OMICRON

Intelligent Road Asset Management Platform

Functional and Technical Requirements of OMICRON Technologies

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Authors

Name	Beneficiary	Details of contribution
Jose Solís Hernández	CEM	Deliverable responsible and author
Paula López Arévalo	CEM	Deliverable Author
Concepción Toribio Díaz	CEM	Deliverable Author
Noemi Jiménez Redondo	CEM	Deliverable Supervisor

Contributors

Contributor	Beneficiary	Nature of contribution
Martín Rivas	IND	Contributions to technical and functional requirements UC1.2, UC1.2.2 and UC1.3.
Ander Ansuategi	TEK	Contributions to technical and functional requirements and legislation.
Federico di Gennaro	AIS	Contributions to legislation assessment.
Viviana Prisco	SDP	Contributions to legislation assessment.
Francisco Javier Pérez	CAT	Coordination of standards and legislation assessment. Contribution to use cases.
Angel Castaño	USE	Contribution to use cases.
Weiwei Chen	UOC	Contribution to use cases and legislation.
	LMS	Contribution to use cases and legislation.
Alice Consilvio	UGE	Contribution to use cases. Main reviewer of the deliverable.
Rafael Martínez	EIF	Contribution to use cases and legislation.
Jose Ramón López	PAV	Contribution to use cases and legislation.
Ana Rito	ARI	Contribution to use cases and legislation.

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Executive Summary

The main objective of deliverable D1.1 is to present the functional and technical requirements of the portfolio of technologies developed in OMICRON, constituting the Intelligent Platform. The deliverable compiles the desired characteristics and functionalities of the solutions in the various project areas:

a. Infrastructure inspection.
b. Virtualisation and communication technologies for maintenance and user support.
c. Digital Twins.
d. Decision support tools.
e. Robotic and digitalisation technologies for intervention.

The report addresses (a) the state of the art of the objective technologies; (b) an assessment of the legislation and standards in the various fields of the project; (c) the functional and technical requirements per project Use Case, considering the guidelines of the stakeholders; and (d) a formal redefinition of the project KPIs.

In this context, the document is structured in the following chapters:

1. **Introduction.** The first chapter of D1.1 is focused on the presentation of the methodology used to define the requirements of the OMICRON technologies. This is based on the IEC PAS 62559 standard, defining Use Cases and related Business Cases.
2. **Assessment of legislation**. In this chapter, the legislation relative to specific technology areas in OMICRON is studied to develop the Use Cases considering the relevant European and national legislation and standards. This study covers relevant areas such as drones; road inspection; robotics; machinery and maintenance; and data treatment.
3. **Technical and functional requirements**. This chapter presents (a) the state of the art and (b) a summary of the requirements of every cluster, high-level and detailed Use Case. This includes a description; a short narrative; their position and connection to other Use Cases; and their actors, scope and objectives.
4. **Project Key Performance Indicators**. In connection to the evaluation tasks in WP6, the formal definition of the specific and overall KPIs of the project are defined in chapter 4.

Finally, the annexes present a detailed IEC PAS 62559 form for every Use Case describing the technical requirements. These address all the available aspects including (a) system requirements, data management and interfaces; (b) technology needs and requirements; and (c) final tools and user interfaces.

Disclaimer

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Acronyms and Abbreviations

Table 1. Acronyms and abbreviations

Acronym or Abbreviation	Description
AI	Artificial Intelligence
AR	Augmented Reality
ARC	Air Risk Class
ATM	Air Traffic Manager
AUTL	Asphalt Ultra-Thin Layers
BC	Business Case
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)
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
EUROCAE	European Organization for Civil Aviation Equipment
EUSCG	European UAS Standards Coordination Group
EVLOS	Extended Visual Line of Sight

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GCS	Ground Control Station
GDPR	General Data Protection Regulation
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 Standarization
KPI	Key Performance Indicator
LMS	Laboratory for Manufacturing Systems and Automation
MD	Machinery Directive
MMW	Millimeter-wave
MOPS	Minimum Operational Performance Standard
NAA	National Aviation Authorities
OSO	Operational Safety Objectives
RAP	Recycled Asphalt Pavement
RSU	Road Side Units
RGB-D	Red Green Blue and Depth images
ROS	Robot Operating System
SAIL	Specific Assurance and Integrity Levels
SORA	Specific Operations Risk Assessment
SRP/CS	Safety-related parts of control systems
UAS	Unmanned Aircraft Systems

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UAV	Unmanned Aerial Vehicle
UC	Use Case
UML	Unified modeling language
UNE	Spanish Association of Standardization
USSP	U-space Service Providers
UTM	UAS traffic management
V2X	Vehicle-to-everything
VE	Virtual Environment
VLL	Very Low Level
VLOS	Visual Line of Sight
VR	Virtual Reality
WP	Work Package

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1 Introduction

1.1 Use Case Requirements Methodology

The objective of OMICRON is to develop an Intelligent Asset Management Platform with a broad portfolio of area-specific innovative technologies to enhance the construction, maintenance, renewal and upgrade of the European road network. The project aims to improve road asset management focusing on four technical pillars:

1. The implementation of digital inspection technologies.
2. The development of road Digital Twins.
3. The construction of road Decision Support Tools.
4. The development of smart construction and intervention solutions for road infrastructures.

This will enable the industrialisation and automation of a vast number of road management tasks which currently still have a high labour component. OMICRON's developments address a wide variety of road systems such as pavement, bridges, tunnels, lighting or signalling systems (Figure 1).

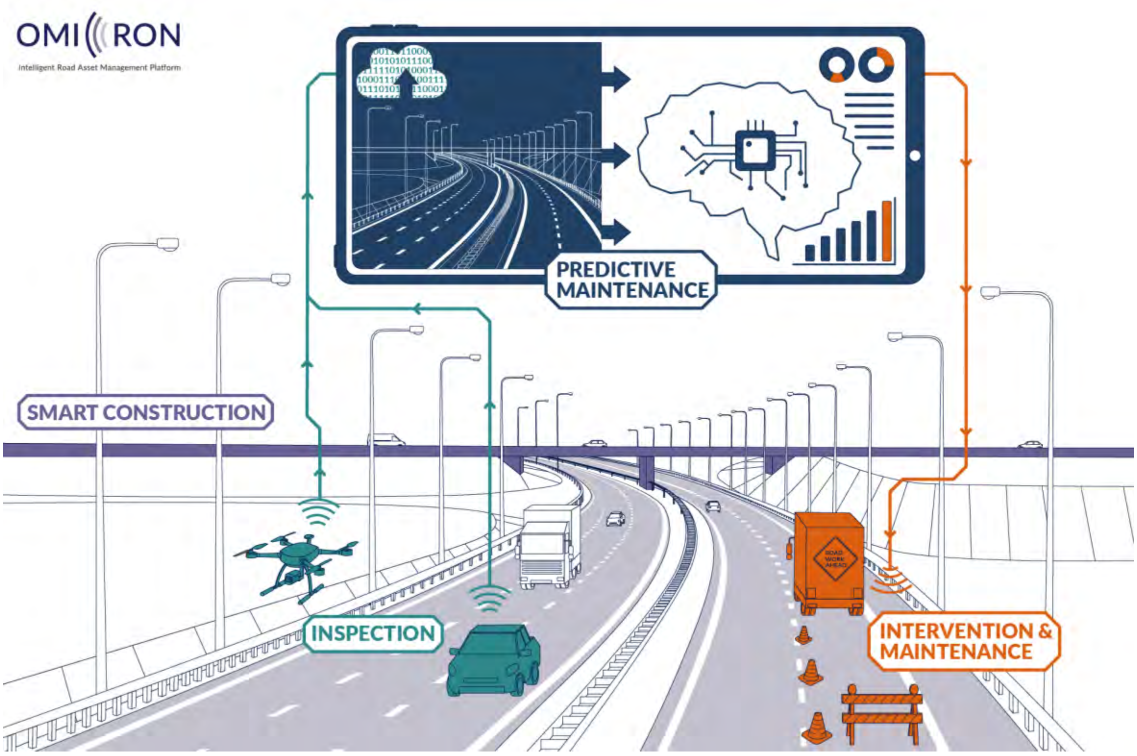

Figure 1. OMICRON solutions

The definition of the requirements of such a wide variety of interconnected technologies must be performed in a structured and organised manner. Therefore, the IEC 62559-2 standard by IEC TC8 has been used, also known as the *Use Case Methodology* [1]. The full standard template is generally used in other domains such as smart grids, but it has been adapted to the background of this project following the following five stages (Figure 2).

1. Description of the Use Case, including:
   a. Type of Use Case.
   b. Scope and objectives.
   c. Narrative of the Use Case.

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   d. KPIs.
   e. Use Case Conditions.
   f. Classification information.
2. Diagrams of the Use Case, including a context diagram and a sequence diagram following UML standards.
3. Technical details of the Use Case, referred to the involved actors.
4. Step by Step Analysis of Use Case, setting a set of scenarios of development in the Use Case.
5. Technical details of the Use Case, from the perspective of the information exchanged.

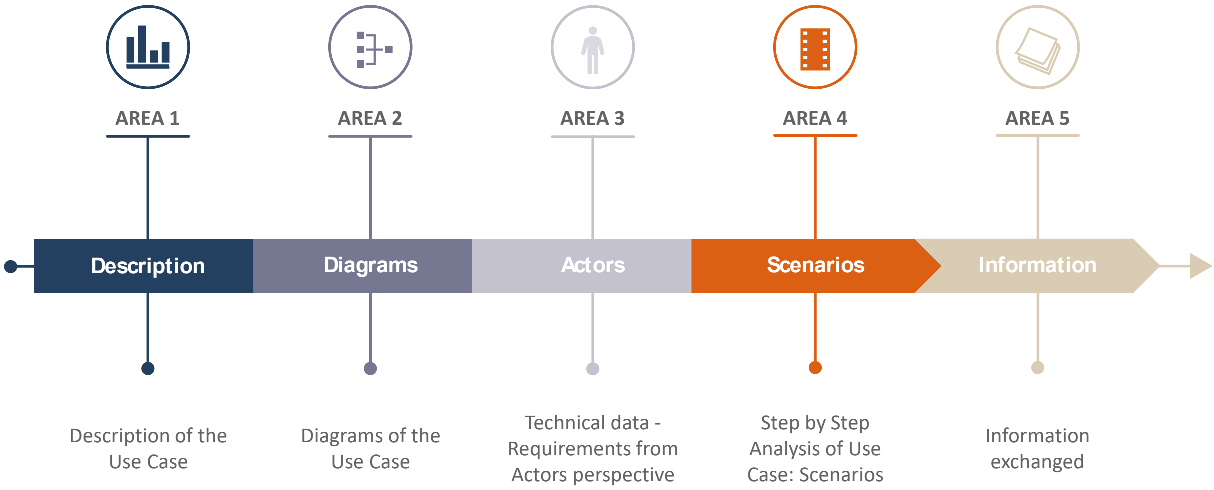

Figure 2. Use Case methodology (IEC PAS 62559-2)

The building of the Use Cases (UCs) is based on four abstract Business Cases (BCs) with no further technical details. The use cases realise the description of the business goals in different layers of granularity and can be differentiated into cluster use cases, high-level use cases and detailed use cases.

- **Cluster use case.** A UC cluster (C-UC) represents a group of high-level Use Cases, which may span several domains, e.g. road inspection.
- **High-level use case.** A high-level UC (HL-UC) describes the general idea of a function together with generic actors. High-level UCs are generic and abstract and can be detailed by other Use Cases. E.g. road inspection with terrestrial vehicles.
- **Detailed use case.** A detailed UC (D-UC) is a list of actions or event steps, defining the interactions between an actor and a system, to achieve a goal. They should be aligned to one domain. E.g. perception systems in infrastructure inspection.

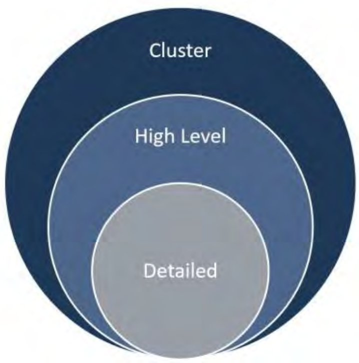

Figure 3. Use case classification

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1.2 Revision of OMICRON Use Cases

The project use cases have been reviewed in order to efficiently address all project technologies. OMICRON's use cases are presented in Table 2.

Table 2. Use Cases definition

Cluster UC	UCs	Brief Description	UC Type	Leader
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	Automatic computation of road index	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

Use Case 1 clusters use cases related to inspection technologies. UC1.1 defines a management tool for Unmanned Aerial Vehicle (UAV) inspection whose features are more deeply developed in UC1.1.1 which addresses long-range inspections and UC1.1.2 which addresses collaborative UAV inspection methods. UC1.2 defines the inspection vehicle technologies. Their features are more deeply developed in UC1.2.1, characterising innovative road perception and monitoring techniques, and UC1.2.2, characterising the automated computation of road indexes. UC1.3 develops the V2X communications.

Use Cases 2 and 3 cluster the use cases related to robotised infrastructure maintenance. UC2.1 defines the Robotic Modular Platform that will support road workers in the installation of safety barriers (UC2.1.1), the installation of cones (UC2.1.2), the cleaning of road assets (UC2.1.3), the signalling during construction works (UC3.1), the sealing of surface pavement cracks (UC3.2) and the removal of lane markings with laser (UC3.3). Finally, the enhancements in the rehabilitation of surface pavement layers are presented in UC3.4.

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Use Case 4 defines a modular solution for hybrid bridges based on a smart design to enhance the construction phase.

Use Case 5 clusters the technologies related to the operation support of other OMICRON technologies. UC5.1 addresses a Virtual Reality platform that allows the teleoperation of robotic resources and the training of workers. UC5.2 addresses an Augmented Reality tool which supports in-field workers with road information and maintenance guidance.

Finally, **Use Case 6** clusters the use cases related to the digitalisation of road infrastructures and predictive maintenance. UC6.1 addresses road Digital Twin technologies and UC6.2 addresses the development of a road Decision Support Tool which will assess and predict infrastructure condition, develop maintenance plans and support decision-making.

1.3 OMICRON Business Cases

OMICRON follows four business cases that are addressed by OMICRON's Intelligent Road Asset Management Platform.

Table 3. Business Cases definition

ID	Brief description	Supporting Use Case
BC1	Smart design for modular construction	UC4
BC2	Digitalization and Automation of road inspection procedure	UC1
BC3	Predictive maintenance based on infrastructure digitization	UC6
BC4	Automation and robotisation of maintenance operations	UC2, UC3, UC5

The various OMICRON use cases cover the whole life cycle of the infrastructure. UC4 supports business cases related to the design and construction phase by means of smart designs that facilitate modular construction. UC1 supports business cases related to inspection procedures. UC2, UC3, UC5 and UC6 support business cases related to the operation and maintenance phase of the infrastructure. Particularly, UC6 supports business cases related to the digitalisation of infrastructures and predictive maintenance; and UC2, UC3 and UC5 address the market related to the automation and robotisation of different road maintenance interventions, as presented in Figure 4.

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BC1 Smart Design for Modular Construction	**BC2** Digitalisation and Automation of road inspections	**BC3** Predictive maintenance based on infrastructure digitalisation	**BC4** Automation and robotisation of maintenance interventions
UC4 Modular construction for bridges	**UC1** Inspection, V2X and User Support	**UC6** Predictive Maintenance	**UC2** Robotics **UC3** Robotics **UC5** AR-VR
	UC1.1 UAVs UC1.1.1 UC1.1.2	**UC6.1** Road digital twin	**UC2.1** UC2.1.1 UC2.1.2 UC2.1.3 **UC3.1** **UC3.2** **UC3.3**
	UC1.2 Vehicle Inspection UC1.2.1 UC1.2.2	**UC6.2** Road decision support tool	**UC5.1** **UC5.2**
	UC1.3 V2X		**UC3.4**

Figure 4. Use cases to business cases matching

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2 Assessment of legislation

The legislation and standards for the various technologies that will be developed and implemented in OMICRON need a thorough analysis to ensure a practical application of the technologies. This section includes a survey of the regulations in relevant areas of the project, namely:

1. Drones.
2. Road inspection.
3. Robotics.
4. Machinery and maintenance.
5. Data treatment.

Besides, any restrictions from standards affecting the technologies to be developed in OMICRON are also analysed and reported.

2.1 Drones

With respect to drones, the new European regulation from EASA is firstly discussed in order to align OMICRON developments within this new framework. Also, further regulation related to the integration of drones into non-segregated airspace (U-space) for Very Low Level (VLL) flights is considered to study its impact in OMICRON works. These two regulatory frameworks are fundamental to achieve a solution that could be used for long-range flights and a high level of autonomy. Both aspects, essential for OMICRON UAV-based solutions from UC1.1, are already considered in these new regulations, but it requires a detailed analysis to agree on how to interpret and implement the requirements imposed by this new regulatory framework. Finally, the study also introduces the current and future standards that are being developed by standardisation bodies such as ISO or EUROCAE.

2.1.1 The new European drone regulatory framework

On 11 June 2019, common European rules on drones, Commission Delegated Regulation (EU) 2019/945 & Commission Implementing Regulation (EU) 2019/947 have been published by the European Union Aviation Safety Agency (EASA), to ensure safe and secure drone operations across Europe. The rules will amongst others help to protect the safety and the privacy of EU citizens while enabling the free circulation of drones and a level playing field within the European Union.

The new rules replace existing national rules in the EU Member States and are the applicable regulation since July 2020. Therefore, it will be applicable when experiments or pilot tests will be carried out in OMICRON.

The common rules will help drone operators to have a clear understanding of what is allowed or not and, at the same time, it will enable them to operate across borders. Once drone operators have received authorization in the state of registration, they are allowed to freely circulate in the European Union. This means that they can operate their drones seamlessly when travelling across the EU or when developing a business involving drones around Europe.

The new rules include technical as well as operational requirements for drones. On the one hand, they define the capabilities a drone must have to be flown safely. For instance, new drones will have to be individually identifiable, allowing the authorities to trace a particular drone if necessary. On the other hand, the rules cover each operation type, from those not requiring prior authorization, to those involving certified aircraft and operators, as well as minimum remote pilot training requirements.

While aiming primarily at ensuring safe operations of drones, the European regulatory framework will also facilitate the enforcement of citizen's privacy rights and contribute to addressing security issues and environmental concerns for the benefit of EU citizens. It will in addition enable the deployment of

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an Unmanned Traffic Management System, the U-space, to support the development of drone operations in low-level airspace, beyond visual line of sight and congested areas.

Categories of operation

The new framework introduces three categories of operation (open, specific and certified) according to the level of risks involved. A different regulatory approach is adopted for each category. Low-risk operations ("open" category) do not require any authorization but are subject to strict operational limitations. For medium-risk operations, operators have to require authorization from the National Aviation Authority based on a standardized risk assessment or a specific scenario (specific category). Finally, in the case of high-risk operations, classical aviation rules apply (certified category).

Open category

Operations in the open category do not require prior authorizations or pilot licenses. However, they are limited to operations in visual line of sight (VLOS), below 120 m altitude and performed with a privately built drone, or a drone compliant with the technical requirements defined in the regulation. To demonstrate this compliance, drones that can be operated in the open category must bear a class identification label (based on CE marking). Additional operational restrictions apply to each class of drone, in particular concerning the distance that must be maintained between the drone and non-involved persons.

Specific category

When the intended operation exceeds the restrictions of the "open" category, the operator should consider operating under the "specific" category (medium risk). Only high-risk operations require compliance to classical aviation rules under the "certified" category (like operating in controlled airspace). Operations involving drones of more than 25 kg and/or operated beyond visual line of sight will typically fall under the "specific" category.

Before starting an operation in the specific category, operators must either perform a risk assessment (using a standardized method – the SORA – that is provided by EASA) and define mitigation measures or verify that they comply with a specific scenario defined by EASA (or the National Aviation Authority). On that basis, they will be able to obtain authorization from the National Aviation Authority (in some cases a simple declaration may be enough). The authorization or the specific scenario will define the authorized operation and the applicable mitigation measures (drone technical requirements, pilot competence, etc.).

Certified Category

The "certified" category (high risk) includes operations involving large drones in controlled airspaces. Rules applicable to the "certified" category will be the same as for manned aviation: drones must be certified for their airworthiness, pilots shall be licensed, and safety oversight will be performed by the relevant National Aviation Authorities and EASA.

2.1.2 The integration of drones into the airspace

One of the main milestones for drones, or Unmanned Aircraft Systems (UAS), to be fully deployable is their future integration into the airspace. For that purpose, the concept of UAS traffic management (UTM) was introduced in 2016 by research organizations, industry and other related stakeholders in the US and Europe. This system is defined as a new ecosystem to enable the real-time organization, coordination, and management of UAS operations in the VLL airspace. The system also includes the potential for Extended VLOS (EVLOS) and Beyond VLOS (BVLOS) simultaneous flights. ICAO published different documents to support the development of the concept.

However, in Europe, instead of UTM the term U-space has been adopted for the same concept: the airspace volume which will be served by specific services to support UAS operations. Moreover, among several projects that have been and are currently focused on the development of this concept, the

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CORUS project must be highlighted since it was the project in which the first CONOPS for the U-space was set. The project focused on VLL airspace, in which the vast majority of UAS operations are expected. It is the airspace zone that is used by aircraft using Visual Flight Rules (VFR). This airspace was divided into three different main zones (see Figure 5).

- X: No conflict resolution service is offered.
- Y: Only pre-flight conflict resolution is offered.
- Z: Pre-flight conflict resolution and in-flight separation are offered.

Type Y airspace will facilitate VLOS, EVLOS and BVLOS flights. Risk mitigations provided by U-space mean Y airspace is more amenable to other flight modes than X. Type Z airspace may be subdivided into Zu and Za, controlled by UTM and ATM (Air Traffic Management) respectively. Za is simply normal controlled airspace and is, therefore, immediately available.

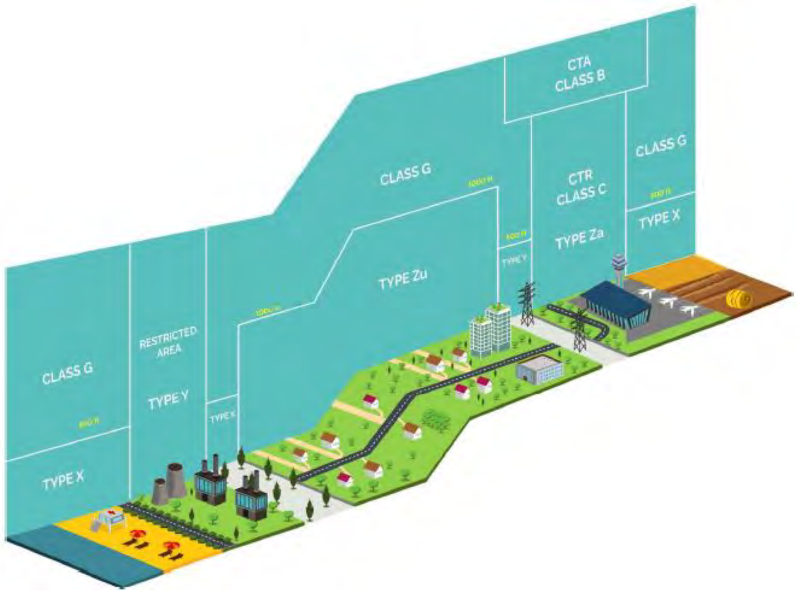

Figure 5. Airspace volumes (credit: CORUS project)

Moreover, the different services to be deployed while implementing U-space were also set. These services were classified into three different groups regarding their deployment phase. The groups are U1 (registration, e-identification, geo-awareness, drone aeronautical information management), U2 and U3 services, being U1 the basic services needed for the safe deployment of the U-space, and U2 and U3 services the advanced U-space Services.

Regarding the regulatory framework that currently applies to the VLL airspace organization, in 2021, in Europe, big steps were given to publishing the regulation package that will be applicable in January 2023.

The following significant regulatory topics that will have an impact on U-space and the U-space Service Providers (USSP) structure should be highlighted:

- States can declare U-space volumes for which services will be given in order to allow for the safe introduction of unmanned aircraft systems.
- Any USSP must be able to deliver the following services at the very least: network identification, geo-awareness, traffic information, and UAS flight authorization. With traffic information, tracking, weather, and conformity monitoring, a minimum number of U-space services are accomplished.
- Unique Common Information Services per U-space.
- A minimum of information must be shared.

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- Flight and priority rules between aircraft will be set.

This European framework for the U-space concept can be found online [2].

2.1.3 Requirements applicable to OMICRON project

Since the intended operations in OMICRON fall into the specific category, SORA (Specific Operations Risk Assessment) methodology must be followed to determine the level of SAIL (Specific Assurance and Integrity Levels) associated with the operation, which is highly related to the Ground Risk Class (GRC) and the Air Risk Class (ARC). Once the level of SAIL is determined, it will derive the level of robustness in which several Operational Safety Objectives (OSO) should be met. These levels are low, medium, and high and, as said, depend on the SAIL. The level of SAIL goes from SAIL I, assigned to those operations with low risk, to SAIL VI, those with the higher risk. However, the operations to be performed in OMICRON would not be higher than SAIL IV. The OSOs can be mainly divided into two different groups:

- Operational OSOs.
- System OSOs.

