data pre-processing	The raw data are pre-processed to evaluate the main road parameters according to current legislation

Maintenance planning	
The operator performs the planning of maintenance interventions	
Input data	**Output data**
Priority	Maintenance plan
Function name	**Function description**
Planning	The maintenance is planned according to the operational constraints

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Figure *5* shows the BPMN model of the current SDP process for short-term maintenance planning. The considered building blocks are described in Table *5*.

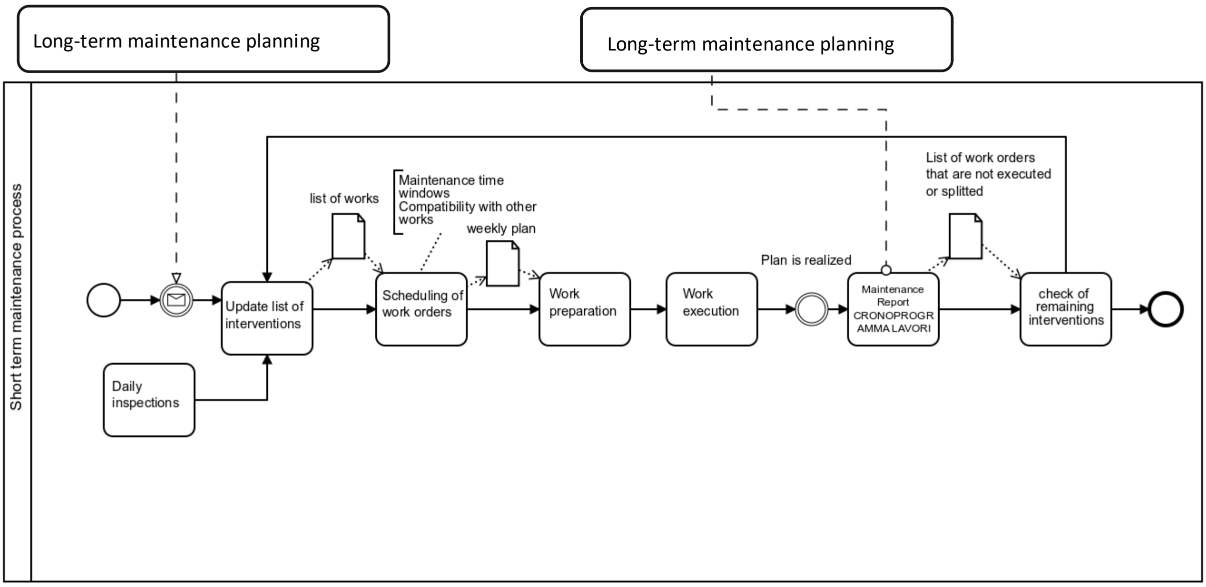

Figure 5. BPMN model of current SDP process for short-term maintenance planning

Table 5. Description of BPMN model of the current process for short-term maintenance planning

Daily inspection	
This block represents the inspections conducted every day by SDP personnel	
Input data	**Output data**
-	New data about infrastructure status
Function name	**Function description**
Data update	Collection of updated information about road infrastructure
Update list of intervention	
The operator updates the list of maintenance activities	
Input data	**Output data**
Road condition	List of interventions to be performed
Function name	**Function description**

Work orders update	If the new information about road assets makes intervention necessary, the list of work orders is updated

Scheduling	
The operator defines the detailed planning of maintenance activities	
Input data	**Output data**
List of interventions Constraints Resources availability	Weekly maintenance plan
Function name	**Function description**
Scheduling	The detailed plan is generated according to the operational constraints such as the compatibility with other maintenance works, the time constraints and the available resources

Work preparation	
The maintenance team prepares the construction site	
Input data	**Output data**
Maintenance plan	-
Function name	**Function description**
Construction site preparation	The construction site is prepared according to the detailed plan of work orders.

Work execution	
The maintenance team performs the activity	
Input data	**Output data**
Activity to be executed	-
Function name	**Function description**
Maintenance, upgrade or renewal	Execution of maintenance, upgrade or renewal activity

Maintenance report

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The maintenance team reports the executed activities	
Input data	**Output data**
Progress in activity execution	Report
Function name	**Function description**
Reporting	The progress in maintenance execution is reported, and any deviation from the plan is communicated

Check of remaining interventions	
The maintenance team communicates the non-executed or partially executed activities	
Input data	**Output data**
Maintenance report	List of non-executed activities
Function name	**Function description**
Work orders update	The non-executed activities are reconsidered in the planning

2.3 Identification and collection of available data

2.3.1 Available data

This section describes the available data from the Final Demonstrator (Strada dei Parchi), focusing on its structure and volume. This analysis will provide a general review, which aims to be useful for future developments in WP5 and the demonstration in WP6.

The data is referred to the A-24 and A-25 motorways, from kilometre 7.250 to kilometre 159.000 in A-24, and from kilometre 73.000 to kilometre 186.500 in A-25. A differentiated section of the A-24 called TPU (Road Section of Urban Penetration) covers from kilometres 7.250 to kilometres 0. The ramps A24-A25 and A25-A24 and the coplanar roads (C1, C2, C3 and C4) are also considered in the datasets. The data is divided depending on the section and the traffic direction. The information is in some cases categorised depending on their belonging to the fast or the regular lane.

As a summary, the information provided for exploration in OMICRON includes:

- The list of highway assets.
- The description of maintenance procedures.
- Measurements of mechanical properties for FWD (Falling Weight Deflectometer).
- Measures from high-performance surveys including SFC, IRI and PDF.
- The maintenance portfolio (Catasto Lavori), i.e. a database of the executed maintenance where the interventions are registered after their execution.

This information will be considered throughout the project, particularly in the final demonstrator.

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2.3.2 Road pavement data

2.3.2.1 Road pavement parameters

This section presents the definition of the main road pavement parameters and thresholds currently used in the maintenance procedures of Strada dei Parchi in the A-24 and A-25 highways.

- **SFC**. Sideway Force Coefficient. This coefficient characterizes the skid resistance of the surface in the transversal direction of a road, expressed as the ratio between the force (N) perpendicular to the rotation of a wheel and the normal reaction (R) of the road surface under the wheel load.

Table 6. SFC acceptance limits

SFC Thresholds	Pavement condition
SFC > 50	Good
50 > SFC > 40	Sufficient
40 > SFC	Insufficient
35 > SFC	Critical

- **IRI.** International Roughness Index, a standardized index that provides a standard scale of measuring evenness.

Table 7. IRI acceptance limits

IRI Thresholds	Pavement condition
IRI <= 2 mm/m	Good
IRI >= 3 mm/m	Critical

- **Category Class**. SFC and IRI measurements are grouped in Category Classes from A to E for IRI and A to F for SFC to plan pavement maintenance. The goal is to keep the road sections above class C. The thresholds for this categorisation are shown in Table 8 and Table *9*:

Table 8. Category class threshold for IRI parameter

Category class	Parameter threshold
Class A	IRI ≤ 1.3
Class B	1.3 < IRI ≤ 2

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Class C	2 < IRI < 2.5
Class D	2.5 < IRI ≤ 3
Class E	IRI > 3

Table 9. Category class threshold for SFC parameter

Category class	Parameter threshold
Class A	SFC ≥ 70
Class B	60 ≤ SFC < 70
Class C	50 ≤ SFC < 60
Class D	40 ≤ SFC < 50
Class E	30 ≤ SFC < 40
Class F	SFC < 30

- **I_{pav}**. Index of road pavement condition. This index is calculated as follows:

$$I_{pav} = 0.6\, I_{a1} + 0.4\, I_{a2}$$

where:

- **I_{a1}** and **I_{a2}**. are parameters calculated using the percentages of each category class of SFC and IRI. They are used to calculate I_{pav}.

$$I_{a1}\ e\ I_{a2} = \%A + 0.75\ \%B + 0.5\ \%C + 0.25\%D$$

- **Deflections**. Deflections are used to calculate elastic modules:
  - **E_0** is representative of the overall state of the pavement.
  - **E_1** corresponds to the top layer of the bituminous conglomerate.
  - **E_2** corresponds to the intermediate layer of foundation (in the granular mix).
  - **E_3** corresponds to the substrate of infinite thickness.

- **Remaining useful life.** The residual life is measured in years for the different layers or the most critical layer. It is calculated based on SFC and IRI results. For a pavement to be considered flexible, it must satisfy the thresholds of Table 10.

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Table 10. Flexible pavement thresholds

Parameter	Threshold
E_1 20 ºC	> 3000 MPa
E_2	> 250 MPa
E_3	> 70 MPa
Residual Life	> 5 years

Other pavement parameters provided are:

- **MDP**. This parameter defines the mean profile depth.
- **H1.** Layer thickness of bituminous conglomerate.
- **H2.** Layer thickness of foundation.
- **SCI.** Surface curvature index.
- **BDI.** Base damage index.
- **BCI.** Base curvature index.
- **Overlay.** Theoretical fatigue reinforcement to withstand project traffic for ten years.

2.3.2.2 Parameter measurement

SFC measurement with SCRIM equipment

SFC reliefs are carried out with specific equipment (SCRIM machine), consisting of a truck with a wheel on it at pressure inflation of 350 kPa (3.5 kgf/cm^2) positioned with a 20° degrees-angle to the motion direction and loaded with a hanging mass of 200 kgf.

The test is conducted in wet conditions, where special equipment supplies water related to the vehicle speed to ensure a layer of water of a constant thickness higher than 0.5 mm. When the wheel, controlled by a hydraulic system and suitably orientated, is placed on the road pavement, an orthogonal force to the rolling plane, corresponding to the transverse component grip, is generated in correspondence with the contact area. Pressure transducers detect the force. Compared to the normal force on the measuring wheel, this force provides the value of the SFC.

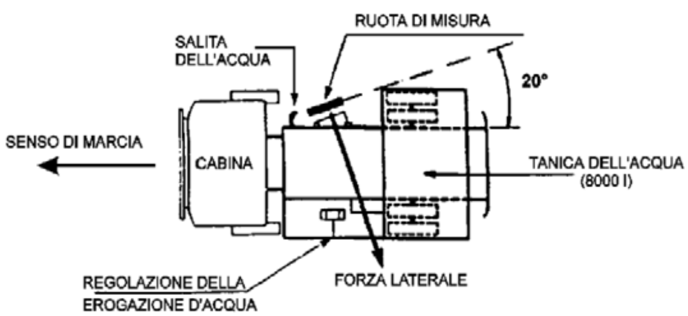

Figure 6. SFC measurement scheme.

The value of SFC is corrected according to current legislation C.N.R. B.U. 147 of 1992, to consider the pavement temperature and vehicle speed.

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IRI (International Roughness Index) measurement with laser PROFILOMETER

The IRI parameter indicates the road roughness defined as the variation in altitude-related to a flat surface. This roughness induces vibrations to vehicles affects driving comfort, operating costs and user safety. The measurements are made with a laser profilometer using the American standard ASTM E1926-08 as reference.

PDF (Pavement Marking Retroreflectivity)

SDP remakes pavement marking twice a year according to contractual constraints (Concessione Unica), so the retro-reflectivity parameter is not used for maintenance planning.

FWD (Falling Weight Deflectometer)

The mechanical properties of pavement are measured with a dynamic deflectometer to simulate the real heavy traffic condition. It is used for defining the residual service life of the pavement. SDP applies this method only to a few highway sections and cannot plan annual maintenance.

Deflections

Deflection measurements provide nine deflections (µm). They are measured through accelerometric transducers and are used by the software R.O.M.E. to calculate the elastic modules.

2.3.2.3 Exploratory Data Analysis

The main data sources used by SDP for decision-making are stored in different types of files addressing both A-24 and A-25 motorways. These include .kml files, maps, written documents and excel files.

The **motorways assets** are completely defined, indicating the position of viaducts, overpasses, tunnels, service areas, payment stations and operational sections. Furthermore, related written reports are documented:

- An inspection and monitoring database that explains the information related to I_a, SFC and IRI calculations.
- Maintenance documents that describe the methodologies used for the ordinary and specific maintenance interventions.
- The Falling Weight Deflectometer (FWD) documents, which includes the essays performed in both directions of certain sections of A-24 for 2018, 2019 and 2020.

The **Falling Weight Deflectometer (FWD)** data is provided for different years. The 2013 files cover the whole motorways in every direction and gather information, approximately every 200 meters, excluding particular sections, about deflections, elastic modules (E_0, E_1 20ºC, E_1, E_2, E_3), deflection basin parameters (SCI, BCI, D_1) and residual life (bituminous conglomerate, substrate and foundation). The 2018 and 2019 files contain charts with latitudes and longitudes, E_1, E_1 20 ° C, E_2, E_3, E_0, the surface temperature, the residual life of the most critical layer, and the overlay for different measurement points located every 200 meters for one section of A-24 in both directions. The 2020 files cover one section of A-24 in both directions providing information about H_1, H_2, E_0, E_1, E_1 20ºC, E_2, E_3, temperature, surface temperature, residual life, overlay, stress and deflections. The volume of data available for these parameters is shown in Table *11*.

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Table 11. Volume of data for elastic modules and residual life parameters

	Direction	Progressive location [km]	Volume of data including Elastic modules, residual life and overlay
2018	Increasing	From 0 to 18.195	92
	Decreasing	From 0 to 18.400	73
2019	Increasing	From 0 to 22.895	86
	Decreasing	From 0 to 22.389	86
2020	Roma-Teramo	From 61.270 to 79.600	78
	Teramo-Roma	From 80.000 to 62.000	78

Furthermore, the available information about **SFC and IRI parameters** is gathered for 2020. These datasets are defined for every section and direction of both motorways, including ramps A25-A24, A24-A25 and coplanar roads C1, C2, C3 and C4. In the SFC information, there are measurements of the following items:

- Kilometric points.
- SFC value per cent.
- SFC value corrected.
- MDP value per cent.
- Speed.
- External temperature and pavement temperature.
- A column that indicates whether the measurement is potentially unreliable.
- A column that specifies any known characteristics of particular events encountered measured every 10 km.

Likewise, in the IRI information, there are measurements of the following items:

- Kilometric point.
- IRI values in the left and right sides in percentage.
- A column specifying any known characteristics of particular events encountered measured every 20 km.

Other sources of data measured by SDP include the same parameters gathered related to their coordinates in two different coordinates systems: UTM and Gauss Boaga.

All in all, the volume of historical data available for IRI and SFC parameters is shown in Table *12*.

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Table 12. The volume of data for SFC and IRI parameters

			Progressive location [km]	SFC [volume of data]	IRI [volume of data]
Normal Lane	TPU	TPU A24-4	From 7.260 to 0	725	362
		TPU A24-1	From 0 to 7.260	725	362
	A24	A24-1	From 0 to 72.000	7200	3599
		A24-4	From 72.000 to 0	7200	3599
		A24bis-1	From 72.000 to 158.990	8699	4348
		A24bis-4	From 158.990 to 72.000	8699	4348
	A25	A25-1	From 72.000 to 186.000	11400	5700
		A25-4	From 186.000 to 72.000	11400	5700
	Ramps	A24-A25	From 0 to 1.700	170	84
		A25-A24	From 0 to 1.840	184	91
	Coplanar	C1	From 7.100 to 0	710	354
		C2	From 0 to 7.100	709	354
		C3	From 0 to 2.900	289	144
		C4	From -2.100 to 0	200	104
Fast Lane	TPU	TPU A24-3	From 7.260 to 0	726	362
		TPU A24-2	From 7.260 to 0	726	362
	A24	A24-2	From 0 to 72.000	7200	3599
		A24-3	From 72.000 to 0	7200	3599
		A24bis-2	From 72.000 to 158.990	8699	4348

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		A24bis-3	From 158.990 to 72.000	8699	4348
	A25	A25-2	From 72.000 to 186.000	11400	5699
		A25-3	From 186.000 to 72.000	11400	5699
	Ramps	A24-A25	From 0 to 1.700	84	170
		A25-A24	From 0 to 1.840	91	184
	Coplanar	C1	From 7.100 to 0	702	354
		C2	From 0 to 7.100	710	354
		C3	From 0 to 2.900	290	144
		C4	From -2.100 to 0	210	104

The SFC and IRI parameters are divided into homogeneous sections, depending on SFC and IRI classes. This information can be gathered in different ways: showing the values of the parameters for every location and in graphical schemes indicating with different colours the classes along the motorways lengths and showing for every homogeneous section the statistic values of media, standard deviation and the variation coefficient. The number of homogeneous sections generated for these parameters is shown in Table *13*.

Table 13. Number of homogeneous sections created for SFC and IRI parameters

	Number of homogeneous sections	
Normal lane	**SFC**	**IRI**
TPU_A24-1	5	8
TPU_A24-4	6	6
A24-1	18	28
A24-4	14	25
A24bis-1	27	26
A24bis-4	18	30
A25-1	29	13
A25-4	15	25

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Fast lane	SFC	IRI
TPU_A24-2	7	4
TPU_A24-3	9	4
A24-2	28	19
A24-3	24	22
A24bis-2	20	22
A24bis-3	25	23
A25-2	35	19
A25-3	30	40

The I_{a1} and I_{a2} parameters needed to calculate I_{pav} are calculated following the datasets previously defined (I_{a1} using the SFC parameters and I_{a2} the IRI parameters). For every section and direction, the road position, measured position, SFC and IRI categories A, B, C, D, E and F (in percentage) calculate the average value and I_{a1} and I_{a2}. A global I_{a1} and I_{a2} are calculated for every section considering both directions. Global I_{a1} and I_{a2} for the whole network are also calculated.

2.3.3 Maintenance data of structures (Viaducts and tunnels)

The health control of structures (viaducts and tunnels) by SDP is entrusted to a qualified team that performs the procedures compliant with Circulars no. 6736 of 07/19/1967, n. 34233 of 02/15/1991 of Ministry of Public Works and subsequent amendments (following the Italian legislation). The procedure implemented is the Numerical Evaluation Method (MVN). The MVN preliminarily catalogues all the possible defects that may arise, specifically in so-called "defect cards". Following the visual inspections, the found defects are reported in the evaluation sheets, reported in Table 14.

Table 14. Defect card for viaducts

Defect Code	Defect description	seen	G	K1			K2			Nº photo	PS	NA	NR	NP	Notes
				0.2	0.5	1	0.2	0.5	1						
	Passive damp spots														
	Active damp spots														
	Traces of drainage														
	Washed out/ sick CIS														
	Stagnant water														
	Crawl spaces														
	Detachment of the concrete cover														

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Defect Code	Defect description	seen	G	K1			K2			Nº photo	PS	NA	NR	NP	Notes
				0.2	0.5	1	0.2	0.5	1						
	Oxidized/corroded armour														
	Modest web injuries														
	Horizontal crack														
	Vertical crack														
	Diagonal crack														
	Pillar injury attack														
	subsequent shots deteriorated														
	Impact damage														
	Out of lead														
	Undermining														
	Washout of the embankment														
	Unevenness of the embankment - deformations														
	Failure of the embankment - stability														
	foundation movements														
	Crush injuries														
	Characteristic injuries of the support areas														
Possible notes															

In this process, a level of defectiveness is assigned for each defect. The evaluation forms are prepared for each structural element and type of material and provide a final number correlated with the overall state of degradation.

Relative Defectiveness (DR, Italian abbreviation). This parameter is defined as the deterioration level of each structural element, calculated as follows.

$$D_R = \sum (G \cdot K_1 \cdot K_2)$$

Absolute Defectiveness (DA, Italian abbreviation). This parameter is the sum of the defects of each structural element.

$$D_A = \sum (N \cdot \ G \cdot K_1 \cdot K_2)$$

Where G is the severity index (1 to 5), and K_1 and K_2 are the extents and intensity coefficients (0.2 - 0.5 - 1.0).

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2.4 Identification of new functionalities

This section proposes an enhanced maintenance process represented via a Business Process Model and Notation (BPMN), following the current state of work in sections 2.1 to 2.3. Starting from the current status described in Section 2.2.3 and proposing new functionalities connected to the OMICRON technologies and solutions applied to the final demonstrator in Italy, the BPMN model depicted in Figure 7 is built.

Namely, the identified improvements are related to the following topics:

- Data collection and monitoring.
- Decision-support.
- Maintenance execution.

A table summarises the new functionalities developed by OMICRON, and the related improvements are reported together with the relevant details for each topic.

The new functionalities for data collection and monitoring are described in Table 15.

Table 15. New functionalities for data collection and monitoring

Current monitoring devices
The currently applied monitoring devices can be distinguished according to the type of performed inspection in: • Diagnostic vehicles running at 80 km/h, used to perform the annual surveys without requiring road interruption. • Traditional vehicles used during the daily inspections by CSA operators for moving along the network, stopping in particular highway points if a defect is detected. Also, in this case, no road section interruption is required.
Improvement by OMICRON
The main improvements expected from OMICRON technologies are: • The automated data collection with a reduction of human effort in performing the visual inspection. • The collection of a new additional type of data by Innovative Vehicle Inspection Technologies UC1 (WP2).
Related Use Cases
The related OMICRON Use Cases are: • UC1.1 UAV inspection of roads. • UC1.2 Automated inspection via a terrestrial vehicle at standard traffic speeds.
Main Advantages
The main benefits that can be achieved through the new technologies are: 1. Long-range capability and wider road area covered during the inspection. 2. Support in the computation of IRI and friction and deflection coefficients. 3. Innovative sensor combination for an enhanced asset capture.

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The new functionalities for decision support are reported in Table *16*.

Table 16. New functionalities for decision support

Current available tools
The currently applied tools to support road operators can be distinguished in tools applicable during the inspection or planning phases. During the high-performance survey, the raw data collected from the surveys are automatically recorded and elaborated to extract the average trend used to define the maintenance plan manually. During the daily inspections, the staff of CSA (Centro Sicurezza Autostradale), which travels every day along the network checking the infrastructure status, is provided with the ROAR application (commercially used by SDP). This application allows assigning the pavement defect photo the exact location and a specific defect code. In the planning phase, a decision is made by the maintenance manager without automated support. Existing tools are usually designed to model the status of urban road infrastructure and are not easily applicable to highways.
Improvement by OMICRON
The main improvements expected from OMICRON technologies are automated data analysis and Decision support using AI techniques (DT and DST from UC6).
Related Use Cases
The related OMICRON Use Cases are: • UC6.1 Road digital twin. • UC6.2 Road decision support tool.
Main Advantages
The main benefits that can be achieved through the new technologies are: • A Digital Twin of road infrastructure that includes data on infrastructure status. • A DST that supports the planning of road maintenance interventions.

The new functionalities for maintenance execution are described in Table 17.

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Table 17. New functionalities for maintenance execution

Current execution
Current execution usually consists of a manual execution performed by the operator on the field.
Improvement by Omicron
The improvement expected from OMICRON is the automated execution by Robotic Technologies (UC2 and UC3 [WP3-WP4]) with the possibility of controlling by remote the technology via Virtual and Augmented reality tools.
Related Use Cases
The considered Use Cases are • UC2.1. Robotic Modular Platform. • UC3.1. Signalling during construction works. • UC 3.3. Removal of lane markings with laser. • UC 5.1. VR platform. • UC 5.2. AR tools.
Main Advantages
The main expected benefits will be: • Robotised installation of safety barriers. • Robotised installation of cones. • Automated cleaning of signals. • Robotised installation of construction signalling. • Automation of the removal of lane marking. • Remote control of robotic facilities, avoiding hazardous situations. • Increase in the information available for the road worker.