However, they affect many different stakeholders taking part in the operation. The OSOs affect to:

- Technical issues with the UAS.
- Deterioration of the external systems supporting UAS operations.
- Human errors.
- Adverse operating conditions.

If the resulted level of SAIL of the operation is lower than III, the requirements for the OSOs are usually low or even optional. However, once the operation is SAIL III or IV, some OSOs should be considered carefully. For instance, for OSO#5, devoted to *"UAS is designed considering system safety and reliability"*, EUROCAE has issued guidelines to meet this OSO in its *"ED-280 Guidelines for UAS safety analysis for the specific category (low and medium levels of robustness)".*

Apart from all the above-mentioned, since some of the OMICRON pilots could be potentially performed in an urban area, some mitigations regarding the ground risk should probably be taken into account. These mitigations are set in SORA in Step#3, and they apply to the GRC increasing or reducing its class depending on the level of robustness applied to it. The mitigations contemplated in SORA are the ones shown in the table below. For example, at least an M3 mitigation will be required in a medium level of robustness.

Table 4. Mitigations for final GRC determination

		Robustness		
Mitigation Sequence	Mitigations for ground risk	Low/ None	Medium	High
1	M1 - Strategic mitigations for ground risk	0: None -1: Low	-2	-4
2	M2 - Effects of ground impact is reduced	0	-1	-2
3	M3 - An emergency response plan (ERP) is in place, the UAS operator is validated and effective	1	0	-1

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Apart from that, there will be also some requirements regarding the airborne part of the operation. The OMICRON pilots will be performed in the VLL airspace. Then, following the classification of the airspace proposed in SORA, the airspace class will be either ARC-b or ARC-c, as explained in Figure 6. This has high implications on SORA's Step 6, devoted to the Tactical Mitigation Performance Requirements (TMPR), which are related to the following functionalities of the UAV: Detect, Decide, Command, Execute and Feedback Loop.

Figure 6. Airspace class in VLL airspace

2.1.4 Current and future standards related to drones

All the topics related to drones, as well as for the U-space, are still far away from a standardisation guideline. However, during the last year, there have been several steps towards the standardisation of several aspects. Some of these steps are taken by different organisations.

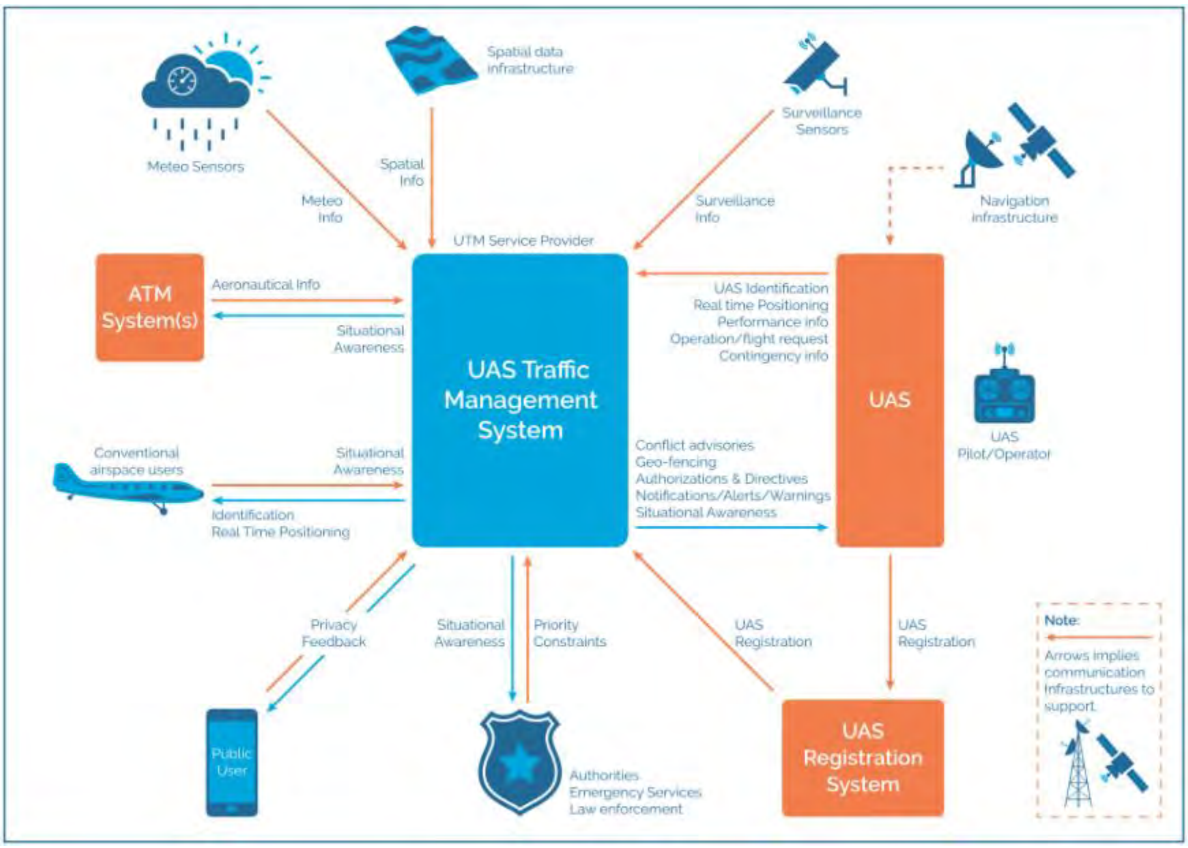

Figure 7. GUTMA UTM architecture proposal *[3]*

- International Organization of Standardization (ISO). This organization released a structure of main functions and functional structure for the UTM in its document ISO UTM Standards 23269

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2020. With that document, ISO intended to launch the development of concepts and tried to work in the comparison of different UTM/U-space systems.

- European UAS Standards Coordination Group (EUSCG) [4]. The main result of this group is the European UAS standardization Rolling Development Plan (RDP). This plan is based on the standardisation roadmap developed by EASA and other organizations, and inputs from the EUSCG members, both civil and military members.
- The European Organization for Civil Aviation Equipment (EUROCAE) is focused mainly on three different topics: geo-fencing, geo-caging and Detect and Avoid systems. It has published three different Minimum Operational Performance Standard (MOPS) regarding one of each of the aforementioned topics.
- The Global UTM Association (GUTMA) is one of the most important associations concerning UTM. This organization encompasses the main organizations, companies and stakeholders involved in the development of technology related to UAS and its integration into the airspace. It has proposed a high-level UTM architecture, involving all the possible types of operations, i.e. VLOS, EVLOS and BVLOS, as well as both remotely piloted and autonomous aircraft. For this organization, a possible UTM architecture is the one shown in Figure 7.

2.2 Road inspection

The requirements and restrictions that European regulation imposes on the road inspection solutions considered in OMICRON will be presented in this section, setting a guideline for the developments of the project.

2.2.1 AI applied to detection of road inspection parameters

Concerning the rules and regulations for the use of artificial intelligence in road maintenance, the lack of official documentation from the European Commission is noteworthy. This is a barrier to the development of technology, mainly because it is not developed under a legislative framework applicable at the time of development and testing, which reduces the impact capacity of the solutions in the short term.

Regarding AI, following various policy papers and guidelines published by high-level working groups on Artificial Intelligence (AI) on the 21st of April 2021, the European Commission issued a set of proposals for the introduction of harmonized rules on artificial intelligence ("Artificial Intelligence Act") and for the amendment of current EU legislation to bring this in line with the new rules [5]. These proposals come in the wake of several concerns raised over the last years regarding the risks and/or negative impact that AI can have on the rights and freedoms of individuals and society at large. Whilst the European Community recognizes the 'wide array of economic and societal benefits across the entire spectrum of industries and social activities' that AI brings with it, the introduction of this proposed regulatory framework aims to achieve a level of legal certainty within the AI industry, to ensure that AI systems are safe and respect European Union (EU) laws and values, to enhance governance and enforcement of existing laws, fundamental rights and applicable safety requirements, to facilitate the development of a single market for lawful, safe and trustworthy AI applications and to prevent market fragmentation.

The document remarks the following objectives:

- Ensure that AI systems placed on the EU market and users are safe and respect existing laws on fundamental rights and wider EU values.
- Ensure legal certainty to facilitate investment and innovation in AI.
- Enhance governance and effective enforcement of existing law on fundamental rights and safety requirements applicable to AI systems.

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- Facilitate the development of a single market for lawful, safe and trustworthy AI applications and prevent market fragmentation.

It proposes rules that complement and require full consistency with existing Union legislation including, but not limited to, the EU Charter of Fundamental Rights, competition law, data protection law and consumer protection law. The proposals also cater for rules pertaining to high-risk AI systems, which will also be integrated into existing sectoral safety legislation to ensure consistency and avoid and/or minimise any duplications and burdens.

The proposal suggests that designated supervisory authorities will have to be appointed to take charge of implementing these legislative requirements in a manner that ensures that the necessary technical expertise and resources are available. The Community is also proposing that existing regulatory authorities are entrusted with the supervision of regulated entities, such as credit institutions and financial services, to supervise and ensure that coherent enforcement of the proposed obligations is observed.

In relation to the detection of road parameters for maintenance work, there is no express mention in the official documents either, although it is left to the member states to establish the relevant regulations for each country. A series of measures to be adopted by the member countries are established:

- Member states shall ensure that safety inspections are carried out on roads in operation with a view to identifying road safety features and preventing accidents.
- Safety inspections shall cover periodic inspections of the road network and checks on the possible impact of road works on the safety of traffic flow.
- Member States shall ensure that periodic inspections are carried out by the competent body. Such inspections shall be carried out with sufficient frequency to ensure an adequate level of safety of the concerned road infrastructure.
- Member States shall establish guidelines for temporary safety measures applicable to road works. They shall also adopt an appropriate inspection program to ensure that these guidelines are properly applied.

This Directive requires the establishment and implementation of procedures related to road safety impact assessments, road safety audits, road network safety management and safety inspections by the Member States.

2.2.2 Requirements applicable to OMICRON project

Within OMICRON, all regulations related to pavement condition analysis and road auscultation will be followed. In the case of Spain, this is included in the Order FOM/3459/2003, of November 28th, which approves the standard 6.3-IC: "Pavement rehabilitation", of the Road Instruction, which will be the reference standard, since the demonstrators where this technology will be tested are located in Spain. All the recommendations and requirements for the calculation of the parameters that determine the pavement condition will be followed. Also, the current monitoring vehicles will be used in order to try to improve their results with new technologies.

According to the current status of the AI regulation, the AI functionalities to develop in OMICRON are out of the high-risk classification, so the existing recommendations and specifications will be followed, and they will be kept up to date according to the possible regulations and communications promoted by the European Commission.

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2.3 Road machinery and maintenance

Concerning machinery and maintenance activities in road scenarios, this section presents the relevant legislation and standards that apply directly to the project use cases. Since the technical demonstrators TD2, TD3 and TD4 will be performed at several sites in Spain, and the Final Demonstrator will take place in Italy, this section not only covers the legislation and standards at European level, but also the particularities of each of these two countries.

2.3.1 Legislation

As discussed in the introduction, this subsection surveys the current legislation and directives from the European Union, and later describes the specific national regulations applicable in Spain and Italy.

2.3.1.1 European legislation

European legislation in terms of safety, signaling and machinery involved in road maintenance is extensive, since the subject is very diverse and lumps together different actors within the tasks involved in the process.

This legislation marks a path that all Member States must comply with, since they must adapt their own legislation, in compliance with the maximum authority that comes from European legislation. The Directives are rules that bind every Member State, in terms of the result to be achieved, leaving to the national authorities the power to choose the form and means, that is, each Member State has to fulfill its aims but is free to prepare its internal development legislation.

The current legislation is shown below, considering all the tasks that are related to the OMICRON project.

- Directive 93/68/EEC of 22 July 1993 amending Directives 87/404/EEC (simple pressure vessels), 88/378/EEC (safety of toys), 89/106/EEC (construction products), 89/336/EEC (electromagnetic compatibility), 89/392/EEC (machinery), 89/686/EEC (personal protective equipment), 90/384/EEC (non-automatic weighing instruments), 90/385/EEC (active implantable medicinal devices), 90/396/EEC (appliances burning gaseous fuels), 91/263/EEC (telecommunications terminal equipment), 92/42/EEC (new hot-water boilers fired with liquid or gaseous fuels) and 73/23/EEC (electrical equipment designed for use within certain voltage limits).
- Directive 2000/14/EC - noise - equipment for use outdoors.
- Directive 2003/10/EC of the European Parliament and of the Council of 6 February 2003 on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (noise).
- Directive 2006/42/EC of the European Parliament and of the Council of 17 May 2006 on machinery, amending Directive 95/16/EC.
- Directive 2008/96/EC of the European Parliament and of the Council of 19 November 2008 on road infrastructure safety management.
- Directive 2014/29/EU of the European Parliament and of the Council of 26 February 2014 on the harmonization of the laws of the Member States relating to the making available on the market of simple pressure vessels.

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2.3.1.2 National legislation

2.3.1.2.1 Safety in road maintenance

Many of the works in road maintenance have to be carried out with the infrastructure in use, i.e. with the presence of traffic on roads. This implies the exposure of workers to an additional risk factor, not only that caused by the work itself but also that associated with the characteristics of the site where the work is to be carried out and the concurrence of other activities.

The difficulty in specifying the interventions to be carried out, together with the concurrence of road traffic and other activities or services in the infrastructure, shows the particular relevance of the aspects related to the management of occupational risk prevention in this type of work. This especially concerns the adoption of preventive measures in the conception of the work, its planning and the establishment of the appropriate means of coordination.

In an attempt to respond to this problem, administrations that manage these infrastructures have tried to standardise and normalize these interventions by issuing several legal provisions that attempt to guide and specify the procedures. These procedures, in many cases of a binding nature, are mainly set out in the following consultation documents:

Spain

- Orden FOM/3459/2003, de 28 de noviembre, por la que se aprueba la Norma 6.3-IC: "Rehabilitación de firmes", de la Instrucción de Carreteras (BOE del 12 de diciembre de 2003, corrección de erratas BOE del 25 de mayo de 2004).
- Real Decreto 345/2011, de 11 de marzo, sobre gestión de la seguridad de las infraestructuras viarias en la Red de Carreteras del Estado (BOE del 12 de marzo de 2011).
- Orden FOM/1649/2012, de 19 de julio, por la que se regula el procedimiento de acreditación y certificación de aptitud de auditores de seguridad viaria de la Red de Carreteras del Estado (BOE del 27 de julio de 2012).
- Orden Circular 30/2012, de 20 de junio de 2012, por la que se aprueban las directrices de los procedimientos para la gestión de la seguridad de las infraestructuras viarias en la Red de Carreteras del Estado.

Italy

- Nuovo Codice della Strada D.L.vo n. 285 del 30/04/1992 e successive modificazioni, dal Regolamento d'esecuzione e d'attuazione del nuovo codice della strada D.P.R. n.495 del 16.12.1992, dal D.P.R. 16 settembre 1996 n. 610.
- D.lgs. 9 aprile 2008, n. 81 TESTO UNICO SULLA SALUTE E SICUREZZA SUL LAVORO.

2.3.1.2.2 Traffic signs

Traffic signs provide clear visual information to the driver, with sufficient time to react and adapt their behavior to the potential danger, one can distinguish several groups:

- Informative signs: Informative signs are intended to orient and guide road users, providing them with the necessary information to reach their destinations in the safest, simplest, and most direct way possible.
- Regulatory signs are intended to notify road users of priorities in the use of roads, as well as existing limitations, prohibitions, restrictions, obligations, and authorizations.

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- Preventive signs: their purpose is to warn road users of the existence and nature of risks and/or unforeseen situations present on the road or in adjacent areas, either permanently or temporarily.

Within the Spanish and Italian road maintenance sector, the provision of these signs is regulated by several regulations and laws, the main ones being these listed below.

Spain

- Real Decreto 2296/1981, de 3 de agosto, sobre señalización de carreteras, aeropuertos, estaciones ferroviarias, de autobuses y marítimas y servicios públicos de interés general en el ámbito territorial de las Comunidades Autónomas (BOE del 9 de octubre de 1981).
- Real Decreto 334/1982, de 12 de febrero, sobre señalización de carreteras, aeropuertos, estaciones ferroviarias, de autobuses y marítimas y servicios públicos de interés general en el ámbito de las Comunidades Autónomas con otra lengua oficial distinta del castellano (BOE del 27 de febrero de 1982).
- Orden, de 2 de agosto de 2001, por la que se desarrolla el artículo 235 del Reglamento de la Ley de Ordenación de los Transportes Terrestres, en materia de supresión y protección de pasos a nivel (BOE del 9 de agosto de 2001). Regula la señalización de pasos a nivel. Modificada por Orden, de 19 de octubre de 2001 (BOE del 30 de octubre de 2001).
- Resolución de 1 de junio de 2009, de la Dirección General de Tráfico, por la que se aprueba el Manual de Señalización Variable (BOE del 13 de junio de 2009). Corrección de errores BOE del 23 de junio de 2009.
- Orden FOM 534/2014, de 20 de marzo, por la que se aprueba la Norma 8.1-IC Señalización vertical, de la Instrucción de Carreteras (BOE de 5 de abril de 2014).
- Orden Circular 38/2016 sobre la aplicación de la disposición transitoria única de la Orden FOM/534/2015, de 20 de marzo, por la que se aprueba la norma 8.1 IC Señalización vertical de la Instrucción de Carreteras.

Italy

Decreto 22 gennaio 2019 Individuazione della procedure di revisione, integrazione e apposizione della segnaletica stradale destinata alle attività lavorative che si svolgono in presenza di traffico veicolare.

2.3.1.2.3 Road markings

The immediate purpose of road markings is to increase the safety, efficiency, and comfort of traffic. They are intended to fulfill one or more of the following functions:

- Delimit traffic lanes.
- Separate traffic directions.
- Indicate the edge of the carriageway.
- Delimit areas excluded from the regular circulation of vehicles.
- Regulate traffic, especially overtaking, stopping, and parking.
- Complete or clarify the meaning of vertical signs and traffic lights.
- Repeat or recall a vertical sign.
- Allowing indicated actions.
- Announce, guide, and orientate users.

Within the Spanish and Italian road maintenance sector, the provision of road markings is regulated by several regulations and laws, the main ones being listed below.

Spain

- Orden, de 16 de julio de 1987, por la que se aprueba la Norma 8.2- IC sobre marcas viales, (BOE del 4 de agosto y 29 de septiembre de 1987).

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- Nota técnica, de 5 de febrero de 1991, sobre borrado de marcas viales.
- Nota de Servicio 2/2007, de 15 de febrero, sobre los criterios de aplicación y de mantenimiento de las características de la señalización horizontal. Anulada parcialmente (criterios técnicos) por la Orden FOM 2543/2014 que aprueba el artículo 700 del PG-3.

Italy

Decreto 22 gennaio 2019 Individuazione della procedure di revisione, integrazione e apposizione della segnaletica stradale destinata alle attività lavorative che si svolgono in presenza di traffico veicolare.

2.3.1.2.4 Road works signalling

Since the OMICRON project is mainly focused on road maintenance tasks, it is worth highlighting the signaling used for road works interventions. Their function, as in the case of permanent signs, is to regulate and warn of dangers or to inform about directions and destinations.

In these cases, both vertical and horizontal construction signs are of a temporary nature, in most cases, an addition to or replacement of existing signs. The regulatory framework, which explains the possible situations, the permitted installations, and the procedures for their installation and subsequent removal, is set out in the following documents issued by the different state administrations.

Spain

- Orden, de 31 de agosto de 1987, por la que se aprueba la Instrucción 8.3-IC sobre señalización, balizamiento, defensa, limpieza y terminación de obras fijas fuera de poblado (BOE del 18 de septiembre de 1987).
- Señalización móvil de obras. Dirección General de Carreteras, 1997. Adecuación de la Norma 8.3-IC sobre Señalización de Obras.
- Orden Circular 15/2003, de 13 de octubre, sobre señalización de los tramos afectados por la puesta en servicio de las obras.

Italy

- SEGNALETICA DI CANTIERE AGGIUNTIVA AL D.M. 10 Luglio 2002 – Strada dei Parchi.
- Manuale per la sicurezza dell'operatore su strada– Strada dei Parchi.
- LINEE GUIDA SICUREZZA OPERATORE SU STRADA ed. maggio 2018 con appendice – Strada dei Parchi.

2.3.1.2.5 Crack sealing

With the course of traffic, asphalt pavements gradually lose their service life and experience failures. These failures gradually appear on the surface in the form of cracks, which are an access route for external atmospheric agents and pollutants, which in turn accelerate the degradation process of the pavement. To mitigate this effect, these cracks can be filled by hot application of bituminous mastics based on elastomer-modified bitumens. The cracks are sealed, preventing their further evolution, degradation, and transmission to new wearing courses.

Spain

The procedure approved by the Spanish administration (Ministry of Transport, Mobility, and Urban Agenda) for the execution of crack sealing works, the scope of its application and the minimum requirements to be fulfilled are set out in the following document:

- Nota de Servicio 2/2015, de 3 de julio, sobre el sellado de grietas en pavimentos bituminosos.

Italy

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Regarding the Italian administration, there are no specific service notes about this topic.

2.3.1.2.6 Machinery

The legislation applicable to machinery safety is extensive and complex, as it is a constantly changing legislation. The following documents show the minimum provisions laid down by the administration, concerning both the general requirements to be met by equipment and the precautions to be taken in its use. Obligations of the employer in relation to the choice, use, maintenance and, where necessary, testing of work equipment. The legislation also sets out the minimum safety conditions required of the equipment in use and establishes that it must comply with the conditions imposed by the commercialization regulations.

Spain

- Real Decreto 1215/1997, de 18 de julio, por el que se establecen las disposiciones mínimas de seguridad y salud para la utilización por los trabajadores de los equipos de trabajo.
- Real Decreto 1644/2008, de 10 de octubre, por el que se establecen las normas para la comercialización y puesta en servicio de las máquinas.

Italy

Regarding the Italian administration, there is no specific legislation about this topic.

2.3.1.2.7 Asphalt pavements

Bituminous mixtures consist of a combination of aggregates and a hydrocarbon binder in such a way that all the particles are enveloped in a continuous and homogeneous manner. They are currently manufactured in fixed or mobile plants and are mainly used in the manufacture of road pavements, as they have certain advantages: their viscoelastic behavior allows them to be easily implemented on-site, presenting a considerable speed of execution, with different thicknesses, good mechanical behavior in service and adaptability to the environment, together with their rolling properties, high regularity, roughness, and slip resistance. In addition to its high sustainability, as it is a fully recyclable product.

Spain

The basic legislation on the procedures for the manufacture, paving and control of asphalt works is contained, almost in its entirety, in the following documents, issued by the General Directorate of Roads, which is dependent on the Ministry of Transport, Mobility and Urban Agenda:

- Pliego de Prescripciones Técnicas Generales para obras de carreteras y puentes (PG-3).
- Orden Circular 40/2017 sobre reciclado de firmes y pavimentos bituminosos.
- Orden Circular OC 3/2019 sobre mezclas bituminosas tipo SMA.

Italy

- Ministero delle Infrastrutture e dei Trasporti-documento a carattere pre-normativo, approvato dalla Commissione Strade del CNR, 2001, “Norme tecniche per la disciplina della costruzione e manutenzione delle infrastrutture stradali”.
- D.M. 16.11.2009: Applicazione della direttiva n. 89/106/CE sui prodotti da costruzione, recepita con decreto del Presidente della Repubblica 21 aprile 1993, n. 246, relativa alla individuazione dei prodotti e dei relativi metodi di controllo della conformita' di aggregati.
- Consiglio Nazionale delle Ricerche, “Catalogo delle pavimentazioni stradali”, B.U. n.178 – 1995.
- Consiglio Nazionale delle Ricerche - Norme Tecniche 15/9/1995 n. 178 Catalogo delle pavimentazioni stradali.

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- Consiglio Nazionale delle Ricerche - Norme Tecniche 14/12/1992 n.147 Norme per la misura delle caratteristiche superficiali delle pavimentazioni.
- Consiglio Nazionale delle Ricerche - Norme Tecniche 24/08/1987 n.121 Norme sui conglomerati bituminosi.
- Consiglio Nazionale delle Ricerche - Norme Tecniche 31/12/1980 n. 81 Norme per l'accettazione dei bitumi per usi stradali.

2.3.1.2.8 Removal of horizontal signs (painting)

Within maintenance operations, the problem to remove or erase existing road markings often arises, either because they are only temporary or because the road conditions have changed, and the lanes need to be restructured. Traditionally there are three main methodologies for its execution:

- Painting over the marking.
- Spraying of granular abrasives or High-pressure water cleaning.
- Gas burner.

The OMICRON project aims to introduce a new methodology based on laser technology, not contemplated until now in the current legislation. In Spain, the current regulations specified by the General Directorate of Roads are as follows:

- Nota técnica sobre el borrado de marcas viales, Madrid 5 de febrero de 1991, Subdirector General de Tecnología y Proyectos, dirección general de carreteras.
- Pliego de Prescripciones Técnicas Generales para obras de carreteras y puentes (PG-3).