According to the identified new functionalities, a new maintenance framework is built and represented by the BPMN model depicted in Figure *7.*

Also, in this case, two planning levels are considered: the long-term and the short-term planning with their reciprocal links.

The main building blocks are described in Section 2.4.1 and Section 2.4.2 for the long-term and the short-term planning, respectively.

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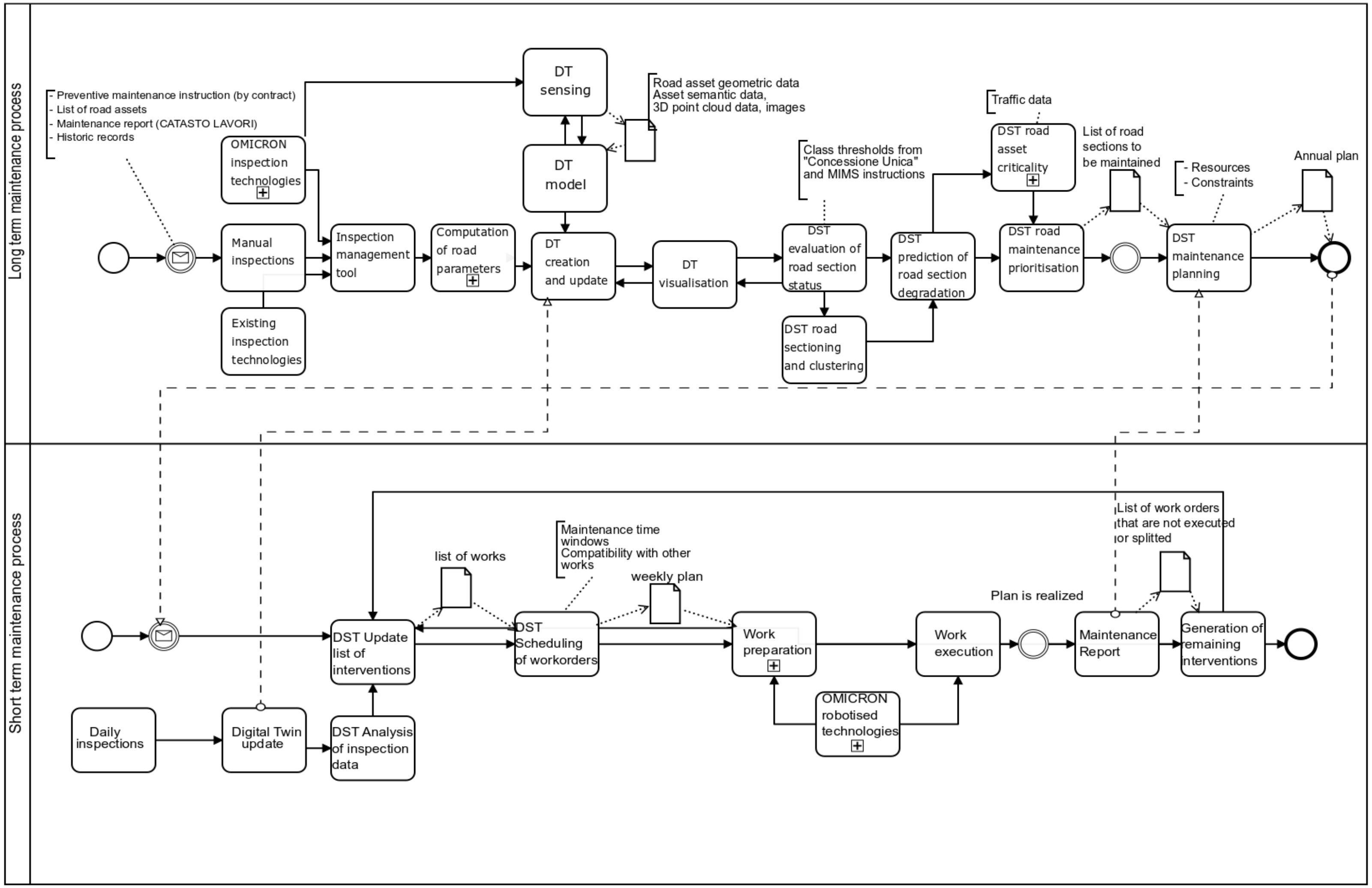

Figure 7. BPMN model of OMICRON maintenance framework

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2.4.1 Long-Term Planning

In this section, regarding Figure 7, the building blocks of the long-term planning framework are reported, considering four main phases:

- The inspection phase (Table *18*).
- The digital twin (Table *19*).
- The Decision Support Tool - asset status evaluation (Table *20*).
- Decision Support Tool - planning (Table 21).

Table 18. Inspection phase

Existing inspection technologies	
This block includes all the existing monitoring technologies applied by SDP for collecting information about road infrastructure status.	
Input data	**Output data**
Inspection frequency by Contract	Raw data about road status
Function name	**Function description**
Data collection	Collection of data about road status parameters
Manual inspection	
This block represents the visual inspections performed by SDP operators on-road assets such as pavement, bridges and tunnels.	
Input data	**Output data**
Inspection frequency by Contract Instruction from SDP internal regulation	Checklist and images about infrastructure status
Function name	**Function description**
Data collection	Collection of data about road status parameters
OMICRON Inspection technologies	
This block represents the new inspections technologies developed by OMICRON WP2	
Input data	**Output data**
Inspection frequency by Contract	New data about road status
Function name	**Function description**

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Data collection	Collection of data about road status parameters using UAVs and terrestrial vehicles
Inspection management tool	
This module represents the inspection management tool (supporting the manual inspections, existing inspection technologies, UAV and terrestrial vehicles) able to notify and report inspection activities	
Input data	**Output data**
Inspection frequency	Inspection report
Function name	**Function description**
Inspection management	Inspection activities are planned and reported
Computation of road parameters	
This module aims to evaluate specific road parameters starting from the raw data.	
Input data	**Output data**
Raw data collected by existing, manual and OMICRON technologies	Evaluation of road parameters about road infrastructure status
Function name	**Function description**
Data pre-processing	The raw data are pre-processed to evaluate the main road parameters according to current legislation

Table 19. Digital Twin phase

DT Sensing	
This module represents the Digital Twin sensors and perception systems installed to collect geometric and position data about road infrastructure to get 3D points	
Input data	**Output data**
-	3D points
Function name	**Function description**
Digital Twin creation	Providing data to build the 3D BIM model
DT model	

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This module aims to build a tridimensional (or bidimensional) model of the road infrastructure using BIM, GIS or other standards.	
Input data	**Output data**
Geometrical data, 3D point clouds	Representation of road assets (3D or 2D)
Function name	**Function description**
Digital Twin creation	Use geometric and position data to build the DT model

DT creation and update	
This module is responsible for populating the digital twin with data about road status	
Input data	**Output data**
Input from inspections and DST	Data to be visualised
Function name	**Function description**
Digital Twin population	Data about road infrastructure are used to populate the DT

DT visualization	
This module is responsible for the visualization of digital twin information	
Input data	**Output data**
Input from inspections and DST	-
Function name	**Function description**
Visualisation	Visualisation of infrastructure model and infrastructure status

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Table 20. Decision Support Tool - Asset status evaluation

DST Evaluation of road status	
This module is aimed at evaluating road asset status through the application of AI methodology	
Input data	**Output data**
Data from DT	Information on road status
Function name	**Function description**
Road status evaluation	Evaluation of current and future infrastructure status

DST road sectioning	
This module performs the sectioning and clustering of road assets/sections according to their status	
Input data	**Output data**
Data about asset status	Clusters of road assets
Function name	**Function description**
Road assets clustering	Grouping road assets according to their status

DST prediction	
This module performs the prediction of degradation trends	
Input data	**Output data**
Data about asset status	Degradation trend
Function name	**Function description**
Road status prediction	Prediction of future infrastructure status

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Table 21. Decision Support Tool - Planning

DST road criticality	
This module evaluates the impact of road assets failure on road network performances	
Input data	**Output data**
Road traffic data	Performance parameters
Function name	**Function description**
Impact evaluation	The impact of road section closure on traffic is evaluated

DST priorisation	
This module is responsible for the prioritization of maintenance activities.	
Input data	**Output data**
Road status Road asset criticality	The ordered list of intervention
Function name	**Function description**
Ordering	The list of maintenance interventions is prioritised according to asset status and criticality

DST planning	
This module performs the planning of maintenance interventions	
Input data	**Output data**
Priority	Maintenance plan
Function name	**Function description**
Planning	The maintenance is planned according to the operational constraints

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2.4.2 Short Term-planning

In this section, regarding Figure 7, the building blocks of the short-term planning framework are described.

Table 22. Short-term planning building blocks

Daily inspection	
This block represents the inspections conducted every day by SDP personnel.	
Input data	**Output data**
-	New data about infrastructure status
Function name	**Function description**
Data update	Collection of updated information about road infrastructure
DT updates	
This module is responsible for the update of DT data.	
Input data	**Output data**
Data from daily inspection	Pre-processed data for DST
Function name	**Function description**
DT updates	The newly available data populate the DT
DST analysis of new data	
This module performs the analysis of newly collected data.	
Input data	**Output data**
Data from DT	Road condition
Function name	**Function description**
Data analysis	The information about road status is updated according to the newly available information
DST update list of intervention	
This block performs the update of the list of maintenance activities.	

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Input data	Output data
Road condition	List of interventions to be performed
Function name	**Function description**
Work orders update	If the new information about road assets makes intervention necessary, the list of work orders is updated

DST scheduling	
This module is responsible for the detailed planning of maintenance activities.	
Input data	**Output data**
List of interventions Constraints Resources availability	Weekly maintenance plan
Function name	**Function description**
Scheduling	The detailed plan is generated according to the operational constraints such as the compatibility with other maintenance works, the time constraints and the available resources

Work preparation	
The construction site is prepared thanks to the OMICRON Robotic Modular platform.	
Input data	**Output data**
Maintenance plan	-
Function name	**Function description**
Construction site preparation	The construction site is prepared according to the detailed plan of work orders.

Work execution	
The OMICRON robotic maintenance platform performs the activity.	
Input data	**Output data**
Activity to be executed	-

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Function name	Function description
Maintenance, upgrade or renewal	Execution of maintenance, upgrade or renewal activity

OMICRON robotised technologies	
OMICRON robotised modular platform performs some activities necessary for the construction site preparation and the maintenance execution.	
Input data	**Output data**
Activity to be executed	-
Function name	**Function description**
Automated preparation and execution	The robotised platform performs the activities remotely controlled by the operator thanks to VR and AR tools

Maintenance report	
This module is responsible for reporting the executed activities.	
Input data	**Output data**
Progress in activity execution	Report
Function name	**Function description**
Reporting	The progress in maintenance execution is reported, and any deviation from the plan is communicated

Identification of remaining interventions	
This module is responsible for reporting the non-executed or partially executed activities.	
Input data	**Output data**
Maintenance report	List of non-executed activities
Function name	**Function description**
Work orders update	The non-executed activities are reconsidered in the planning

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3 Demonstration Methodology

This chapter presents detailed information addressing each stage of the demonstration in OMICRON, considering all the different activities that will be carried out, the different technologies that will be tested and the different boundary conditions.

On Stage 1, the inspection, emergency, and standard intervention technologies developed in OMICRON will be tested safely in controlled but real environments at TRL5, using dedicated laboratory or partners' facilities.

On Stage 2, four demonstrators will cooperate in the testing and deployment of the several OMICRON solutions:

- Technical Demonstrator 1 (TD1). The modular solution for bridge overpasses will be tested via: (1) an in-lab analysis (TRL5) of a scaled model of the connections that will be designed to link the different components and (2) a virtual demonstrator.
- Technical Demonstrator 2 (TD2). The demonstration of pavement inspection methodologies and V2I communications will be performed at the A-2 in Spain, which is part of the CEF Atlantic Corridor (TRL7).
- Technical Demonstrator 3 (TD3). Pavement rehabilitation and maintenance technologies will be demonstrated at the A-92 in Spain as part of the Mediterranean corridor (TRL7).
- Technical Demonstrator 4 (TD4). The demonstration of the crack sealing technology developed in OMICRON will be executed at the A-7 in Spain, which is part of the Mediterranean CEF corridor (TRL7).

On Stage 3, the final demonstration of OMICRON's Intelligent Platform at TRL 7 will showcase both in-field and digital technologies. It will be performed at the A24 in Italy as part of the Scandinavian-Mediterranean CEF Corridor. There will be a possibility to test specific assets (such as tunnels and viaducts) under natural traffic conditions. This demonstrator will include the DT and the DST, inspection technologies, and robotic developments in OMICRON. It will also be fed with information from the testing phase and the technical demonstrators.

The following table shows a complete overview of the several Use Cases already identified within Deliverable D1.1 "*Functional and technical requirements of OMICRON technologies*", together with the different stages where these Use Cases will be developed or tested.

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Table 23. Use Cases versus Demo Stages Matrix

					STAGE 1	STAGE 2				STAGE 3
Cluster UC	**UCs**	**Brief Description**	**UC Type**	**Leader**	**IN-LAB**	**TD1**	**TD2**	**TD3**	**TD4**	**Final Demo**
UC1. Inspection, V2X and User Support	**UC1.1**	UAVs: Management tool	HL-UC	USE	√					√
	UC1.1.1	UAV Long range inspections	D-UC	CAT	√					√
	UC1.1.2	Multi-UAV inspection	D-UC	USE	√					√
	UC1.2	Terrestrial inspection vehicle	HL-UC	IND	√		√			√
	UC1.2.1	Innovative sensor combination	D-UC	UOC	√		√			√
	UC1.2.2	Automation of auscultation process	D-UC	IND	√		√			√
	UC1.3	V2X communications	D-UC	IND	√		√			√
UC2. Routine and Emergency Maintenance Interventions	**UC2.1**	Robotic modular platform	HL-UC	TEK	√				√	√
	UC2.1.1	Installation of safety barriers	D-UC	TEK	√					√
	UC2.1.2	Installation of cones	D-UC	TEK	√					√
	UC2.1.3	Road assets cleaning	D-UC	TEK	√					√
UC3. Extraordinary Maintenance Interventions	**UC3.1**	Signalling during construction works	D-UC	CEM	√					√
	UC3.2	Sealing of surface pavement cracks	D-UC	PAV	√				√	
	UC3.3	Removal of lane markings with laser	D-UC	PAV	√					
	UC3.4	Rehabilitation of surface pavement layers	D-UC	EIF				√		
UC4. Bridge Modularisation		Modular construction for bridges	D-UC	TDU		√				
UC5. Road Personnel Support	**UC5.1**	VR platform for robot teleoperation	D-UC	LMS	√				√	√
	UC5.2	AR tools for worker support	D-UC	LMS	√		√		√	√
UC6. Predictive Maintenance	**UC6.1**	Road digital twin	D-UC	UOC			√			√
	UC6.2	Road decision support tool	D-UC	CEM	√					√

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3.1 Stage 1 Protocol - In-Lab Testing

Stage 1 Protocol is defined in this sub-section, following the information provided in Deliverable D1.1. The data mainly relates to activities foreseen in laboratory conditions or partners' premises. This will provide a TRL 5 testing baseline for some technologies, providing information to the next demonstration stages.

The information is presented in a tabular format to facilitate readability and provide concise information on a use case basis.

UC1.1. UAVs Management tool

Stage 1 Protocol	UC1.1. UAVs Management tool
Objective	The main goal is to test the developed technologies in a controlled scenario for multi-UAV and Beyond Visual Line Of Sight (BVLOS) operations, carrying out several tests to validate the different developments towards the final demonstrator.
Activities	• Configuration of Management Tool: site map and inspection resources. • Define different inspection missions: long-range and multi-UAV. • Execute inspection missions: select predefined inspection, upload trajectories to UAVs, launch inspection and monitor in real-time. • Collect data after UAVs have landed.
KPI	The following KPIs will be measured in the final demonstrator, but an estimation could be obtained during Stage 1 tests: • KPI 1 Exposure time of road workers and users to hazardous situations derived from inspection tasks should be reduced by 65%. • KPI 5 Traffic disruptions due to inspection tasks should be reduced by 50%. • KPI 9 Maintenance and inspection activity costs are reduced at least 10%.
Expected Outputs	Test report analysing UAVs Management Tool performance and usability.
Expected duration	Several experiments will be necessary to validate the developments, but the final test will be in ATLAS Experimental Flight Center during 3-4 working days.
Link with Stage 2	N.A.
Link with Stage 3	The maturity level of the developed technologies will be increased towards the final demonstrator.

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Stage 1 Protocol	UC1.1. UAVs Management tool
Boundary conditions	These boundary conditions do not apply to Configuration use case nor Retrieve Data use case but to Execution use Case. Applicable drone regulations will apply, but ATLAS facilities count with segregated airspace with an extension of 1,000 km^2 that will easily allow testing a long-range inspection scenario. OMICRON will apply to the STS-ES-02 standard scenario for the specific category of the European drone regulations regarding BVLOS operations with airspace observers over a controlled land area in a sparsely populated environment.
Constraints	Weather conditions may prevent carrying out the tests, so a plan for a 2-week campaign is planned to have alternative days for the actual testing.
Stakeholders to be involved	Technological partners: USE, CAT. Feedback will be requested from UOC regarding the inspection definition interface.
Authorization	ATLAS test centre has been booked for this demonstration.
Design specifications	All tests involving flights will be performed with the highest safety standards, activating the ground personnel's segregated airspace around ATLAS and IPEs. A safety pilot can take control of each UAV and terminate the flight in unexpected events.
Customization activities	N.A.

UC1.1.1. UAV Long range inspections

Stage 1 Protocol	UC1.1.1. UAV Long range inspections
Objective	The main goal is to test the developed technologies in a controlled scenario for Beyond Visual Line Of Sight (BVLOS) operations, carrying out several tests to validate the different developments towards the final demonstrator.
Activities	• To configure, execute and monitor an inspection mission. • To develop Detect&Avoid technologies for the UAV. • To collect data using onboard sensors.
KPI	KPIs will be measured in the final demonstrator.
Expected Outputs	The UAV will cover a long distance while maintaining safety during the inspection mission.

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Stage 1 Protocol	UC1.1.1. UAV Long range inspections
Expected duration	Several experiments will be necessary to validate the developments, but the final test will be in ATLAS Experimental Flight Center during a single day.
Link with Stage 2	N.A.
Link with Stage 3	The maturity level of the developed technologies will be increased towards the final demonstrator.
Boundary conditions	Applicable drone regulations will apply, but ATLAS facilities count with segregated airspace with an extension of 1,000 km^2 that will easily allow testing a long-range inspection scenario. The STS-ES-02 will be applied, a standard scenario for the specific category of the European drone regulations regarding BVLOS operations with airspace observers over a controlled land area in a sparsely populated environment.
Constraints	Weather conditions may prevent the tests, so we may plan a 1-week campaign to have alternative days for the actual testing.
Stakeholders to be involved	Technological partners: USE, CAT.
Authorization	ATLAS test centre has been booked for this demonstration.
Design specifications	All tests will be performed with the highest safety standards, activating the ground personnel's segregated airspace around ATLAS and IPEs. A safety pilot can take control of the UAV and terminate the flight in unexpected events.
Customization activities	N.A.

UC1.1.2. Multi-UAV inspection

Stage 1 Protocol	UC1.1.2. Multi-UAV inspection
Objective	The main goal is to test the developed technologies in a controlled scenario for multi-UAV operations, conducting several tests to validate the different developments.
Activities	Two different inspection missions will be performed to test the technologies: a simultaneous multi-view inspection of a vertical asset and a road inspection with a failing UAV replacement. Both missions will be configured and executed using the UAVs Management Tool. The vertical asset inspection will simulate a bridge inspection. ATLAS facilities include several buildings and power line towers that could be used as inspection targets.

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Stage 1 Protocol	UC1.1.2. Multi-UAV inspection
	 The road inspection mission will be performed using the ATLAS landing track as the inspection target.  The mission will be launched with two UAVs and, after one of them fails, a backup UAV takes over to complete the inspection mission. Once the missions are executed, onboard sensors data are collected.
KPI	The following KPIs will be measured in the final demonstrator, but an estimation could be obtained during Stage 1 tests: • KPI 1 Exposure time of road workers and users to hazardous situations derived from inspection tasks should be reduced by 65%. • KPI 5 Traffic disruptions due to inspection tasks should be reduced by 50%. • KPI 9 Maintenance and inspection activity costs are reduced at least 10%.
Expected Outputs	Test report analysing the performance of multi-UAV inspection missions.
Expected duration	Several experiments will be necessary to validate the developments, but the final test will be in ATLAS Experimental Flight Center during 3-4 working days.
Link with Stage 2	N.A.
Link with Stage 3	N.A.
Boundary conditions	Applicable drone regulations will apply, but ATLAS facilities count with segregated airspace with an extension of 1,000 km^2 that will easily allow testing a multi-UAV inspection scenario.
Constraints	Weather conditions may prevent the tests, so we may plan a 2-week campaign to have alternative days for the actual testing.
Stakeholders to be involved	Technological partners: USE, CAT.

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Stage 1 Protocol	UC1.1.2. Multi-UAV inspection
	Feedback will be requested from UOC regarding data gathered.
Authorization	ATLAS test centre has been booked for this demonstration.
Design specifications	All tests will be performed with the highest safety standards, activating the ground personnel's segregated airspace around ATLAS and IPEs. There will be a safety pilot for each UAV. The safety pilot can take control of the UAV and terminate the flight in unexpected events.
Customization activities	N.A.

UC1.2.2. Automation of auscultation process control of road parameters

Stage 1 Protocol	UC1.2.2. Automation of auscultation process control of road parameters
Objective	Initial testing of the algorithm for detecting the track position of an auscultation vehicle.
Activities	• Search for databases with video images showing the traffic lane lines. • Train the model to generate intelligence in the detection of traffic lane lines. • Generate a generic model for the detection of lane lines on any road.
KPI	Not applicable at this stage.
Expected Outputs	Algorithm for detection of road lane lines.
Expected duration	Each test will last about two working days, and it will be repeated as many times as needed during the duration of Task 2.3.
Link with Stage 2	The model created in phase one will be the basis for testing the phase 2 pilot environment.
Link with Stage 3	The model created in phase one will be the basis for testing the phase 3 pilot environment.
Boundary conditions	N.A.
Constraints	Lack of datasets. Different camera positions in the images collected during the first data collection campaigns.
Stakeholders to be involved	Just the partners involved in the development of the demonstrator (IND and its third parties PRO and IFT)

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Stage 1 Protocol	UC1.2.2. Automation of auscultation process control of road parameters
Authorization	Not needed
Design specifications	N.A.
Customization activities	N.A.

UC2.1. Robotic platform

Stage 1 Protocol	UC2.1. Robotic platform
Objective	Test the hardware and software of the prototype modular robotic platform, carrying out several tests of the different parts that make up the system.
Activities	- Robot arm. Execute movements - Power Supply and communication interfaces. Test that all elements are on and can communicate. - Tools. Test the change of tools and the operation of each tool - VR. Execute teleoperation - Perception system. Test the performance detecting several assets.
KPI	Not applicable at this stage.
Expected Outputs	Test report summarizing Robotic modular platform's performance and usability.
Expected duration	Each test will last about three working days and will be repeated as many times as needed during the duration of Task 6.3
Link with Stage 2	N.A.
Link with Stage 3	N.A.
Boundary conditions	N.A.
Constraints	N.A.
Stakeholders to be involved	Technological partners: TEK, LMS. Feedback will be requested from PAV and SDP.
Authorization	Not needed
Design specifications	All tests will be performed safely in a controlled environment, and IPEs are needed.