2.3.2 Standards

Specific EU harmonized or Spanish/Italian standards are listed in the following different subsections, following important key points for the OMICRON project.

2.3.2.1 Machinery

Regarding EU standards, a set of them aims at the free market circulation on machinery and at the protection of workers and consumers using such machinery. It defines essential health and safety requirements of general application, supplemented by a number of more specific requirements for certain categories of machinery. In this project, the main standards regarding machinery to be considered are the following:

- EN 13019:2001+A1:2008: Machines for road surface cleaning - Safety requirements.
- EN 13020:2015. Road surface treatment machines - Safety requirements.
- EN ISO 12100-2:2004 Safety of machinery - Basic concepts, general principles for design - Part 2: Technical principles (ISO 12100-2:2003).
- EN 13524:2003+A2:2014. Highway maintenance machines - Safety requirements.
- ISO 22242:2005. Road construction and road maintenance machinery and equipment — Basic types — Identification and description.
- ISO 22242:2005/Amd 1:2013 Road construction and road maintenance machinery and equipment — Basic types — Identification and description — Amendment 1.
- EN 500-6:2006+A1:2008. Mobile road construction machinery - Safety - Part 6: Specific requirements for paver-finishers.
- EN 500-1:2006+A1:2009. Mobile road construction machinery - Safety - Part 1: Common requirements.

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- EN 500-2:2006+A1:2008. Mobile road construction machinery - Safety - Part 2: Specific requirements for road-milling machines.
- EN 500-3:2006+A1:2008. Mobile road construction machinery - Safety - Part 3: Specific requirements for soil-stabilising machines and recycling machines.
- EN 500-4:2011. Mobile road construction machinery - Safety - Part 4: Specific requirements for compaction machines.
- EN 15436-1:2008. Road service area maintenance equipment - Part 1: Terminology.
- EN 15436-4:2009. Road service area maintenance equipment - Part 4: Delivery acceptance of the machines by the users.
- EN 15436-2:2015. Road service area maintenance equipment - Part 2: Performance assessment.
- EN 15436-3:2015. Road service area maintenance equipment - Part 3: Classification.
- ISO 15143. Earth-moving machinery and mobile road construction machinery -- Worksite data exchange -- Part 1: System architecture, Part 2: Data dictionary, Part 3: Telematics data.
- ISO 15643:2020. Road construction and maintenance equipment — Bituminous binder sprayers and synchronous bituminous binder sprayers-chip spreaders — Terminology and commercial specifications.
- ISO 15645:2018. Road construction and maintenance equipment — Road milling machinery — Terminology and commercial specifications.
- ISO 15878:2021. Road construction and maintenance equipment — Paver-finishers — Commercial specifications.
- EN ISO 3744:2011. Acoustics - Determination of sound power levels and sound energy levels of noise sources using sound pressure - Engineering methods for an essentially free field over a reflecting plane (ISO 3744:2010).

2.3.2.2 Crack sealing

Road conservation and maintenance include a series of basic operations, aimed not only at providing a service to the road user but also at the preservation of roads. Among these actions, the methodology for “sealing cracks in pavements” is regulated by the following technical standards:

- EN 14188-1:2004. Joint fillers and sealants - Part 1: Specifications for hot-applied sealants.
- EN 14188-2:2004. Joint fillers and sealants - Part 2: Specifications for cold-applied sealants.
- EN 14188-3:2006. Joint fillers and sealants - Part 3: Specifications for preformed joint seals.
- EN 14188-4:2009. Joint fillers and sealants - Part 4: Specifications for primers to be used with joint sealants.

2.3.2.3 Horizontal signalling

Road marking is under the following regulations and guidance:

- UNE 48103:2014 Pinturas y barnices. Colores normalizados.
- CEN/TR 16958:2017. Road marking materials - Conditions for removing/masking road markings.
- LINEE GUIDA PER LA DEFINIZIONE DEI REQUISITI TECNICO FUNZIONALI DELLA SEGNALETICA ORIZZONTALE UNI/TR 11670:2017.
- UNI EN 1436:2008 Materiali per segnaletica orizzontale - Prestazioni della segnaletica orizzontale per gli utenti della strada.

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- UNI ISO 3905:1990 - Prodotti vernicianti. Determinazione del rapporto di contrasto (potere coprente) delle pitture chiare ad una determinata resa superficiale utilizzando carte a contrasto nero-bianco.

2.3.2.4 Vertical signalling

Road traffic signs and signals need to be simple and concise so people can understand them quickly. The following are the main EN standards aim to regulate traffic signs.

- EN 12899-1:2007. Fixed, vertical road traffic signs - Part 1: Fixed signs.
- EN 13422:2019. Vertical road signs - Portable deformable warning devices and delineators - Portable Road traffic signs - Cones and cylinders.
- Il Regolamento (UE) n. 305/2011 che "fissa condizioni armonizzate per la commercializzazione dei prodotti da costruzione e che abroga la direttiva 89/106/CEE".
- Il DPR n. 495 del 16 dicembre 1992 "Regolamento di esecuzione ed attuazione del Nuovo Codice della Strada", con le modifiche e le integrazioni apportate dal DPR n. 610 del 16 settembre 1996 "Regolamento recante modifiche al decreto del Presidente della Repubblica 16 dicembre 1992 n. 495".
- La Direttiva del Ministero delle Infrastrutture e dei Trasporti n. 4867/RU del 5 agosto 2013 "Istruzioni e linee guida per la fornitura e posa in opera di segnaletica stradale".
- Il Decreto 10 luglio 2002 del Ministero delle Infrastrutture e Trasporti "Disciplinare tecnico relativo agli schemi segnaletici, differenziati per categoria di strada, da adottare per il segnalamento temporaneo".
- La norma armonizzata UNI EN 12899-1:2008 "Segnaletica verticale permanente per il traffico stradale – Parte 1:Segnali Permanenti".
- La norma UNI EN 11480:2016 "Linee guida per la definizione dei requisiti tecnico-funzionali della segnaletica verticale (permanente) in applicazione alla UNI EN 12899-1:2008.

2.3.2.5 Asphalt pavement

The current Spanish General Technical Specifications for road and bridge works constitutes a set of instructions for the development of road and bridge works and contains the standard technical conditions regarding materials and work units. In this project, every standard referred to the "Pliego de Prescripciones Técnicas Generales para obras de carreteras y puentes (PG-3)" and "Orden Circular OC 3/2019 sobre mezclas bituminosas tipo SMA (Stone Mastic Asphalt)" will be applicable.

The following are the main standards to consider regarding asphalt pavement and related activities in this project:

- UNE 41265-1:2020 IN. Materiales para firmes de carreteras. Ejecución y control. Parte 1: Control térmico de mezclas bituminosas.
- UNE-EN ISO 13473-1: 2019. Caracterización de la textura de los pavimentos mediante el uso de perfiles de superficie. Parte 1: Determinación de la profundidad media del perfil (Characterization of pavement texture by use of surface profiles — Part 1: Determination of mean profile depth).
- UNE-EN 13036-1:2010. Características superficiales de carreteras y aeropuertos. Métodos de ensayo. Parte 1: Medición de la profundidad de la macrotextura superficial del pavimento mediante el método volumétrico (Road and airfield surface characteristics - Test methods - Part 1: Measurement of pavement surface macrotexture depth using a volumetric patch technique).

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- UNE-EN 12697-6: 2012. Mezclas bituminosas. Métodos de ensayo para mezclas bituminosas en caliente. Parte 6: Determinación de la densidad aparente de probetas bituminosas (Bituminous mixtures - Test methods - Part 6: Determination of bulk density of bituminous specimens).

2.4 Robotics

Regarding the robotic modular platform and its subsystems (AI), a review of current regulations in robotics is presented, focusing on collaboration and cooperation tasks. Then, the requirements and restrictions that these regulations impose on the robotic modular platform solution considered in OMICRON are presented. Finally, the current and future status of AI regulations is presented, which is an emerging issue in jurisdictions globally, including the European Union.

2.4.1 The current regulatory framework for robotics

The current regulatory framework concerning robotics is governed by compliance with a series of standards, technical specifications and technical reports published by the ISO. A list of standards is listed in Table 5.

Table 5. ISO standards for robotics

Standard Number and Title	Abstract
ISO 10218-1:2011 **Robots and robotic devices - Safety requirements for industrial robots - Part 1: Robots**	It specifies requirements and guidelines for the inherent safe design, protective measures and information for use of industrial robots. It describes basic hazards associated with robots and provides requirements to eliminate, or adequately reduce, the risks associated with these hazards.
ISO 10218-2:2011 **Robots and robotic devices - Safety requirements for industrial robots - Part 2: Robot systems and integration**	It specifies safety requirements for the integration of industrial robots and industrial robot systems as defined in ISO 10218-1, and industrial robot cell(s). The integration includes the following: - The design, manufacturing, installation, operation, maintenance and decommissioning of the industrial robot system or cell. - Necessary information for the design, manufacturing, installation, operation, maintenance and decommissioning of the industrial robot system or cell. - Component devices of the industrial robot system or cell.
ISO 12100:2010 **Safety of machinery - General principles for design - Risk assessment and risk reduction**	It specifies basic terminology, principles and a methodology for achieving safety in the design of machinery. It specifies principles of risk assessment and risk reduction to help designers in achieving this objective. These principles are based on knowledge and experience of the design, use, incidents, accidents and risks associated with machinery. Procedures are described for identifying hazards and estimating and evaluating risks during relevant phases of the machine life cycle, and for the elimination of hazards or sufficient risk reduction. Guidance is given on the documentation and verification of the risk assessment and risk reduction process.

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ISO 14120:2015 **Safety of machinery - Guards - General requirements for the design and construction of fixed and movable guards**	It specifies general requirements for the design, construction, and selection of guards provided to protect persons from mechanical hazards.
ISO 13855:2010	It specifies safety of positioning of safeguards with respect to the approach speeds of parts of the human body.
ISO 13854:2020	It specifies Minimum gaps to avoid crushing of parts of the human body.
ISO/TS 15066:2016 **Robots and robotic devices - Collaborative robots**	It specifies safety requirements for collaborative industrial robot systems and the work environment and supplements the requirements and guidance on collaborative industrial robot operation given in ISO 10218-1 and ISO 10218-2.
ISO 13849-1:2015 **Safety of machinery - Safety-related parts of control systems - Part 1: General principles for design**	It provides safety requirements and guidance on the principles for the design and integration of safety-related parts of control systems (SRP/CS), including the design of the software. For these parts of SRP/CS, it specifies characteristics that include the performance level required for carrying out safety functions. It applies to SRP/CS for high demand and continuous mode, regardless of the type of technology and energy used (electrical, hydraulic, pneumatic, mechanical, etc.), for all kinds of machinery.
ISO 13849-2:2012 **Safety of machinery - Safety-related parts of control systems - Part 2: Validation**	It specifies the procedures and conditions to be followed for the validation by analysis and testing of the specified safety functions, the category achieved, and the performance level achieved by the safety-related parts of a control system (SRP/CS) designed in accordance with ISO 13849-1.
ISO 3691-4:2020	Industrial Trucks – Safety requirements and verification – Part 4: Driverless industrial trucks and their systems.
ISO/TR 22100-5:2021	Safety of machinery — Relationship with ISO 12100 — Part 5: Implications of artificial intelligence machine learning.
ISO/TR 22100-2:2013	Safety of machinery — Relationship with ISO 12100 — Part 2: How ISO 12100 relates to ISO 13849-1.

The publication by the European Union of the **proposed AI regulation** and the **revision of the Machinery Directive** which affects industrial robots will modify some of these standards.

A brief description of these revisions, new regulations and their implications is described in chapter 2.4.3 for **AI regulation** of this deliverable.

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2.4.2 Applicable requirements in OMICRON regarding human-robot collaboration

This section is intended to cover restrictions and requirements that the above-mentioned standards impose on OMICRON's modular robotic platform solution, in case of human-robot collaboration.

The objective of this section is not to perform a risk assessment for each of the defined use cases but to focus on those operations that contain a collaborative/cooperative task between robot and operator. Table 6 shows each use case and whether there is human-robot collaboration in each of them.

Table 6. Use cases with human-robot collaboration/cooperation

OMICRON use cases and human-robot cooperation/collaboration	
Use case	Cooperation/collaboration
UC2.1.1 Safety barriers	✓
UC2.1.2 Installation of cones (collection of cones)	✗
U2.1.3 Road assets cleaning	✗
UC3.1 Signalling during construction works	✗
UC3.2 Sealing of surface pavement cracks	✗
UC3.3 Removal of the lane marking	✗

According to the analysis carried out and as can be seen in Table 6, the only use case in which there is a collaboration between operator and robot is the use case for *installation of safety barriers*. In this use case, the robot helps the operator to support the weight of the barrier and to move the barrier towards the fixing posts to ease the operator's assembly work.

In terms of standards, this use case falls under ISO/TS 15066 collaborative robots [6]. This technical specification describes safety requirements for collaborative industrial robot systems and the work environment and supplements the requirements.

In the OMICRON project, the use of a collaborative robot is not planned because the consortium does not have a collaborative robot available with the required load capacity to handle a safety barrier.

Therefore, for this use case, two safety measures will be implemented to allow the operation to be carried out by the industrial robot in a safe way.

The first of these will be to use the robot's own safety functions to limit the speed of each of the axes. In this way, the operation can be carried out safely. In order to obtain extra safety, a second measurement will be that the operation will always be supervised by another person who can stop the robot's movement instantaneously by means of an emergency stop button.

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2.4.3 Status of AI regulation and the European Commission proposals for laying down harmonized rules

2.4.3.1 Motivation of AI regulation

Artificial intelligence is a technology whose applications are growing exponentially. It will certainly change our lives by improving many aspects of it, such as healthcare, agricultural efficiency, improving production efficiency.

However, the use of Artificial Intelligence (AI) brings with it several potential risks, such as opacity in decision-making, gender or other types of discrimination, intrusion into our private lives or its use for criminal purposes.

All of this led the European Commission to undertake a process to establish a regulation of AI that would allow the benefits of its application to be realised while protecting citizens from the potential risks of its use.

2.4.3.2 History of the Process

In 2019, the European Commission convened two advisory bodies to publish ethical guidelines for reliable AI. As a result of this consultative process, seven key requirements were established that systems making use of AI must meet in order to be considered reliable: Human agency and oversight; Technical Robustness and safety; Privacy and data governance; Transparency; Diversity, non-discrimination and fairness; Societal and environmental well-being; and Accountability.

Based on these ethical directives, the European Commission published the white paper "On Artificial Intelligence: A European Approach to Excellence and Trust", with the aim of launching a debate to reach a political consensus The White Paper on AI is structured around two main dimensions: promoting excellence and building trust in AI. In addition, the white paper included the commitment of releasing a regulatory action and the key elements of the future framework. One of them was the risk-based approach suggesting that mandatory legal requirements—derived from the ethical principles—should be imposed on high-risk AI systems.

The European Commission decided not to define AI but to list a series of techniques that lead to the system being considered as AI. These techniques listed were:

- Machine learning approaches, including supervised, unsupervised and reinforcement learning.
- Logic- and knowledge-based approaches, including knowledge representation, inductive (logic) programming, knowledge bases, inference and deductive engines, (symbolic) reasoning and expert systems.
- Statistical approaches, Bayesian estimation, search and optimisation methods.

It is worth remarking that only the AI systems that present an increased level of risk will be subject to legal requirements. The AI Act is based on the idea that developing trustworthy technologies will drive the acceptance of AI. The AI Act has adopted a risk-based approach represented in Figure 8.

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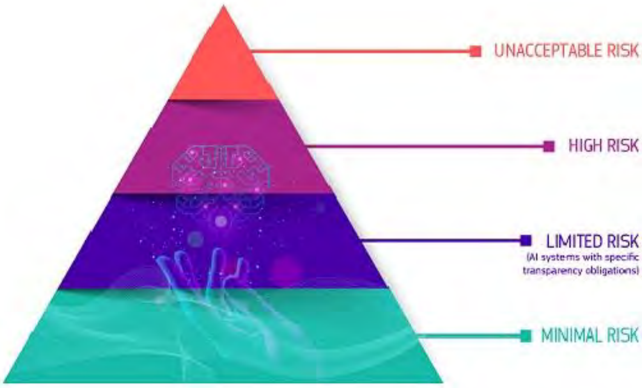

Figure 8. The AI Act's hierarchy of risk (credit: European Commission)

Unacceptable risk: All AI systems considered a clear threat to the safety, livelihoods and rights of people will be banned, from social scoring by governments to toys using voice assistance that encourages dangerous behaviour.

High-risk: AI systems identified as high-risk include AI technology used in: Critical infrastructures, Educational or vocational training, Safety components of products, Employment, workers management and access to self-employment, Essential private and public services, Law enforcement that may interfere with people's fundamental rights, Migration, asylum and border control management and Administration of justice and democratic processes.

Limited risk, i.e. AI systems with specific transparency obligations: when using AI systems such as chatbots, users should be aware that they are interacting with a machine so they can take an informed decision to continue or step back.

Minimal risk: The proposal allows the free use of applications such as AI-enabled video games or spam filters. Most AI systems currently used in the EU fall into this category, where they represent minimal or no risk.

An AI system that falls into the high-risk category must follow the workflow shown in Figure 9.

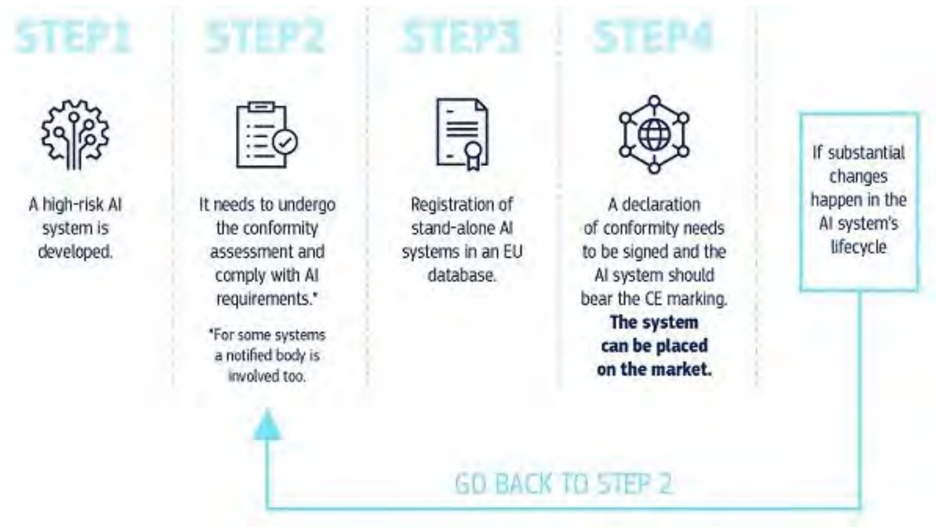

Figure 9. Flow for providers of high-risk AI system (credit: European Commission)

On April 21st 2021, the European Commission published the draft of the regulation laying down harmonized rules on artificial intelligence, where the strict mandatory requirements for AI system placed on the EU market are specified.

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2.4.3.3 Industrial robots and AI regulation

Industrial robots are regulated by the Machinery Directive (hereafter MD). Within the process of AI regulation, the European Commission presented its proposal for a regulation of the European Parliament and of the Council on Machinery Products, which intends to reach harmonising health and safety requirements for machinery. This has been proposed as part of a process including the Commission's proposal for a Regulation on Artificial Intelligence (AI). The proposed Machinery Regulation results both from the need to ensure coherence with the EU's AI policy and from the need to review the Machinery Directive 2006/42 (MD) since the MD does not sufficiently cover new risks originating from emerging technologies:

- Potential risks that originate from a direct human-robot collaboration, as the collaborative robots (co-bots) that are designed to work alongside humans, and employees, are exponentially increasing.
- Risk originates from connected machinery.
- The way software updates affect the 'behaviour' of the machinery after its placing on the market.
- Conduct a full risk assessment on machine learning applications before the product is placed on the market.
- The current MD foresees a driver or an operator responsible for the movement of a machine, but does not consider the possibility of no driver, and sets up no requirements for autonomous machines.

The revision of the machinery implies some changes:

- Directive to regulation.
- New requirements regarding cyber threats.
- Not possible to self-certify by following C-standards.
- The list of dangerous machines can be extended by the commission.

The proposal is receiving many suggestions and criticisms, especially about the cataloguing and marking of high-risk machines, as well as the mandatory third-party reliability assessment applicable to all high-risk machines. The high-risk designation would be misleading for customers and damaging to the reputation of European manufacturers. The third-party assessment fundamentally changes the current practice and would have massive implications for the affected machinery manufacturers, in particular SMEs, due to increased costs and lead times [7].

Therefore, it is expected that the new regulation will undergo modifications from the initial proposal.

2.4.3.4 OMICRON use cases and AI

Within the robotic and machinery use cases of the OMICRON project, there are several functionalities or tasks which are carried out by AI-based algorithms. Table 7 shows each use case and the associated AI functionality.

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Table 7. Robotics and machinery use cases where AI is used

OMICRON use cases and IA	
Use case	**AI functionality**
UC2.1.1 Safety barriers	Perception system based on AI to supply the **position of the vertical posts or human reference** regarding the robotic system.
UC2.1.2 Installation of cones (collection of cones)	Perception system based on AI to supply the position of the **cone to be collected** regarding the robotic system.
U2.1.3 Road assets cleaning	Perception system based on AI to supply the position of the **asset to be cleaned** regarding the robotic system
UC3.1 Signalling during construction works	Perception system based on AI to supply the position of the signal to be placed.
U3.2 Sealing of surface pavement cracks	Perception system based on AI to supply the position of **the pavement cracks to be sealed** regarding the robotic system
U3.2 Removal of the lane marking	Perception system based on AI to supply the position of **the lane marking to be removed** regarding the robotic system

Within the regulatory framework of the AI, machines that use AI as part of safety functions are defined as high-risk.

As can be seen, none of the functionalities or tasks performed by AI within the OMICRON project can be considered as a safety function, although it is true that an inappropriate operation of these functionalities could lead to some risk in the form of an incident. Therefore, in each of the use cases, the appropriate measures will be enabled to mitigate these risks.

2.4.3.5 Conclusions

The European Commission does not want to miss the opportunity of integrating AI into systems, which will give Europe a quantum qualitative leap, but these must be reliable and secure in order to have penetration and success in the global market.

This has led to a phase of regulation definition that involves many actors as well as the redefinition of many standards and directives.

The regulations are under discussion and some terms of the proposal can certainly be changed.

According to the current status of the AI regulation, the AI functionalities to develop in OMICRON project are out of the high-risk classification.

Conforming to the European Commission's roadmap, the expected date for the entry into force of the AI regulation is around 2023. The revision of the Machinery Directive may be finalised between 2024-2025.

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Therefore, the expected entry into force will be towards the end of the OMICRON project. However, during the project, those aspects of this new regulation will be monitored, as these may affect the developments. This will enable their application in the future exploitation of the developments, which is expected to take place with the new regulation in force.

2.5 Data treatment

The data treatment legislation analysis has to be aligned to the ethics deliverables (D9.1 to D9.2) and to the data management plan (D8.2) to be delivered by M9. This Chapter looks at relevant European legislation in the field of data processing, such as the GDPR, along with specific methodologies and standards such as the FAIR data principle. Furthermore, in this section, data security and ethical aspects are considered and the requirements and the applicability of the analysed methodologies and standards, within the project Use Cases and demonstrators, are also discussed.

2.5.1 Data regulation framework

The project members of OMICRON are committed to the ethical standards and guidelines of Horizon 2020, regardless of the country in which the different stages of the research and the demonstrations will be performed, and they ensure that all data transfers will be legitimate under all relevant regulatory requirements at all times.

The relevant data frameworks to be considered for the OMICRON project are 1) GDPR (as the collected data may contain personal data), 2) EU Regulations 2019/947 and 2019/945 (EASA Civil drones – unmanned aircraft) and the U-Space Regulation (as UAVs will be used in the project, section 2.1) and 3) FAIR data principle. These frameworks are discussed in detail below.

Each member of the consortium who collects, transfers or stores data had also appointed a Data Protection Officer who is responsible for ensuring that all data accumulated and kept follow the applicable data protection rules.

1. GDPR [8].

The OMICRON project is fully compliant with the regulations outlined in the General Data Protection Regulation (also known as GDPR) within Regulation (EU) 2016/679 of the European Parliament and of the Council of 27 April 2016 on the protection of natural persons about the processing of personal data and on the free movement of such data.

As of May 2018, the GDPR is applicable in all Member States in the European Union, as well as in the countries in the European Economic Area (EEA). The main intention of GDPR is to provide and strengthen citizens' fundamental rights, to give them more control over their personal data, and furthermore, to ensure and secure their privacy to the maximum extent possible in the digital era via refining and perfecting existing laws on data protection or creating new ones.