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Stage 1 Protocol	**UC2.1. Robotic platform**
	A mechanism will be included to stop the process immediately to avoid accidents.
Customization activities	N.A.

UC2.1.1. Installation of safety barriers

Stage 1 Protocol	**UC2.1.1. Installation of safety barriers**
Objective	Test the safety barrier installation assistance process in a controlled environment. Test that the robot picks the barrier, moves it close to the operator, and this operator adjusts the position by hand.
Activities	- Place the barriers in the specific position on the vehicle. - Execute the positioning procedure. - Videotape the experiments. - Fill in the operator satisfaction questionnaire: Safety and Usability.
KPI	- Execution time. - Operator acceptance.
Expected Outputs	Test report summarizing the results.
Expected duration	Each test will last about one working day and will be repeated as many times as needed during the duration of Task 6.3
Link with Stage 2	N.A.
Link with Stage 3	Real operators will do real barrier fixing in the poles
Boundary conditions	For the robot: ISO 10218-1, ISO 10218-2, ISO/TS 15066, ISO 12100, ISO 13849-1, ISO 13849-2, ISO 60204-1. For the headset: UL 8400, IEEE P2048.
Constraints	No real road maintenance operators. Weather conditions
Stakeholders to be involved	TEK. Feedback will be requested to PAV and SDP
Authorization	Not needed
Design specifications	All tests will be performed safely in a controlled environment, and IPEs are needed. A mechanism will be included to stop the process immediately to avoid accidents. All technologies will be tested separately and, finally, as a whole:

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Stage 1 Protocol	**UC2.1.1. Installation of safety barriers**
	- Vision system to detect the operator - Tool for handling the safety barrier - Trajectories performed by the robot AR system to provide info to the operator.
Customization activities	N.A.

UC2.1.2. Installation of cones

Stage 1 Protocol	**UC2.1.2. Installation of cones**
Objective	Test the placement and collection of cones process in a controlled environment. Identify the maximum velocity of the vehicle at which the robot can pick and place the cones with a specific success ratio.
Activities	- Select a relevant road scenario close to TEK. - Execute the positioning of the cones at different speeds. - Execute the removal of the cones at different speeds. - Videotape the experiments.
KPI	Vehicle velocity and success ratio
Expected Outputs	Test report summarizing the results.
Expected duration	Each test will last about three working days and will be repeated as many times as needed during the duration of Task 6.3
Link with Stage 2	N.A.
Link with Stage 3	Similar cones are expected in the final scenario.
Boundary conditions	Local authorities' permission. For the robot: ISO 10218-1, ISO 10218-2, ISO/TS 15066, ISO 12100, ISO 13849-1, ISO 13849-2, ISO 60204-1. For the headset: UL 8400, IEEE P2048.
Constraints	Weather conditions
Stakeholders to be involved	Technological partners: TEK. Feedback will be requested to PAV and SDP
Authorization	Not needed
Design specifications	All tests will be performed safely in a controlled environment, and IPEs are needed.

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Stage 1 Protocol	UC2.1.2. Installation of cones
	A mechanism will be included to stop the process immediately to avoid accidents. All technologies will be tested separately and, finally, as a whole: - Vision system to detect the cones - Tool for handling the cones - Trajectories performed by the robot AR system to provide info to the operator
Customization activities	N.A.

UC2.1.3. Road assets cleaning

Stage 1 Protocol	UC2.1.3. Road assets cleaning
Objective	Test a signal cleaning process in a controlled environment. Test that the robot can identify the signal's shape and execute the trajectory to cover the entire surface to clean the signal.
Activities	- Place a set of different shape signals. - Execute the cleaning procedure. - Monitor the coverage of the spraying. - Videotape the experiments.
KPI	Area coverage
Expected Outputs	Summary of tests results
Expected duration	Each test will last about one working day and will be repeated as many times as needed during the duration of Task 6.3.
Link with Stage 2	N.A.
Link with Stage 3	Similar shape signals are expected
Boundary conditions	For the robot: ISO 10218-1, ISO 10218-2, ISO/TS 15066, ISO 12100, ISO 13849-1, ISO 13849-2, ISO 60204-1. For the headset: UL 8400, IEEE P2048.
Constraints	Weather conditions. The cleaning quality also depends on the spraying parameters, which are out of scope.
Stakeholders to be involved	Technological partners: TEK. Feedback will be requested from PAV and SDP.
Authorization	Not needed

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Stage 1 Protocol	UC2.1.3. Road assets cleaning
Design specifications	All tests will be performed safely in a controlled environment, and IPEs are needed. A mechanism will be included to stop the process immediately to avoid accidents. All technologies will be tested separately and, finally, as a whole: - Vision system to detect the signals. - The spraying system. Trajectories performed by the robot.
Customization activities	N.A.

UC3.2. Robotised sealing of surface pavement cracks

Objective

The main expectation is to test the new technologies in a controlled environment before the technical demonstrator. Besides, to test each technology previously and individually in each company.

Expected Duration

The first intervention will be performed in Pavasal facilities due to the difficulty of transporting trucks and sealing machines. It will take place in July 2023, and another intervention will occur in October 2023, before the technical demonstrator. The duration of each experiment could last from 2 days to 5 days if needed.

Figure 8. Pavasal Facilities

Before this intervention, TEK will test the robotic platform performance at their facilities, using a simplified configuration without a real sealing application. The main features to be tested are crack identification, robot trajectory generation and execution, and the control logic.

Stakeholders

- Technological partners: TEK, LMS.
- Pavasal employees: operators, technicians, and people in charge of Sector V-1 preservation.
- Subcontracted companies if needed: rent machinery, certification company.

Design Specification

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All tests will be performed safely in a controlled environment, and IPEs are needed like leak-proof clothes.

Safety. It will include a mechanism to stop the process immediately to avoid accidents. Test design for that should obtain a binary result, it works correctly or not.

Functionality. New elements modified or added to the machine and tool should be tested firstly with some liquid with similar properties to bitumen without high temperatures. After that, the same test will be done with bitumen at 180ºC.

- Bitumen flow is regular and constant.
- Bitumen reaches asphalt at 180ºC.
- Pumps and electro-valves open and close in the right way.
- Heating regulator systems reach and hold the temperature indicated.
- The blowing system works with enough pressure to expulse impurities from asphalt.
- The blowing system heats the surface layer.
- The sealing and blowing system could be individually implemented.

Logistics.

- Enough space for all equipment.
- Charge and discharge are quick and easy.
- Stability test.
- Truck mobility in small distances.

Features to be tested.

1. All technologies will be tested in groups and finally, as a whole.

   - The vision system information and AR display match.
   - Robots follow the trajectory.
   - The control system manages machines and tools.
   - The operator interacts with the AR system, and the robot or machine responds correctly.

2. Velocity process and system reliability.

3. Previous functionality test of each technology developed.

   - Pavasal: Sealing machine, tool and truck.
   - TEK: robot, vision and control system.
   - University of Patras: UR and AR display system.

4. Testing all technologies in Pavasal facilities as a prototype of technical demonstrator, as presented in the following figure.

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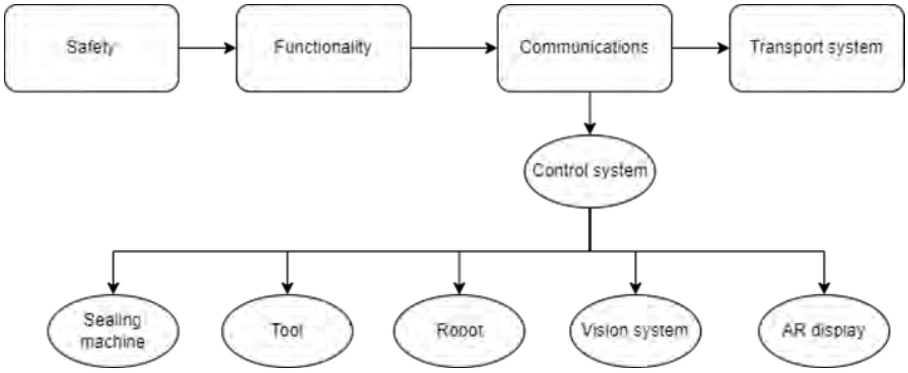

Figure 9. UC3.2

The following table presents a summary of the stage 1 testing of this Use Case.

Stage 1 Protocol	UC3.2. Robotised sealing of surface pavement cracks
Objective	To test the new technologies in a controlled environment.
Activities	To collect relevant data for KPIs with traditional methods and previous tests in Pavasal facilities.
KPI	KPIs will be measured in a real context, stage 2.
Expected Outputs	A checklist will be created to check all tests described in the design specifications, and it will be increased during technology development if new functionalities appear.
Expected duration	During summer and autumn 2023, experiments with the whole system with TEK and LMS.
Link with Stage 2	Perform only the execution stage in a controlled environment to check operation functionality.
Link with Stage 3	N/A
Boundary conditions	- Certificates of modified machines and vehicles (CE certificate). - Work risk prevention for chemical materials: *Ley 31/1995 de Prevención de Riesgos Laborales (PRL)* - Transport: ITV and driver licenses
Constraints	- Weather conditions: wind or rain - People on vacation: operators, coordinators, stakeholders, etc. - National holidays in any country of involved people
Stakeholders to be involved	Technological partners and PAV employees
Authorization	N/A
Design specifications	Safety, functionality, logistics and communications test with the new methods.

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Stage 1 Protocol	UC3.2. Robotised sealing of surface pavement cracks
Customization activities	Training for AR and VR systems in Pavasal facilities.

UC3.3. Robotic removal of lane markings with laser

Objective

The main expectation is to perform a proof of concept about removing horizontal signalling with a new innovative technique, laser technology, that improves quality and reaches a good performance in terms of process time.

KPIs

The following KPIs apply:

- **KPI 3 Operator safety:** Reduce the number of people in dangerous zones in maintenance areas by 90%.
- **KPI 9 Saving costs:** Using a modular robotic platform shall reduce the workforce needed, reducing costs by 26%.

To evaluate these KPIs will be necessary to collect the following data:

Workers

- Person, job position and time during the intervention.
- Person, job position and time exposed to danger

Time

- Total time intervention
- Time to execute previous activities (logistics, signalling, equipment assembly)
- Action time
- Execution speed

Logistic costs

Other relevant data is also presented below:

- Environmental data: power, gaseous emissions.
- Quality control by visual inspection.

Design Specifications

The following design specifications apply.

Samples with different combinations of paints and asphalt mixes:

- Paint: with additives (spheres), positive soundtracks (strudel) and negative soundtracks.
- Asphalt mixes: AC16, AUTL, BBTM.

Relevant properties for laser equipment:

- Power: 1000 W or 1500 W
- Decoating mechanisms: combustion or ablation, depending on the pulse duration.
- Fixed or compacted structure.
- Two mirror scanning head optics.
- Spot size influences productivity.

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Quality:

- Not to lose roughness: friction coefficient will be measured.
- Homogeneous shape result checked by visual inspection.
- No emissions of dangerous gases due to paint combustion.

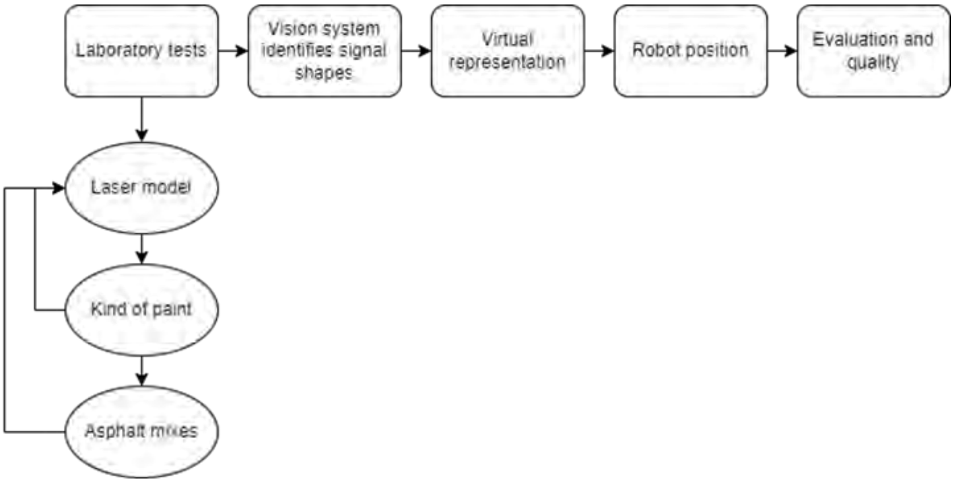

Figure 10. UC3.3

The following table presents a summary of the stage 1 testing of this Use Case.

Stage 1 Protocol	UC3.3. Robotic removal of lane markings with laser
Objective	To perform a proof of concept about removing horizontal signalling with a new innovative technique.
Activities	- To build samples with different paints and asphalt mixed. - To test several laser technologies. - To recognise shape signals and to position. - To evaluate the result by quality control of CRT.
KPI	KPI 3 and KPI 9
Expected Outputs	The main expected output is to develop the technology capable of removing the paint from different asphalt mixes so that the shape signal is homogeneous with the road. The proof of concept reaches TRL5 state.
Expected duration	The final test will occur in TEK facilities, where the complete system will be checked in different conditions (shapes and asphalt textures). Three days are planned to perform the experiments and check the results.
Link with Stage 2	N.A.
Link with Stage 3	
Boundary conditions	- Gaseous emissions from paints: *Ley 34/2007 de calidad del aire y protecciones de la atmosfera, BOE*.

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	- Controlled environment against radiation: *Real Decreto 783/2001 Reglamento sobre la protección sanitaria contra radiaciones ionizantes.*
Constraints	- People on vacation: operators, coordinators, stakeholders, etc. - National holidays in any country of involved people
Stakeholders to be involved	- Technological partners: TEK, LMS - Pavasal technicians
Authorization	N.A.
Design specifications	Testing different asphalt mixes and paints with various laser equipment and parameters.
Customization activities	AR interface in the Spanish language.

UC5.1. VR platform for robot teleoperation

Objective

The objective of this use case in Stage 1 is to integrate and test the developed teleoperation technologies with the existing platform developed by TEK. Thanks to this initial integration and testing, the communication requirements will be fully clarified for the following stages and the respective demonstrators. The VR teleoperation in this stage will be tested for cleaning and crack-sealing cases.

Aside from the teleoperation service, the VR based training tool for inexperienced workers will also be tested for the cleaning and crack sealing cases.

KPI

<u>KPI 2 - Emergency, ordinary and extraordinary maintenance intervention times</u>. Using the robot for the interventions by itself and the ease of its manipulation through the VR teleoperation developments will reduce the time needed for the interventions. Additionally, the training tool will teach inexperienced workers how to perform the interventions efficiently and quickly, reducing the time of the interventions executed by new workers.

<u>KPI 3 - Volume of people in dangerous zones in road maintenance areas</u>. The teleoperation will allow the operator to not be in the field, automatically reducing the number of people on the road. The operator, being in a remote location, for example, in the office, will be completely safe during the intervention.

For KPI 2, metrics will be measured in an initial stage. The intervention completion time will be calculated as executed by LMS and TEK researchers and compared to traditional methods given by the end-users.

For KPI 3, the validation of fewer people in dangerous zones is automatically proven by the teleoperation element.

In the cases of crack-sealing and cleaning, both VR and AR methods will be used, and a comparative analysis of each will be performed.

Design Specifications

Aside from the VR headset, a PC to handle communications and ROS will be needed for the setup and the robotic setup. The technologies will be initially tested with a robot in LMS premises. Once the solution is transferred to TEKNIKER, the communications will need to be configured again for the new

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hardware. Any possible differences like drivers, if the TEKNIKER robot is different from the LMS robot, will also be considered. Additionally, suppose the sensors in TEK's premises are other. In that case, compatibility issues need to be solved, and the software translating the sensor data to useful data for the virtual environment might need modifications. Below a diagram of the basic communications is presented.

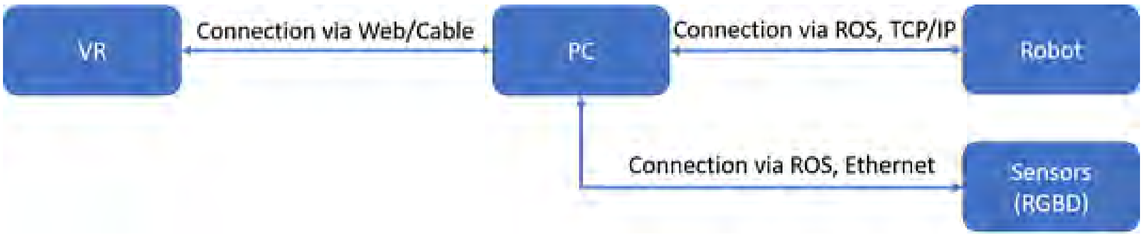

Figure 11. UC5.1 interfaces

The VR headset will be connected to the PC via Web or cables. The PC will be running ROS and will establish a connection with the robot and the sensors via the drivers provided by ROS.

The teleoperation developments in this Stage will be used for the interventions identified as most useful for crack-sealing and cleaning. In both cases, they will be used for teleoperation, to control the robot and perform the process from a remote location. Below, the concept for the teleoperation is shown.

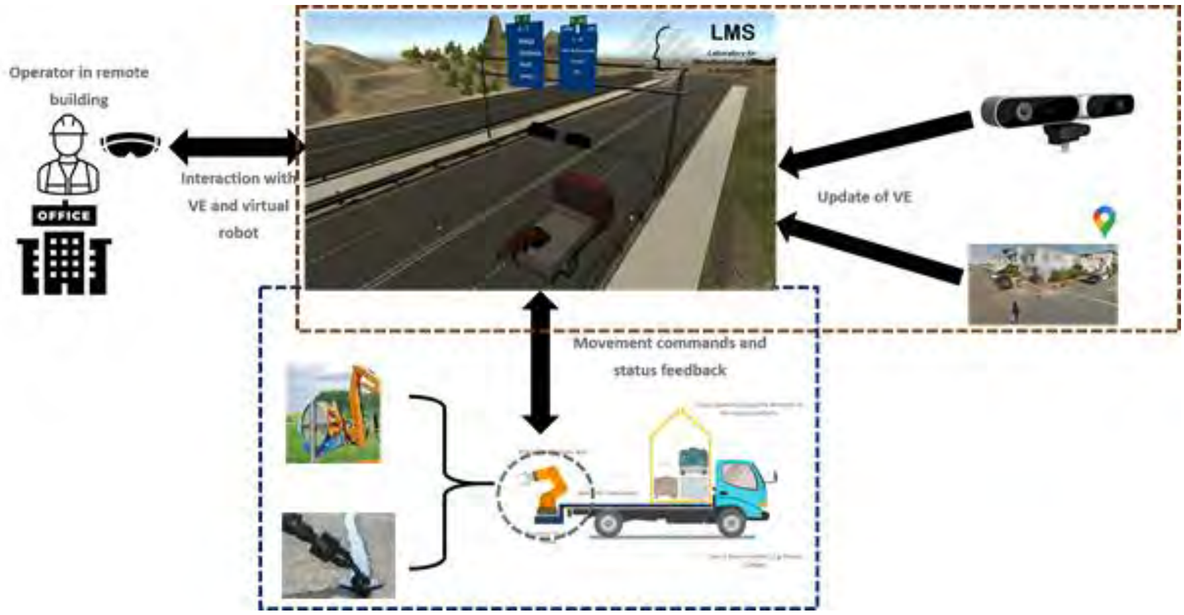

Figure 12. UC5.1 teleoperation concept

The operator will interact with the dynamic Virtual environment and the virtual robot, which will communicate with the real robot through ROS, allowing the operator to remotely move it by moving the virtual robot to perform the cleaning or crack-sealing interventions. The main components except the PC are evident in the image.

All LMS and partner's facilities tests will follow the proper safety protocols.

Finally, the following table presents a summary of the stage 1 testing of this Use Case.

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Stage 1 Protocol	UC5.1. VR platform for robot teleoperation
Objective	• Test the web-based VR platform for the teleoperation of the robotic resources in a controlled environment before the demonstrators • Test the VR based training tool that allows the training of inexperienced road workers in relevant procedures
Activities	• Test the dynamic virtual environment regarding online update speed and how faithful the representation of the real environment is. • Test interaction mechanisms between operator and VE and operator and robot regarding their usefulness for the use case and their proper modelling • Test the validity of the communication architecture (between VR and robotic platform), regarding the speed of communication, latency between command and execution • Testing the effectiveness of the training scenarios for teaching operators
KPI	KPI 2 KPI 3
Expected duration	Tests will begin at LMS for at least two weeks and then will be integrated to TEK developments in their facilities, in a workshop, approximately three days.
Link with Stage 2	Validate functionalities and define communications for the demonstrators
Link with Stage 3	Validate functionalities and define communications for the demonstrators
Boundary conditions	For the headset: UL 8400, IEEE P2048, for the robot: ISO 10218-1, ISO 10218-2, ISO/TS 15066, ISO 12100, ISO 13849-1, ISO 13849-2, ISO 60204-1
Constraints	N.A.
Stakeholders to be involved	TEK
Authorization	N.A.
Design specifications	- Master PC for communications, VR headset, robotic platform - Connection of VR headset and PC over the Internet - Connect a PC to Robot via TCP/IP and ROS connection. - Existing robots and sensors will be used first in LMS for in-lab testing before moving the solution to the partner's facilities.

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Stage 1 Protocol	UC5.1. VR platform for robot teleoperation
	- To integrate the application to TEK's platform, the sensors installed by TEK will need to be connected to the application, and any compatibility issues must be eliminated. - Any needed connections, such as the web and TCP/IP connections, will need to be installed in TEK's platform. - ROS drivers may need to change depending on the drivers LMS used in their Lab and the drivers of TEK's robot. - The teleoperation developments will be used in the following interventions: - Cleaning - Crack sealing
Customization activities	N.A.
Expected Outputs	• Evaluate capabilities of VR platform for the teleoperation of robotic resources, ready to be used in the demonstrators. • Evaluate the capabilities of the VR-based training tool, ready to be used in the demonstrators.

UC5.2. AR for worker support

Objective

The objective of this use case in Stage 1 is to test the developed AR tools for worker support in interventions and validate the communication between the AR tools and the robotic platform of TEK. Thanks to this initial integration and testing, the AR technologies will be validated for all the interventions. Any lack or needed improvement will be identified for the betterment of the application in the preparation of Stage 2 and Stage 3 demonstrators. The AR application will work on two types of devices, a tablet and an AR headset, according to their usefulness to each intervention. In particular, the tablet will be used for the *signals and cones, cleaning, laser-based paint removal* and *crack-sealing* interventions, and the AR glasses will be used for the *safety barriers* intervention.

KPI

KPI 2 - Emergency, ordinary and extraordinary maintenance intervention times. Using the robot for the interventions by itself and the ease of its manipulation through the AR developments will reduce the time needed for the interventions. Additionally, the AR application's step-by-step instructions will help the workers complete the interventions more efficiently and in less time.