GDPR grants citizens a set of rights that must be ensured by any natural or legal person who obtains and processes personal data. These citizens have the right to:

- receive information about the way and means of the processing of their personal data,
- gain access to their personal data held about them,
- ask for the correction of incorrect or incomplete personal data,
- ask for their personal information to be deleted when it is no longer needed,
- refuse to have their personal data processed for marketing purposes,
- request the restriction of the processing of their personal data in specific cases,
- ask for their personal data in a structured, commonly used and machine-readable format and send it to another controller, and

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- demand that decisions based on automated processing impacting individuals or having a substantial impact on them and based on their personal data be made by people, not machines.

2. EU Regulations 2019/947 [9] and 2019/945 (EASA Civil drones - unmanned aircraft) [10] and U-Space Regulation [11]

EU Regulations 2019/947 and 2019/945 set out the framework for the safe operation of civil drones in the European skies [12] (refer to section 2.1). Regarding data privacy and data protection, EU Regulation 2019/947 regulates that UAS operators and remote pilots should ensure that they are adequately informed about applicable Union and national rules relating to the intended operations, in particular with regard to safety, privacy, data protection, liability, insurance, security and environmental protection.

According to EU Regulation 2019/945 the following points are required from UAS operators (the requirements vary based on the class of the unmanned aircraft system):

- Be safely controllable with regards to stability, manoeuvrability and data link performance.
- Unless tethered, in case of a loss of data link, have a reliable and predictable method for the UA to recover the data link or terminate the flight in a way that reduces the effect on third parties in the air or on the ground.
- Unless tethered, be equipped with a data link protected against unauthorised access to the command-and-control functions.
- Be equipped with a geo-awareness function that provides: an interface to load and update data containing information on airspace limitations related to UA position and altitude imposed by the geographical zones, as defined by Article 15 of Implementing Regulation (EU) 2019/947, which ensures that the process of loading or updating of this data does not degrade its integrity and validity.

The management of drone traffic is also regulated in the U-space Regulation which was adopted in April 2021 and will become applicable as of 26 January 2023. Member States may still embark on pioneering implementations before this date and are not obliged to deploy a U-space everywhere in their airspace by the same date.

According to Annex III ‘Data quality, data latency and data protection requirements referred to in Article 5(4)(b) and Article 7(5)(c)’:

- In order to meet the data quality requirements, providers of common information services and U-space service providers shall ensure that:
    1. Data quality is maintained.
    2. Verification and validation techniques are employed to ensure that data is received without corruption and that corruption does not occur at any stage of the data process.
    3. The metadata is collected and preserved.
    4. The transfer of data is subject to a suitable authentication process such that recipients are able to confirm that the data or information has been transmitted by an authorised source.
    5. Error reporting, error measurement and corrective action mechanisms are established and maintained.
- In order to protect the data, providers of common information services and U-space service providers shall:
    1. Implement security policies, including data encryption and protection of critical data.

2. Protect the open secure interoperable communication protocols from intentional unauthorised electronic interactions that may result in an unacceptable breakdown in communications.
3. Identify, assess, and mitigate, as necessary, the security risks and vulnerabilities.
4. Adhere to security standards and regulations regarding where data can be stored and ensure that third-party providers agree to follow security practices.
5. Describe a policy for employee awareness and training and tools to reduce insider risks and protection of data – including intellectual property. In doing so, they shall monitor the user and network activity to provide insight into ecosystem vulnerabilities and threats.
6. Deploy solutions that augment threat detection and intelligence capabilities and ensure the use of technology safeguards.

According to Annex V 'Exchange of relevant operational data and information between U-space service providers and air traffic service providers in accordance with Article 7(3)':

1. The exchange of information shall be ensured through an agreement on a service level laying down the quality of information and through the exchange model used for the relevant operational data and information.
2. The exchange model shall:
    a. enable the management and distribution of information in digital format;
    b. describe the exchanged information features, their properties, attributes, data types, and associations;
    c. include data constraints and validation rules;
    d. apply a standard data encoding format;
    e. provide an extension mechanism by which groups of users can extend the properties of existing features and add new features that do not adversely affect standardisation within and across Member States.
3. U-space service providers and air traffic service providers shall use a recognised encryption method.
4. U-space service providers and air traffic service providers shall use a common secure interoperable open communication protocol.

In addition to applying the frameworks mentioned above, as a drone operator, it is necessary to register the equipment in the country of demonstration cases. The National Aviation Authorities (NAAs) requires registration on the following sites:

- Italy: https://www.d-flight.it/portal/
- Spain: https://www.seguridadaerea.gob.es/en/ambitos/drones
- Portugal: https://www.anac.pt/vPT/Generico/drones/Paginas/AeronavesCivisPilotadasRemotamente.aspx

The project implementation will require close contact with National Aviation Authorities to agree on how to interpret the frameworks' requirements to OMICRON.

3. FAIR data principle [13]

According to the 'Guidelines on FAIR data management in Horizon 2020' the OMICRON project aims to make the research data findable, accessible, interoperable and reusable (FAIR), to ensure it is soundly managed.

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The FAIR principles are especially important for data collected and generated by machines such as drones and robots which are also included in OMICRON project.

In order to get searchable data from the dataset collected by drones/UAVs, well-defined, specified metadata and parameters are needed. The required data need to be accessed through authentication and of course authorisation. The data can be integrated with other data sources and should be interoperable with other systems and workflows as part of reusable OMICRON's digital twins.

2.5.2 Data processes and methodologies

Data collection is performed within WP2 through different Advanced Digital Inspection Technologies. In particular, UAVs and vehicle inspection technologies will be exploited to collect data and images that will be used to build a Digital Twin of road infrastructure.

The **main data processes regarding inspections** are:

- Data collection through sensors (laser, video, etc.).
- Pre-process of collected data.
- Transfer of collected and pre-processed data to Digital Twin.

The **data collected by the Advanced Digital Inspection Technologies** developed in OMICRON and the data from already existing legacy monitoring and inspection technologies will be processed within WP5, including:

- A **Digital Twin (DT).** This will provide a representation of the infrastructure using both information from new and existing systems.
- A **Decision Support Tool (DST).** This will process the information available from the Digital Twin to perform nowcasting and forecasting of the infrastructure status and generate optimal maintenance intervention planning solutions.

The **main data process aspects and related standards and methodologies within the DT** are the following:

- **Definition of repositories to store the data.** Due to the heterogeneity of the data used, different types of repositories will be needed to ensure good performance. Some of the identified repositories will be (a) time-series databases for sensor data; (b) relational databases for structured information; (c) RDF store for semantic information.
- **Data integration and standardisation.** Integration of different sources of data**,** the definition of the proper structure considering standards from BIM, such as IFC, Object Catalogues, CityGML, etc.
- **Definition of the processing chain** for the processing of low-level data into high-level information for example through UML and BPMN.
- **Building and populating the data model** considering standardisation processes of building such as SMART, OGC, CEN and others.
- **Accessing the data** the DT platform will serve. This will be developed using NGSI-LD information model and API standardised by ETSI.

Furthermore, the **main data process aspects and related standards and methodologies within the DST** are presented as follows:

- **Get data from DT** definition of link and interfaces with DT.
- **Get information from data** extracting meaningful information and knowledge about road infrastructure conditions through nowcasting and forecasting methodologies.

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- **Use the extracted information to propose solutions** use the information and the knowledge about intervention capabilities to suggest possible solutions through advanced optimization models.
- **Populating the platform** with the obtained information and suggested options.
- **Access to the extracted information and evaluated solutions** development of a visualisation platform for road operators.

All the data management phases will be conducted in line with the specifications defined in the ethics deliverables (D9.1 and D9.2) and in the data management plan (D8.2) to be delivered by M9. In particular, the FAIR (Findable, Accessible, Interoperable and Reusable) principles will be applied.

The main issues that will be addressed regarding the data process are:

- **Data protection**, following the applicable regulations in terms of protection of personal data, including: (a) the General Data Protection Regulation (GDPR); and (b) other EU or Member State data protection legislation.The **security measures** to be implemented will be defined in the data management plan.
- **Compatibility and transferability** of information from/to existing systems and external databases will be achieved thanks to the definition of proper standards. The standards and interfaces between existing legacy systems and the newly developed technological solutions will be defined during the project. In particular, the integration of tools within OMICRON's intelligent platform.
- **Data accessibility**. The collected information/data, regarding road infrastructure, operation or usage, will be accessible but remain confidential throughout the project and, furthermore, it will only be used inside the consortium. A consent form will be provided to participants. The IT architecture to guarantee the accessibility of the data will be defined during the project.
- **Ethical principles**, considering the highest standards of research integrity as set out, for instance, in the European Code of Conduct for Research Integrity. Data processing within OMICRON will be lawful, fair and transparent. It will not involve personal data and, furthermore, it will only involve data that are necessary and proportionate to achieve the specific research tasks or purposes for which they will be collected. Therefore, only the specific data needed to meet the research objectives of OMICRON will be used.

2.5.3 Application of standards and methodologies

This section provides a summary of the application of standards and data treatment methodologies to the OMICRON Use Cases. The information related to data, regulation framework, standards and methodologies is gathered in Table 8. In the column for "Data", all the data processed is listed, including incomes and outcomes. In the column for "Regulation framework and standards", the different normative and standards specific to each Use Case are presented. In the "Methodologies", the methodologies for the data processing of every Use Case are briefly described.

Further information in this respect can be found in the Annex to this deliverable.

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Table 8. Review of use cases and methodologies

UC		Methodologies	Regulation framework and standards	Data
UC1	UC1.1 UC1.1.1 UC1.1.2	The data will be transferred to the Digital Twin	EU Regulations 2019/947 and 2019/945 U-Space Regulation NAAs registration FAIR data principle	Data collected through UAVs inspection Site map and inspection resources 3D maps built using the collected data
	UC1.2	The data will be processed using AI and ML	FAIR data principle	Historical archive Data collected through sensor combination
	UC1.2.1			Data collected through image data collection and laser scanning
	UC1.2.2	The images will be processed using deep learning models		Historical archive (videos) Data collected through sensor combination (videos) Data from external factors (weather, number and type of vehicles, etc.)
	UC1.3	Data stored in C-ITS Hub Data standardized using formats such as DATEX II, ECO-AT, ETSI and BSM	FAIR data principle	Data stored related to the presence of traffic, accidents, lane closures due to road works or adverse weather, including geographical information about the roadwork, lanes affected, speed recommendations, affection and information distance, detailed road history incident, and trace
UC2	UC2.1 UC2.1.1 UC2.1.2 UC2.1.3	The information is processed in a Master PC and sent to a VR device through web-based media	FAIR data principle	Kilometre-points data provided by the road administration with the points codes of the maintenance interventions Images collected through RGB-D vision camera Sensors

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UC3	UC3.1	The images from the camera are processed to identify the visual references		Kilometre-points data provided by the road administration with the points codes of the maintenance interventions. Images collected by RGB-D camera
	UC3.2	Artificial Vision and Artificial intelligence is used to process data		Images collected by RGB-D camera
	UC3.3	Images are processed through AI techniques		Images collected by RGB-D camera
	UC3.4	Information will be processed to provide decision-support		Data from temperature, density over time, dose, amount of material, speed of deployment, macrotexture and distance between the extension and the compacting vehicle, obtained through: • Distribution sensors • Paver sensors • Roller sensors
UC4		The final demonstrator will be modelled following building information modelling (BIM).		Internal documentation Virtual demonstrator providing a full BIM design of the bridge
UC5	UC5.1	The information Exchange between the virtual device and the remote sensors and robots is done through a Master PC	FAIR data principle	Data provided from: • Sensors • OMICRON inspection technologies • Digital twin
	UC5.2	The communication between the AR tools and the other resources is made through the Master PC		

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UC6	UC6.1	Definition of repositories to store the data Data integration and standardization Definition of processing chain Building and populating the data model Access to the data	FAIR data principle	Historical records Data provided by the OMICRON digital inspection technologies Data from existing sensors, processes and measuring devices
	UC6.2	Get data from DT Extract information from data Use the extracted information to propose solutions Populating the platform Access to the extracted information and evaluated solutions		Historical records Data provided by the OMICRON digital inspection technologies Data from existing sensors, processes and measuring devices Data from the digital twin

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3 Technical and functional requirements

The objective of this section is to present a summary of the technical and functional requirements of the OMICRON Use Cases: UC1 addressing inspection, V2X communications and user support; UC2 focusing on routine and emergency maintenance interventions; UC3 focusing on large and extraordinary maintenance actions; UC4 tackling the modularisation of bridge construction; UC5 addressing road personnel support; and UC6 committing to DTs and predictive maintenance. The detailed requirement forms of each of these cluster use cases are available in Annex C.

3.1 UC1. Inspection, V2X communications and user support

3.1.1 UC1.1. Management tool for UAVs

3.1.1.1 State of the art

The management of a UAV is performed using a ground control station (GCS). A GCS is typically a software application, running on a ground-based computer, that communicates with the UAV via wireless telemetry. It displays real-time data on the UAVs performance and position and can serve as a “virtual cockpit”. A GCS can also be used to control a UAV in flight, uploading new mission commands and setting parameters. There are many commercially available GCS [14] [15] [16],including open-source solutions [17] [18] [19] as shown in Figure 10.

Figure 10. Off-the-shelf ground control stations: DJI GS Pro [3] (left) and QGroundControl [6]

These solutions have two main limitations. First, some of them can visualize multiple UAVs in the visual interface, but they cannot manage several UAVs at the same time. Open-source solutions can be modified to extend multi-UAV capabilities, like the functionalities added to the QGroundControl application in [20], and custom-made solutions have also been developed in research projects [21] [22], but they have not been enough tested.

The second limitation is that they allow to upload waypoints to the UAVs (they manage trajectories), but they do not manage high-level tasks and they cannot replan the route in real-time in case of unexpected events. For example, high-level task definition for cinematography applications has been developed in [23]. They propose a novel language for cinematography mission description and a procedure to translate those missions into plans that can be executed by autonomous drones [24], as shown in Figure 2. A high-level mission specification language is described in [25] and task definitions for cooperative construction application can be found in [26].

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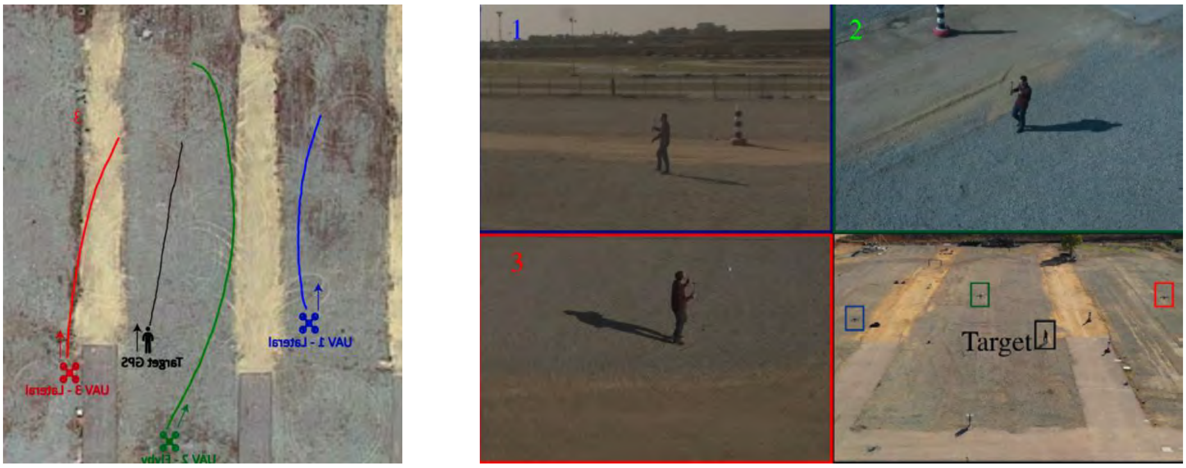

Figure 11. Three UAVs following a target in a media production application [11]

3.1.1.2 Summary of technical requirements

3.1.1.2.1 Brief introduction

UC1.1 includes the actions to be performed with the objective of covering the needs of validating a solution for UAV-based inspections. The definition of the UC contains different activities to ensure the whole operative, including:

- The definition and configuration of an inspection mission, its execution and its real-time monitorization.
- The flexibility to cope with one or several UAVs in an inspection operation.
- The data processing needed to share the data collected during the inspection.

The description and definition of the complete use-case, the actors involved, the diagrams and the step-by-step analysis will be documented following a template, IEC PAS 62559 based.

3.1.1.2.2 Target problem to be solved by the Use Case

Concerning the list of KPIs collected in OMICRON project, it is possible to match the tasks involved in the use-case with a subset of the main targets of the project.

- The development of advance road inspection modules using UAV will allow the reduction of the exposure time by 65% of road workers and users to hazardous situations derived from inspection tasks.
- The development of digital inspection modules will allow the automation and robotisation of inspection, reducing the traffic disruption due to inspection task by at least 50%.
- The development of automated inspection will allow the enhancements in inspection and intervention.

3.1.1.2.3 Main requirements extracted from the requirement form

From the perspective of involved actors, the UC is defined by the following requirements:

- Inspector and UAV operator must have knowledge of the construction site and the inspection resources.
- UAV operator must have knowledge of UAV technology and performance.
- UAVs, UAV operator and safety pilot are subject to current national or European regulations.

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3.1.1.2.4 Methodology

The Use Case requirements are collected following the template based on IEC PAS 62559. A summary of this definition is presented in the following table.

Table 9. Summary of UC1.1

Title	UAVs: Management Tool
Short Narrative	The inspector will use the UAVs Management Tool to define the inspection operation and the UAV operator will execute the inspection when required. Moreover, the inspector will also be able to retrieve the data gathered after the inspection is performed.
Cluster Use Case	UC1: Inspection, V2X communications and user support
Connection to other Use Cases	UC1.1.1: UAV long range inspections UC1.1.2: Multi-UAV
Actors	Inspector, UAV operator, Safety pilot, Management tool, UAV
Scope	The scope of the use case is the validation of the UAVs Management Tool that will allow to define and execute long-range and multi-UAV inspection. After the inspection is performed the data will be gathered. The UAVs Management Tool allows to define the locations and images that should be obtained for two different types of inspection: long-range inspection and multi-UAV inspection.
Objectives	Definition and configuration of multi-UAV and long-range inspection missions. Execution and monitoring of multi-UAV and long-range inspection operation. Retrieval of data collected.

3.1.2 UC1.1.1. UAV long range inspections

3.1.2.1 State of the art

Inspection operations on road infrastructures have traditionally been handled manually, which entails large amounts of time and effort due to the large distances to cover. In essence, standard approaches have various aspects that limit the frequency, cost-effectiveness and comprehensiveness of road evaluations. Obtaining these data is expensive, requires the expertise of qualified and experienced inspectors, can be time consuming, tedious and dangerous for inspectors, can disrupt traffic and cause road damage and provides descriptive information for a limited number of areas. Human judgments are not only prone to inaccuracies, but they also make comparison assessments difficult. This raises challenges of scalability and data reliability, which are increasingly being addressed by automatic and/or semi-automatic methods of assessing pavement conditions.

Industry has begun to use Unmanned Aerial Vehicles (UAVs) for inspection works in recent years, and this is one of the applications with the highest potential [27]. Overall, using UAVs for road infrastructure inspection is beneficial because to the volume (large stretches of road) and hence the ability to inspect longer distances at lower prices compared to manned aviation. The use of UAVs for automating road inspections is generally restricted by regulations. Current commercial products [28] [29] take advantage of regulatory gaps in order to be useful in such scenario, such as flying within

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Visual Line Of Sight (VLOS), a low platform weight which minimizes risks in case of falls, or the operation in rural areas with low population. These inspections, on the other hand, are usually local (VLOS) and only consider one UAV per operation. This has a direct impact on the operation's efficiency, preventing widespread use of this new technology for infrastructure inspections. Moreover, these operations are no longer valid according to the recently published European drone regulation [30] that came into force in 2021.

The use of UAVs as a digital inspection tool for road assets is only viable and efficient if they can cover several kilometers. In order to release the full potential of UAV technology to this field, Beyond VLOS (BVLOS) operations must be permitted. However, the necessary flight authorizations would require the development of additional technologies that will guarantee the safety of operations. One of the key factors is the integration of UAVs into non-segregated airspace, and for this, the development of lightweight Detect&Avoid systems will allow the UAVs to cover longer distances safely. There are research works on conflict management resolution using Automatic Dependent Surveillance – Broadcast (ADS-B) transponders [31] [32]. However, this relies on the assumption that non-cooperative aircraft, especially commercial aircraft, have a transponder installed which is constantly broadcasting their status. Other authors have implemented ground-based aircraft detection systems based on radio [33], video [34] or audio [35], targeting other UAVs or model aircraft that could interfere with the inspection mission. Nevertheless, ground-based detection systems have a limited range that could prevent to fully take advantage of long-range UAV inspections.

In order to achieve a robust and scalable Detect&Avoid system, it seems reasonable to host such system onboard the UAV that is performing the inspection operation. It is very common to find approaches that make use of cameras for the detection of obstacles (other UAVs, birds, etc.). Due to the amount of information provided, given their affordability, availability and low weight, vision-based approaches are very popular, even though they entail an important associated processing complexity [36] [37] [38] [39] [40] [41]. Nevertheless, most of the recent research on UAV detection from images is dominated by Deep Learning approaches using trained Convolutional Neural Networks (CNNs) [42] [43] [44], which yield better results with higher accuracies than classic approaches.

Although there is a wide literature about Detect&Avoid systems for UAVs, they have been mainly validated at low Technology Readiness Level (TRL). OMICRON will develop a Detect&Avoid system, based on on-board sensors, that will automatically detect other manned aircrafts using novel AI techniques, as well as intelligent replanning algorithms to automatically avoid other aircraft whenever they are detected. This and other technologies will enhance the use of UAVs for inspection to the next level, improving the efficiency to a level that will facilitate a much wider adoption of the technology in the civil infrastructure sector.

3.1.2.2 Summary of technical requirements

3.1.2.2.1 Brief introduction

UC1.1.1 includes the actions to be performed with the objective of covering the needs of validating a solution for long range inspections using a UAV-based technology system. The definition of the UC contains different activities to ensure the whole operative, including:

- The capacity of configuring an inspection mission, its execution and the monitorization during the system operation.
- The existence of one or many UAV-platforms, which main goal is the capacity of ensure the shared airspace with other aircrafts or unexpected air objects using Detect&Avoid technologies.
- The capacity of sharing collected data during inspection time, providing a rich amount of information obtained from the on-board sensors.

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The description and definition of the complete use-case, the actors involved, the diagrams and the step-by-step analysis will be documented following a template, IEC PAS 62559 based.

3.1.2.2.2 Target problem to be solved by the Use Case

Concerning the list of KPIs collected in OMICRON project, it is possible to match the tasks involved in the use-case with a subset of the main targets of the project.

- The development of advance road inspection modules using UAV will allow the reduction of the exposure time by 65% of road workers and users to hazardous situations derived from inspection tasks.
- The development of digital inspection modules will allow the automation and robotisation of inspection, reducing the traffic disruption due to inspection task by at least 50%.
- The development of automated inspection will allow the enhancements in inspection and intervention task, reducing at least 10% the cost of road inspection and maintenance.

3.1.2.2.3 Main requirements extracted from the requirement form

From the perspective of involved actors, the UC is defined by the following requirements:

- Inspector and UAV operator must have the knowledge of the construction site and the inspection resources.
- Current national or European regulation are mandatory, and both the UAV operator, the safety pilot and the UAV are governed by it.

3.1.2.2.4 Methodology

The Use Case requirements are collected following the template based on IEC PAS 62559. A summary of this definition is presented in the following table.

Table 10. Summary of UC1.1.1

Title	Long Range inspection
Short Narrative	The inspector will make use of a UAV-based solution to examine a specific section of a road. After specifying the required information, the UAV operator will plan the mission accordingly, and the UAV will autonomously cover the desired area to acquire high-quality images for building a precise 3D map afterwards, while ensuring the safety of the full mission making use of automatic obstacle detection and avoidance capabilities.
Cluster Use Case	UC1: Inspection, V2X communications and user support UC1.1: UAV inspection
Connection to other Use Cases	UC1.1.2: Multi-UAV inspections
Actors	Infrastructure owner, Road concessionaire, Road contractor, Road constructor, Civil engineering contractor, Industrial partner, University and research partner, Retailer, User, Robotic element

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Title	Long Range inspection
Scope	The scope of the use case is the validation of a UAV-based solution for the long-range inspection of road infrastructure, with the highest levels of safety during the flight.
Objectives	Definition and configuration of long-range inspection mission. Execution and monitoring of long-range inspection operations. Develop Detect&Avoid technologies for the UAV, allowing both the sharing of airspace with other aircrafts and the achievement of remote long range and low altitude inspection flights. Retrieval of data collected.

3.1.3 UC1.1.2. Multi-UAV inspection

3.1.3.1 State of the art

The deployment of multiple UAVs provides significant improvements in infrastructure inspection operations. It allows to reduce the time spent on data collection in the field and the impact of a UAV failure.