KPI 3 - Volume of people in dangerous zones in road maintenance areas. The manipulation of the robot can be performed with the tablet from inside the truck in some situations, which will reduce the number of people on the road. Also, safety alerts will inform the operator of the dangerous zones of the road.

For KPI 2, metrics will be measured in an initial stage. The intervention completion time will be measured as executed by LMS and TEK researchers and compared to traditional methods given by the end-users. Time of completion can be compared between runs without instructions and runs with instructions.

For KPI 3, the validation of fewer people in dangerous zones is automatically proven by the operation from within the truck, as fewer people will be on the road.

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In the cases of crack-sealing and cleaning, both VR and AR methods will be used, and a comparative analysis of each will be performed.

Design Specifications

An AR headset and a tablet will be needed for the setup, and a PC to handle communications and run ROS connected to a robot. Initially, the application will be tested with a robot in the LMS premises. The application will be tested with TEKNIKER's platform on their premises for the final testing. The communications will need to be configured again for the new hardware and any possible differences like drivers. It will also be considered if the TEKNIKER robot is different from the LMS robot. Below, a diagram of the basic communications is presented.

Figure 13. UC5.2 interfaces

The AR headset or tablet will connect to the PC via the web, while the PC will be connected to the Robot via ROS drivers.

The AR developments in this Stage will be used in the following interventions:

- Cleaning: Driver to use the tablet to perform the process themselves, eliminating the need for a second operator
- Crack sealing: The operator will use the tablet to control the robot from inside the vehicle
- Laser-based: The operator will use the tablet to control the robot from inside the vehicle
- Signals and cones: Visualization to the driver to manually press a button and release cones for placing, AR visualization of roar with graphics overlay for removal
- Safety barriers: Operator will utilize the AR glasses to command the robot to go to the desired position (rough placement) using gestures. Also, to be used for the provision of safety and process information.

Below, the concept for AR for operator support is shown.

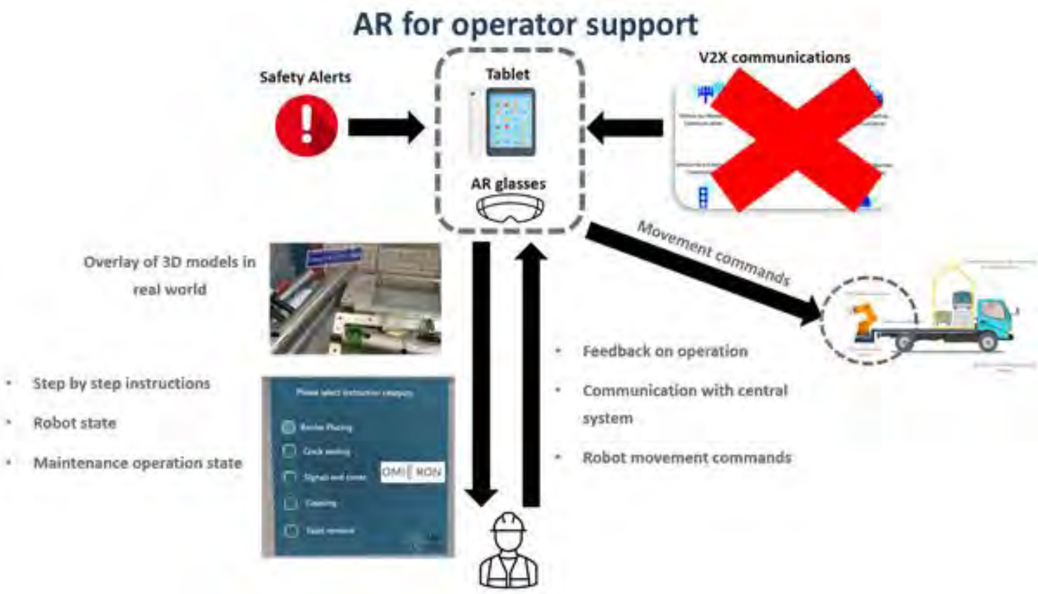

Figure 14. UC5.2 AR support

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The operator will receive instructions and information through the AR wearables and will also be able to communicate with entities in the system and the robot. There will be no V2X communication with the AR application at this stage.

All LMS and partner's facilities tests will follow the proper safety protocols.

Finally, the following table presents a summary of the stage 1 testing for the AR technologies.

Stage 1 Protocol	UC5.2. AR for worker support
Objective	Test the AR tools that will support in-field road workers in a controlled environment before the demonstrators.
Activities	• Test the safety measures during the various interventions by AR feedback on simulated errors or accidents. • Test the clarity and level of completeness of the step-by-step instructions on maintenance operations using operator feedback. • Testing the operator's awareness of the surrounding environment. • Testing the robotic control enabled via tablet or glasses.
KPI	KPI 2 KPI 3
Expected duration	Tests will begin at LMS for at least two weeks. Then will be integrated into TEK developments in their facilities, in a workshop, approximately three days.
Link with Stage 2	Validate functionalities for the demonstrators
Link with Stage 3	Validate functionalities for the demonstrators
Boundary conditions	For the headset: UL 8400, IEEE P2048
Constraints	N.A.
Stakeholders to be involved	TEK
Authorization	N.A.
Design specifications	- Master PC for communications, AR headset, tablet, robotic platform - Connection of AR headset and PC over the Internet - PC connected to Robot via TCP/IP and ROS connection - Existing robots will be used first in LMS for in-lab testing before moving the solution to the partner's facilities. - Any needed connections, such as the web and TCP/IP connections, will need to be installed in TEK's platform.

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Stage 1 Protocol	UC5.2. AR for worker support
	- The application will need to be connected to the robot as well. ROS drivers may need to change depending on the drivers LMS used in their Lab and the drivers of TEK's robot. The AR developments will be used in the following interventions: - Cleaning - Crack sealing - Laser-based - Signals and cones - Safety barriers
Customization activities	N.A.
Expected Outputs	• Evaluated AR tools to support in-field workers with road information, maintenance guidance and robot control

UC6.2. Decision Support System

Stage 1 Protocol	UC6.2. Decision Support System
Objective	The main objective of the stage 1 demonstration for OMICRON's Decision Support Tool is to test the different functionalities of the tool using historical data and any other source of data. • Analyse and predict the infrastructure conditions. • Road sectioning. • Evaluation of risk. • Assessment of criticality. • Evaluate the maintenance impact on traffic. • Maintenance planning.
Activities	The two main activities in this stage are: • The collection of historical data from the final demonstrator. • The collection of data from OMICRON's inspection technologies. To perform real tests on the DST.
KPI	KPI 4. The volume of major intervention actions. KPI 11. Road infrastructure maintenance costs.
Expected duration	5-6 months
Link with Stage 2	N.A.
Link with Stage 3	Final Demonstration of the DST

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Stage 1 Protocol	UC6.2. Decision Support System
Boundary conditions	Not applicable at this stage, as far as the data follows the FAIR principle.
Constraints	The lack of data available from OMICRON inspection technologies could be an issue throughout the project and during the demonstration phase. This activity is precisely addressed to face this potential problem in advance.
Stakeholders to be involved	CEM, UGE, UOC, AIS, SDP.
Authorization	N.A.
Design specifications	Not applicable at this stage
Customization activities	The tests related to the DSS will have to be tailored to the available data.
Expected Outputs	Obtain a full preliminary assessment of OMICRON's Decision Support Tool functionalities.

3.2 Stage 2 Protocol – Technical Demonstration

3.2.1 TD1. A-3 Porto

Objective

The digital upgrade of the construction works presents itself as mandatory in the forthcoming years. While the construction industry transversally recognizes its need, the same will face meaningful challenges in terms of competitiveness among its players and other sectors of the economy until this upgrade proves itself as effective. Similarly, all efforts that may lead to either standard, modular or out-of-site prefabrication solutions will strengthen the outcome of digital integration since they lead to lean, predictable and monitored interventions on the construction sites.

A hybrid bridge solution was the one adopted to design new overpasses in a motorway widening (A3 – Maia / Santo Tirso's branch, Porto, Portugal, from 2 to 3 or 4 lanes), with no digital assistance, such as BIM, for the design and the construction stages. In a digital era, even today, the content of the projects is mainly interpreted by humans. If such content becomes represented by BIM models of the construction beyond this traditional representation, the project interpretation would be prosecuted by humans and informatics machines.

BIM platforms reveal themselves as reliable tools to support decisions in construction activities due to their ability to concentrate all the information in a unique digital model while promoting cooperation among all the involved stakeholders. A BIM model can be considered a rich data representation, advanced, smart, and parameterised construction project. Moreover, the project activities evolved so that their processes coincide simultaneously, with the information being transmitted from the designers to the contractors when it is not yet fully established and complete.

One of the most appealing benefits of BIM models is their consistency when representing the data, given the fact that they present the following features:

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- BIM models diminish the data superposition through all the processes and turn the representations less redundant.
- BIM models narrow down the errors in the design information, especially to design compatible installations (e.g. HVAC, electricity, hydraulics).
- Managing changes during both the design or the construction is also highly improved.
- BIM models unite and turn the exchange of data and information among the different construction stakeholders.

The BIM models usually shine when dealing with the conflicts that recurrently appear. Although their detection can arise while the model is assembled, conflicts are better identified with the model integration through its rendering. For the several intervenients, the resolution of conflicts becomes less troubled. At the same time, the site manager sees its evolution more harmoniously, with advantages for all but especially for the main stakeholder, the site owner.

Activities and Use Cases

An in-situ characterization campaign was performed in the hybrid bridge in A3 – Maia / Santo Tirso to certify the correct behaviour without significant deviations from ARI's intended base design solution, already within the scope of the OMICRON's project, to confirm this assertion. ARI will use the same work to upgrade the solution in terms of its structural behaviour by improving the design of the connection between concrete and steel and, if feasible, harnessing the effect of the prestress to enhance the behaviour.

Both TDU and ARI believe that the best way to mitigate any traffic disruptions from constructing an overpass over a fully operational motorway is to deploy a modular portion of its deck over it, something that can be done overnight. Some parts of the bridge will not be modular, namely its abutments and piers, but those have close to none or very little interference with the motorway circulation during construction. These modularisation hypotheses will all be subjected to evaluation inside the BIM model without jeopardizing any others that may arise while the model is being assembled.

CEM will develop the BIM model of the bridge. Two inputs will be available for its assemblage, distinguished by its nature, either design or technology-related.

ARI will handle design-related inputs, mainly by providing:

- Detailed bridge geometry, such as dimensions, layouts and shapes.
- Material characteristics and specifications.
- Other relevant design data may be important to include and access through the BIM model.
- Detailed construction-related data such as construction sequences, activities, durations.

These inputs will consider all the enhancements and redesigns developed and obtained through on-site and in-lab testing during the OMICRON project.

TDU has a set of technological centres focused on different services to which the construction sites recurrently call to assist their works. These centres are nowadays classified accordingly to the specialities where they intervene, which are:

- Specialized Equipment for Construction (DEC), either heavy or light, both for use on-site or to facilitate transports (by land or sea) to the same sites.

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- Framework Operational Centre (COC), with a brand new fully operational department for cutting and bending of concrete reinforcements and a consolidated knowledge on how to apply and operate pre-stressing tendons, namely through assembling, tensioning and force control.
- Metal Mechanics Fabric (MMF) with industrialized equipment for metalwork, in particular, three robotised lathes, a Computer Numerical Control (CNC) equipment to cut and drill steel pieces, a CNC for welding works and still an industrial painting stove.
- Concrete Branch Plant (CBP), with a significant experience in concrete mixtures with specific compositions for special construction works, such as bridges, tunnels, geotechnical stability, among others.
- Concrete and Fillers Laboratory (CFL) does the quality control for the CBP. It assists any other need in fillers and special mixtures, especially for geotechnical works, the mother-core activity of TDU.

All these technological centres are established in TDU Operational Yard in Montijo, Lisbon, Portugal, where the pre-fabrication of the bridge girder will be studied. Their expertise will be used to propose and discuss the best technological solutions for the design and BIM model creation. Therefore, the technology centres will act as stakeholder in this Use Case and Demonstrator.

All in all, a virtual demonstrator will by these means be established with two specific and clear purposes for the OMICRON's agenda, namely:

- To develop an enhanced modular solution for hybrid bridge decks, taking into account the design (led by ARI and CEM), manufacturing (TDU's technology centres), transportation (TDU) and construction (TDU) stages, as well as traffic disruptions.
- To improve the design of the steel-concrete connection in hybrid bridges. Starting from the existing pre-stressed solutions, the idea is to enhance the design to facilitate and optimise the assembly and the production of the steel parts. In this manner, the entire process will lead to an upgrade of the hybrid bridge structural solution to be used in the 038 overpass in the A3 highway - Santo Tirso Interchange.

Expected Outputs

Each construction working plan is usually exclusive to a specific project. The evaluation of the alternatives and the planning decisions, when framed by the available time and space for the construction, can be improved and sustained while recurring to BIM softwares (for the time being the 4th dimension obtained through render). Such allows capturing and dynamically managing the interactions between parts by live-streaming those interactions.

When used as a management tool, many advantages arise regarding the physical and time-consuming aspects of the construction. For the transformation in a time of the construction site inside a visual landscape, it is expected to:

- Improve the communication between the construction process interventions, smoothing the decisions.
- Improve the evaluation, integration and monitoring of the design alterations.
- Evaluate the use of alternative materials or different constructive procedures, both in the design stage and while the construction is ongoing, especially focused on achieving a sustainable and environment-friendly construction industry.

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- Evaluate and develop the activities procedures, as well as the application solutions of the materials and construction products more effective for the project.
- Speech and train the construction teams, especially before they begin any complex, challenge or dangerous activity, or in a new construction method or technique.

Moreover, exclusively for the OMICRON's agenda, it is expected to develop a solution that allows the industrialisation of the overpass deck construction, which in turn leads to:

- Reduction of construction/deconstruction material waste, reduction of manpower, as well as of scaffolding, at the construction site.
- Reduction of the time consumed to materialize the construction and, more importantly, of the traffic interruptions/disruptions, measurable with the BIM 4D CAD model.
- Improve the materials and construction products delivery on-site, which are particularly important for construction sites where the available space is minimal or located far away from their factories, in this case, the Operational Yard of TDU, in Montijo, Lisbon.

Finally, the following table presents a summary of the stage 1 testing for the AR technologies.

Stage 2 Protocol	**UC4. Modular construction for bridges**
Objective	• Unite and simplify the exchange of data and information among the different stakeholders; • Less troubled resolution of conflicts; • Site evolution in a more harmonious way.
Activities	To create the BIM model, CEMOSA will receive the needed inputs, which are of two types, structural and technological. The structural inputs will be given by ARI, while TDU will provide the technological ones.
KPI	• KPI 3. Volume of people in dangerous zones in road maintenance areas. • KPI 7. Bridge construction traffic disturbance. • KPI 10. Contribution to the circular economy.
Expected Outputs	• Improve the communication between the construction process interventions, smoothing the decision calls, by sustaining them; • Improve the evaluation, integration and monitoring of the design alterations; • Evaluate the use of alternative materials or different constructive procedures, both in the design stage and while the construction is ongoing, primarily focused on achieving a sustainable and environment-friendly construction industry; • Reduction of construction/deconstruction material waste, reduction of manpower, as well as of scaffolding, at the construction site;

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Stage 2 Protocol	UC4. Modular construction for bridges
	• Reduction of the time consumed to materialize the construction and, more importantly, traffic interruptions/disruptions, measurable with the BIM 4D CAD model.
Expected duration	13 months
Link with Stage 1	Not applicable
Link with Stage 3	Suppose the final demonstration to be held by SDP at the A24 in Italy includes any potential overpass replacement, allegedly at a design stage. In that case, the methodology used in the persecution of this virtual demonstrator could be translated to it.
Boundary conditions	Not applicable
Constraints	• Authorization issues for Monitoring campaign (resolved). • In lab testing - availability of LNEC's laboratory and testing equipment (under analysis).
Stakeholders to be involved	TDU, ARI, CEM. BRISA. LNEC - Laboratório Nacional de Engenharia Civil.
Authorization	As a virtual demonstrator, no special authorization will be needed to develop the Technical Demonstration.
Design specifications	The development will be aligned with the solutions' requirements and specifications. As such, shall comply with their design specifications.
Customization activities	• Industrialization of the deck construction, where most of the components are built in the production plant and transported to the site ready for assembly; • Use of robotised equipment for the steel beams production, such as cutting, assembling and welding of different elements, allowing a highly automated construction; • Also, for the production of the precast beams, the use of robotised equipment can be applied to rebar's bending and assembling, pre-stressing tendons assembling, tensioning and force control, as well as for the formwork geometry control and concrete cast; • Optimization of the materials uses and consumption since lightness is key for a competitive, functional, environmentally friendly and structurally safe solution.

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3.2.2 TD2. A-2 Highway in the North East of Madrid

Objective

The Technical Demonstrator 2 (TD2) objective is to test some of the technologies developed in the project to improve the safety and efficiency of road maintenance work in the field. TD2 will be held at the A-2 highway in the surroundings of Madrid (as part of the Atlantic Corridor), where C-ITS equipment will be deployed to demonstrate the potential of V2X communications during maintenance activities. In addition, an inspection vehicle will collect images during the auscultation campaigns to improve the process of the calculation of road parameters using AI techniques.

This demonstrator will serve as a final test of integrating the vehicle inspection technologies and the V2X communication technologies, ensuring appropriate replicability in the final demonstrator. Furthermore, the required data to develop the AI algorithm to improve IRI computation and the Sideway Force Coefficient (SFC) will be captured to train the algorithm.

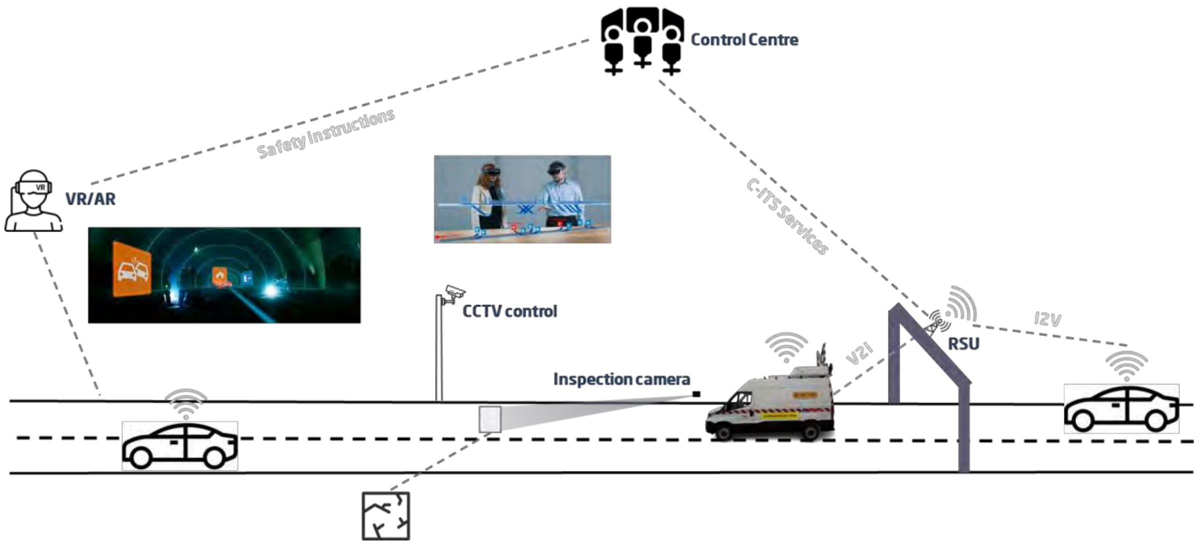

Figure 15. Technical Demonstrator 2

Activities and Use Cases

Within the TD2, the testing of 4 technologies developed within the project will be carried out, corresponding to the following use cases:

- UC1.2 – Inspection vehicle.
- UC1.3 – V2X communications.
- UC5.2 – AR tools for worker support.
- UC6.1 – Road digital twin.

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UC1.2 - Inspection vehicle

In this demonstrator, the developments made in the use cases UC1.2.1 and UC1.2.2 will be tested. UC1.2.2 seeks to improve the current auscultation systems to improve maintenance activities on the road surface. With time and use, minor defects appear in the road surface that can endanger the safety of drivers, so the condition of the road surface must be monitored regularly. This task is done through specialised monitoring vehicles that measure IRI or Sideway Force Coefficient (SFC) parameters. The quality of these assessments depends on the point on the road where the samples are taken. It is essential that the vehicle is centred in the lane and that the measuring wheel is positioned in the theoretical track. From that point, images are taken during the measurements (as per the figures below.

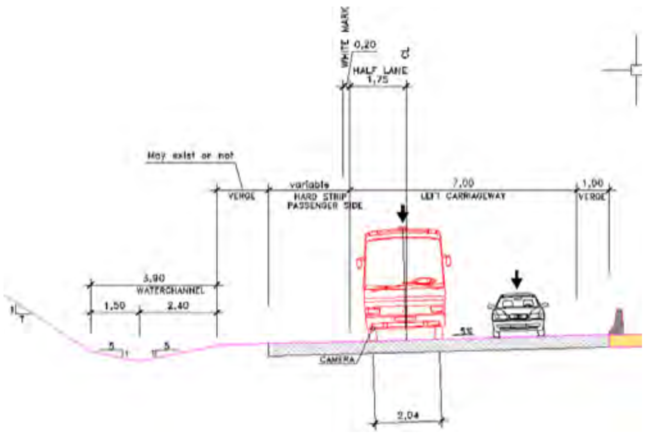

Figure 16. IRI and SFT auscultation positioning

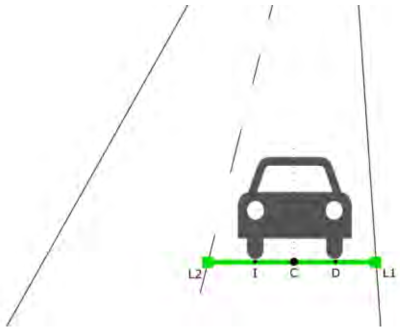

Figure 17. IRI and SFT measurement points

Currently, to check that the Sideway Force Coefficient (SFT) measurement has been carried out correctly, with the measuring vehicle centered on the lane and with the test wheel on the right-hand side of the measuring lane, a technician-operator views the recordings made during the auscultation equipment's travels, which means a reduction in efficiency and a waste of resources in a very tedious task, leading to an increase in costs.

The demonstrator aims to automate the whole process of viewing the recordings. The objective is to automatically infer the degree of deviation of the monitoring vehicles concerning the lane they are driving (right lane). As it is shown in Figure 17, it is desired to extract the position of the centre point of the vehicle (C) and the two wheels (I and D) concerning the endpoints (L1 and L2). This process will be done from a video taken with a camera installed on the right front wheel.

Specifically, to develop a specialised model for this task, the following algorithms will be studied:

1. Segment the lane dividing lines and fitting of a polynomial. This method is a two-phase algorithm. First, the lane dividing lines will be segmented and once detected, a polynomial will be fitted over them. Although this method promises good results, it is computationally very demanding.
2. Row-wise inference. This type of algorithm is less computationally demanding than the first one. It consists of dividing the image into a mesh of small square superpixels. Subsequently, it is estimated row by row of this mesh of superpixels with a higher probability of containing a dividing line.
3. Design methods based on Deep Learning and refinement of the previous models. Some examples of this type of method are the use of recurrent networks or Kalman filters to relate segmentations in consecutive frames or the use of Spatial-CNN.

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The proposed techniques are based on generating models that learn from a large amount of data. In particular, the proposed models will need a considerable amount of road images and the associated masks indicating the pixels belonging to the dividing lines. The generation of this type of data is expensive. A two-phase process is proposed to facilitate and speed up the development of the model:

1. Phase 1. In this first phase, the model will be trained with open datasets of road images. In this phase, a battery of tests will be performed with the algorithms mentioned above (or similar), and the one that best suits the problem will be selected. This first phase will be carried out in Stage 1 In-Lab Testing.
2. Phase 2. This will be the refinement phase. In this phase, the model selected in phase 1 will be trained with a proprietary dataset generated from images collected from the A-2 highway, where the technical demonstrator 2 will be developed.

UC1.3 – V2X communications

This demonstrator includes using vehicle-to-infrastructure communication (V2X) technology. Specific C-ITS services will be developed to indicate that maintenance work is being performed on the road so that vehicles can manoeuvre accordingly and avoid situations that could put maintenance operators at risk.

The two main reliable, low-latency V2X radio access technologies are DSRC and C-V2X. The technology-neutral allocation of ITS in many countries allows both DSRC and C-V2X to operate in the 5.9 GHz band, limited by the relevant technical regulatory conditions.

DSRC is designed to operate primarily in the ITS band, while C-V2X can operate in ITS and licensed cellular bands. DSRC adopts a decentralized approach to spectrum utilization, while C-V2X supports centralized and decentralized modes to control radio resources. Both DSRC and C-V2X are being tested extensively for higher reliability, lower latency and higher throughput.

Within this demonstrator will be used DSRC technology is already a technology known by Indra, and that has been used in innovation developments. The aim is to deploy short-range communication antennas, RoadSide Units (RSU), which will enable C-ITS services to be sent to vehicles travelling on the A-2 highway in Madrid.

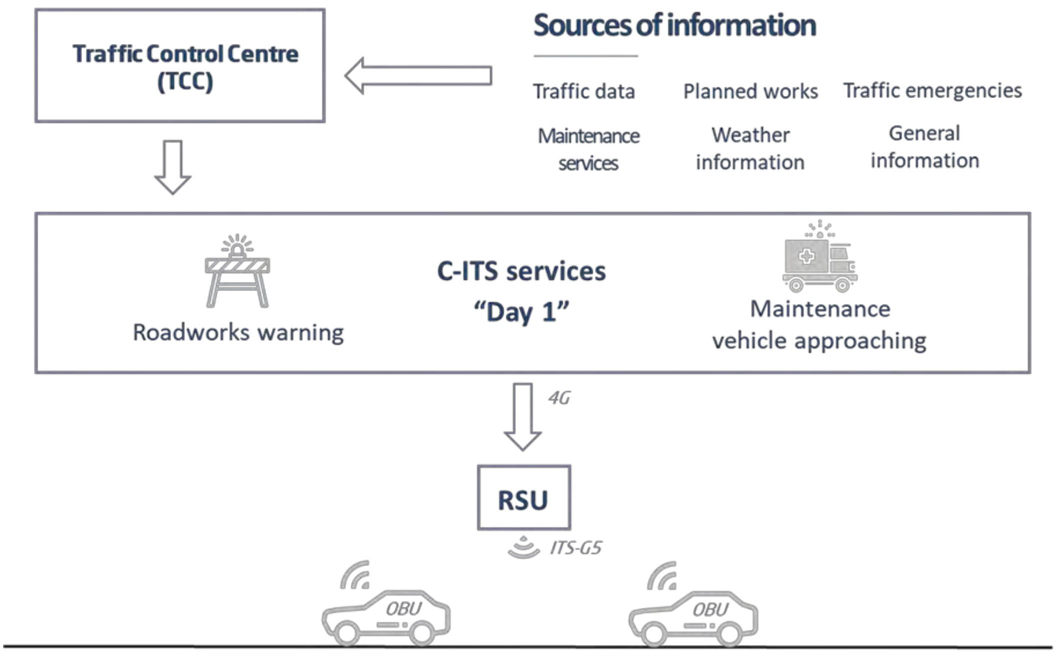

Figure 18. Technical Demonstrator 2 information

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For this purpose, a C-ITS control centre will integrate information related to planned maintenance activities on the road, provided by the maintenance service of the road section operator, Acciona. Acciona will generate a road maintenance event when road vehicle maintenance is on the road. Road maintenance events will be based on information collected by the operator by CCTV or by other sensors or communication. A C-ITS "Day 1" Road Maintenance service will be created based on this information. This service will provide an I2V communication-based safety alert, warning vehicles in case of a road maintenance vehicle is in the area, either in the same path of travel or crossing an intersection ahead.

These services will be sent through the DENM (Decentralized Environmental Notification Message) data format when executing plans, registering incidents, and executing their ETSI Resources. For the exchange of messages between the C-ITS control centre and the RSU, an ActiveMQ broker, a C-ITS Gateway process and an MQTT broker are used:

- The C-ITS control centre publishes and receives messages directly to the server's internal ActiveMQ broker.
- The C-ITS Gateway acts as a message router and calculates the quadpathtree topics.
- The MQTT broker serves as an external interface to the RSU.

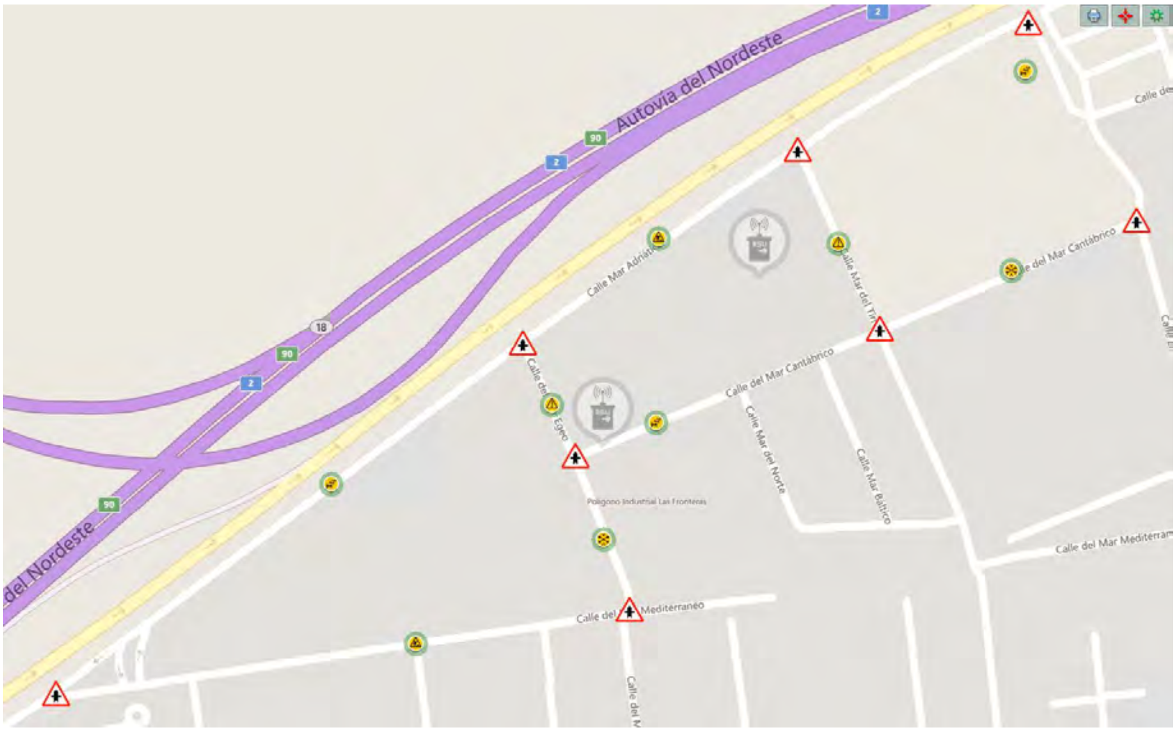

Figure 19. Example map of the C-ITS control centre with two RSU placed in it

UC5.2 – AR tools for worker support

Technical Demonstrator 2 foresees the development of an AR/VR solution to support maintenance workers on the road during their work. The main objective is to solve the following challenges through digitised procedures in different viewing environments. First of all, there are many difficulties accessing information and documents in real-time when the worker is in the field, including a lack of support from expert knowledge. In addition, there is a lack of traceability of the actions carried out by field technicians, which represents a significant lack of transparency and efficiency. Finally, the displacement to solve a problem by an expert requires a lot of time and money.

Within this demonstrator, the following tasks are going to be addressed:

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- Creation of the digital room: 2D / 3D multiplatform visualisation and interaction software that allows to view any element and data required (Simple Visualization, Augmented Reality), using any technology and platform available (Mobile, Tablet, PC and AR Devices and VR).
- Creation of a model repository. The source repository stores 3D models of the system, data sources, and data models.
- Testing the training mode of the platform for a technician.
- Testing the remote mode of the platform (technician and remote expert).

The expected outputs, once the project is completed, it will allow improving the capabilities of the maintenance services in the field, being provided with technical information in real-time to improve the speed and quality of maintenance activities on the road:

- Evaluate the AR platform to provide the status of the systems to be maintained visually.
- Evaluate the AR platform to facilitate and guide the user in maintenance, repair or training tasks.

UC6.1 – Road digital twin

This demonstrator aims to create an operational Digital Twin of a section of the A-2 highway is planned. The aim is to connect in real-time the information of the elements susceptible to interoperability of a 3D digital model to the databases that manage the systems that manage and operate the sensorisation and the remote control of the physical asset.

The objective is not a faithful graphic representation of the road, but to put the information of the road management systems and interact with them in a three-dimensional context.

For this purpose, the following activities will be carried out:

- Identify the interoperable elements of the physical asset with which the model communicates.
- Generate the typology of the 3D elements and provide them with the geometry and attributes necessary for their identification and connection.
- Generate a 3D context to place the 3D elements (digital model).
- Connect the database associated with the digital model with the physical asset management system.

In addition, a BIM Execution Plan (BEP) will be drafted to determine the use of the model, the levels of definition and development, and the necessary attributes to be met by the elements to be modelled and contextualized.

Once all the road elements have been defined, it will be decided what type of information is most useful to include in the DT, thus obtaining a DT of a physical asset, in this case, the A-2 highway.

Related KPIs

The following KPIs will apply.

- KPI 1. Exposure time of road workers and users to hazardous situations derived from inspection tasks.
- KPI 4. Volume of major intervention actions.
- KPI 5. Traffic disruptions due to inspection tasks.
- KPI 6. Traffic disruptions due to maintenance interventions.
- KPI 8. Congestion due to traffic disturbances.

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- KPI 12. Road Hazard Index.
- KPI 13. Availability of the network. Impact of a reduced number of disruptions due to accidents and interventions.
- KPI 14. Availability of the network. Impact of the reduction of traffic disruptions due to maintenance.

Expected Duration

Technical demonstrator 2 will be extended until the end of the project, where the first tests (Stage 1) will start in August 2023 (M28) and will end in April 2024 (M36), where testing of the demonstrator in the real environment of the A-2 highway in the NE of Madrid will start (Stage 2). The demonstrator will be completed in July 2024 (M39).

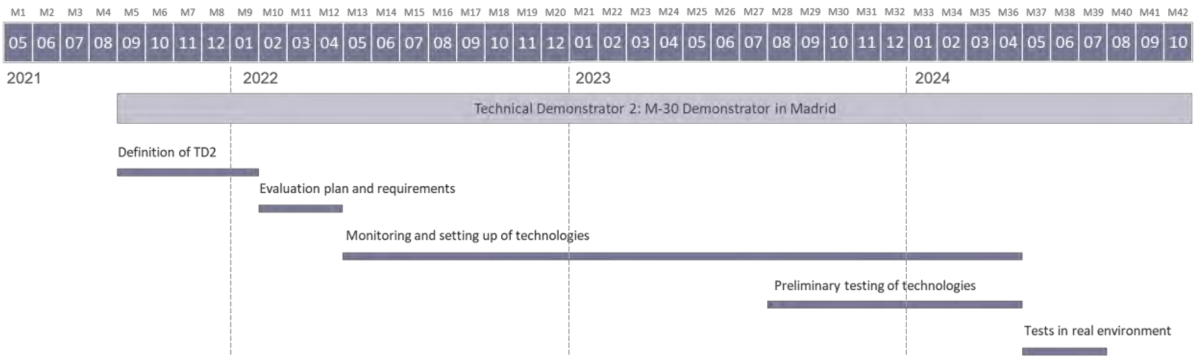

Figure 20. TD2 Timeline

Boundary conditions

UC1.3 – V2X

All developments and technologies involved will follow the standard promoted by the European Commission in terms of C-ITS. In this case, the IEEE 802.11p standard will be followed, which defines the ETSI-ITSG5 standard[1]:

The data format used for C-ITS services will be DENM (EN 302 637-3 - Decentralized environmental notification message).

Stakeholders to be involved

This demonstrator involves two project partners, Indra and the University of Cambridge; two third-parties, Prointec and IFT; and an end-user road operator, Acciona.

Indra will be the leader of the demonstrator. Indra will deploy 1-2 antennas RSU on A-2 Highway in the Northeast of Madrid, so it will also be in charge of developing the short-range V2X communications. In addition, Indra will provide AR/VR tools to the maintenance operators in the field and all the arrangements for access to permissions for these tests in the real scenario.

[1]ETSI-ITSG5 standard. https://www.etsi.org/deliver/etsi_en/302600_302699/302663/01.02.00_20/en_302663v010200a.pdf.

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Prointec will manage the creation of a digital twin of the road where the information provided by the sensors of the technologies deployed on-site can be incorporated in real-time. In addition, Prointec will monitor the pavement inspection through artificial intelligence cameras to improve the auscultation process developed by IFT.

The University of Cambridge will test its three-camera system (LIDAR, RGB and near-infrared) for pavement inspection to extract low-level road information.

Acciona is the concessionaire of the section where it carries out both replacement and major repairs to the infrastructure and all the ordinary maintenance tasks, road maintenance and administrative management tasks for the operation of the road, which allows having available maintenance vehicles to carry out tests. They will provide the maintenance vehicles during the tests. They will also provide A-2 digital maps to enhance the digital twin creation.

Authorisations and related processes

Acciona will provide the necessary permissions to perform the tests in a real environment to simulate a real use of the systems developed within the technologies involved.

Expected Outputs

The main expected outputs of the Use Case are presented as follows.

- Improvement of the auscultation of parameters such as the Sideway Force Coefficient (SFC) and IRI using an AI camera inspection system.
- AR/VR tools for supporting field maintenance and first aid.
- Maintenance C-ITS services for V2X communication.
- Operational Digital Twin of the A-2 Highway.

The specificities of each Use Case in this demonstrator are presented in the following tables.

UC1.2.2. Automation of auscultation process control of road parameters

Stage 2 Protocol	UC1.2.2. Automation of auscultation process control of road parameters
Objective	Improvement of the auscultation process for the computation of road parameters such as: • Sideway Force Coefficient (SFC) • International roughness index (IRI)
Activities	The demonstrator aims to automate the whole process of viewing the recordings. The objective is the automatic inference of the degree of deviation of the monitoring vehicles concerning their driving lane. Work is going to be carried out in 2 phases: • 1 Phase: Train the model with open datasets of road images and test the three algorithms. • 2 Phase: Refinement and trained with a dataset of the A-2 highway (TD2).
Expected duration	Aligned with the schedule of TD2.

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Stage 2 Protocol	**UC1.2.2. Automation of auscultation process control of road parameters**
Link with Stage 1	Some tests will be carried out with historical images of other roads to train the algorithms and decide which of the three proposed solutions have the most significant potential.
Link with Stage 3	N/A
Boundary conditions	• Lack of historical images • How to collect images during auscultation
Constraints	N/A
Stakeholders to be involved	IFT, Prointec, Acciona
Authorization	Acciona will provide maintenance vehicles for the collection of road images. They will provide historical data.
Design specifications	TBD
Customization activities	TBD
Expected outputs	Automated detection of inference of the degree of monitoring vehicles deviation concerning the lane in which they are driving

UC1.3. V2X communications

Stage 2 Protocol	**UC1.3. V2X communications**
Objective	• Ensure road safety and driving efficient conditions during maintenance activities • Test the technologies in the CEF Atlantic Corridor equipped with V2X technology in A-2 Highway in the NE of Madrid • Develop C-ITS "Day 1" and "Day 1.5" services adapted to road maintenance works
Activities	• IEEE 802.11p standard will be followed, which defines the ETSI-ITSG5 standard • The data format used for C-ITS services will be DENM (EN 302 637-3 - Decentralized environmental notification message). For the exchange of messages between the C-ITS control centre and the RSU, an ActiveMQ broker, a C-ITS Gateway process and an MQTT broker are used: • The C-ITS control centre publishes and receives messages directly to the server's internal ActiveMQ broker. • The C-ITS Gateway acts as a message router and calculates the quadpathtree topics.

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Stage 2 Protocol	UC1.3. V2X communications
	• The MQTT broker serves as an external interface to the RSU.
Expected duration	Aligned with the schedule of TD2
Link with Stage 1	N/A
Link with Stage 3	This technology is going to be deployed in the final demonstrator in Italy
Boundary conditions	Suitable installation conditions for the RSUs must be met to ensure communication with the vehicles. Preferably on porticos or light poles, away from elements that may act as a barrier, such as bridges or buildings.
Constraints	N/A
Stakeholders to be involved	Indra, Acciona
Authorization	Acciona has to allow the installation of RSU antennas on the A-2 highway and ensure their maintenance during the development of the pilot.
Design specifications	To be defined later in the project
Customization activities	To be defined later in the project
Expected outputs	Maintenance and user support platform using V2I and I2V communications

UC5.2. AR tools for worker support

Stage 2 Protocol	UC5.2. AR tools for worker support
Objective	The objective is to solve the following challenges through digitized procedures in different viewing environments: • Difficulties in accessing information and documents in real-time. • Lack of support through expert knowledge. • Lack of traceability of the actions carried out by field technicians. • Displacement to solve a problem by an expert requires a lot of time and money.
Activities	• Creation of the digital room: 2D / 3D multiplatform visualization and interaction software allow us to view any element and data required (Simple Visualization, Augmented

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	Reality) using any technology and platform available (Mobile, Tablet, PC and AR Devices and VR). • Creation of a model repository: The source repository stores 3D models of the system, data sources, and data models. • Testing the training mode of the platform for a technician • Testing the remote mode of the platform (technician and remote expert)
Expected duration	Each test will last about two working days, and it will be repeated as many times as needed during the duration of Task 2.3
Link with Stage 1	N/A
Link with Stage 3	We have to explore the compatibility of the decentralised control centre with the AR/VR tools developed in WP3 to deploy the final demonstrator.
Boundary conditions	N/A
Constraints	The timing will be dependent on the maintenance planning of the A2
Stakeholders to be involved	Just the partners involved in the development of the demonstrator (IND and its third parties PROI and IFT)
Authorization	Not needed
Design specifications	• PC to install the platform • AR headset for the maintenance operator • AR headset for the expert technician • Tablet headset for the maintenance operator
Customization activities	The platform will be configured to maintain a road device such as an RTU (Remote Terminal Unit) or a variable message sign (VMS) to test it.
Expected outputs	• Evaluate the AR platform to provide the status of the systems to be maintained visually. • Evaluate the AR platform to facilitate and guide the user in maintenance, repair or training tasks.

UC6.1. Road Digital Twin

Stage 2 Protocol	UC6.1. Road Digital Twin
Objective	Connect the information of the interoperable elements of a 3D digital model to the database(s) in real-time. The database manages the systems for the sensorization and the remote control of the physical asset.
Activities	• Identify the interoperable elements of the physical asset with which the model communicates.

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	• Generate the typology of the 3D elements and provide them with the geometry and attributes necessary for their identification and connection. • Generate a 3D context to place the 3D elements (digital model). • Connect the database associated with the digital model with that of the physical asset management system.
Expected duration	Aligned with the schedule of TD2
Link with Stage 1	N/A
Link with Stage 3	N/A
Boundary conditions	Those of the physical asset management systems themselves.
Constraints	It is not a question of making a hyper-realistic model of the physical asset, but to make the exercise of putting in three-dimensional context the information of the asset management systems and interacting with them.
Stakeholders to be involved	Acciona, Prointec, Indra
Authorization	N/A
Design specifications	A BIM Execution Plan (BEP) will be drafted to determine the use of the model, the levels of definition and development, and the necessary attributes to be met by the elements to be modelled and contextualized.
Customization activities	N/A
Expected outputs	Develop a Digital Twin for physical assets.

3.2.3 TD3. A-92 Seville

Objective

The main objective ofthis TD is to demonstrate smart solutions to support the replacement of surface pavement layers, using automation technologies and fostering the use of AUTLs (Asphalt for Ultra-Thin Layers).

1.- Automation technologies to support the asphalt pavement construction automation-monitoring system cover the following steps. Tack coat (emulsion) application, asphalt mix laydown, and compaction operation. The main architecture of the system, the development of the required hardware and the software structure, and the implementation process are the most important activities of this part of the whole objective.

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Figure 21. Pavement rehabilitation process

2.- The second part of the whole objective will consist of the design of sustainable Asphalt Ultra-Thin Layers AUTL) combining AUTL technologies with Warm Mix Asphalt (WMA) technologies and waste or recycled materials (Reclaimed Asphalt Pavements, RAP, and crumb rubber).

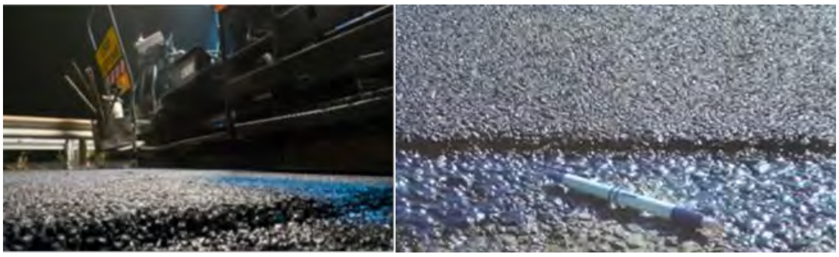

Figure 22. AUTL examples

Activities and Use Cases

The asphalt pavement construction automation-monitoring system covers the following steps of the process:

- Tack coat (emulsion) application.
- Asphalt mix laydown.
- Compaction operation.

The main architecture of the system, the development of the required hardware and the software structure, and the implementation process are key activities to develop in this demonstrator.

The system has to perform automatic data collection and data transmission. It should automatically provide feedback to the construction site for real-time asphalt pavement construction control and automation.

The entire process has to work automatically without much human intervention and covers the whole project throughout the entire construction period in real-time.

Statistical analysis of current asphalt mix tests and lay down. Compaction monitoring data, collected at the pilot section, has to be performed to indicate what variables or parameters are correlated with laydown and compaction density and macrotexture, whereas rolling passes, finishing rolling temperature and asphalt mix laydown temperature, among others, may be correlated with density and macrotexture.