Methods for planning cooperative multi-UAV missions have been successfully applied to the optimal area coverage problem for inspection applications [45] [46], search and rescue [47] or road traffic monitoring [48]. In general, these methods don't consider constraints due to the integration of the UAVs in the U-space environment [49] and they do not replan the trajectories if a UAV fails or an unexpected event happens. Moreover, it is assumed that the trajectories are synchronized even though there aren't real-time trajectory corrections to cope with different delays and wind conditions for example. In [50], an event-based mechanism is used to synchronize shot execution among the drones and to account for inaccuracies during shot planning in a cinematography application as shown in Figure 12.

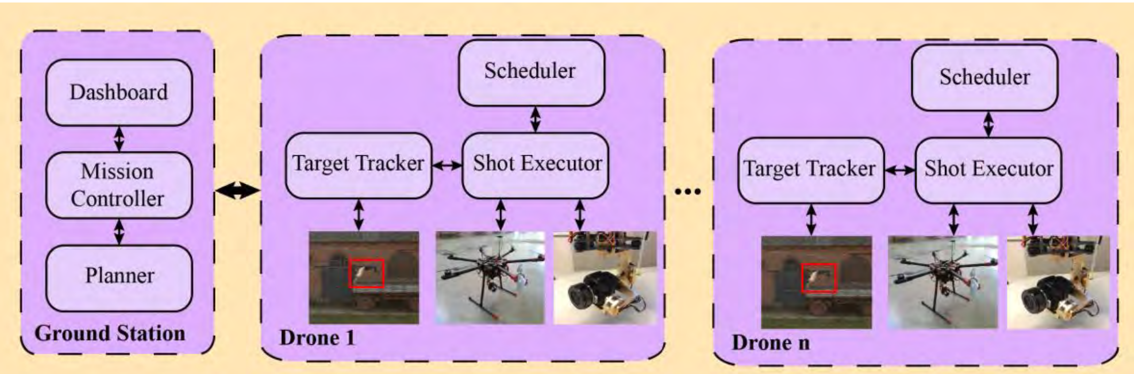

Figure 12. A scheduler component allows to synchronize multiple UAVs in a cooperative cinematography application [6]

Moreover, a scheduler module allows to perform a real-time task replanning in case of a UAV failure, as shown in Figure 13.

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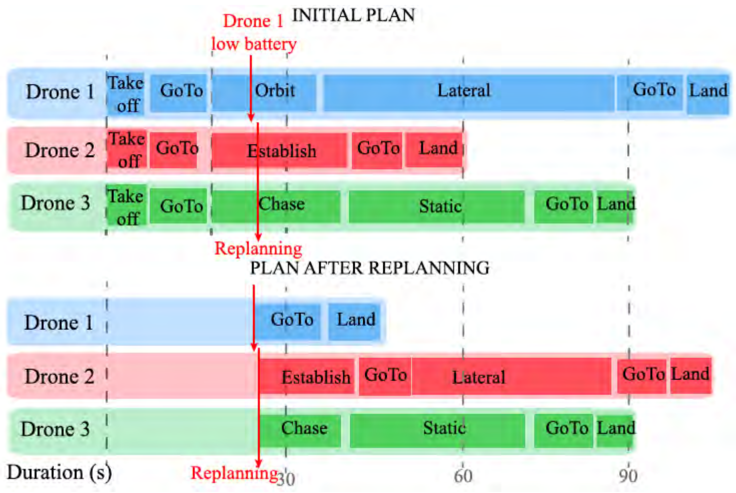

Figure 13. Timeline of re-planning in a simulated mission. Drones were executing the initial plan when the battery alarm of Drone 1 went off. A new plan was computed assigning the remaining tasks to other drones [6]

In persistent surveillance applications a probability collective based approach has been proposed for dynamic replanning in [51].

3.1.3.2 Summary of technical requirements

3.1.3.2.1 Brief introduction

UC1.1.2 includes the actions to be performed with the objective of covering the needs of validating a solution for UAV-based inspections. The definition of the UC contains different activities to ensure the whole operative, including:

- The definition and configuration of a multi-UAV inspection mission, its execution and its real-time monitorization.
- The flexibility to perform coordinated inspections (sharing the inspection tasks among several UAVs) or cooperative inspections (backup UAVs available to take over in case of other UAV failure).
- The data processing needed in order to share the data collected during the inspection.

The description and definition of the complete use-case, the actors involved, the diagrams and the step-by-step analysis are fully documented in Annex C.

3.1.3.2.2 Target problem to be solved by the Use Case

Concerning the list of KPIs collected in OMICRON project, it is possible to match the tasks involved in the use-case with a subset of the main targets of the project.

- The development of advance road inspection modules using UAV will allow the reduction of the exposure time by 65% of road workers and users to hazardous situations derived from inspection tasks.
- The development of digital inspection modules will allow the automation and robotisation of inspection, reducing the traffic disruption due to inspection task by at least 50%.
- The development of automated inspection will allow the enhancements in inspection and intervention task, reducing at least 10% the cost of road inspection and maintenance.

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3.1.3.2.3 Main requirements extracted from the requirement form

From the perspective of involved actors, the UC is defined by the following requirements:

- Inspector and UAV operator must have knowledge of the construction site and the inspection resources.
- UAV operator must have knowledge of UAV technology and performance.
- UAVs, UAV operator and safety pilots are subject to current national or European regulations.
- UAVs must be ready to fly on a predefined take-off area before executing the inspection.

3.1.3.2.4 Methodology

The Use Case requirements are collected following the template based on IEC PAS 62559. A summary of this definition is presented in the following table.

Table 11. Summary of UC1.1.2

Title	Multi-UAV
Short Narrative	The inspector will use the UAVs Management Tool to define a multi-UAV inspection operation and the UAV operator will execute the inspection when required. Moreover, the inspector will also be able to retrieve the data gathered after the inspection is performed.
Cluster Use Case	UC1: Inspection, V2X communications and user support
Connection to other Use Cases	UC1.1: UAVs: Management Tool
Actors	Inspector, UAV operator, Safety pilot, Management tool, UAV
Scope	The scope of the use case is the validation of the UAVs Management Tool that will allow to define and execute an inspection operation by a team of UAVs. After the inspection is performed the data will be gathered. The UAVs Management Tool allows to have active UAVs and backup UAVs. In case of failure of an active UAV, the Management Tool autonomously reconfigure the inspection mission, activating a backup UAV to complete the inspection.
Objectives	Definition and configuration of multi-UAV inspection missions. Execution and monitoring of multi-UAV inspection operations. Reconfiguration in case of UAV failure if a backup UAV is available. Retrieval of data collected.

3.1.4 UC1.2. Inspection vehicle

3.1.4.1 State of the art

Road infrastructure maintenance is traditionally a labour-intensive industry whereby a major portion of the cost involves the proverbial “boots on the ground” to manually check and periodically maintain a stretch of road or a zone. This constant manual intervention leads to high costs and delays in road upkeep.

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While inspection by auscultation is mainly based on objective indicators obtained through certain standard measuring instruments, visual inspection is carried out by the professional experience of technicians who evaluate the condition of the pavement based on its appearance, which introduces a certain subjectivity in the assessment of damage. Despite this subjectivity, in the urban environment the most common method of inspection is visual, mainly due to the difficulty of obtaining objective indicators in an environment characterized by the presence of intersections, significant variations in traffic speed and major traffic fluctuations. To minimize the subjectivity linked to visual inspection, a fundamental support are pavement catalogs or manuals in which the types of deterioration are shown with images, descriptions and quantification modes.

In the management of road condition monitoring is necessary to have a series of parameters that make it possible to determine the real condition of the infrastructure, with a unified criterion, throughout the entire road network. In the case of roads, we are talking about infrastructures that interact enormously with users, to the point that sometimes they leave their lives on them, so these parameters are even more important.

In this sense, as already mentioned above, two lines of analysis of the surface condition of roads are established. On the one hand, visual inspection is the review performed by a competent technician to a structure in which he observes its properties visually to characterize its functional and service condition. On the other hand, auscultation is the evaluation of the functional and structural condition of an infrastructure with high-performance equipment; in the case of pavements, it is done almost continuously, very quickly and without significantly affecting the circulation of vehicles.

Both functional and structural evaluation of the pavement are performed with the use of these technologies. In the functional evaluation some properties are measured such as:

- Macrotexture. It facilitates road-tire contact in the presence of water and maintain this adherence at high speeds, observing that the minimum macrotexture is observed according to the road category.
- Surface evenness. It determines the rolling quality of vehicles on the road surface, preventing sliding and avoiding vibrations and oscillations. It is calculated through the IRI (International Roughness Index), currently calculated using response type vehicles or vehicles with laser equipment such as those used in texture measurement as well.

In the structural evaluation, studies are focused on:

- Deflection. It measures the response of the pavement to traffic loads over time. It is currently measured with deflectographs, curviameters or impact deflectometers [52].

3.1.4.2 Summary of technical requirements

The high costs derived from traditional road inspection technologies can be brought down by a significant margin by introducing the latest computer vision (CV) and artificial intelligence (AI) based technologies to largely automate the process of extracting valuable road damage information from image data and find the most pressing problems. In addition, traditionally, road maintenance is usually corrective, due to the difficulty of monitoring and the high cost, which does not offer a service that guarantees the best conditions of safety and efficiency to the vehicles that circulate on the deteriorated roads. Thus, a change in maintenance patterns is sought, moving towards preventive maintenance with early detection of pathologies. This use case will try to evolve and digitize the

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current auscultation systems using new technologies still under research. The use of two different solutions will be studied, both on-board the inspection vehicle, as per the two detailed use cases.

During the development of the use case and as a requirement from the perspective of the involved actors, an inspector will use the inspection vehicle to detect the road condition and collect the road information, so the knowledge of the inspector is necessary in such task. In addition, the master PC will handle communications for multiple sensor connection, solving the automatic computation of road parameters. A different PC may also be used for road information collection before deploying the inspection vehicle.

The collection of the use case requirements and methodology used are based on the IEC PAS 62559 use case methodology, which includes information such as the description of the Use Case, diagrams of the Use Case, technical data, actors, a step-by-step analysis of Use Case, and the information exchanges within the Use Case (Annex C).

This Use Case includes the information and the technologies developed in the UC1.2.1 Innovative sensor combination and in the UC1.2.2 Automatic computation of road indexes.

Table 12. Summary of UC1.2

Title	Inspection vehicle
Short Narrative	Within this use case, various pavement inspection technologies will be tested on board a vehicle that, driving at normal road speed, can collect pavement information in an automated way. Subsequently, by applying machine learning and artificial intelligence, it is expected to obtain a value of the classic parameters of road auscultation calculation, such as the IRI (International Roughness Index) or deflection, and thus establish an effective preventive maintenance plan, which reduces the long-term cost and improves the safety and service life of road infrastructures.
Cluster Use Case	UC1: Inspection, V2X communications and user support.
Connection to other Use Cases	Includes UC1.2.1 and UC1.2.2 Relation with UC6.1
Actors	Inspector, Master PC
Scope	The scope of this use case is the development of in-vehicle inspection and auscultation technologies to improve current road surface inspection systems, through the automatic detection of the most relevant parameters for analysing the condition of the road.
Objectives	1. Investigate new pavement monitoring technologies to improve traditional methods. 2. Establish the points where it is necessary to carry out rehabilitation actions at an early stage to extend the useful life of existing roads. 3. Recognize the points where there are elements in poor condition that hinder the circulation of vehicles and can cause incidents. 4. Successful implementation of innovative sensors that will support the road inspection. 5. Successful development of innovative sensors that will perform data acquisition and data analysis, to support road inspection.

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3.1.5 UC1.2.1. Innovative sensor combination

3.1.5.1 State of the art

UOC will use the experience with innovative sensor developments from previous work to pave the way for the new developments regarding innovative sensor combinations and automatic computation of road parameters in OMICRON.

Some key points to be taken into account are listed as follows.

- Regular inspections and maintenance of roads support traffic safety.
- Inspection technologies may benefit from the latest developments in sensor systems, camera technology and computer vision.
- Lidar, radar or camera systems mounted on satellites, aeroplanes, UAVs or cars gather data that are mapped automatically into environment models.

Innovative sensor technologies, including stereo vision and odometry, have been used for recording, modelling and analyzing some large test sites, such as in “Digital Roads New Zealand” [53]. It is demonstrated how data can be used for detecting changes in road geometry, such as various forms of road surface distress. An important novelty of the shown solution is the scale of the project (i.e. size of the digitised area using car-mounted sensors) together with the achieved very high accuracy in road-geometry analysis.

In OMICRON, road assets will be first classified and then the innovative sensor combination for detection and inspection will be used. However, some researchers propose a different classification system of the road assets according to their defects and maintenance techniques driven by the computer visual monitoring approach [54]. The result in any of the cases is a large map containing all the aforementioned elements.

A workflow could be better developed to support automated road monitoring and determine faults in the road, which can also suggest appropriate actions based on a set of detectable symptoms [55]. By using the proposed workflow, the main classes of defects in the road that an automated visual detection system for the road should be capable of detecting have been identified and have been used for the training of Convolutional Neural Networks (CNN).

Furthermore, road detection is an important task in autonomous navigation systems. A road detection framework induced by the inverse depth of LiDAR’s point cloud will be proposed. One can explore the fusion of a 3-D LiDAR and a monocular camera, where the 3-D point cloud of LiDAR is projected onto the camera’s image frame, to exploit both range and colour information. At the same road detection task, the project can also propose an inverse-depth aware fully convolutional neural network (CNN) based on image information and a line scanning strategy based on an inverse-depth histogram of LiDAR’s point clouds. Finally, a conditional random field fusion method could integrate the two road detection results [56].

The project may also apply technologies such as stereo vision and visual odometry to model and analyse extensive segments of roads. Applications of developed systems have been evaluated at test sites in New Zealand, again within “Digital Roads New Zealand” [57].

Within OMICRON, work will continue along the lines of the current innovation sensor combination applications, using artificial intelligence and machine learning techniques, to detect the road conditions and facilitate information to the digital twin tools and decision support system, supported by experts in road supervision and maintenance.

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3.1.5.2 Summary of technical requirements

3.1.5.2.1 Brief introduction

UC 1.2.1 includes the actions to be performed with the objectives of covering the use of the innovative sensors and devices to inspect the road. The definition of the UC contains different activities to ensure the whole operative, including:

- The on-site road inspector will make use of the innovative sensors and devices to inspect the road.
- The innovative sensors, such as LiDAR’s point cloud, monocular cameras, stereo cameras, GPS devices, and IMUs will be installed into the inspection vehicles.
- These sensors support the inspector to quickly obtain the information and road features, which will enable them to determine maintenance work orders.
- When there is a need for an inspection task, the inspector will perform road inspection using the inspection vehicles and get the required maintenance road sections.

The description and definition of the complete use case, the actors involved, the diagrams and the step-by-step analysis are presented in Annex C.

3.1.5.2.2 Target problem to be solved by the Use Case

Concerning the list of KPIs collected in OMICRON project, it is possible to match the tasks involved in the use case with a subset of the main targets of the project.

- Exposure time of road workers and users to hazardous situations derived from inspection tasks. Reduction of the exposure time by 65% due to the use of automated UAV and terrestrial inspection vehicles.
- Traffic disruptions due to inspection tasks. The automation and robotisation of inspection tasks in OMICRON should reduce traffic disruptions by at least 50%.
- Maintenance and inspection activity costs. The enhancements in inspection and intervention tasks in OMICRON will reduce costs by at least 10%.

3.1.5.2.3 Methodology

The Use Case requirements are collected following the template based on IEC PAS 62559. A summary of this definition is presented in the following table.

Table 13. Summary of UC1.2.1

Title	Innovative Sensor Combination
Short Narrative	In this use case, the on-site inspector will use innovative sensors to obtain information of road surface and analyse the information to support their road operations and maintenance
Cluster Use Case	Detailed Use Case
Connection to other Use Cases	UC1.2: Inspection vehicle and automatic computation of road parameters UC6.1: Road digital twin Digitalization and Automation of road inspection procedures
Actors	Inspector, offline operator.

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Title	Innovative Sensor Combination
Scope	The scope of this use case is the application of innovative sensor combinations in road information and parameter acquisition and road detection, as well as the application of machine learning and artificial intelligence technology to automatically calculate road parameters.
Objectives	a. Successful implementation of innovative sensors that will support road inspection. ○ Achieve an improvement in the inspection management of road maintenance workers. ○ Improve the inspection efficiency during the road maintenance. b. Successful development of innovative sensors that will perform data acquisition and data analysis, to support road inspection. ○ Provide the data acquisition, including image data collection and laser scanning data acquisition.

3.1.6 UC1.2.2. Automatic computation of road pavement indexes

3.1.6.1 State of the art

The automatic image processing through AI is postulated as the future of pavement condition assessment since it allows the development of models capable of objectively and automatically performing such assessment. These methods stand out for their versatility, since they are not only capable of providing good results in classification tasks, but by supplying the information correctly, the model can detect objects within an image and segment the area they occupy. In other words, in addition to identifying the type of damage, it is able to quantify it.

In this field, work has been done in the development of AI models based on Convolutional Neural Networks (Deep Learning) based on the ResNet architecture to identify the deterioration in flexible pavements. In this way it is possible to differentiate between: longitudinal cracks, transverse cracks, crocodile skin cracks, weathering and spalling, voids, patching, culverting, road markings, and undamaged pavement. The models share to a greater or lesser extent a basic outline of phases, including:

1. On-board image acquisition.

2. Video filtering and processing.

3. Image filtering and processing.

4. Damage identification and classification.

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Figure 14. Automatic processing of images

The goal is to obtain the mask of a given image in which those pixels that belong to a crack are tagged accordingly. Concretely, there is a segmentation problem, in which it is necessary to infer two different classes, background and crack [58] [59].

There are several ways to face this segmentation problem. Classical methods include approaches such as histogram thresholding (Otsu thresholding), analysis of local parameters and edge detection, growing algorithms and clustering methods [60]. However, in the recent years it has been proven the superior performance of deep convolutional neural networks (CNN) approaches. Precisely, three main deep learning approaches have been considered to face the instance segmentation problem [61]:

1. U-Net based architectures. This type of CNNs include encoder-decoder structures that allow extracting the most complex features of the image, and residual connections that result in a better propagation of the information through the neural network.
2. Multi-scale models (FPN, Feature Pyramid Networks). The main advantage of this method is the great performance at extracting features at different scales.
3. Attention-based models (R-CNN). These models propose a region of the image in which the object may be located, and a posterior segmentation process is carried out.

Within OMICRON, work will continue along the lines of the current crack detection models, trying to obtain a classification of the road according to the basic parameters of characterization of its condition, such as IRI or deflection, using artificial intelligence and machine learning techniques, supported by experts in road supervision and maintenance.

3.1.6.2 Summary of technical requirements

This use case will try to evolve and digitize the current auscultation systems using new technologies, still under research, on an on-board inspection vehicle system.

To achieve the detection of these parameters, an operator will receive a set of georeferenced images acquired using a terrestrial vehicle. A deep learning model will be used to detect the anomalies in the road pavement.

To predict the evolution of the pathologies on the road, the software will use another algorithm that will take as input a time-series of images from an image archive. Other necessary inputs will be external factors as the weather, number and type of vehicles that drove between the maintenance sessions.

Both models will initially be trained with a dataset generated and labelled in an early stage. In addition, the model has the capability to improve its performance, by being retrained with new images collected during different drives.

The output that the operator will receive will be the location of the cracks in the images, and in the case images from previous drives and information of external factors are available how the cracks will evolve after certain time stamp.

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During the development of the Use Case and as a requirement from the perspective of the involved actors, a road worker will use the appropriate hardware and software components installed in the maintenance vehicle to acquire images and their metadata for a precise geo-localisation of the pathologies and the posterior analysis and computation of road index. In addition, an offline operator will treat those collected images using a specific software.

This UC will develop technologies included in the UC1.2 Inspection vehicle, as presented in Figure 14.

Table 14. Summary of UC1.2.2

Title	Automatic computation of road index
Short Narrative	In this use case, the operator will receive a video or a set of images acquired during a maintenance drive. The system will inform of the location of cracks in the road, and in the case the system already has previous drives stored in an archive of images, it will predict the evolution of the state of the road.
Cluster Use Case	UC1: Inspection, V2X communications and user support.
Connection to other Use Cases	It is included in UC1.2
Actors	Road Worker, Offline Operator.
Scope	The scope of this use case is the development of in-vehicle inspection and auscultation technologies to improve current road surface inspection systems, through the automatic detection of the most relevant parameters for analysing the condition of the road using optical images.
Objectives	1. Development of innovative modules for detection and prediction of road pathologies 2. Design, implement and validate an algorithm for the detection of pathologies in the road pavement 3. Design, implement and validate an algorithm to predict the evolution of pathologies of the road pavement

3.1.7 UC1.3. V2X communications

3.1.7.1 State of the art

Today's vehicles are already connected devices in many aspects. However, in the very near future they will also interact directly with each other and with the road infrastructure. This interaction is the domain of Cooperative Intelligent Transport Systems (C-ITS), which will allow road users and traffic managers to share information and use it to coordinate their actions.

Therefore, the European Commission adopted a European Strategy on Cooperative Intelligent Transport Systems (C-ITS), a milestone initiative towards cooperative, connected and automated mobility. The objective of the C-ITS Strategy is to facilitate the convergence of investments and regulatory frameworks across the EU, in order to see deployment of mature C-ITS services in 2019 and beyond. This includes the adoption of the appropriate legal framework at EU level by 2018 to ensure legal certainty for public and private investors, the availability of EU funding for projects, the continuation of the C-ITS Platform process as well as international cooperation with other main regions of the world on all aspects related to cooperative, connected and automated vehicles. It also involves continuous coordination, in a learning-by-doing approach, with the C-ROADS platform, which gathers real-life deployment activities in Member States. [62]

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According to the C-ITS Deployment Platform having been organised by the European Commission, cooperative Intelligent Transport Systems (C-ITS) shall use mature ad-hoc short-range (like ETSI ITS G5) and complementing wide-area communication technologies (like 3G, 4G, future 5G) that allow road vehicles to communicate with other vehicles, traffic signals, roadside infrastructure and other road users. The cooperative V2X systems are also known as vehicle-to-vehicle communications (V2V), vehicle-to-infrastructure communications (V2I) or vehicle-to-person (V2P) communications. In summary, the wireless data exchange between the different actors and ITS stations and related functions are named cooperative V2X communication. It supports a number of information, warning and assistance services, which will be gradually deployed in coordinated innovation phases during the oncoming years. [63]

Cooperative V2X systems in vehicles analyse the data received and warn the driver against dangers, e.g., if they approach the end of a traffic jam or a construction site or if a vehicle in front suddenly brakes hard. This way, cooperative V2X systems support foresighted driving, display dangers not even visible to the driver and help to avoid accidents. For the driver, the data exchange remains completely unnoticed until a danger threatens. Cooperation between the road users e.g., for supporting lane merging will be enabled where required by future standardised message sets.

The cooperative V2X data exchange between the road users and with the infrastructure works anywhere and at every time where cooperative users come closer to each other. By reducing the distance between cooperative users, the quality of cooperative V2X communication improves. By this principle, critical road safety situations and resulting accidents can be avoided. Manually driven vehicles profit from cooperative V2X as well as all levels of assistance and automation up to fully self-driving cooperative automated vehicles.

Services such as providing information about traffic light signal phases and their predicted changes or barriers on the route in real time furthermore support smooth and comfortable travelling. By avoiding strong accelerations, fuel and energy consumption of vehicles can be reduced with favoured effects on lowering noise and emissions. These services are called C-ITS services, which provide information about the vehicle's environment on the road. C-ITS service are organised as a function of the information provided and the cooperation of the vehicles regarding this information. Day 1 services focus on exchanging information enhancing foreseen driving, which are being deployed and are already available in cooperative V2X vehicles on European roads. Day 2 services improve the service quality and share perception and awareness information. Day 3+ adds further sophisticated services like sharing intentions, supporting negotiation and cooperation that paves the way towards cooperative accident-free automated driving. Services related to phases of Day 2 and Day 3+ are investigated in R&D projects that are generating the knowledge for developing related customised functions and standards. Having tested and demonstrated the new functionalities and enabling technologies, the innovations are fed into standardisation and profiling of the next deployment phase.

As of 2019, the first European vehicle manufacturers have started production of mass vehicle models equipped with standard Day 1 functionality based on cooperative V2X wireless ad-hoc communication technology ETSI ITS G5. This automotive C-ITS deployment has been complemented by more than 19 C-ITS infrastructure deployments of C-Roads pilots that are a joint initiative of European Member States and road operators for testing and implementing C-ITS services in light of cross-border harmonisation and interoperability.

This ongoing C-ITS deployment phase was prepared by a series of corridor projects and pilots forming the first examples of testing, proofing and demonstrating cooperative V2X under real traffic conditions in Europe. Test fields have been arising in different countries, pointedly equipping traffic infrastructure with ITS stations and proving cooperative V2X services under real traffic conditions with assistance of

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cooperative V2X capable vehicles fleets. Large scale field tests like simTD in Germany and the European DRIVE C2X, AUTOC-ITS [64] projects have proven the cooperative V2X functionalities, benefits and cross-border operation on proving grounds as well as on real roads. Such initiatives followed-up on R&D projects which during the past decades have investigated the potential impact and technical feasibility and the benefits of C-ITS with focus on ETSI ITS G5 based ad-hoc cooperative V2X communication to traffic safety, efficiency, driving comfort and automation.