Many factors are associated with pavement construction quality. Although a well-established pavement construction control system exists in Europe, its monitoring procedures have two shortcomings: firstly, despite the use of some automatic detection equipment, such as the Pavement Quality Indicator for Asphalt mixes density measurement in the field, the system is highly dependent

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on manual data collection, with this having low cost-efficiency, as well as being inaccurate. Secondly, manual quality control can test limited project samples rather than monitoring and testing the entire project. As the sampling rate is low, data resolution is not as high as required.

The system to be developed should automatically collect, analyse, and deliver several key parameters in field tack coat application, paving and compaction operations, automatically providing feedback of the pertinent online information to operators at the construction site.

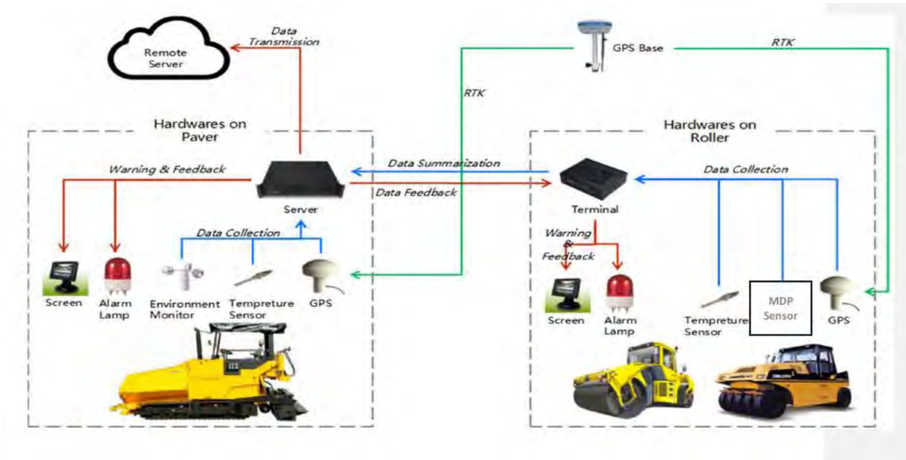

Figure 23. Pavement rehabilitation process workflow

Today's major challenge in automating the control process is measuring project performance indicators (PPIs). The technical demonstrator will include the deployment of a system whose functionality consists of three layers (Figure 24).

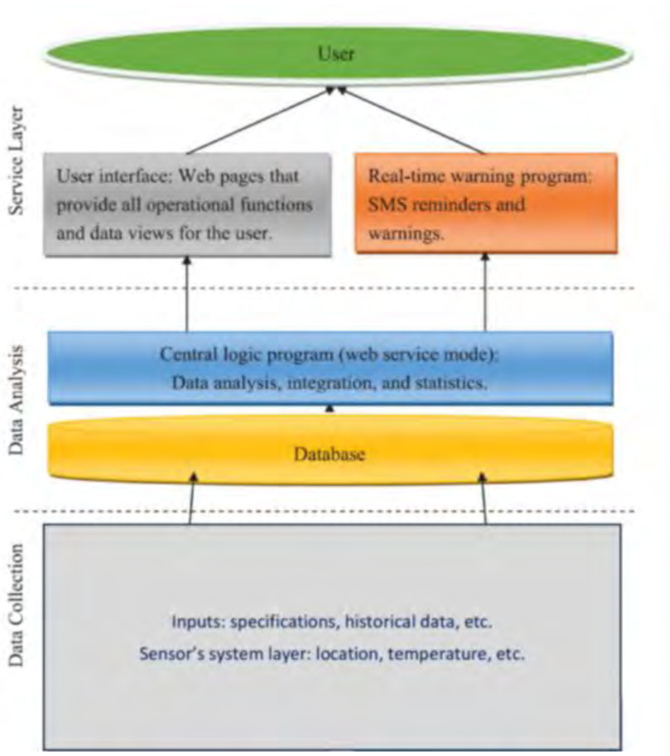

Figure 24. Pavement rehabilitation services

- **Data collection layer.** This is the basic layer, responsible for data collection and uploading in real-time. Inputs: specifications, historical data, and sensor measurements.

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- **Data analysis layer.** The database and the central logic program form the core component. This program is developed in web service mode, which does not directly interact with users, but provides a variety of functional interfaces to the service layer.
- **Service layer.** This layer, which directly communicates with users, could be formed by the web pages and SMS message warning program.

On the other hand, the scope of the activities to foster Asphalt Ultra-Thin Layers will consist of obtaining RAP, virgin aggregates, asphalt binders of different grades and crumb rubber, making recycled mixes with design asphalt content(s), testing the samples, and analysing the results.

A successful AUTL design depends on many factors, including avoiding high variability in RAP, selecting the right recycling agent if needed, determining the optimum amount of the recycling agent, and selecting the correct temperature for mixing and compaction. The end product is expected to be workable and compacted in the field to desirable air voids, provide sufficient stability against traffic to prevent rutting, and have enough durability against moisture, traffic, and environmental damage over its design life.

Figure 25. Pavement rehabilitation design

Related KPIs

KPI 2. Surface pavement layer rehabilitation with AUTL means higher paving speed than other surface layers. Thus, pavement works can save up to 20% of the time in these processes. On the other hand, traffic may be allowed on the treated surface after only 2 hours under ideal weather conditions.

KPI 6. Less traffic disruption is expected due to maintenance intervention on the pavement as sealing cracks or pit repairs.

KPI 9. Ultra-thin overlays (less than 2.0 cm) offer an economical resurfacing, preservation and renewal paving solution for roads requiring safety and smoothness improvements.

To evaluate these KPIs, it will be necessary to collect the following data:

1. Workers:
   - Person, job position and time during the intervention.
2. Time:
   - Total time intervention.
   - Action time: tack coat application, paving, compaction, etc.
3. Other costs: materials and life cycle calculation.

Other relevant data:

- Environmental data: power, fuel, CO_2 emissions, virgin and recycled materials.
- Quality control: surface functional parameters (macrotexture, friction pavement, etc.).

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Expected Duration

- Period to perform technical demonstrator: From January to March 2024.
- The technical demonstrator will be developed in less than one workday.
- The pilot section, probably, will be executed at night-time (22:00h to 6:00h) from Sunday to Thursday.

Boundary conditions

Asphalt pavement related Spanish General Technical Specifications and requirements from Ministry of Transport (MITMA, *Ministerio de Transporte, Movilidad y Agenda Urbana*), as stated but not limited to:

- Norma 6.3 IC: Rehabilitación de firmes.
- Pliego de Prescripciones Técnicas Generales para obras de carreteras y puentes (PG-3).

Constraints

- Traffic issues: Previous accidents in the work zone and days or hours of dense traffic.
- Weather conditions: wind speed or rain probability.
- Authorisation delays: bureaucracy, pandemic, etc.

Stakeholders to be involved

Technology partners and others if needed:

- Project partners: Tekniker, Cemosa.
- Workers of public traffic entity DGT.
- Road Administration/Owner staff.
- EIFFAGE employees: Head of maintenance and conservation department, operation technicians, and machinery operators.
- Subcontracted companies if needed: e.g., road marking technicians and operators.

Authorisations and related processes

It is necessary to obtain the authorisation to perform pavement surface pilot section for the specific workplace (name of the road and pilot section location) by the Andalusia Regional Administration in charge of the operation and maintenance of the A-92 highway.

The administrative resolution will consider boundary conditions like timeline and execution days.

Design specifications

The demonstration road will be in the Mediterranean corridor, A-92 Highway between K.P. 0,000 to 50,000, which will allow checking the influence of weather conditions and locally available materials on the replaced pavement performance. This validation will provide an opportunity to observe construction from start to finish, take samples, record observations through the construction, monitor early-life performance, and provide recommendations for future applications.

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It has to be considered future maintenance interventions until the deadline demonstrator:

- Crack sealing, pit repairs, etc.
- Other rehabilitations of surface pavements layers.

The work zone estimated will be localized on the heavy traffic lane. The pilot section will have a minimum length of 500 meters.

Customization activities for the demonstrator

The graphical interfaces and menus of the applications will need to be translated to Spanish since the demonstrator will be held in Spain, and Spanish workers will use the applications.

Operational planning:

- Visual Inspection.
- Location and timing plan definition.
- Final authorisation.

Operational execution:

- Previous tasks: Machinery and equipment preparation and transport to the work zone.
- Asphalt surface pavement layer execution and data collection (execution of the pilot section).
- Post activities: other activities related to testing or further inspections.

Expected Outputs

Demonstration of pavement installation technologies, improved intervention times (at least up to 20% of the time) and execution quality (surface homogeneity and project performance indicators).

Finally, the summary of the developments of UC3.4 in TD3 is presented below.

Stage 2 Protocol	UC3.4. Smart rehabilitation of surface pavement layer
Objective	Smart solutions to support the replacement of surface pavement layers, using automation technologies and fostering the use of AUTLs (Asphalt for Ultra-Thin Layers).
Activities	- The asphalt pavement construction automation-monitoring system: the architecture of the system, the development of the required hardware and the software structure. - The activities to foster Asphalt Ultra-Thin Layers will obtain RAP, virgin aggregates, asphalt binders of different grades and crumb rubber, make recycled mixes with design asphalt content(s), test the samples, and analyse the results.
KPI	KPI 2. Higher paving speed compared to other surface layers. KPI 6. Less traffic disruption due to maintenance intervention on the pavement as sealing cracks or pit repairs. KPI 9. Ultra-thin overlays (less than 2.0 cm) offer an economical resurfacing, preservation and renewal paving solution.
Expected duration	Period to perform technical demonstrator: From January to March 2024.

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Stage 2 Protocol	UC3.4. Smart rehabilitation of surface pavement layer
	The technical demonstrator will be developed in less than one workday.
Link with Stage 1	No link. However, there is a high possibility to test the Smart System and the designed AUTL in previous trials before the TD3 pilot section execution. That is to confirm two things: 1.- The monitoring system should be proven effective and reliable before being implemented in the A-92 highway construction pilot section. 2.- The AUTL end designed product is workable. It can be compacted in the field to desirable air voids, providing sufficient stability against traffic to prevent rutting and having enough durability against moisture, traffic, and environmental damage over its design life.
Link with Stage 3	Data provided to the final demonstrator will be: - Operation costs. - Intervention times. - Report of intervention zone executed (pilot section) and its outputs.
Boundary conditions	Asphalt pavement related Spanish General Technical Specifications and requirements from MITMA (Ministerio de Transporte, Movilidad y Agenda Urbana), as stated but not limited to: - Norma 6.3 IC: Rehabilitación de firmes. - Pliego de Prescripciones Técnicas Generales para obras de carreteras y puentes (PG-3).
Constraints	- Traffic issues: Previous accidents in the work zone, Days or hours of dense traffic, etc. - Weather conditions: wind speed or rain probability - Authorisation delays: bureaucracy, pandemic, etc.
Stakeholders to be involved	Technology partners and others if needed: Tekniker, Cemosa.
Authorization	It is necessary to obtain the authorisation to perform pavement surface pilot section for the specific workplace (name of the road and pilot section location) by the Andalusia Regional Administration in charge of the operation and maintenance of the A-92 highway.
Design specifications	Hardware, software, machinery adaptation or customization, asphalt mix materials and asphalt mix working formula will be designed according to the Spanish and European related specifications (stated in D1.1).
Customization activities	Operational plan and operational execution activities.

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Stage 2 Protocol	UC3.4. Smart rehabilitation of surface pavement layer
Expected outputs	Demonstration of pavement installation technologies, improved intervention times (at least up to 20% of the time) and execution quality (surface homogeneity and project performance indicators).

3.2.4 TD4. A7 Valencia

Objective

The main expectation is to test new technologies at extraordinary road maintenance activities to achieve high safety standards:

- Robotising operations.
- Reducing the exposure time of operators on the road.

Activities and Use Cases

The technical demonstrator will include the deployment of the following technologies:

- UC 3.2 Robotised sealing of surface pavement cracks.
- The multipurpose robotic platform, including the developments in T4.2, T4.3 and T4.4.
- The VR-AR technologies from WP3 and WP4.

Related KPIs

KPI3. Operation safety: Reduction of the number of people in dangerous zones in maintenance areas by 75%.

KPI9. Saving costs: The enhancement in inspection and intervention tasks in OMICRON will reduce costs by 13%.

The evaluation of the KPIs will be possible collecting the following data:

- Workers:
  - Person, job position and time during the intervention.
  - Person, job position and time exposed to danger.

- Time:
  - Total time intervention.
  - Time to execute previous activities (logistics, signalling, robot assembly, heating machine).
  - Action time: blowing, sealing, pouring of aggregates.
- Other costs: external machinery.

Other relevant data:

- Environmental data: power, CO_2 emissions
- Quality control by visual inspection
- Work velocity: linear metres fixed

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Expected Duration

The period to perform the technical demonstrator goes from October 2023 to March 2024, preferably during November 2023 because it matches the planned schedule of the conservation road centre.

The technical demonstrator will be developed in 2 weeks with three opportunities to perform an entire workday. Those three days will be distributed along the period to solve any technical or mechanical problem that could appear.

The law establishes that the maintenance activities along highways can be executed only in the nighttime (22:00h to 6:00h) from Sunday to Thursday to limit the impact on traffic. The maintenance work is subdivided into sections that can be completed in one work shift, 8 hours.

Boundary conditions

Instructions and regulations from the Spanish Ministry of Transport (MITMA, *Ministerio de Transporte, Movilidad y Agenda Urbana).*

- Pavement rehabilitation: *Norma 6.3 IC: Rehabilitación de firmes.*
- Crack sealing: *Nota de servicio 2/2015: Sellado de grietas en pavimentos bituminosos.*
- Construction site signalling: *Norma 8.3 IC: Señalización de obras*
- Fixed works signalling: *Manual de ejemplos de señalización de obras fijas*

Internal procedures:

- Signalling (*PE 02: Colocación y retirada de señalización de preaviso*).
- Lane closures (*PE 03: Ejecución de cortes de carril en autovías y carreteras convencionales*)

Constraints

- Traffic issues:
  - Previous accidents in the work zone.
  - Days of massif traffic due to near holidays.
  - Days of significant events in Valencia.
- Social conditions:
  - People on vacation: operators, coordinators, stakeholders, etc.
  - National holidays in any country of involved people.
  - Authorities' prohibition: bureaucracy, pandemic, etc.
- Weather conditions:
  - Wind or rain.

In case of a delay in the technical demonstrator, it would be possible to change to A7 highway in sector CS1 in Castellón (as Pavasal may not have the maintenance activities in the expected sector due to the expiration of the contract with Sector-V1). Anyway, PAVASAL counts on MITMA support, and it has committed to perform the intervention.

Stakeholders to be involved

- Technology partners: Tekniker, LMS.
- Workers of public traffic entity DGT.
- Ministry staff.

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- Pavasal employees:
    - COEX head: Jordi Mayals.
    - Operation heads: Vlad Cioara and Rosa Sanjuan.
    - Operators for signalling.
    - Machinery operators.
    - Trained operators for new technologies.
    - Technicians.
- Subcontracted companies if needed: e.g. crane.

Authorisations and related processes

From the Ministry of Transport (MITMA), it is necessary to authorise the concrete workplace (name of the road) through the State Road Demarcation in Comunidad Valenciana. The application should be processed at least three months before deadline work maintenance execution and sent by current digital media (SGS).

The final resolution will consider boundary conditions, including timeline and execution days that match what the Sector V1 officers meeting agreed.

Anyway, once the authorisation is obtained, it will be necessary to inform to conservation centre about the corresponding Tele-route report to avoid constraints in work zones.

Besides, the road preservation centre communicates daily to the Management Traffic Centre of Valencia, part of DGT and the Ministry of Interior, the maintenance interventions planned during the day.

Design specifications

The demonstrator will be performed at the E-15/A-7 motorway between K.P. 306+700 to 353+470, known as ByPass of Valencia. It is managed by Sector V1, part of the Mediterranean CEF corridor in Spain.

A-7 is a highway connecting the North and South sides of Valencia through a bypass, and it links all the other routes to the city centre. A-7 motorway is a suitable location for testing Omicron's results as it includes several pavements cracks for heavy traffic, and it is mandatory to perform maintenance activities at night.

The most favourable work zone is established to perform the technical demonstration to OMICRON's project for sealing pavement cracks with robot and vision technologies.

It has to be considered future maintenance interventions until timeline demonstrator:

- Other sealing surface pavement cracks.
- Rehabilitations of surface pavements layers.

The estimated work zone will be localized on the right and central lane, Valencia-Alicante direction, between K.P. 307 and 311. However, the concreted place must be agreed upon with road maintenance officers of the V-1 sector.

Other design specifications:

- A maintenance plan is defined according to the annual plan of Road Conservation Centre, sector V-1.

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- Maintenance activities will be executed on the left lane for the road of two total lanes. On the other hand, central and left lanes will be performed for roads of three lanes.
- A simple and quick mechanism for robotic assembly platform.
- Artificial light.
- Maximum slope of 5% to avoid bitumen overflows.
- The limited capacity of observer people during work maintenance.
- The conditionate place for stakeholders.

Maintenance planning:

Figure 26. Maintenance planning workflow

Maintenance execution:

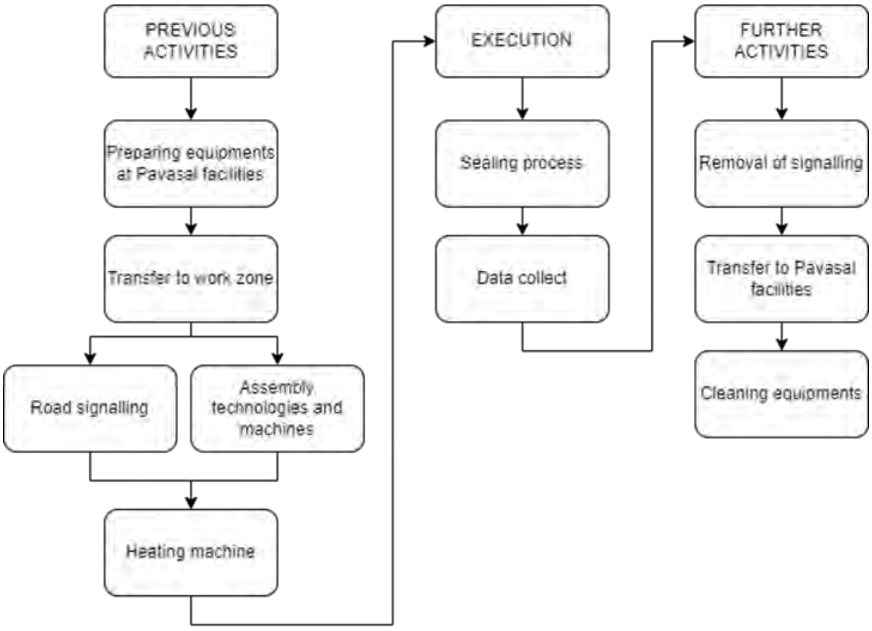

Figure 27. Maintenance execution workflow

Customization activities for the demonstrator

The graphical interfaces and menus of the applications will need to be translated to Spanish since the demonstrator will be held in Spain, and Spanish workers will use the applications.

Expected Outputs

The main expected output will demonstrate that the automatic process is just as valid as the manual and traditional model but decreases danger and maintains quality with the same execution speed.

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Another output will be to perform a complete workday with the new solution and collect all data for the final demonstrator.

Finally, an overview of the applicable Use Cases in this TD4 is presented below.

UC3.2. Robotised sealing of surface pavement cracks

Stage 2 Protocol	UC3.2. Robotised sealing of surface pavement cracks
Objective	The main expectation is improving **safety** during extraordinary maintenance activities.
Activities	- UC 2.1 – Robotic modular platform - UC 3.2 – Sealing of surface pavement cracks - UC 5.1 – VR platform for robot teleoperation - UC 5.2 – AR tools for worker support
KPI	KPI 3 and KPI 9
Expected Outputs	- To demonstrate the automatic process - Decreasing danger but maintaining quality and execution velocity. - To be able to perform a complete workday with the new solution. - Collect necessary data for the final demonstrator.
Expected duration	A complete work shift (8h) at night during the autumn period.
Link with Stage 1	Functionality system has been demonstrated in Stage 1.
Link with Stage 3	Operation costs, intervention times, report of intervention zone executed and its location.
Boundary conditions	Instruction form MITMA (Ministry of Transport).
Constraints	Traffic due to accidents, weather: rain or wind, pandemic situation or legal issues due to contract with preservation road.
Stakeholders to be involved	Technological partner, ministry and necessary PAV employees.
Authorization	A formal request to MITMA and communication to DGT
Design specifications	E-15/A-7 motorway between pp.kk 306+700 to 353+470. The work zone shouldn't have more than 5% of slope to avoid overflows of bitumen, and it must include a conditionate place for assembling and preparing the whole system.
Customization activities	AR interface in the Spanish language

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UC5.1. VR platform for robot teleoperation

Stage 2 Protocol	UC5.1. VR platform for robot teleoperation
Objective	The objective of this use case in Stage 2 is to integrate the teleoperation technologies in PAVASAL's setup and validate them in the real intervention of crack-sealing. This integration will provide insight and validate the practical benefit of the teleoperation since it will be used on a real road outside of the lab. Aside from the teleoperation service, the VR based training tool for inexperienced workers will continue to be tested and refined for the crack-sealing case.
Activities	Integrate and validate VR teleoperation capabilities in crack sealing
KPI	The relevant KPIs and the impact of VR technologies will be similar to those listed in Stage 1. In this stage, the impact of the developments for KPI 2 and KPI 3 will be validated further, in a demonstrator environment in the outside world, with actual road workers. In the case of crack-sealing, both VR and AR methods will be used, and a comparative analysis of each will be performed.
Expected duration	It will depend on the duration of the demonstrator defined by PAV.
Link with Stage 1	Information on the integration of VR technologies will be taken from the lab testing
Link with Stage 3	Validate functionalities for the final demonstrator
Boundary conditions	For the headset: UL 8400, IEEE P2048, for the robot: ISO 10218-1, ISO 10218-2, ISO/TS 15066, ISO 12100, ISO 13849-1, ISO 13849-2, ISO 60204-1
Stakeholders to be involved	TEK, PAV
Authorization	N/A
Design specifications	The design specifications are similar to the ones analysed in Stage 1. The differences are: • The communications must be installed for PAV's setup. • Since the demonstrator and the robot will be on the road, the operator for the teleoperation will be in a remote location, and communication must be established for a great distance. That may require more hardware, such as one PC in the remote location and one in the truck. • The teleoperation will be applied to the crack-sealing intervention only.

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Stage 2 Protocol	UC5.1. VR platform for robot teleoperation
Customization activities	The graphical interfaces and menus of the application will be translated to Spanish for the needs of the demonstrator, which will be in Spain, utilized by Spanish workers.
Expected Outputs	• Validate capabilities of VR platform for the teleoperation of robotic resources, ready to be used in the final demonstrator. • Validate VR-based training tool capabilities, ready to be used in the final demonstrator.