OMICRON will try to generate specific C-ITS Day 1, 1.5 services focused on road maintenance, to guarantee the safety of the working personnel deployed in the field, through the sharing of information to the vehicles circulating in the area affected by the maintenance work.

3.1.7.2 Summary of technical requirements

This UC will address the development of V2X communications to improve the safety conditions of maintenance workers on the road.

For this purpose**,** there is an already existing C-ITS Hub available that acts as a control center where all the necessary and key information for communication with the sensors deployed on the road is collected. This information comes from traffic authorities, maintenance managers, weather agencies, road operators, etc., and is integrated in different standardized formats such as DATEX II, ECO-AT, ETSI and BSM, as well as allowing integration with other environments and C-ITS modules and gateways. The C-ITS Hub, thanks to this information, develops the so-called C-ITS services, which are classified according to the information they share:

- C-ITS "Day 1 service - Safety Priority" C-ITS "Day 1.
- C-ITS "Day 1.5" service - Traffic management.
- C-ITS "Day 2" service - Services for Automated.
- C-ITS "Day 3" service - Services for cooperation.

Currently, only "Day 1" services have been standardized by the European Commission, but work is already underway to standardize "Day 2" services. In this use case, only "Day 1" and "Day 1.5" services will be addressed. These services will be generated in the C-ITS Hub and will be sent to the vehicles through the sensors deployed on the road. A roadwork warning service will be generated to indicate the presence of maintenance vehicles and personnel in the field. The detailed information sent includes geographical information about the roadwork, lanes affected, speed recommendations, affection and information distance, detailed road history incident, and trace.

The sensorisation consists of Road Side Units (RSU) and equipment and connections necessary for their operation. These units are short-range communication antennas that operate under the ETSI ITS-G5 standard, and are located at the map interface of the C-ITS HUB. The RSUs receive the services generated by the C-ITS HUB and transmit them to the vehicles passing through the section where the information regarding road maintenance conditions is effective.

The connected vehicles that incorporate the on-board module will receive the information related to the maintenance area, so that they can avoid it and ensure the safety conditions of the maintenance operators.

During the development of the UC and as a requirement from the perspective of the involved actors, a system operator will manage the information to be sent to vehicles and infrastructure, who has a complete knowledge of Horus system and traffic management, a verifier that confirms the real status of C-ITS message. Regarding the systems, an ETL will continuously know the status of C-ITS messages and ready to transform the information in Horus system to messages, the Horus system will integrate and manage all the information about the road, the Horus gateway will manage the triggering of V2X

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messages, the RSU will receive and send info between Horus system and OBU and the OBU will connect with RSU, and manage information relative to V2X.

This Use Case will develop technologies that will be related to UC5 (Road personnel support) and UC6 (Digital Twin and Predictive maintenance), as shown in the following summary table.

Table 15. Summary of UC1.3

Title	V2X communications
Short Narrative	V2X communications allow the exchange of key information between vehicles and infrastructure, in relation to events occurring on the road, such as the presence of traffic, accidents, lane closures due to road works or adverse weather. In this use case, the capabilities of ETSI ITS-G5 standardized short-range communication will be exploited to improve safety conditions during maintenance works, through the deployment of sensorization on the road and the deployment of on-board modules in vehicles.
Cluster Use Case	UC1. Inspection, V2X communications and user support
Connection to other Use Cases	Relation to UC5 and UC6
Actors	System operator, verifier, ETL, Horus system, Horus gateway, RSU, OBU.
Scope	Exploit the capabilities of V2X communications in the field of road maintenance and road user support to ensure road safety and driving efficient conditions during maintenance activities.
Objectives	1. Demonstrate the usability of V2X communication for reducing dangerous situations during maintenance activities on the road. 2. Provide key information to vehicles regarding road maintenance reducing the time of the travel. 3. Contribute to the development of the Ten-T Corridor from Madrid.

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3.2 UC2. Routine and emergency maintenance interventions

3.2.1 UC2.1. Robotic modular platform

3.2.1.1 State of the art

The maintenance of the roads is a process that has traditionally been carried out by humans, and tasks such as crack sealing, road asset cleaning, safety barriers installation etc. usually involve tedious and repetitive operations. Therefore, the automation of these processes has been a trending topic for long time ago.

Figure 15. Tool for lane marking removal

In recent years, the introduction of task-specific machines led to an improvement in the working conditions of the operators (particularly physical conditions) that used to manually carry out those tasks. Nevertheless, the autonomy of these task-specific machines is very small, and the decision-making/control is on the human side. Additionally, these ad-hoc apparatus are designed to be useful in very specific tasks and although some of them offer the possibility to be modified to be used in similar tasks, they usually lack flexibility. In Figure 15, a tool specifically designed for lane marking removal can be seen, which can be exchanged with some other tools.

Currently, modular robotic platforms have emerged to overcome the shortcomings and have shown a great flexibility and adaptability. These platforms are composed of a variety of blocks which can be interchanged with the idea of adapting it to be useful for a wide variety of tasks. Besides, those systems show a high level of autonomy since are endowed with cognitive skills, where the information of multiple sensors is fused and used to feed AI based decision making models.

Crack sealing is one of the most dangerous, costly and labour-intensive operations where a lot of work has been done to be automated. For instance, in [65] [66] a machine was designed to move in the XY axes to automatically seal cracks in roads, although the detection and mapping of the cracks was done manually. In [67], authors proposed an automatic crack detection method based on machine vision and an automatic crack sealing system also using an XY robot. In both cases the machines were driven to the region of interest attached to a vehicle. Fully autonomous systems have also been designed e.g. the one presented in [68], that are able to autonomously locate and seal the cracks. However, all of the presented solutions have been specifically designed for the task and these machines cannot be used for other tasks.

Cone laying and removal is another common repetitive and labour-intensive task where workers assume big risks when the process is manually done. In [69], a cone removal machine is developed, installed in a truck. The proposed system is not autonomous and fully depends on the human driver who guides the machine up to the cones. In the approach proposed in [70], a modular and automatic cone laying machine is proposed, which mounts two UR robotic arms in a truck. The system is endowed with sensors and cameras and an on-board computer, which lets the system have certain cognitive abilities. Additionally, mobile safety barrels are studied in [71], where instead of designing a platform to install and remove them, authors give the ability to move to the assets.

As far as the road asset cleaning task is concerned, although it is a task that is usually manual, there are also solutions that try to increase the automation level of the task and reduce the workload of the

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workers. In [72], a typical crane that is usually used to clean traffic assets is shown, which has an extensible arm with a specific rotatory tool. This kind of machines, however, do not have any autonomy and the operator is the one who takes the decisions and controls the crane. In the robotic solution proposed in [73], the problem of cleaning streetlights is tackled. Although the designed robot fulfils the needs for that specific problem, it is an ad-hoc solution and cannot be easily used in other tasks.

Finally, two of the least automated but important tasks are the installation of safety barriers and the removal of lane markings. The installation of safety barriers requires high dexterity and it is a labour-intensive task, hence, it is one of the most complex tasks to automate. Furthermore, the removal of lane markings (independently of which technology is used) is usually performed via human-driven trucks that are used with specific removal tools attached.

In general, all the reviewed solutions show a very low level of autonomy and they lack flexibility. In spite of the fact that most of the tasks are very repetitive, the control of those machines is usually in the side of the human. Besides, although most of them are useful in their specific problem, they are hardly applicable to other tasks since they have been designed for very specific tasks and not in a modular way.

3.2.1.2 Summary of technical requirements

The robotic modular platform for road maintenance operations developed in OMICRON will support road workers in multiple maintenance activities, including placement and collection of signals and cones, installation of safety barriers, cleaning of road assets, and removal of lane markings.

In order to achieve these objectives, the robotic modular platform will be comprised of a robotic arm, a perception module, and a set of tools to assist in several emergency, ordinary and extraordinary maintenance interventions. The robot arm is to be mounted on a trailer (or similar platform, to be defined in T3.1) that can be easily hooked up to the back of a vehicle (e.g. a truck) which carries the machinery and material necessary for the operation, as shown in Figure 16.

This initial proposed design will be reviewed in task T3.1 of the project, specifically dedicated to the design of the architecture of the modular robotic platform, and may give arise to modifications in order to find the best solution for the maintenance operations envisaged.

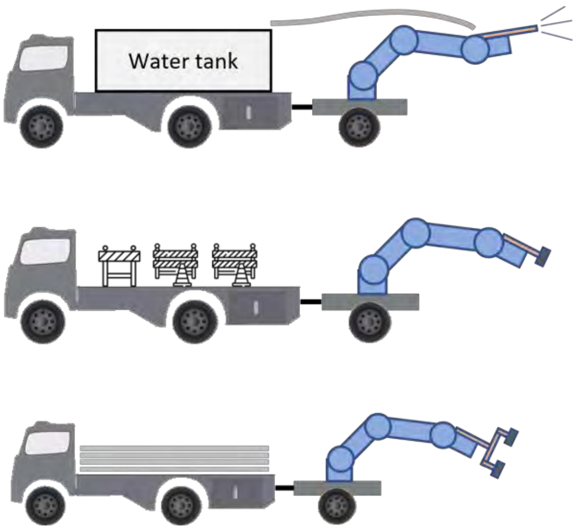

Figure 16. Concept of robotic modular platform for road maintenance operations

The vehicle shall contain enough space to store the assets and must obviously be able to carry the complete robotic system. Along with this, it must also be able to move at a low speed, as some interventions require small movements to continue the work. The robotic modular system will need a perception system that combines artificial vision and artificial intelligence, to allow the robotic arm to locate the road assets of interest for each intervention. Moreover, this perception system will need to be able to operate under low light conditions, as this type of operation is often carried out at night. Additional requirements are described in the specific use cases for each maintenance intervention.

Table 16. Summary of UC2.1

Title	UC2.1 Robotic Modular Platform
Short Narrative	The robotic modular platform to be developed in OMICRON will support road workers in their maintenance activities, like placing / removing signals and cones, installing safety barriers or cleaning road assets. For these activities, a perception system that combines Artificial Vision and AI tools is needed, which will allow the robotic system to detect the elements of interest and to adapt autonomously the motions of the robot arm according to the status of the road and the elements to be manipulated. Additionally, a set of interchangeable tools will be designed to tailor the system to a set of maintenance and renewal processes.
Cluster Use Case	UC2: Routine and emergency maintenance interventions
Connection to other Use Cases	UC2.1.1 Installation of safety barriers; UC2.1.2 Installation of cones; UC2.1.3 Road assets cleaning; UC3.1 Signalling during construction works; UC3.2 Sealing of surface pavement cracks; UC3.3 Removal of lane markings with laser
Actors	Road administration, Road worker, Vehicle
Scope	Road maintenance workers shall be supported in their intervention activities. These activities comprise among others, placing and removing traffic signals and cones, installing safety barriers or cleaning road assets. For these activities, operators need to walk along the road with traffic, even cross it, and carry large loads. These activities force the operators to constantly take very high risks, both from the ergonomic and safety points of view. Additionally, the use of a modular robotic platform should reduce the execution times and the corresponding workforce needed, resulting in a remarkable reduction in maintenance costs.
Objectives	1. Daily work support. The aim of the use case is to assist operators improving their working conditions. 2. Operator safety. A modular robotic platform reduces the exposure of workers to construction sites and also reduces intervention times, thereby reducing the probability of an accident. 3. Saving costs. The robotic solution has as a direct result the reduction of execution times and the corresponding workforce needed. This will result in a reduction in maintenance costs. 4. Road safety. The robotised interventions with the modular robotic platform are executed more effectively and efficiently, thus ensuring the proper functioning of the traffic flow and preventing road users from being killed or seriously injured. 5. Availability of the network. The effective and efficient robotised interventions reduce the traffic disruptions.

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3.2.2 UC2.1.1. Installation of safety barriers

3.2.2.1 State of the art

Nowadays, the installation of safety barriers is a manual process. Commercial systems (based or not on robotics) has not been found. Only some part of the whole process of installation of safety barriers is carried out in a semi-assisted way. The main assisted process of installing safety barriers is the guardrail post driving. [74].

Figure 17. Post Pounding machine

One application of zero gravity manipulator over guardrails has been found but the application of the manipulator is limited to the field of storage and logistics. [75].

Regarding scientific articles, nothing relevant was found about the process. Perhaps, the field of study and such a specific task have been a barrier to find scientific articles. Nevertheless, one patent has been found named the automatic mounting robot for safety guardrail of highway [76]. It is a Chinese patent, and the description of the solution is quite general without technical specifications. It just mentions that the system is formed by a control system and an operating system and their subsystems. Other patents about safety barriers in the field of maintenance have been found but not specifically in the task of installation. [77] [78].

3.2.2.2 Summary of technical requirements

The robotic modular system aims to support road workers in the process of installing safety barriers in roads, more specifically on the placement and adjustment of the barrier on the post. The robot arm shall provide a way for the worker to easily adjust the position with respect to the vertical posts. The worker shall be able to move manually the robot to adjust the position, while the robot maintains the weight of the guardrail.

In order to achieve these objectives, the robotic modular system will need a perception system which allows the robotic arm to locate the visual references (posts and workers). This perception system will need to be able to operate under low light conditions, as this type of operation is often carried out at night. In addition, the robot arm needs to offer a way for the worker to easily adjust the position of the barrier with respect to the vertical posts. The robot must be able to move loads of up to 40 kilos (which is the approximate weight of a guardrail). Along with this, a specific tool also needs to be designed to manipulate the metal barriers, allowing to grab and release the barrier, ensuring that it will not come loose during the process.

In this use case, the road worker drives the vehicle pushing the modular robotic platform to the first place where a safety barrier needs to be fixed to the posts that were already installed. The worker positions the vehicle in such a way that the robotic platform is close enough to perform the operation.

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After that, the road worker starts the identification of visual references. When the post is identified, the road worker starts the safety barrier picking process. After that, the robot places the safety barrier in the right position, next to the post. Then, the robot enters in sensitive mode, so the worker can easily move the robot to adjust the position with respect the vertical posts and fix the safety barrier. Finally, the road worker starts the release process to move the robot to the start position. This process is repeated for all the safety barriers that need to be installed.

Table 17. Summary of UC2.1.1

Title	UC2.1.1 Installation of Safety Barriers
Short Narrative	The robotic system to be developed in OMICRON will support road workers in the process of installing safety barriers in roads. For this process, a perception system is needed which allows the robotic arm to locate the visual references (posts and/or workers) and place the barriers in the right position. Then, the robot will offer a way for the worker to easily adjust the position of the barrier with respect to the vertical posts. Additionally, a specific tool will be designed to manipulate the metal barriers.
Cluster Use Case	UC2: Routine and emergency maintenance interventions
Connection to other Use Cases	UC2.1 Robotic Modular Platform; UC2.1.2 Installation of cones; UC2.1.3 Road assets cleaning; UC3.1 Signalling during construction works; UC3.2 Sealing of surface pavement cracks; UC3.3 Removal of lane markings with laser
Actors	Road administration, Road worker, Vehicle, Vision camera, Robot arm, Barrier handling tool, AR headset
Scope	A robotic system shall support road maintenance workers in the process of installing safety barriers. This process comprises the manual handling of high loads, including the elevation and support of the fence while it is being adjusted to the post, and certain types of forced postures. All this leads to frequent injuries to the workers. Additionally, the use of a robotic arm for the positioning and support of the fence should reduce the installation time, resulting in a reduction in maintenance costs.
Objectives	1. Daily work support. The aim of the use case is to assist operators improving their working conditions. 2. Operator safety. The robotic system reduces the exposure of workers to the handling of high loads and certain types of forced postures, thereby reducing the probability of injury. 3. Saving costs. The robotic solution has as a direct result in the reduction of the corresponding workforce needed. This will result in a reduction in maintenance costs.

3.2.3 UC2.1.2. Installation of cones

3.2.3.1 State of the art

In recent years, traffic flow on the roads is becoming heavier with the increasing number of vehicles. Traffic cones are a kind of very important mark used to guide vehicles through the maintenance

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operations. Placing cones on the road by hand poses a risk to road workers, especially at night. However, currently cones are mainly placed and retrieved by operators manually.

The automation of cone handling requires an identification of the cones, especially in the cone collection operation. With the development of research on autonomous vehicle, intelligent technology such as object recognition has become a more and more hot topic, and there exists several research works in the recognition and detection of traffic cones. [79] proposes a special machine vision system with two monochrome cameras and two colour cameras that was used to recognize the colour and position of the traffic cones. In [80], traffic cone localization and angle measurement system are designed from the perspective of digital image processing based on monocular camera. The system can assist the traffic cone cart to automatically identify and locate the traffic cones during the process of collecting traffic cones.

Other researchers use the fusion of sensor information to detect cones. A method based on vision and radar sensors information fusion is proposed to detect traffic cone in [81]. They use homography to calibrate camera and radar, from which the radar data can be mapped on the image and a small corresponding image patch can be easily cut-out. In [82], a perception system fusing a millimeter-wave (MMW) radar and a monocular camera is proposed. Firstly, the detections of MMW radar are converted to regions of interest (ROIs) on the image. Then, these ROIs are classified by four classifiers using Deformable Part Model (DPM).

Deep learning has also been used for cone detection. There are various publicly available datasets that provide annotated traffic cones data [83] [84] [85]. Not only databases, but several models [86] [87] [88] are also available that have been trained for traffic cones detection. These models may serve also as a starting point for further training based on the specific applications and requirements.

There are several commercially available automated machines to place and retrieve cones. For example, Janschitz GmbH has developed X-Cone 2.0 [89], a fully automatic traffic-cone management system that can deploy as well as collect traffic cones. Arrowes has also developed an automated cone truck [90], which requires only a single operator to safely deploy and retrieve cones on site. It can be operated on both side (left or right) and can operate forward or reverse. Another example is CONER [91], a truck based automatic cone handling machine, designed to deploy traffic cones while driving forward and to collect them in reverse gear, thus keeping the vehicle in a safe lane at any time, pacing between cones can be freely set between 5 - 100 m. These vehicles are trucks specialised on traffic-cone management, being hardly applicable to other tasks (Figure 18).

Figure 18. Specialised truck for cone management

Figure 19. Remotely controlled traffic cones

Instead of using vehicles to place and collect traffic cones, some prototypes of remotely controlled traffic cones were showcased at New Civil Engineer's Techfest [92] (Figure 19). These cones have been designed to be deployed from vehicles and be able to form remotely any shape or formation required.

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In the approach proposed in [93], a modular and automatic cone laying machine is proposed, which mounts two UR robotic arms in a truck. The system is endowed with sensors and cameras and an on-board computer, which lets them the system to have cognitive abilities.

The reviewed solutions are in general too specialised vehicles designed for the specific purpose of managing cones, and hardly applicable to other types of tasks.

3.2.3.2 Summary of technical requirements

The robotic modular system aims to support road workers in the maintenance process of placing and collecting cones. The robot arm shall perform the task of placing and collecting cones while the vehicle that carries the robotic system is moving.

In order to achieve these objectives, the robotic modular system will need a perception system that combines artificial vision and artificial intelligence, able to detect the location of the cone. The system will consist in an RGB-D sensor which provides a RGB image and the point cloud, a computation system based on a powerful GPU and a deep learning algorithm to detect the cone from the data. Computation system will need to be fast enough to calculate the position of the cones to allow to grasp them. Moreover, this perception system will need to be able to operate under low light conditions, as this type of operation is often carried out at night. In addition to this, the robot flange should be able to reach near the pavement for grasping and placing the cones. Therefore, this should be considered when installing the robot in the vehicle. On the other hand, there must be a cone storage place within reach of the robot arm, from where the robot picks up the cones. The robot must also be equipped with a specific tool that combines the action to grasp the cones without damaging them.

In this use case, the road worker drives the vehicle to the point in which the cones need to be placed. The worker uses a display to manually start the cones placement process. While the vehicle is moving at low speed, the robot arm moves to the cone storage area, to pick up the cone. The robot waits for the worker to send a signal via the display to place the cone on the road. This process is repeated along the route to be signalled.

In the cone picking process, the worker must also initiate the process manually via the display. The robot arm is positioned in a defined cone pick-up position close to the road. The perception system detects the cones and sends this information to the robot, so that it updates its position according to this information. Once the cone is close enough to the robot, the robot picks it up and places it in the storage area. This process is repeated along the trajectory along which the cones are to be collected.

Table 18. Summary of UC2.1.2

Title	UC2.1.2 Installation of cones
Short Narrative	The robotic system to be developed in OMICRON will support road workers in the maintenance process of placing and collecting cones. For this process, a perception system that combines Artificial Vision and Artificial Intelligence is needed, which will allow to the robotic system to locate the cones regarding robotic arm. Additionally, a specific tool will be designed to: (1) place the cones on the road (2) collect the cones from the road.
Cluster Use Case	UC2: Routine and emergency maintenance interventions
Connection to other Use Cases	UC2.1 Robotic Modular Platform; UC2.1.1 Installation of safety barriers; UC2.1.3 Road assets cleaning; UC3.1 Signalling during construction works; UC3.2 Sealing of surface pavement cracks; UC3.3 Removal of lane markings with laser

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Title	UC2.1.2 Installation of cones
Actors	Road administration, Road worker, Vehicle, Perception system, Robot arm, Display, tool
Scope	Currently the road maintenance workers are in charge of placing and collecting the temporary signalling such as cones. Usually, the cones are placed and collected manually by road workers. The road worker hangs from the vehicle a heavy cone in their hands. This is very demanding from the point of view of physical health. Moreover, the operation of dropping the cones demands expertise and concentration from the worker in order to avoid the cones to be placed in an incorrect way. It might produce that the cone invades the opposite traffic lane with the corresponding hazard to drivers. The use of a modular robotic arm should reduce the corresponding workforce needed, resulting in a reduction in maintenance costs.
Objectives	1. Daily work support. The aim of the use case is to assist operators improving their working conditions. 2. Operator safety. The robotic system reduces the exposure of workers in the placement and collection of the cones, thereby reducing the probability of an accident. 3. Driver safety. The robotic system reduces the possibility of cones not placed in the right position, thereby reducing the probability of an accident for drivers. 4. Saving costs. The robotic solution has as a direct result the reduction of the corresponding workforce needed. This will result in a reduction in maintenance costs. 5. Equivalent quality to worker. The installation of cones by means of robotics system should be even better that the worker quality, as it would avoid fallen cones when they are being placed, as it happens sometimes in the case of cones set from a truck in movement.

3.2.4 UC2.1.3. Road assets cleaning

3.2.4.1 State of the art

Signs are placed to help ensure the motoring public's safety. When signs are not legible, they cannot serve that purpose. To maintain maximum retro reflectivity, performance and acceptability, signs should be kept clean and free from dirt, road tar, oil and bituminous material. The cleaning of signaling and lightning elements is an extremely repetitive task which is currently performed manually by road workers.

In the computer vision community, the recognition and detection of traffic signs are a well-researched problem. Researchers have proposed numerous solutions for the automatic detection of traffic signs, intended for use in both unmanned vehicles and driver assistance systems, which require solving the problem of traffic sign recognition. The study in [94] presents an automated computer-vision based method that detects, classifies, and localizes traffic signs via street-level image-based 3D point cloud models. The proposed pipeline integrates 3D object detection algorithm. Study [95] presents an algorithm that obtains promising, reliable, and high performance in both detecting traffic signs in 3-D point clouds and recognizing traffic signs on 2-D images. The traffic sign detection task is accomplished based on 3-D point clouds by using bag-of-visual-phrases representations, whereas the recognition task is achieved based on 2-D images by using a Gaussian-Bernoulli deep Boltzmann machine-based hierarchical classifier.

Most of the current traffic signs automatic detection solutions are based on deep learning. A lightweight and accurate convolutional neural network for detecting traffic signs is proposed in [96].

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Their experiments on the German Traffic Sign Benchmark datasets show that the detection locates the traffic signs with average precision equal to 99.89%. The study in [97] has designed and implemented a detector by adopting the framework of faster R-convolutional neural networks (R-CNN) and the structure of MobileNet. Here, color and shape information have been used to refine the localizations of small traffic signs, which are not easy to regress precisely. Study [98] presents a traffic sign detection algorithm based on a deep convolutional network. To achieve real-time Chinese traffic sign detection, they propose an end-to-end convolutional network inspired by YOLOv2, obtaining a detection speed of 0.017 seconds per image. Furthermore, study [99] proposes a recognition system to address the issue of detecting and recognizing a large number of traffic-sign categories suitable for automating traffic-sign inventory management. Most of existing approaches perform well on traffic signs needed for advanced driver-assistance and autonomous systems. However, this represents a relatively small number of all traffic signs (around 50 categories out of several hundred) and performance on the remaining set of traffic signs remains an open question.

There are still some challenges in traffic sign detection. On the one hand, some traffic signs of small size are more difficult to detect than those of large size so that the small traffic signs are undetected. On the other hand, some false signs are always detected because of interferences caused by the illumination variation, bad weather and some signs similar to the true traffic signs. Study [100] proposes a cascaded R-CNN with multiscale attention method to solve the undetection and false detection. Traffic sign detection is also challenging in cases of a complex background, occlusions, distortions, and so on. The research shown in [101] pays close attention to channel-wise feature responses to propose an end-to-end deep learning-based saliency traffic sign detection method and overcome the above-mentioned challenges.

The research on traffic light detection is also widely presented in literature. Study [102] presents a robust technique to detect traffic lights during both day and night conditions and estimate their distance. This solution is based initially on color properties, by applying a fuzzy clustering provides a better division of the traffic light colors. Then, the distance between traffic lights and the vehicle is estimated by applying Bayesian filters to the traffic lights represented on the frame. The system is able to detect the traffic lights with 99.4% of accuracy in the range of 10 to 115 m. A deep neural network-based model for reliable detection and recognition of traffic lights using transfer learning is presented in [103]. The model was trained on dataset containing different images of traffic light signals in accordance with Indian Traffic Signals. Study [104] proposes a method that combines a conventional approach, which is fast but weak to false positives, and a CNN, which is not suitable for detecting small objects but a very powerful classifier. The method shows promising results against false positives in urban environment because of the complex backgrounds. Research [105] proposes a traffic light recognition system where adaptive thresholding and deep learning are used for region proposal and traffic light localization, respectively. The classification part of the algorithm gives a total of 89.60% true detection rate, while the regression part of the model produced a correct location of the traffic light in 92.67% of cases.

Deep learning algorithms require large datasets for the training of the models. There are various public data sets of annotated traffic signals data [106] [107] [108] [109] [110] which reflect different conditions. These public datasets may serve as a good starting point for training and testing new traffic signal detection models.

Not only databases, but several models [111] [112] [113] [114] [115] are also available that have been trained for traffic signal detection. These models may serve also as a starting point for further training based on the specific applications and requirements.

As far as the road asset cleaning task is concerned, although it is a task that usually is manually done, there are also a few solutions that try to increase the automation level of the task and reduce the workload of the workers. For instance, Alborz Electric Power Distribution Company and Tehran University have started a joint project in order to build and utilize robots that can be used to clean streetlamps and paint their poles [116].

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All in all, there are still not many solutions that automate the process of cleaning road assets, being a process that is still mainly done manually.

3.2.4.2 Summary of technical requirements

The robotic modular system shall assume the operation of cleaning the road assets, minimizing the exposure of road workers to traffic. The assets considered are traffic signals located on the sides of the road and the lighting that is at reach of the robot.

In order to achieve these objectives, the robotic modular system will need a perception system that combines artificial vision and artificial intelligence, to allow the robotic arm to locate the road signs. The system will consist in an RGB-D camera mounted on the robot arm that takes images that will serve to identify the traffic signs and lights. Moreover, this perception system will need to be able to operate under low light conditions, as this type of operation is often carried out at night. Then, the robot will calculate the trajectory to cover the surface of the road sign. The robot must also be equipped with a tool mounted on the robotic arm flange that allows to clean the road assets by spraying water.

In this use case, the road workers drive the vehicle to the point where there are assets that need to be cleaned. On arrival, they stop at the location of the first asset. After that, the road worker positions the end-effector of the robotic arm, by using a web-based VR platform. The web-based VR platform allows the operator to teleoperate the robotic arm in real time. The remote operator receives a video stream from the vision camera, facilitating the remote operation. Once positioned, the road worker uses the display of the VR headset to start the asset identification process. When the asset is identified by the system, the road worker selects manually the asset cleaning process. The asset identification and characterisation data are used then by the road assets cleaning robotics system to calculate the trajectory that the robot arm needs to execute to cover the surface of the asset. Then, the robot arm is positioned at the beginning of the trajectory. After this point, the road assets cleaning robotics system activates the tool to start spraying water. The robotic arm will then execute the trajectory with a given constant speed. When the trajectory finishes, the road assets cleaning robotics system deactivates the tool. Once finished the cleaning, the road worker moves forward to the next asset. This process is repeated for all the kilometric points where assets need to be cleaned.

Table 19. Summary of UC2.1.3

Title	UC2.1.3 Road assets cleaning
Short Narrative	The robotic system to be developed in OMICRON will support road workers in the process of cleaning road assets. For this process, a perception system is needed which will allow the robotic arm to locate the road signs. Then, the robot will calculate the trajectory to cover the surface of the road sign. Additionally, a specific tool will be designed to clean the signs with pressurized water.
Cluster Use Case	UC2: Routine and emergency maintenance interventions
Connection to other Use Cases	UC2.1 Robotic Modular Platform; UC2.1.1 Installation of safety barriers; UC2.1.2 Installation of cones; UC3.1 Signalling during construction works; UC3.2 Sealing of surface pavement cracks; UC3.3 Removal of lane markings with laser
Actors	Road administration, Road worker, Vehicle, Vision camera, Robot arm, Cleaning tool, VR headset, Remote operator

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Title	UC2.1.3 Road assets cleaning
Scope	A robotic system shall support road maintenance workers in the process of cleaning road assets. This process comprises the manual cleaning by the road workers, which entails an exposure of workers to traffic, with a high probability of suffering accidents. Additionally, the use of a robotic arm for the cleaning of road assets should reduce the cleaning time, resulting in a reduction in maintenance costs.
Objectives	1. Daily work support. The aim of the use case is to assist operators improving their working conditions. 2. Operator safety. The robotic system reduces the exposure of workers to the handling of high loads and certain types of forced postures, thereby reducing the probability of injury. 3. Saving costs. The robotic solution has as a direct result the reduction of the corresponding workforce needed. This will result in a reduction in maintenance costs.

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3.3 UC3. Large and extraordinary maintenance actions

3.3.1 UC3.1. Signalling during construction works

3.3.1.1 State of the art

In recent years, task-specific machines have been introduced in road operations. However, the autonomy of these task-specific machines is very small, and the decision-making/control is on the human side. The ASCI (Automation System for Curtain-wall Installation) has been applied to construction sites to allow the decision-making/control on the human side by a human-robot cooperative system which is used to cope with various and untypical construction environments [117]. Additionally, these ad-hoc machines are designed to be useful in very specific tasks and although some of them offer the possibility to be modified to be used in similar tasks, they usually lack flexibility. An example of this type of technology could be the robot traffic cop designed for in real-time applications, teleoperated and monitored through augmented glasses [118].

Currently, modular robotic platforms are emerging to overcome the aforementioned shortcomings and have shown a great flexibility and adaptability. These platforms are composed of a variety of blocks which can be interchanged with the idea of adapting it to be useful for a wide variety of tasks. Multi-task robotic platforms can be applied to a great variety of areas: the robotic platform RABIT (Robotics Assisted Bridge Inspection Tool) provides rapid and automated condition assessment of concrete bridge decks using multiple non-destructive evaluation technologies [119], the multi-sensor robotic platform for ground mapping and estimation agricultural vehicle, performs tasks like seeding, ploughing, fertilising with limited human supervision [120].

In particular, the placing and removing of the temporary signs for maintenance works is performed manually. Commercial systems based or not in robotics have not been found.

3.3.1.2 Summary of technical requirements

Previous to any road works, it is mandatory to place the required signalling in order to (1) inform users and (2) order traffic along the section under works. The placing of temporary road signs is currently performed manually by the workers; hence, it is an extremely risk task since they have to carry out this task while traffic is active, having to run across several lanes sometimes.

The scope of UC3.1 is to implement the operation of placing and removing the temporary signs for maintenance works by means of a robotic arm to be developed in OMICRON. The use of robotic technologies for placing and removing temporary signals during road works will increase the safety of the operators who will no longer be exposed to doing this task manually while traffic is active. In addition to increased safety, the automation of this task will lead to a reduction in execution times, which will increase the capacity of the network as there will be less impact on traffic.

The context of this use case is a road that is going to be partially closed due to maintenance works. An industrial robotic arm will be installed on a trailer attached to or carried by a truck or van that is driven by an operator. The different temporary signals that need to be placed during the execution of the works on the road will be positioned by the robotic arm installed on the trailer. Then, once the works on the road are finished, the robotic arm will remove the signals. Signals will be recognised by a perception module which will allow the robotic arm to identify the position of the elements to be removed.

This UC will contribute to the following Key Performance Indicators:

- KPI 2. Emergency, ordinary and extraordinary maintenance intervention times.
- KPI 3. Volume of people in dangerous zones in road maintenance areas.
- KPI 6. Traffic disruptions due to maintenance interventions.
- KPI 9. Maintenance and inspection activity costs.

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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.

In the primary scenario, the road worker uploads into the vehicle all the signs to be placed along the right-side of the road. The road worker drives the vehicle placing the modular robotic platform to the first place where a road sign needs to be placed. The worker positions the vehicle in such a way that the robotic platform is close enough to perform the operation. After that, the road worker starts the road signs picking process. Then, the robot places the road sing into the target position. Finally, the road worker starts the release process to move the robot to the start position. Then, the road worker drives the vehicle to the next position where a road sign needs to be installed. This process is repeated for all the road signs that need to be installed on the right side of the road.

After carrying out the interventions on the road, the temporary signs must be removed. This task will also be performed with the help of the robotic arm. The road worker drives the vehicle to a position in which the robotic platform is close enough to perform the operation. Then, the road worker starts the identification of visual references process. When the road sign is identified, the road worker starts the road signs picking process. After that, the robot places the road sign in the vehicle. Finally, the road worker starts the release process to move the robot to the start position. This process is repeated for all the road signs to be removed.

Table 20. Summary of UC3.1

Title	Safe signalling during construction works
Short Narrative	A robotic modular arm shall support the execution of different road maintenance interventions such as placing and removing temporary signals during works on the road. The use of robotic technologies for placing and removing temporary signals during road works will increase the safety of the operators who will no longer be exposed to doing this task manually while traffic is active, with the risks that this entails. In addition to increased safety, the automation of this task will lead to a reduction in execution times, which will increase the capacity of the network as there will be less disruptions to traffic.
Cluster Use Case	UC3 Large and extraordinary maintenance actions
Connection to other Use Cases	This use case is related to use cases for routine and emergency maintenance interventions: • UC2.1 Robotic Modular Platform. • UC2.1.1 Installation of safety barriers. • UC2.1.2 Installation of cones Use Cases for Large and extraordinary maintenance actions: • UC3.2 sealing of surface pavement cracks. • UC3.3 Removal of lane marking with laser.
Actors	Road administration, road worker, robot arm, vision camera, sign handling tool.

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Title	Safe signalling during construction works
Scope	Previous to any road works, it is mandatory to place the required signaling on site in order (1) to inform users and (2) to order traffic along the section under works. This operation is currently done manually by the workers; hence, it is an extremely risky task since they have to perform this task while traffic is active, having to run across several lanes. The scope of the proposed Use Case is to implement the operation of placing and removing the temporary signs for maintenance works by means of the robotic arm to be developed in OMICRON.
Objectives	The objectives of this Use Case are: • Daily work support. The aim of the use case is to assist operators improving their working conditions. • Operator safety. The aim of the use case is to increase the safety of operators when placing construction site signs. • Reduced traffic disruptions. Another objective of this use case is to reduce the execution time of this task through the use of automated robotic systems. This will lead to shorter traffic disruptions. This will also have an effect in the overall costs.

3.3.2 UC3.2. Sealing of surface pavement cracks

3.3.2.1 State of the art

Periodic checks and maintenance of the road pavement are a crucial step. Especially, crack sealing is an important procedure used to extend the life of road pavement. The history of crack detection is old, and this process has been traditionally done manually by specialist engineers, scanning the surface using eye observation. Since the manual approach completely depends on expert knowledge and experience, it lacks objectivity in the quantitative analysis [121]. In this context, automatic image-based crack detection is proposed as a replacement.

Recently, more and more researchers have developed solutions for automatic crack detection and location. Literature presents different techniques to automatically identify the crack and its depth using image processing techniques. Figure 20 shows the basic architecture for the crack detection using image processing technique [122].

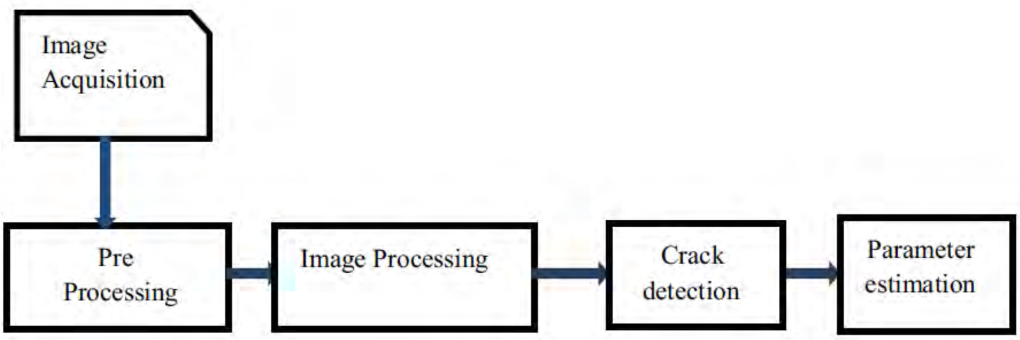

Figure 20. The architecture of image processing based crack detection

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The first step (image acquisition) is a very critical step since the final decision depends totally on the camera's observation. Some systems use cars supported by machine vision system and others use UAVs supported by 3-D sensors. By literature review, crack images can be classified into six ways. (1) Visible light images: the images are taken from satellite, aerial, surface, ground, under microscope, etc., and the resolution of the images is high. (2) Laser images: mainly adopted for image processing and analysis of three-dimensional cracks, and crack size varies from less than 1 millimetre to several meters. (3) CT images: generally used for the analysis of micro cracks in a laboratory, and the crack size is from micrometre to millimetre. (4) Radar images: utilized for the cracks with a depth and satellite image processing. (5) Ultrasonic images: applied for wavelet transform and curvelet transform. (6) Infrared images: used for the measurement of crack depth for special occasions. It is no doubt that the fusion of two or more kinds of image information is useful for crack extraction and analysis [123].

After the image acquisition, the collected images are pre-processed. The aim of image pre-processing is to enhance cracks for better visualization and subsequently processing. After pre-processing, the next step is to do image segmentation or crack extraction. Image segmentation is an old topic of image process and pattern recognition. The current tendency is to combine different algorithms for a special application domain. Similarity based algorithms like thresholding have been applied to the domain of cracks in the pavement engineering applications [124]. The discontinuity-based algorithms are different from the similarity-based ones, which concentrate on the linear features that mainly corresponds to crack boundaries, interesting object surface details, etc. The image gradient magnitude information is used to trace the crack curves [125].

In most cases, the crack detection is very hard using traditional computer vision techniques because of (1) low contrast between cracks and surrounding pavement; (2) intensity inhomogeneity along the cracks; and (3) possible shadows and other noise with the similar intensity to the cracks. Recently, neural network and deep learning is being a new trend for the classification and recognition of pavement cracks, obtaining the best results. Study [126] suggested a deep learning framework on convolutional neural network (CNN) and a Naïve Bayes data fusion scheme for analysing individual video frames for 810 crack detection, and their method achieves a detection accuracy of 98.3%. Study [127] studied a method for concrete crack detection by using deep learning based semantic segmentation. [128] studied the recognition of asphalt pavement crack length with deep convolutional neural networks. [129] used deep learning semantic segmentation for CT images. [130] made a method for the detection of asphalt pavement cracks based on general regression neural network (GRNN) neural network. Detailed examples are given in the following parts. [131] proposed a method by using a deep architecture of CNN for concrete crack detection. Their designed CNN is trained on 40 K images of 256 × 256 pixel resolutions, and consequently, records with about 98% accuracy. They scanned any image size larger than the resolution of 256 × 256 pixels. The robustness and adaptability of the method is tested on 55 images with the resolution of 5888 × 3584 pixels.

Conventional crack sealing operations exposes workers to dangerous conditions such as the traffic and the manipulation of high temperature materials, being a labour intensive and hazardous task. Therefore, several efforts have been made to automate the process of crack sealing. [132] proposes a laboratory prototype of an automatic pavement crack sealing platform, which uses a modified three-dimensional (3D) printer and computer vision. A modified 3D printer based on fused deposition modelling (FDM) is combined with an image capturing platform, an image processing algorithm, and a path planning method to form the automated pavement crack sealing platform, which can automatically detect pavement cracks and seal them with bitumen emulsion sealant. [133] develops and implements a kind of manipulator system for roadway crack sealing, which consists of a six-degree-of-freedom (6-DoF) manipulator with a novel crack sealing end-effector, a stereo camera, an air pump, a glue barrel, and a laptop. The paper presents the hardware construction and working schematic of the manipulation system. [134] puts forward an automated system, currently in development, which include automated condition assessment measures to detect road defects and repair technologies using a novel three-dimensional (3D) printing method to seal road cracks and potholes. [135] presents

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the development of a sealing robot system to seal various shapes of concrete surface in rough conditions for a long time. An impedance force tracking controller with slope estimator is proposed to calculate the surface slope in real time using the robot position.

Currently there are already some patents related to the inspection and sealing of road cracks. [136] is a system for acquiring, processing, storing, analysing and reporting data relating to the condition of a road or other pavement surface in real time. The system also includes a processor in the computer for processing the images to detect and classify cracks and other pavement surface features. A distributed road assessment system is patented in [137]. It includes a distributed road assessment system includes road assessment pods and a road assessment server. Each road assessment pod transmits to the road assessment server occurrence information describing each occurrence of road damage that is newly detected on a current scan of a road. [138] is a roadway crack sealing apparatus which includes a crack sealing assembly having an emulsion container supported on a frame, wheels supporting the frame, a handle extending from the frame, a lever operable to control selectively open and close an emulsion outlet, and a video camera positioned to permit an operator to visually locate and follow a roadway crack during the sealing process.

3.3.2.2 Summary of technical requirements

The robotic modular system aims to support the road workers in the process of sealing cracks, particularly in the direct application of bituminous mixes at high temperatures. A robotic arm shall assume the operation of the pipes of the machine and the application of the sealing material over the cracks, minimizing the exposure of workers to the manipulation of the material and, hence, preventing accidents.

In order to achieve these objectives, the robotic modular system will need a perception system that combines artificial vision and artificial intelligence, to allow the robotic arm to locate the road signs. The system will consist of a RGB-D camera for road perception, mounted on the robot arm to take images of the road that will serve as input to the system to identify cracks. Moreover, this perception system will need to be able to operate under low light conditions, as this type of operation is often carried out at night. The robotic system will be attached to a vehicle that transport it. This vehicle shall contain enough space to house a generator set, a compressor, the sealing machine, and the sealing material. The robot must also be equipped with a specifically designed too that combines the heating, blowing and injection of mastic in a single solution. The tool must allow for independent activation/deactivation of blowing and injection.

In this use case, the road workers drive the vehicle to the first point where cracks need to be sealed. When they arrive, they stop at the beginning of the cracks. After that, the road worker positions the end-effector of the robotic arm. The remote operator uses a web-based VR platform to position the robotic arm end-effector over the crack. The web-based VR platform allows remote operator to teleoperate the robotic arm in real time. The remote operator receives a video stream from the vision camera, facilitating the remote operation. Once positioned, the road worker manually starts the crack identification by using the display of the VR headset. Therefore, a vision camera provides data for the crack sealing robotic system for identifying and characterising the cracks. After this identification and characterisation, the information is sent to the VR headset to be shown to the road worker. Then, the road worker selects manually the cracks to be sealed (the VR headset shows visually the identified cracks, and the worker manually selects the cracks that will be sealed). After that, the road worker starts the crack sealing process. The crack identification and characterisation data are used by the cracks sealing robotics system to calculate the trajectory that the robot arm needs to execute. Once, finished the sealing, the road worker moves forward a small distance using the vehicle to repeat the process again until the crack area is covered. This process is repeated for all the kilometre points where cracks need to be sealed.

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Table 21. Summary of UC3.2

Title	UC3.2 Sealing of surface pavement cracks
Short Narrative	The robotic system to be developed in OMICRON will support road workers in the maintenance process of sealing cracks in surface pavement layers. For this process, a perception system that combines Artificial Vision and Artificial Intelligence is needed, which will allow the robotic arm to locate and characterise (in terms of geometry) the cracks and generate the robot trajectory to track the width and length of the crack. Additionally, a specific tool will be designed to: (1) apply hot air flow on the crack, to remove any material inside and prepare the surface for the sealing material and (2) apply sealing material.
Cluster Use Case	UC3: Large and extraordinary maintenance actions
Connection to other Use Cases	UC2.1 Robotic Modular Platform; UC2.1.1 Installation of safety barriers; UC2.1.2 Installation of cones; UC2.1.3 Road assets cleaning; UC3.1 Signalling during construction works; UC3.3 Removal of lane markings with laser
Actors	Road administration, Remote worker, VR headset, Vehicle, Sealing machine, Vision camera, Robot arm, Sealing tool
Scope	Road maintenance workers shall be supported in the process of sealing cracks in surface pavement layers. This process comprises operating pipes of a dedicated machinery by a worker to follow and seal the crack. The machine heats up bituminous mixes to high temperatures. The manipulation of the bituminous materials can be dangerous, as they are very adherent, so any single mistake can induce severe burns in the worker. Additionally, the use of a modular robotic arm should reduce the corresponding workforce needed, resulting in a reduction in maintenance costs.
Objectives	1. Daily work support. The aim of the use case is to assist operators improving their working conditions. 2. Operator safety. The robotic system reduces the exposure of workers to the manipulation of the bituminous materials and to the impact of material that can come out during the blow operation, thereby reducing the probability of an accident. 3. Saving costs. The robotic solution has as a direct result the reduction of the corresponding workforce needed. This will result in a reduction in maintenance costs. 4. Equivalent quality to worker. The sealing of the cracks done by the robotic system have the equivalent quality to those sealed by the road worker.

3.3.3 UC3.3. Removal of lane markings with laser

3.3.3.1 State of the art

Temporary road markings are routinely used as a tool to redirect traffic, in the context of pavement reconstruction and improvement works. Once these works are completed, temporary markings must be removed. Due to the nature of the different technologies available for this task, it is not uncommon to have suboptimal results, in terms of the surface state of the pavement (colour, texture, cracks) or incomplete removal, which can cause confusion among motorists when navigating these lanes. The

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potential danger of this situation is exacerbated under conditions of reduced visibility, such as night-time or with bad weather conditions.

Currently, there are several methods available to contractors for removal of markings: grinding, high pressure water jet, hot compressed air burning, oxygen burning, hydroblasting, shot blasting, and sand blasting (Figure 21).

a)

b)

Figure 21. Different methods for the removal of markings: a) Grinding *[1]* and b) water-jet (PAVASAL)

These methods result in damage to the road that can create problems for motorists, among the most important of which is scarring of the pavement, where ghost stripes, images of the old marking, are created [139]. It must be noted that grinding, water blasting and sand blasting are predominantly used [140] nowadays.

The OMICRON project proposes the use of laser technology as an alternative for removal of markings. Cleaning by laser radiation has become, despite its relative youth, a solid alternative to more traditional methods of thermal, mechanical, and chemical nature in a wide range of materials and applications, such as paint stripping, decoating of polymers, artwork, antiques and historic buildings restoration, biological and nuclear decontamination, mould cleaning and particle removal in the microelectronic and optical industries.

Advantages over current technologies include high accuracy of the deposited energy, its non-contact nature, flexibility, and ease of automation. Besides this, it is also an eco-friendly process, since potentially toxic and polluting organic solvents, as those employed in chemical-based techniques, are rendered unnecessary.

Several cleaning mechanisms can be found, depending on the optical response of the coating to the laser wavelength. If the photon energy is bigger than the component typical binding energy, then photochemical ablation may take place, as is the case with polymer ablation via ArF laser [141]. If the coating is transparent to a high degree, absorption takes place at the substrate level, and interface phenomena are responsible for coating removal. These phenomena can encompass, for example, heating, volume expansion or shock wave production. This is the case for graffiti paint cleaning from facades or metallic surfaces, when using ns YAG radiation at 1064 nm. For short pulsed-based processes, the removal mechanism is based on micro-plasma bursts, shockwaves, and thermal pressure, resulting in sublimation and ejection of the target material.

Therefore, the laser characteristics must be selected carefully, as a function of the coating to be removed and the substrate type. In general, for metallic substrates, pulsed sources in the nanosecond regime are common. Longer pulses induce deeper thermal effects on the substrate, and therefore, the risk of damaging the material is bigger. Shorter pulses, namely pico and femtosecond, may work for particular contaminants, although due to their low average power and high cost, they are not appropriate for industrial use.

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Regarding wavelength, ultraviolet (UV) from excimer lasers, low infrared spectrum from solid state lasers (Nd:YAG, fibre, diode, etc.) and, in some special cases, medium infrared spectrum (CO_2 sources) are the preferred choices [142]. Some authors have also explored continuous wave (CW) cleaning, in particular the use of high-power diode laser to remove chlorinated rubber coatings from concrete surfaces [143], [144]. Cleaning by combustion is aggressive to the substrate, although if the base material is not of a sensitive nature, as is the case with concrete, diode CW cleaning can provide high efficiency at a relatively smaller cost. The combination with a scanning system can further enhance productivity.