UC5.2. AR for worker support

Stage 2 Protocol	UC5.2. AR for worker support
Objective	The objective of this use case in Stage 2 is to integrate the AR technologies in PAVASAL's setup and validate them in the real intervention of crack-sealing. This integration will provide insight and validate the practical benefit of the worker support tools since it will be used on a real road outside of the lab.
Activities	Integrate and validate the AR support tool for crack sealing
KPI	The relevant KPIs and the AR technologies' impact will be similar to those listed in Stage 1. In this stage, the impact of the developments for KPI 2 and KPI 3 will be validated further, in a demonstrator environment in the outside world, with actual road workers. In the case of crack-sealing, both VR and AR methods will be used, and a comparative analysis of each will be performed.
Expected duration	It will depend on the duration of the demonstrator defined by PAV.
Link with Stage 1	Information on the integration of AR technologies will be taken from the lab testing
Link with Stage 3	Validate functionalities for the final demonstrator
Boundary conditions	For the headset: UL 8400, IEEE P2048
Stakeholders to be involved	TEK, PAV
Authorization	N/A
Design specifications	The design specifications are similar to the ones analysed in Stage 1. The differences are:

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Stage 2 Protocol	UC5.2. AR for worker support
	• The communications must be installed for PAV's setup. The AR developments will be applied to the crack-sealing intervention only.
Customization activities	The graphical interfaces and menus of the application will be translated to Spanish for the needs of the demonstrator, which will be in Spain, utilized by Spanish workers.
Expected Outputs	• Evaluated AR tools to support in-field workers with road information, maintenance guidance and robot control

3.3 Stage 3 Protocol – Final Demonstration

Objective

In this section, the Final Demonstrator in Italy is described, including some potential test-bed that can be used to deploy the technologies. SDP motorway is set up as a strategic and barycentric motorway system for mobility on the east-west route of the country's central corridor. It plays a vital role in supporting the mobility of production activities, communications, commerce, tourism, and the social and economic development of the country.

The motorways A24 and A25 cross a nature area rich and diverse. In that regard, it should be noted that the presence in the territory of six Natural Parks is highlighted in green in the figure.

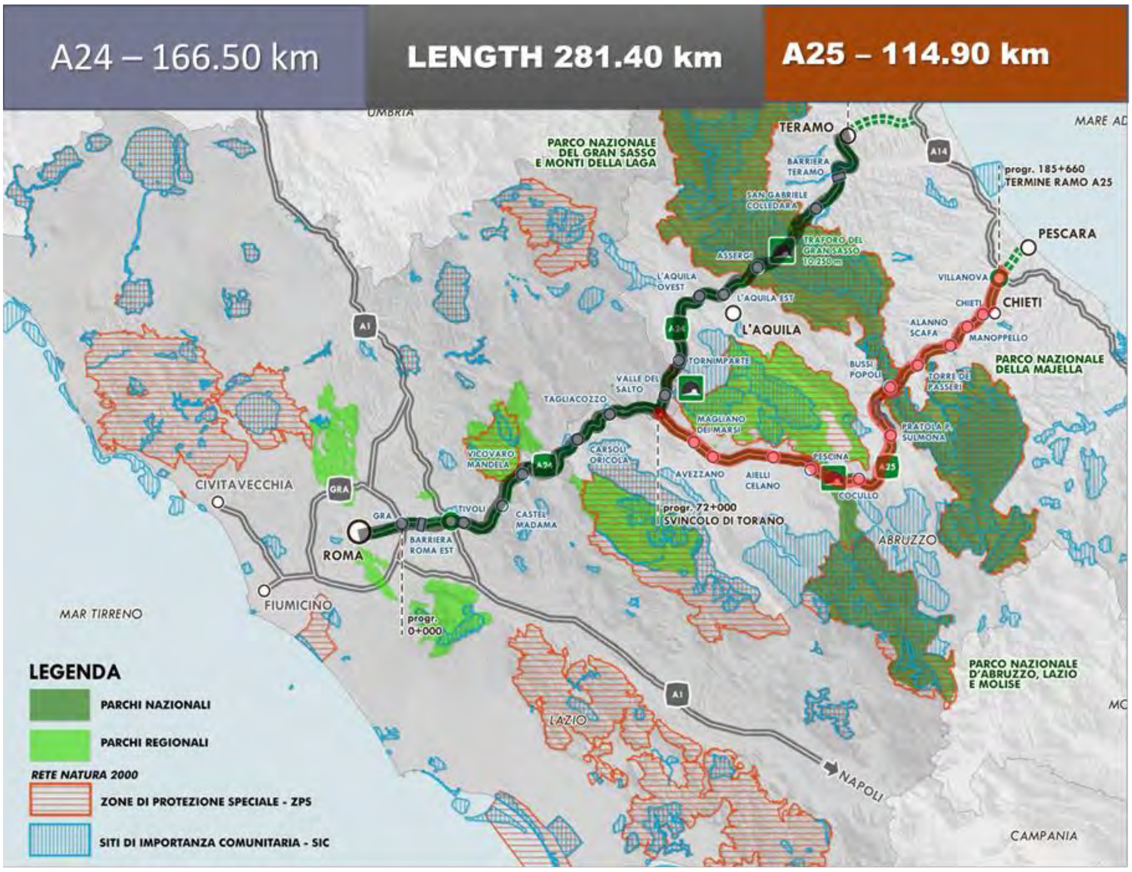

Figure 28. Overview of Strada dei Parchi motorways: A24 and A25

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This Demo aims to test all the technologies developed on Strada dei Parchi infrastructure within an existing work zone and worksites specifically created.

Besides this, areas such as station yards, service areas, and parking areas close to the highway can be used for technology that cannot be tested on the roadway due to regulation.

There are already several options that can be used as test-bed and in line with the expectation of the partners that will develop the OMICRON technologies and solution, as is described in Chapter 2

Figure 29. Urban segment of the A24 motorway – connection with Rome

As the infrastructure manager, SDP will be available to test technologies that were not originally planned to be applied to the final demo. However, this topic should be revised and updated in agreement with all partners, considering the project's boundary in terms of resources and time. Any additional test and activity should be discussed, agreed and eventually financed with extra funds (e.g. SDP own resources) in case of specific interest.

In the following tables, the set of activities to be carried out are presented, together with the main authorizations that will be requested, the stakeholders to be involved, the needed equipment and the duration and timing of the different tests. It is worth remembering that the situation may change during the project, so updating this information set will be mandatory when approaching the planning phase of tests.

UC1.1. UAVs: Management tool

Stage 3 Protocol	UC1.1. UAVs: Management tool
Objective	The main goal is to test the UAVs Management Tool in a realistic scenario for a long-range inspection mission.
Activities	- Configuration of Management Tool: site map and inspection resources. - Define different long-range inspection missions. - Execute inspection missions: select predefined inspection, upload trajectory to UAV, launch inspection and monitor in real-time. - Collect data after the UAV has landed.

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Stage 3 Protocol	UC1.1. UAVs: Management tool
KPI	KPI 1. Exposure time of road workers and users to hazardous situations derived from inspection tasks should be reduced by 65%. KPI 5. Traffic disruptions due to inspection tasks should be reduced by at least 50% KPI 9. Maintenance and inspection activity costs are reduced at least 10%
Expected Outputs	Test report analysing UAVs Management Tool performance and usability.
Expected duration	Several experiments will be necessary before the final validation, but the final test will occur during a single day.
Link with Stage 1	The first version of the UAVs Management Tool is initially evaluated during stage 1 tests in ATLAS. No compatibility or interoperability issues are expected with that version.
Link with Stage 2	N/A.
Boundary conditions	These boundary conditions do not apply to *Configuration* use case nor *Retrieve Data* use case but to *Execution* use Case. The STS-ES-02 standard scenario for the specific category of the European drone regulations will be applied regarding BVLOS operations with airspace observers over a controlled land area in a sparsely populated environment.
Constraints	Weather conditions may prevent the tests, so we may plan a 1-week campaign to have alternative days for the actual testing.
Stakeholders to be involved	Technological partners: USE, CAT Feedback will be requested to UOC regarding the inspection definition interface SDP / AIS should provide a site map
Authorization	○ ENAC – Authorization on D-Flight portal ○ Request to navigabilita@enac.gov.it & protocollo@pec.enac.gov.it
Design specifications	All tests will be performed with the highest standards of safety. A safety pilot can take control of the UAV and terminate the flight in unexpected events.

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UC1.1.1 & UC1.1.2. UAV Long range & Multi-UAV inspection

Stage 3 Protocol	UC1.1.1 & UC1.1.2
Objective	The main goal is to test the developed technologies in a realistic scenario for Beyond Visual Line Of Sight (BVLOS) and multi-UAV operations, carrying out an inspection mission.
Activities	- To configure, execute and monitor an inspection mission. - To develop Detect&Avoid technologies for the UAV. - To collect data using onboard sensors.
KPI	KPI 1 (exposure time). KPI 5 (traffic disruption). KPI 9 (maintenance and inspection costs).
Expected Outputs	The UAV will cover a long distance while maintaining safety during the inspection mission.
Expected duration	Several experiments will be necessary before the final validation, but the final test will occur during a single day.
Link with Stage 1	The technologies developed for Stage 1 will be improved for higher levels of robustness towards the final demonstrator.
Link with Stage 2	N/A
Boundary conditions	The STS-ES-02 standard scenario for the specific category of the European drone regulations will be applied regarding BVLOS operations with airspace observers over a controlled land area in a sparsely populated environment.
Constraints	Weather conditions may prevent the tests, so we may plan a 1-week campaign to have alternative days for the actual testing.

Stakeholders to be involved	Technological partners: USE, CAT
	Take-off/landing area should be coordinated with SDP/AIS
	○ MIMS (Ministry of Sustainable Infrastructure and Mobility).
	○ ANSFISA (National Security Agency for Roads and Railways) .
	  ○ Mr Domenico De Bartolomeo domenico.debartolomeo@ansfisa.gov.it
	  ○ Mr Emanuele Renzi emanuele.renzi@ansfisa.gov.it
	○ ENAC (National Aviation Authority)
	  ○ Mr Alessio Quaranta a.quaranta@enac.gov.it

Authorization	○ ENAC – Special Project permission: to be requested six months in advance

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Stage 3 Protocol	UC1.1.1 & UC1.1.2
	○ ENAC – Authorization on D-Flight portal ○ Request to navigabilita@enac.gov.it & protocollo@pec.enac.gov.it
Design specifications	All tests will be performed with the highest standards of safety. A safety pilot can take control of the UAV and terminate the flight in unexpected events.

UC2.1.1. Installation of safety barriers

Stage 3 Protocol	UC2.1.1. Installation of safety barriers
Objective	The objective of this use case is to validate the safety barrier installation assistance process in a real intervention scenario. This validation will provide insight into the benefit of using the modular robotic platform in the safety barrier assistance process since it will be used in a real road outside of the controlled environment in Stage 1.
Activities	- Execute the safety barrier installation assistance process. - Videotap the experiments - Measure the KPIs - Fill in the operator satisfaction questionnaire: Safety and Usability.
KPI	- KPI2 - KPI3
Expected Outputs	Validate the modular robotic platform for the safety barrier installation assistance process.
Expected duration	It will depend on the duration of the final demonstrator defined by SDP.
Link with Stage 1	Safety barriers similar to those used in Stage 1 are expected.
Link with Stage 2	N/A
Boundary conditions	For the robot: ISO 10218-1, ISO 10218-2, ISO/TS 15066, ISO 12100, ISO 13849-1, ISO 13849-2, ISO 60204-1. For the headset: UL 8400, IEEE P2048.
Stakeholders to be involved	SDP, TEK, LMS
Design specifications	Similar to Stage 1. The technologies will be first tested separately and, finally, the intervention as a whole:

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	- Vision system to detect the operator - Tool for handling the safety barrier - Trajectories performed by the robot - AR system to provide info to the operator
Customization activities	The graphical interfaces and menus used by the VR system will be translated to Italian.

UC2.1.2. Installation of cones

Stage 3 Protocol	UC2.1.2. Installation of cones
Objective	The objective of this use case is to validate the placement and collection of cones process in a real intervention scenario. This validation will provide insight into the benefit of using the modular robotic platform in the placement and collection of cones process since it will be used in a real road outside of the controlled environment in Stage 1.
Activities	- Execute the placement of cones process. - Execute the collection of cones process. - Videotap the experiments. - Measure the KPIs.
KPI	- KPI2 - KPI3
Expected Outputs	Validate the modular robotic platform for the placement and collection of cones process.
Expected duration	It will depend on the duration of the final demonstrator defined by SDP.
Link with Stage 1	Cones similar to those used in Stage 1 are expected.
Link with Stage 2	N/A
Boundary conditions	For the robot: ISO 10218-1, ISO 10218-2, ISO/TS 15066, ISO 12100, ISO 13849-1, ISO 13849-2, ISO 60204-1. For the headset: UL 8400, IEEE P2048.
Stakeholders to be involved	SDP, TEK, LMS
Design specifications	Similar to Stage 1. The technologies will be first tested separately and, finally, the intervention as a whole: - Tool for handling the cones

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Stage 3 Protocol	UC2.1.2. Installation of cones
	- Trajectories performed by the robot - AR system to provide info to the operator
Customization activities	The graphical interfaces and menus used by the AR system will be translated to Italian.

UC2.1.3. Road assets cleaning

Stage 3 Protocol	UC2.1.3. Road assets cleaning
Objective	The objective of this use case is to validate the signal cleaning process in a real intervention scenario. This validation will provide insight into the benefit of using the modular robotic platform in the signal cleaning process since it will be used in a real road outside of the controlled environment in Stage 1.
Activities	- Execute the signal cleaning process. - Videotap the experiments. - Measure the KPIs.
KPI	- KPI2 - KPI3
Expected Outputs	Validate the modular robotic platform for the signal cleaning process.
Expected duration	It will depend on the duration of the final demonstrator defined by SDP.
Link with Stage 1	Signals with shapes similar to those used in Stage 1 are expected.
Link with Stage 2	N/A
Boundary conditions	For the robot: ISO 10218-1, ISO 10218-2, ISO/TS 15066, ISO 12100, ISO 13849-1, ISO 13849-2, ISO 60204-1. For the headset: UL 8400, IEEE P2048.
Stakeholders to be involved	SDP, TEK, LMS
Design specifications	Similar to Stage 1. The technologies will be first tested separately and, finally, the intervention as a whole: - Vision system to detect the signals. - The spraying system. - Trajectories performed by the robot. - VR to teleoperate the robot.

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Stage 3 Protocol	UC2.1.3. Road assets cleaning
	The intervention will be carried out on those signals within the robot's range.
Customization activities	The graphical interfaces and menus used by the VR system will be translated to Italian.

UC3.1. Signalling during construction works

Stage 3 Protocol	UC3.1. Signalling during construction works
Objective	The objective of this use case is to validate the signalling process during construction works in a real intervention scenario. This validation will provide insight into the benefit of using the modular robotic platform in the signalling process during construction works since it will be used in a real road outside of the controlled environment in Stage 1.
Activities	- Execute the process of signalling. - Videotap the experiments. - Measure the KPIs. - Fill in the operator satisfaction questionnaire: Safety and Usability.
KPI	- KPI2 - KPI3
Expected Outputs	Validate the modular robotic platform for the signalling process during construction works.
Expected duration	It will depend on the duration of the final demonstrator defined by SDP.
Link with Stage 1	Signals similar to those used in Stage 1 are expected.
Link with Stage 2	N/A
Boundary conditions	For the robot: ISO 10218-1, ISO 10218-2, ISO/TS 15066, ISO 12100, ISO 13849-1, ISO 13849-2, ISO 60204-1. For the headset: UL 8400, IEEE P2048.
Stakeholders to be involved	SDP, TEK, CEM
Design specifications	Similar to Stage 1. The technologies will be first tested separately and, finally, the intervention as a whole: - Vision system to detect the operator - Tool for handling the signal

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Stage 3 Protocol	UC3.1. Signalling during construction works
	- Trajectories performed by the robot - AR system to provide info to the operator
Customization activities	The graphical interfaces and menus used by the AR system will be translated to Italian.

UC5.1. VR platform for robot teleoperation

Stage 3 Protocol	UC5.1. VR platform for robot teleoperation
Objective	The objective of this use case in Stage 3 is similar to the goal in Stage 2. In this case, the VR teleoperation and training tool developments will receive a final validation in SDP's setup and demonstrator. The teleoperation will be used in the cleaning intervention.
Activities	Integrate and validate VR teleoperation capabilities in cleaning
KPI	The relevant KPIs and the impact of VR technologies are similar to those listed in Stages 1 and 2. In this stage, the impact of the developments for KPI 2 and KPI 3 will be validated further, and the TRL of the technologies will reach its final level. The validation will be enhanced by its use in different demonstrators in different sites, by workers who may use different processes for the interventions. Both VR and AR methods will be used in the case of cleaning, and a comparative analysis of each will be performed.
Expected duration	It will depend on the duration of the final demonstrator defined by SDP.
Link with Stage 1	Information on the integration of VR technologies will be taken from the lab testing
Link with Stage 2	Further information from integrating into demonstration level will be taken from TD4
Boundary conditions	For the headset: UL 8400, IEEE P2048, for the robot: ISO 10218-1, ISO 10218-2, ISO/TS 15066, ISO 12100, ISO 13849-1, ISO 13849-2, ISO 602041
Stakeholders to be involved	SDP, TEK, PAV
Design specifications	The design specifications are similar to the ones analysed in Stage 1. The differences are: • The communications must be installed for SDP's setup.

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Stage 3 Protocol	UC5.1. VR platform for robot teleoperation
	• Changing the hardware may be needed to cover the distance between the site and the remote operator, similar to Stage 2 The teleoperation will be applied to the cleaning intervention only.
Customization activities	The graphical interfaces and menus of the application will be translated to Italian for the needs of the demonstrator, which will be in Italy, utilized by Italian workers.
Expected Outputs	• Validated VR platform for the teleoperation of robotic resources • Validated VR based training tool

UC5.2. AR for worker support

The design specifications are similar to the ones analysed in Stage 1, **with the key difference that in this Stage, the AR tool will receive information from V2X communications and visualize it**. Below, the connection between the different entities is shown.

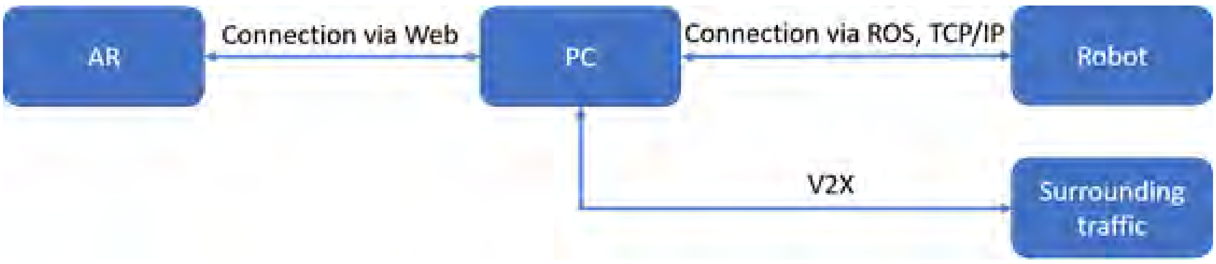

Figure 30. AR connections

The AR developments will be used in the following interventions:

- Cleaning: Driver to use the tablet to perform the process themselves, eliminating the need for a second operator.
- Signals and cones: Visualization to the driver to manually press a button and release cones for placing, AR visualization of roar with graphics overlay for removal.
- Safety barriers: The operator commands the robot to go to the desired position (rough placement) using gestures. Also to be used for the provision of safety and process information.

The concept, with the V2X communications active, is shown below:

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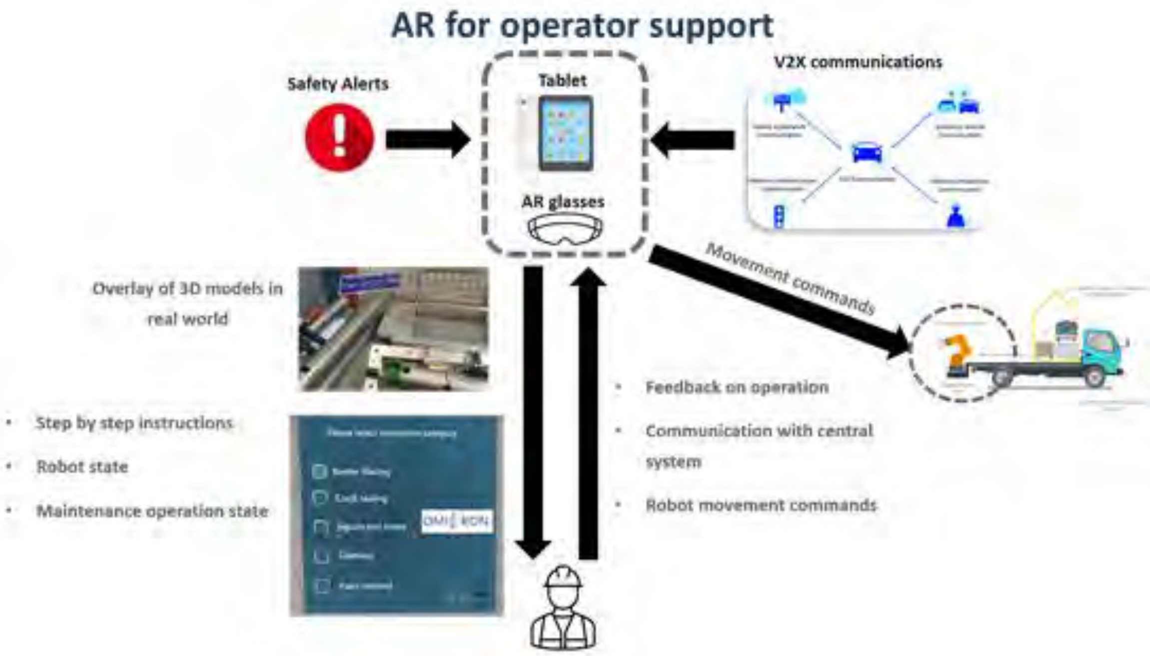

Figure 31. AR for operator support

A summary of the demonstration of this use case is presented in the following table.

Stage 3 Protocol	UC5.2. AR for worker support
Objective	The objective of this use case in Stage 3 is similar to the goal in Stage 2. In this case, the AR operator support tools will receive a final validation in SDP's setup and demonstrator. The teleoperation will be used in the cleaning intervention.
Activities	Integrate and validate the AR support tool for: • Cleaning • Signals and cones • Safety barriers
KPI	The relevant KPIs and the AR technologies' impact will be similar to those listed in Stages 1 and 2. In this stage, the impact of the developments for KPI 2 and KPI 3 will be validated further, and the TRL of the technologies will reach its final level. The validation will be enhanced by its use in different demonstrators in different sites, by workers who may use different processes for the interventions. Both VR and AR methods will be used in the case of cleaning, and a comparative analysis of each will be performed.
Expected duration	It will depend on the duration of the final demonstrator defined by SDP.
Link with Stage 1	Information on the integration of AR technologies will be taken from the lab testing

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Stage 3 Protocol	UC5.2. AR for worker support
Link with Stage 2	Further information from integrating into demonstration level will be taken from TD4
Boundary conditions	For the headset: UL 8400, IEEE P2048
Stakeholders to be involved	SDP, TEK, PAV
Design specifications	The design specifications are similar to the ones analysed in Stage 1, with the key difference that in this Stage, the AR tool will receive information from V2X communications and visualize it.
Customization activities	The graphical interfaces and menus of the application will be translated to Italian for the needs of the demonstrator, which will be in Italy, utilized by Italian workers.
Expected Outputs	Evaluated AR tools to support in-field workers with road information, maintenance guidance and robot control

UC6.1. Road digital twin

Stage 3 Protocol	UC6.1. Road digital twin
Objective	To create a digital twin with three-dimensional geometric and condition information for the road management systems and interact with them. To generate the 3D models of roads by implementing the digital twin technology, such as scanning, image processing, etc. To connect and use all the data available, in order to maximize the capability to get and use information from on-field sensors, remote control of assets, linking all these elements to the 3D digital model.
Activities	• Identify the interoperable elements of the physical asset with which the model communicates. • Generate the typology of the 3D elements and provide them with the geometry and attributes necessary for their identification and connection. • Generate a 3D context to place the 3D elements into a digital twin model. • Connect the database associated with the digital model with the physical asset management system.

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Stage 3 Protocol	UC6.1. Road digital twin
KPI	KPI14. Volume of major intervention actions. The target of KPI 14 is the reduction of major intervention actions by 10% due to better maintenance planning. KPI 11. Road infrastructure maintenance cost. OMICRON's Intelligent Platform will reduce maintenance costs by at least 12%, using an enhanced evaluation system with Digital Twins and an enhanced planning system, OMICRON's Decision Support Tool.
Expected Outputs	Full demonstration of the functionalities of OMICRON digital twin platform: operational Digital Twin of a section of the A24 highway.
Expected duration	4-6 months
Link with Stage 1	The interoperability of Digital twin platform with other systems, including a decision support system Feedback on the user interface and functioning of the Road Digital Twin.
Link with Stage 2	Validate functionalities and user interface of the road digital twin for the demonstrators.
Boundary conditions	The specific information requirement. Data collection issue. Collaboration among partners.
Constraints	Data collection part: 1. Technical requirements from WP1. 2. Inspection data from WP2. 3. Output generated by WP2 and WP4.
Stakeholders to be involved	DT: UOC, CEM, UGE, REG, TEK, CAT, USE, IND. DST: UGE, CEM.
Authorization	Digital twin platform: SDP
Design specifications	N/A
Customization activities	Digital twin creation

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UC6.2. Road decision support tool

Stage 3 Protocol	UC6.2. Road decision support tool
Objective	The main objective of the stage 3 demonstration for OMICRON's Decision Support Tool is to use the different functionalities of the tool in a real environment using historical data and data coming from OMICRON's Inspection Technologies. • Analyze and predict the infrastructure condition. • Road sectioning. • Evaluation of risk. • Assessment of criticality. • Evaluate the maintenance impact on traffic. • Maintenance planning.
Activities	Complete testing of OMICRON's Decision Support System at SDP premises integrating information and decisions at several levels: • Historical data. • Legacy systems data. • OMICRON inspection technologies data. • Information coming from UC6.1 (DT). • Prediction of road asset condition. Generation of enhanced maintenance planning.
KPI	KPI 4. The volume of major intervention actions. KPI 11. Road infrastructure maintenance costs. KPI 12. Road Hazard Index KPI 13 and KPI 14. Availability of the network
Expected duration	1 month
Link with Stage 1	Feedback on the functioning of the DST
Link with Stage 2	N.A.
Boundary conditions	The lack of data available from OMICRON inspection technologies could be an issue throughout the project and during the demonstration phase. This activity is precisely addressed to face this potential problem in advance.
Constraints	The DST will need data to work. There are certain areas taken into account in advance: • Architecture and interface to the DT. To be covered in task T5.1 for the DT architecture. • Data availability. Historical data, which must be covered from Stage 1.

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Stage 3 Protocol	UC6.2. Road decision support tool
	• Data availability. OMICRON inspection data must be considered, as the data from the inspection in the FD must be fed to the DT and the DST. The duration of the demonstrator and the tasks must be tailored to enable the final demonstration of the DST. From the DST point of view, the demonstration of technologies should follow this sequence: 1. **Demonstrate the inspection technologies** to have available data for the DST. 2. **Demonstrate the robotic technologies.** 3. **Demonstrate the DST taking into account the inputs from points** 1 and 2.
Stakeholders to be involved	DT AND DST: CEM, UGE, UOC, AIS, SDP. Inspection: IND, UOC, CAT, USE.
Authorization	Not applicable in principle.
Design specifications	Not applicable, although close interaction with SDP's ICT group will be required.
Customization activities	The BPMN flowchart defined in section 2.4 applies.
Expected Outputs	Demonstrate the functionalities of OMICRON's Decision Support Tool.

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4 Demonstrator Workshop Conclusions

A Demonstrator Workshop was held on the 15th of December 2021, as part of the General Assembly that took place in CEMOSA's headquarters in Malaga. The main objectives of the Workshop were as follows.

1. To define OMICRON's testing and demonstration activities to provide a guideline for developing technologies and actions to be carried out in WP6.
2. To validate the approach, refine requirements and provide the first tool design specification.

The activities of the Workshop were identified as follows:

- To present the results of the Deliverable D1.2.
- To validate the approach, refine requirements and provide the first tool design specification.
- To get all partners' feedback and further stimulate any idea on the final application.

The brainstorming and discussion session was organised according to the three demonstration stages (as shown in Figure 32):

- Stage 1. This stage relates to the in-lab testing activities.
- Stage 2. This stage relates to the different activities in the Technical Demonstrators (TD).
- Stage 3. This stage relates to the Final Demo in Italy, where almost most technologies will be tested.

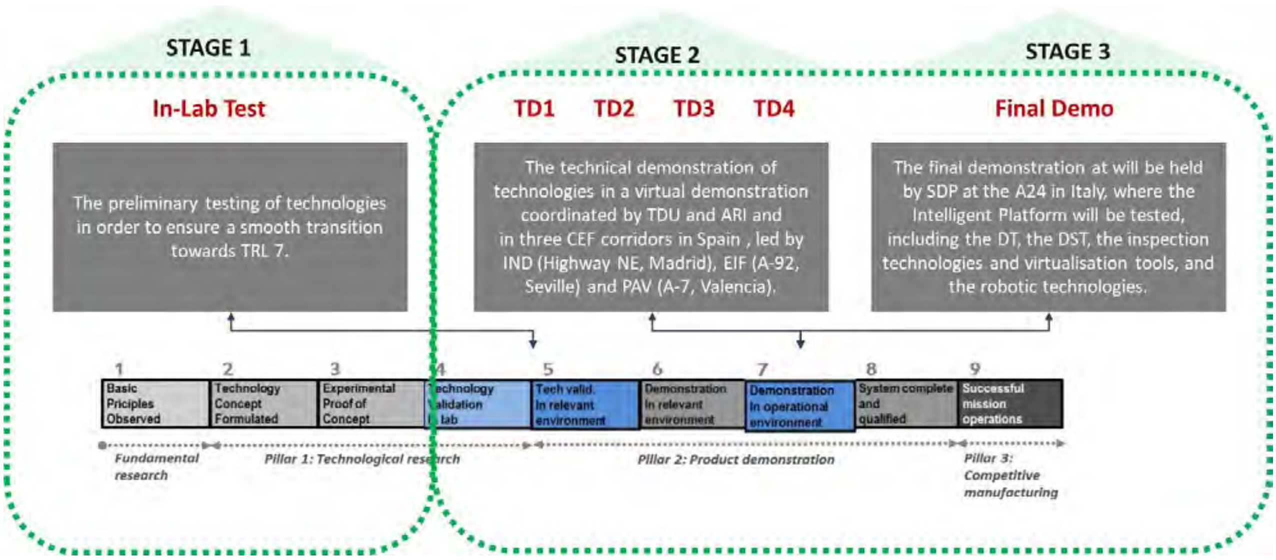

Figure 32. Overview of the three main stages related to the technology deployment and testing

All the feedback related to each Use Case has already been included in the previous Chapter 3. The main points discussed during the Workshop among all the partners are presented within this chapter.

Stage 1

In this Stage, activities will take place in the lab test. Therefore, the main discussion points were related to the facilities and the laboratory features, together with the possibility of already using some information at the lab stage from the technical demonstrators.

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The main issues discussed are the following:

- *UC 1.2.2 Automation of auscultation process control of road parameters.* IND provided a detailed explanation of their technology. This Use Case will be calibrated using data from the final demo, so there is a need to coordinate this activity to facilitate communication between partners in advance.
- *UC3.2. Sealing surface pavements cracks.* PAV will develop this Use Case in their facility, in a controlled environment, testing also the component that LMS and TEK will develop.
- *UC3.3. Removal of lane markings with laser.* PAV and TEK will jointly cooperate to test different samples and lasers to identify the most efficient combination for the next application on the technical demonstrators. The activities will be carried out in TEK's facilities so that no additional risks can influence the development of the technology. Moreover, the feasibility of shipping the technology for a potential application on the final demo is still unknown: it seems complicated due to safety and logistic reasons, but this option will be further discussed and evaluated in the project's following phases.

Stage 2

After the discussion on Stage 1 for the in-lab testing, the Technical Demonstrators were presented with updated information and considered the application of the different Use Cases. Each partner contributed to the session in brainstorming mode.

Technical Demonstrator 1 (TD1)

ARI presented TD1. This Use Case will be developed and tested within the TD1 is UC 4 - Modular construction for bridges.

The activities have already started. An additional point will be to calculate the carbon footprint to have an idea of the life-cycle-analysis added value of that solution, which can also benefit from the CO_2 consumption point of view. Moreover, the only limitation is the availability of the LNEC laboratory testing equipment and facilities.

The main point raised was the applicability of this modular construction of bridges to other typologies. This part will be further investigated during the next phases of the project. As additional work beyond the Grant Agreement, CEM also proposed further investigating the possibility of integrating this Use Case by developing a preliminary Digital Twin (using the own resources of CEM), starting from the BIM model produced for this Technical Demonstrator. This possibility will be further evaluated in the project, considering the time and resources available by CEM and the rest of the partners.

Technical Demonstrator 2 (TD2)

IND presented TD2. This Technical Demonstrator has changed location from Madrid's M-30 ring road to Madrid's A-2 highway connection to Guadalajara due to enhanced demonstration possibilities in the new location. The concessionaire of the A-2 highway is *Acciona Concesiones*, which has a close relationship with IND.

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Figure 33. Localisation and overview of A2 (Reference: Acciona)

The Use Cases that will be developed and tested within the TD2 are:

- **UC 1.2.** Terrestrial inspection vehicle.
- **UC 1.3.** V2X communications.
- **UC 5.1.** VR platform for telerobot operation.
- **UC 5.2.** AR tools for worker support.

The main points discussed during the workshop concerning this demonstrator are summarised below:

1. UC1.3. There is the need to open the discussion with the infrastructure manager (Acciona Concesiones) to select a proper testing environment.
2. IND and LMS should start a discussion to avoid a potential overlapping in the Augmented Reality Use Cases and maximise the impact of the technology deployment without replicating activities.
3. According to IND, there will be no risk of interference with existing tolling systems or other devices during the deployment of the V2X communications technology.
4. Further details will be needed regarding the Use Cases deployment, such as the timing and duration of the activities. However, these details cannot be defined at this stage.

Technical Demonstrator 3 (TD3)

EIF presented TD3. This Use Case will be developed and tested within this TD is UC 3.4, Smart rehabilitation of surface pavement layer.

The main points discussed during the workshop concerning this demonstrator are summarised below:

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1. The Use Case application on the infrastructure can be affected by many different factors, such as weather, duration of the activity, etc. All these items will be investigated and analysed to ensure the potential replicability of the deployment in other demos (e.g. the final demo in Italy), and a comparison with state-of-the-art practice will be made to understand the efficiency of the solution in terms of resources, money and time.
2. The potential applicability of the technology on the final demo site in Italy was discussed. The technology can help address several needs already identified by the infrastructure manager (SDP), such as the asphalt rehabilitation within service areas, parking areas and the facility near the motorway carriageway.
3. As an additional feature, the possibility of sharing the information in real-time with drivers (using V2X communication) was discussed. From a technical point of view, it is feasible. Still, the technology will be tested on another technical demonstrator, so this option will be discussed later in the project to check the interest and evaluate the feasibility of performing this extra activity.
4. Also, the interaction with the Digital Twin should be clarified. The Use Case activity will generate a huge amount of data that will be primarily sent to the operator on-site. Still, then some set of data can be shared to "populate" the Digital Twin set of information and provide additional info for the infrastructure manager, mainly related to execution quality.

Technical Demonstrator 4 (TD4)

TD4 was presented by PAV together with LMS. The Use Cases that will be developed and tested within this TD are:

- **UC 3.2**. Robotised sealing of surface pavement cracks.
- **UC 5.1**. VR platform for telerobot operation.
- **UC 5.2**. AR tools for worker support.

The main points discussed during the workshop concerning this demonstrator are summarised below:

1. PAV provided a detailed overview of the technologies, also highlighting some concerns about external factors that can influence the deployment of the technology (included in the paragraph above related to TD4 in Chapter 3):
    - Weather risk: the operation should be performed in stable conditions, without rain or heavy wind.
    - Traffic and regulatory issues, and national holidays.
2. Some technological aspects should be clarified in the following WPs (e.g. WP5), providing more details, for example, on the communication aspects between the system and the platform and in terms of the interface to the operator to select the proper choice.
3. Regarding operators, specific training will be designed and performed in PAV facilities and extended to the other workers before on-field testing. Moreover, an alignment between the work done within the inspection Use Cases developed in WP2 (e.g. preliminary crack inspection) and the UC 3.2 Robotised sealing of surface pavement cracks will be considered to eventually coordinate (even though it is not foreseen in the DoA) the deployment of both technologies.
4. A further point of consideration was related to the current contract between PAV and the road operator. This contract will expire before deploying the technology on-site, even though there is a low risk of a non-extension. PAV is already tackling this potential issue by addressing the

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possibility of performing the activity in advance (to be checked with TEK) or identifying another site with the same characteristics.

5. Regarding UC 5.1 and UC 5.2, LMS will consider providing language localisation for training for AR tools and the virtual platform. The application will be made in Spain and Italy, so local employees and workers will use these tools. The idea is to translate the content to the local language to avoid potential language issues. The effort will be made with the respective partners involved in the demonstrators.

Stage 3: Final Demo

SDP presented the main features of the demo site, together with the detailed description of the preliminary sites selected for carrying out the deployment of the different use cases. The pre-identified test sites were described. However, they re-confirmed their availability in using the best place according to the Use Cases needs, in compliance with the boundary conditions and regulatory framework identified within chapter 3 above.

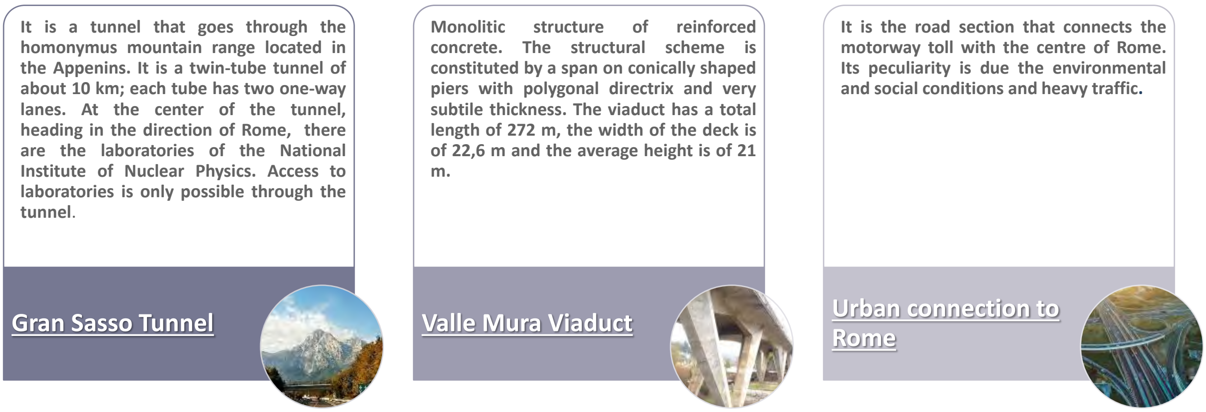

Figure 34. Overview of the three identified demo-sites

On the final demo, almost all the Use Cases will be tested, namely:

- **UC1.1**. UAVs: Management tool.
- **UC1.1.1.** UAV Long range inspections.
- **UC1.1.2.** Multi-UAV inspection.
- **UC1.2.** Terrestrial inspection vehicle.
- **UC1.2.1.** Innovative sensor combination.
- **UC1.2.2.** Automation of auscultation process control of road parameters.
- **UC1.3.** V2X communications.
- **UC2.1.** Robotic modular platform.
- **UC2.1.1.** Installation of safety barriers.
- **UC2.1.2.** Installation of cones.
- **UC2.1.3.** Road assets cleaning.
- **UC 5.1**. VR platform for telerobot operation.
- **UC 5.2**. AR tools for worker support.
- **UC 6.1**. Road digital twin.
- **UC 6.2**. Road decision support tool.

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The main points discussed during the workshop concerning the final demo are summarised below:

1. The discussion started by addressing the first set of Use Cases. The idea is to focus on pavements and other relevant assets such as bridges, tunnels, roadside vegetation, and vertical signs on the road.
2. To provide a tailored specification for the Use Case 1, SDP will compile and provide a detailed list of possible activities, needs, and (if available) some previous inspections made with drones, highlighting the main weak points and where the OMICRON project can add value.
3. Regarding the possibility of testing the *UC2.1.2 Installation of cones*, SDP stated their willingness to test the possibility of removing another type of cone (called Defleco, which is commonly used in temporary work zones) that are typically installed on the pavement with a specific glue. This topic, at the moment, is not feasible because the Use Case was initially designed with "traditional" cones, so this topic will be further investigated and detailed in the next phases of the project.

Figure 35. Defleco cone example

4. SDP also provided their availability to test Use Cases that were not originally planned to be tested on the final demo site. Still, it could be relevant for them as the infrastructure manager, for example, UC 3.2 for the robotised sealing of surface pavement cracks.
5. A dedicated meeting will be organised with UOC to understand the main requirements for the road management platform to align the request and start collecting relevant data from SDP. It is crucial to understand which data will be needed, the available data from SDP, the format, any interoperability issue with legacy systems, and the infrastructure manager's usability.
6. As a final comment, the UC6.2 Road decision support tool was discussed. The main issue is related to the deep interconnection with other Use Cases and technologies developed within the OMICRON project. The idea proposed by CEM is to have a sequence of activities:
    - The demonstration would start with the inspection technologies testing, having an allocated timeframe of around one month.
    - In a second step, the deployment of the robotic technologies would be performed.
    - As a final step, the Digital Twin and Decision Support Tool would be demonstrated using the information acquired in the previous steps.

The following figure presents the discussion and conclusion drawn from it.

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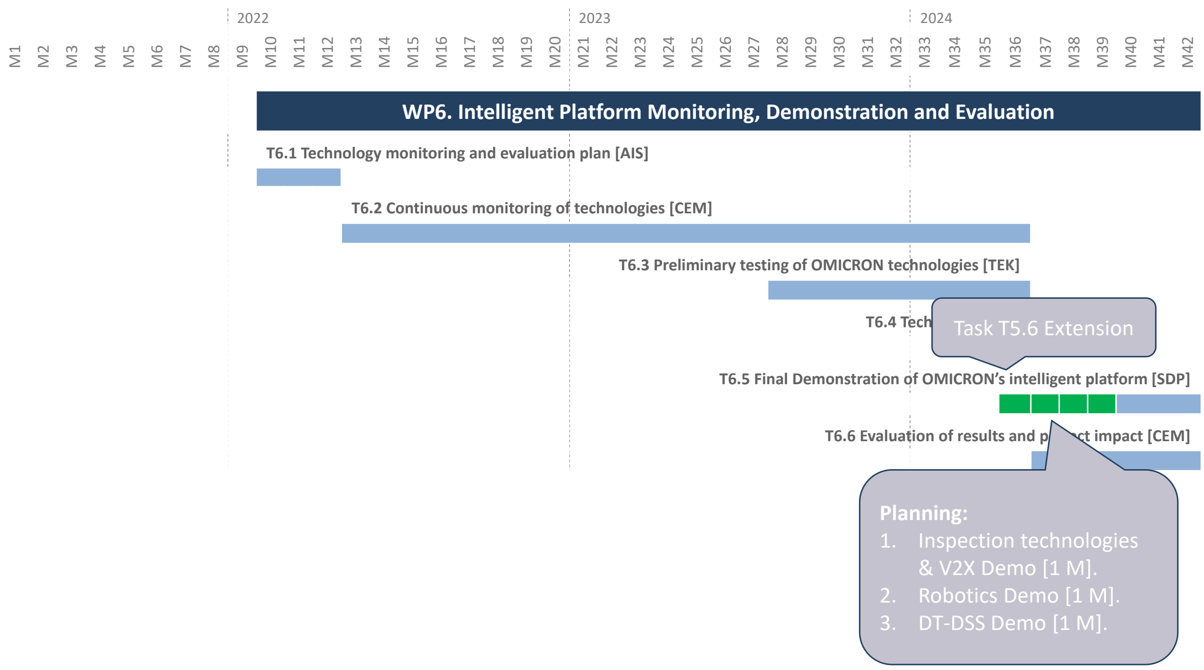

Figure 36. Proposed timeline for the demonstration in the FD in Italy

This initial idea will have to be refined throughout Work Package 6 to define the best demonstration methodology possible for the OMICRON technologies.

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5 Conclusion

Deliverable D1.2 presents the outcomes of the last two tasks of WP1: Task 1.3, which is related to the identification of the current inspection and maintenance processes of the final demo responsible (SDP) and Task 1.4, which deals with the definition of testing and demonstration activities, as a preliminary guideline for the development of the technology and activities that will be carried out in WP6: "Intelligent Platform Monitoring, Demonstration and Evaluation".

Namely, deliverable D1.2 provides detailed information related to the following points:

1. Link with D1.1, which is the baseline.
2. Analysis of the road operator's current inspection and maintenance processes, SDP (final demonstrator).
3. Definition, through decision process modelling techniques, of the current models identifying actors, roles and structures of the final demonstrator responsible (SDP) together with the main information and data available related to relevant assets (pavement, bridges and viaducts).
4. Preliminary assessment of the technology deployment on the three different stages, identifying the activities, timing and duration, and the first design specifications for the various technical demonstrators where the activities will be carried out.
5. Definition of the demonstrator boundary conditions and authorisation to host the deployment of the different technologies, involving the relevant stakeholders in the process.
6. The outcome of the Workshop held in Malaga in December 2021 was an occasion to discuss ideas regarding the deployment of the OMICRON technologies and the main features and conditions of the technical demonstrators.

The Workshop provided a good brainstorming session useful as a first debate among the Use Case owners and the Technical Demonstrator partners. This activity represents only the first step towards WP6. On this work package, the ideas and information included in this deliverable must be updated, including the relevant development of the Use Cases in Stage 1 (In-Lab Test), Stage 2 (application on the first four Technical Demonstrators) and Stage 3 (Final demonstrator).

The link with the technical work packages is explicit and coherent. The development of the different technologies will align with the preliminary information provided in this document. All the information will be used as a baseline to release a technology monitoring and evaluation plan (Task 6.1) to guide all partners in the testing activities.

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