Paint coating removal using lasers has been attempted over recent years using a number of different systems, the most notable of which are CO_2 laser [145], Nd:YAG laser [146], excimer laser systems [147] as well as high power diode lasers.

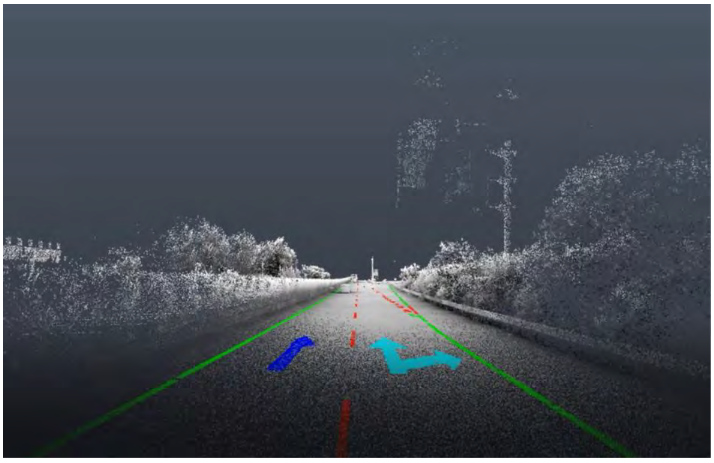

Figure 22. Automatic extraction of road markings [11]

The potential of laser-based removal of road markings has only been explored, to the consortium's best knowledge, in two contributions [140], [148], using CO_2 and Nd:YAG laser sources respectively. In both cases the feasibility was demonstrated at the laboratory level, although the cost and productivity were mentioned as deterrents for industrialization. In particular, for the YAG system, removal yield was calculated at 8 hours per mile (~4.87h/km). Currently, the situation has changed dramatically, since both the cost of the systems has reduced, and the available average power has increased.

The OMICRON approach also includes a vision system, which must guide the positioning of the robotized optical head (Figure 22). In this way, the system can adapt to different situations, such as deviations from a straight line or the removal of wide markings (wider than the field of view provided by the optical system). Previous publications have established the feasibility of automatic detection of road markings, for example [149].

3.3.3.2 Summary of technical requirements

The methods currently applied to remove the paint from the road can create confusion (the sign is still somewhat visible) and grip problems (due to the application of black paint). The potential danger of this situation is exacerbated under conditions of reduced visibility, such as night-time or with bad weather conditions.

A laser-based cleaning system is proposed as a promising alternative method to current road marking removal technologies. This solution is expected to improve the quality of the cleaning process of horizontal signs while maintaining the friction properties of the road. A robotic arm shall perform the laser cleaning while vehicle is stopped. Once the process is finished, within the field of action of the arm and available field of view of the optical system, the vehicle shall slowly move a distance equivalent to the reach of the robot arm and repeat the process.

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To achieve these objectives, the robotic modular system will need a perception system that combines artificial vision and artificial intelligence, which can detect the shape and size of the markings to be removed, as well as to generate the required trajectories and guide the robotised laser head. Moreover, this perception system will need to be able to operate under low light conditions, as this type of operation is often carried out at night.

In this use case, the road workers drive the vehicle to the first point where there are markings that need to be removed. When they arrive, they stop at the position of the first marking to be removed. After that, the road worker positions the end-effector of the robotic arm. The web-based VR platform allows remote operator to teleoperate the robotic arm in real time. The remote operator receives a video stream from the vision camera, facilitating the remote operation. Once positioned, the road worker starts the marking identification. Therefore, a vision camera provides data for the marking removal robotic system for identifying and characterising the markings. After this identification and characterisation, the information is sent to the VR headset to be shown to the road worker. When the markings are identified, the road worker manually selects the markings to be removed using the VR headset. Then, the road worker starts the marking removal process. The marking identification and characterisation data are used by the markings removal robotics system to calculate the trajectory that the robot arm needs to execute. Once the removal is completed, the road worker moves forward a small distance using the vehicle to repeat the process again until the markings are removed. This process is repeated for all the kilometre points where markings need to be removed.

Table 22. Summary of UC3.3

Title	UC3.3 Removal of lane markings with laser
Short Narrative	A laser-based cleaning system is proposed as an alternative method to current road marking removal technologies. The approach relies on a robotic modular arm to mount the optical head, together with a perception system that combines Artificial Vision and Artificial Intelligence, which can detect the shape and size of the markings to be removed, as well as to generate the required trajectories and guide the robotised laser head.
Cluster Use Case	UC3: Large and extraordinary maintenance actions
Connection to other Use Cases	UC2.1 Robotic Modular Platform; UC2.1.1 Installation of safety barriers; UC2.1.2 Installation of cones; UC2.1.3 Road assets cleaning; UC3.1 Signalling during construction works; UC3.2 Sealing of surface pavement cracks
Actors	Road administration, Remote worker, VR headset, Vehicle, Laser machine, Vision camera, Robot arm
Scope	A novel laser-based cleaning system shall be implemented for road marking removal. Currently available methods can create problems for motorists (scarring of the pavement, ghost stripes, etc.) OMICRON approach combines a vision system and the use of a modular robotic arm. All in all, it is expected that this solution should improve the quality of the cleaning process and reduce the corresponding workforce needed, resulting in a reduction in maintenance costs. Although the case is described considering all the necessary elements for an eventual industrial implementation, it will be provided as a proof of concept at laboratory scale in the framework of the project.

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Title	UC3.3 Removal of lane markings with laser
Objectives	1. Operator safety. The robotic system reduces the exposure of workers to laser radiation and to the impact of gaseous materials that are generated during the interaction, thereby reducing the probability of an accident. 2. Saving costs. The robotic solution has as a direct result the reduction of the corresponding workforce needed. This will result in a reduction in maintenance costs. 3. Equivalent or superior quality to worker. The laser removal by the robotic system has equivalent or superior quality than that provided by the road worker using current technologies.

3.3.4 UC3.4. Rehabilitation of surface pavement layers

3.3.4.1 State of the art

Asphalt mix pavement overlays represent a common technique used for pavement rehabilitation and maintenance. These works **involve different steps**: preparing an existing pavement surface for overlay; tack coat (asphalt emulsion) application; and asphalt mix laying and compaction.

Tack coat application

A distributor is used to apply the liquid asphalt material used for tack coats. The distributor consists of an insulated tank mounted on a truck or trailer. A power-driven pump forces the asphalt through a system of spray bars and nozzles onto the construction surface. The distributor is designed to apply a controlled and metered amount of bituminous material.

Four important features must be considered:

1) Desired Application Rate: Litres per m^2.
2) Forward Ground Speed: Meters per minute.
3) Asphalt Pump Output: Litres per minute.
4) Width of Spray: Meters.

Placement of asphalt mixture

Asphalt mixtures are spread and finished with the use of paver finishers. The paver spreads the mixture in either a uniform layer of a desired thickness or a variable layer to a desired elevation and cross section. The paver consists essentially of a tractor and a screed. The tractor receives, conveys, and augers the mixture to the screed and propels the screed forward.

Several factors, such as the paving speed, head of material, mix consistency, pre-compaction, and screed angle of attack influence the vertical position of the screed. If any one of these factors is varied during the paving operation, the variation causes a change in the mat depth, density, and/or texture.

In this step, asphalt mix temperature and environmental and geolocation factors should be measured and meet limitations stated in the national or international specifications. In this regard, thermal profiles are used to check the level and variability of the mixture temperature behind the paving machine.

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Compaction

Different types of rollers are used for compacting asphalt: two-axle tandem, three-wheeled, pneumatic tire, vibratory, oscillatory, and trench rollers. All the rollers have steel wheels, except for the pneumatic-tire roller which has rubber wheels. **The rolling operation is required to obtain a fully compacted mat**. **On the other hand, safety, skid resistance and noise of roads highly depend on the characteristics of pavement surface texture (macro-texture and micro-texture).** Surface macrotexture also highly depend on compaction process. To determine macrotexture values, different measurement procedures are applied. Measurement results values are compared to limit values, describing the quality of macrotexture on the examined road section.

Figure 23. On the left, MTD or sand patch texture detail, as per EN13036-1. On the right, MPD laser profilometer details

Furthermore, Asphalt for Ultrathin Layers (AUTLs) are thinner asphalt mixtures of aggregates and plain or polymer modified bitumen, which may contain fibre additives.

AUTL (Asphalt for Ultrathin Layer)

The use of Asphalt for Ultra-Thin Layers (AUTL) constitutes a greener and more agile methodology in pavement rehabilitation. The AUTL as a "skin" provides favourable functionalities such as noise reduction potential, relatively low rolling resistance, some anti-spray properties, and efficient light reflection. The main aim regarding to AUTL, in this use case, is to identify opportunities for further improving the design and the application of AUTL. **AUTL optimisation will be explored while dealing with separate stages of AUTL application ranging from mix design to its application in the field.**

Figure 24. AUTL details

3.3.4.2 Summary of technical requirements

The automation of the **surface pavement layer rehabilitation process**, providing decision-support information along the whole process will improve it and will enhance human operator decisions.

The automation of the process will result in higher performance and immediate opening to traffic. Moreover, maintenance techniques can be used to reduce the overall cost of pavement by increasing its useful life. The characteristics of the AUTL (skid resistance, noise level) guarantee greater safety and

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comfort for road users. The reduced thickness of the set-up achieved will save resources: energy, aggregates, and bitumen.

The information to be used will be collected by means of sensors and other sensing gadgets. The timestamped added value information will include, among other:

i) Temperature.
ii) Density over time.
iii) Dose.
iv) Amount of material (depth and level).
v) Speed of deployment.
vi) Macrotexture.
vii) Distance between the extension and the compacting vehicle.

A brief summary of the requirement form prepared for this use case is presented in the following table.

Table 23. Summary of UC3.4

Title	Smart rehabilitation of surface pavement layer
Short Narrative	Adaptation of existing machinery to automate extraordinary maintenance tasks. This will include the replacement of pavement surface layers fostering the use of AUTLs (Asphalt for Ultra-Thin Layers) using recycled materials in its composition.
Cluster Use Case	UC3: Large and extraordinary maintenance actions.
Connection to other Use Cases	Use Case 1.2.
Actors	Road owner or concessionaire company; Machinery drivers and operators; Machinery (Emulsion distributor, Asphalt Paver; Roller / Compactor); sensor systems (weather station, geolocation sensors, temperature sensors, density sensors, texture sensors, etc.)
Scope	Adaptation and automation of machinery dedicated to the replacement of asphalt pavement layers. Integration of smart automation solutions to support the replacement of surface pavement layers.
Objectives	Following OMICRON's Specific Objectives (SO) and Environmental Objectives (EO): **SO5.2.** Smart solutions to support the replacement of surface pavement layers, using automation technologies and fostering the use of AUTLs (Asphalt for Ultra-Thin Layers). The automation of paving interventions in OMICRON will lead to reductions in overall project costs and time and will enhance pavement lifetime via a better execution. **EO2.** Promoting the use of AUTLs in pavement rehabilitation via enabling technologies which will reduce costs and the amount of material needed, ensuring the required final mechanical properties. **EO3.** Fostering the use of recycled materials in pavement rehabilitation to address national and local demands for increased recycling and environmentally friendly

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	asphalt mixtures. The project will incorporate in the demonstrators AUTLs with high percentages of Recycled Asphalt Pavement (RAP).

3.4 UC4. Modular construction for bridges

3.4.1 State of the art

In the structural engineering world, there are several different situations and contexts in which the word "hybrid", as in "Hybrid Bridge", may be used. For all intents and purposes, within this project, the term will refer to those types of structures that are built with different materials - typically concrete and steel - in different parts or locations within the physical domain of the structure. The resulting material distribution is chosen following criteria related with the internal stress distribution due to the different weights of the elements, based on resistance or stiffness and because of functional advantages such as ease, speed or method of installation.

In this sense, hybrid bridges have been around since the middle of the 20^{th} century. As a solution, it has been mostly widespread in the domain of large-span bridges where the different weight and mechanical characteristics of both materials, as well as their adequate positioning, becomes increasingly influential in the design and cost of the whole structure.

For smaller spans, it has been shown that it is a less competitive solution, especially when compared to pure, conventional, full concrete options, mainly because of the increased cost of the steel parts. On the other hand, however, this solution may still have advantages over composite structures or fully precast concrete designs, the former due to the smaller quantities of steel involved and the latter because the precast concrete elements become less efficient for all but the small to medium spans.

In the later years, these solutions have gained some momentum, and became somewhat more widespread, along with the composite steel-concrete and precast concrete counterparts that preceded them. An example of its use in the realm of smaller spans, which has put them to the test, was the construction of highway overpasses. Its premanufactured nature and construction methods provided a possible answer to the increasing demands on road concessionaries to mitigate costly and risky operations on both workers and users and limit the need of traffic interruptions to avoid those risks. The hybrid solutions present themselves as the middle ground between both worlds by combining the cost-effectiveness of using premanufactured components and the increased structural efficiency of selectively using the construction materials.

This is the point at which the project picks up; by providing an approach of improvement on the stronger aspects of the solution, namely the modularity of its components and an optimized design and construction process, it aims to establish itself as the standard methodology in the context of road infrastructures.

3.4.2 Summary of technical requirements

3.4.2.1 Brief introduction

Traditionally, the construction of bridge structures over or under highways relies on methodologies that present a variety of risks and shortcomings leading to a heavy human presence in the vicinities of bridges and at the construction sites themselves, along with traffic disruptions that hinder the usage of the highway infrastructure partially or totally, even if for a limited time. Progressively, road concessionaries were forced to comply with new standards and regulations that demanded increased safety and sought the measures that also guaranteed the maintenance of a high level of service, with the associated economic benefits.

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3.4.2.2 Target problem to be solved by the Use Case

A short number of solutions have been proposed and used that not only allow the reduction of construction time and manpower usage, but also require the infrastructure to be interrupted for much shorter periods of time. The conventional concrete bridges were replaced by precast concrete bridges or composite steel-concrete solutions. The former suffered from being less structurally efficient, requiring increased deck heights whereas the latter revealed to be less than optimal due the use of the expensive steel while also having higher maintenance costs.

Some other solutions have emerged and have been tested, that seek to gather the best qualities of both worlds: erecting concrete structures in the side spans, further away from the road line and replacing the main central span with a pre-manufactured, put-in-place steel segment which, once connected to the side concrete parts, re-establishes the structural continuity of the bridge. This differentiated layout and material distribution along the length of the bridge also contributed to its structural efficiency, by indirectly balancing the side-to-central span ratio, which is usually very shifted towards the main span, in order to maximize clearance. This optimization process can be taken even further by using precast concrete side spans, eliminating operations such as reinforcement assembly and concrete pouring in the proximities of the main infrastructure altogether, thereby greatly reducing the human presence executing risky assembly and preparation tasks during the interventions.

By taking the knowledge acquired with the experimental use of these existing "hybrid" solutions, the OMICRON project intends to further enhance their performance and optimize their design and production process in order to achieve a flexible solution template that can be easily adapted to the many possible road profiles, hence requiring different span arrangements, and a robust connection layout on the steel parts, towards a quicker, easier and safer assembly procedure on site.

3.4.2.3 Main requirements extracted from the requirement form

During OMICRON, an optimised hybrid solution will be developed, namely the improved design of a connection piece, using data acquired with on-site load and in-lab testing campaigns.

This enhanced solution, and the data gathered in its design, shall be used to assemble a BIM model that ultimately will showcase and demonstrate the practical results and achievements sought by the project.

Overall, this use case aims to have a positive impact on the execution times, which will increase the capacity of the network as there will be less disruption to traffic and will reduce the number of accidents, while also contributing to an increase in the percentage of recycled and recyclable materials that go into the construction of the structure.

This UC will contribute mainly to the following Key Performance Indicators:

- KPI 3 Volume of people in dangerous zones in road maintenance areas.
- KPI 7 Bridge construction traffic disturbance.
- KPI 10 Contribution to circular economy.

Finally, a summary of the requirements of the UC is provided in the table below.

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Table 24. Summary of UC4

Title	Modular construction for bridges
Short Narrative	The construction of concrete traditional bridges represents long construction times and traffic interruptions. Trying to minimise these disruptions and at the same time contributing to circular economy, a hybrid modularised solution is proposed. An enhanced modular solution for hybrid bridges will be developed, aiming to minimise construction site operations while fostering the use of industrial pre-manufactured components. The goal of the methodology will be to create modularised solutions to build bridges (focusing on highway overpasses) avoiding or minimising traffic interruptions. The methodology will provide enhanced information both in terms of the mechanical behaviour and in terms of manufacturing (and installation) advantages compared to traditional solutions.
Cluster Use Case	UC4
Connection to other Use Cases	Connection to the platform in UC6
Actors	Enineering Companies, Construction companies, Road Contractors.
Scope	Design of a modular and hybrid solution for bridges, focusing mainly on highway overpasses, through optimization of the assets and methods used in bridge construction and an increased industrialization level by introducing optimized processes in the bridge components production pipeline
Objectives	1. Solution will allow industrialization of deck construction, which leads to: • Reduction of construction/deconstruction material waste, • Reduction of manpower at the construction site, • Reduction of scaffolding, • Reduction in construction time, • Reduction in traffic interruption time. 2. Solution will allow an increased use of recycled materials: • Increased usage of steel.

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3.5 UC5. Road personnel support

3.5.1 UC5.1. VR platform

3.5.1.1 State of the art

Previous work from LMS

LMS will use its experience with VR developments from previous work to pave the way for the new developments regarding Virtual Reality teleoperation and training, in OMICRON. The scope of [150] is the design of Virtual Environments (VE), which will act as an example and guide for the creation of the OMICRON VE. [151] will serve as an example for the training capability for road workers of the VR developments in OMICRON. In [152], robot control was implemented through VR with the purpose of reprogramming a production line, repurposing the robot operations without the need for an operator present in the scene. [153] uses VR technologies to assess KPIs in the workplace which can then be used to enhance decision-making support made by the production engineers. VR training of workers demands the proper simulation of real processes in a VE, an example of which [154] proposes, in the simulation of a welding process. [155] presents a case of robot programming through AR technologies, and even though they are not the same as VR, they are similar enough to provide a good example.

Previous work from other sources

LMS will also use prior knowledge from other sources. In [156] a set of presented guidelines that define an ideal user interface utilizing virtual reality desktop for collaborative robot teleoperation in unknown environments will help in the construction of the user interface creation of the VR developments. The connection between commercial VR tools and robotic infrastructure is presented in [157], while in [158] the interaction between ROS (Robot Operating System) and VR teleoperation is researched. [159] makes a comparison of different VR interfaces, the results of which will be utilized as examples for intuitive robot manipulation developments, as will the results of [160] where teleoperation is researched via VR and the use of deep learning scene reconstruction for the creation of the VE. [161] provides knowledge on possible delays in the communication of the VR with the robots over the network and how to avoid them, while [162] presents a highly interactive and immersive Virtual Reality Training System which will also serve as an example for OMICRON’s VR training system. In [163] an evaluation of VR training took place, the results of which can be used to raise the efficiency of the OMICRON VR training.

3.5.1.2 Summary of technical requirements

The main goal of this use case is the development of Virtual Reality technologies for the purpose of remote robotic resources’ teleoperation and for the training of workers for the various road interventions for maintenance.

The teleoperation developments aim to enhance the safety of the operator who handles the robotic resources in interventions, by enabling remote control of the resources. By controlling the resources from a distance, the operator does not need to be on the road, where traffic may make their job dangerous. The training developments aim to teach new workers in the interventions of road maintenance in a Virtual Environment, where they can train in any kind of simulated intervention before they have to apply themselves in the actual road.

In the case of teleoperation, the operator responsible for manipulating the robotic resources in the road environment will access a Virtual Reality device (e.g Oculus) in his work environment of choice, which can be remote, far from the road environment where the robotic resources will be situated. They will “enter” the Virtual Environment which will be a twin of the real environment and will receive continuous, real-time feedback from it, thus enabling their complete awareness of the real environment from a remote location. The Virtual Device will establish communications with a Master PC, which in turn will act as an intermediary between the Virtual Device and the remote sensors and

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robot. The kinematics of the robots will have been modelled in the Master PC, and a web-based communication between the Master PC and the actual robot will have been established. Using this communication, and with the modelled kinematics, the operator will be able to manipulate the remote real robotic resources by manipulating the virtual robotic resources, as the real ones will copy the virtual ones. With this teleoperation, the operator will be able to move the robotic resources to execute road maintenance or monitoring operations.

In the case of training, any new road worker or an experienced road worker working on new operations will need training for their tasks on the road. Using a Virtual Environment with a VR device, which will be a twin of an actual road environment, the new worker will be able to train on the road operations from a safe environment, without supervision from experienced workers. Inside the environment, there will be instructions and models representing all the tools the worker will need for their operations. Every occurrence in the real environment that the worker will have to respond to in their work can be modelled in the Virtual Environment, thus a realistic experience will be provided in a digital environment identical to a real one.

The **KPIs associated to this use case** are:

1. KPI 2: Emergency, ordinary and extraordinary maintenance intervention times.
    a. Development of automated and robotised intervention procedures.
2. KPI 3: Volume of people in dangerous zones in road maintenance areas.
    a. Due to the remote teleoperation, the operator will not have to be on the road.

Finally, a summary of the main information from the use case is presented in the following table.

Table 25. Summary of UC5.1

Title	Robot Teleoperation Using Virtual Reality
Short Narrative	The operator will use a VR device to access a Virtual Environment. Using the VE, the operator will be able to manipulate the remote robotic resources that are situated on the road, from a safe place. Aside from this, new operators will be trained in the safe Virtual Environment on the operations they will later work on in the road.
Cluster Use Case	UC5: Road personnel support
Connection to other Use Cases	The developments of UC5.1 will support UC2
Actors	(1) Operator; (2) New road worker (trainee); (3) Robotic resources
Scope	The scope of the use case is the validation of a Virtual Reality platform that will enable the teleoperation of robotic resources engaged in road maintenance activities, as well as the training of new road workers.

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Title	Robot Teleoperation Using Virtual Reality
Objectives	• Utilization of a web-based VR platform for the teleoperation of the robotic resources. ○ Construction of Virtual Environment using data from various resources (google images, cameras). ○ Validate the capability to directly control the position of the robotic resources and the movement of robotic arms, allowed by reception of localization data of the resources. • Utilization of VR based training tool that allows the training of new road workers in relevant procedures.

3.5.2 UC5.2. AR tools

3.5.2.1 State of the art

Previous work from LMS

LMS will use its experience with AR developments from previous work to pave the way for the new developments regarding Augmented Reality Support, in OMICRON. [164] presents an "Operator Support Module" for AR instructions, utilizing ROS based connection capability, allowing its connection with various industrial modules and [165] provides a support system for the operator that provides production and process related information as well as to enhance the operators' immersion in the safety mechanisms, dictated by the collaborative workspace. [166] also presents instruction sequences presenting the models to be assembles with 3D CAD models. [167] proposes a framework that supports the operator by presenting the status of the shopfloor, and also assesses the ergonomics in human–robot shared tasks.

Previous work from other sources

LMS will also use prior knowledge from other sources. [168] presents review of AR applications in maintenance, thus providing feedback on a multitude of research, [169] presents an AR framework to support operators in maintenance with 3D visual instructions and also allows the remote monitoring of the operator's work. [170] presents a review of the various challenges when developing AR applications, which will assist in overcoming them, [171] also presents AR technologies in maintenance in excavations, where AR visualization is used for the enhancement the worker's safety. [172] aims to increase the knowledge of the adaptation and usability of augmented reality for the training of operators, which makes use of the concept of expert systems from the field of artificial intelligence to determine information content on-line.

3.5.2.2 Summary of technical requirements

This use case will focus on the **development of Augmented Reality technologies**, for the purpose of connecting with V2X communications, receiving information on the road status, and providing step-by-step instructions to workers performing road interventions.

The on-site operator will make use of an AR device (e.g. AR glasses). The AR device will be loaded with software to support the operator. The AR device will connect to a master PC, which will handle communications with other resources. The operator will receive information from V2X communications from the road, giving them information about the situation of the road, and improving the safety conditions by informing them about the traffic. When there is a need for maintenance operations, the operator will perform road maintenance operations using the step-by-

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step digital instructions provided by the AR tools. The operator will also use the tools to manage the maintenance operations.

The **KPIs associated with this use case** are:

1. KPI 2: Emergency, ordinary and extraordinary maintenance intervention times.
    - Workers equipped with the AR device will take less time to complete their part in interventions due to the instructions.
2. KPI 3: Volume of people in dangerous zones in road maintenance areas.
    - The AR tool with its instructions will speed up the process and help workers be less time in dangerous positions, as well as providing road information which will aid them in avoiding dangerous situations.

Finally, a summary of the main information from the use case is presented in the following table.

Table 26. Summary of UC5.2

Title	AR tools
Short Narrative	In this use case, the on-site operator will use AR devices with tools developed to support them on their road operations and maintenance.
Cluster Use Case	UC5: Road personnel support
Connection to other Use Cases	The developments of UC5.1 will support UC2
Actors	Road operator
Scope	The scope of this use case is the validation of AR tools that support in-field workers with road information and maintenance guidance
Objectives	1. Successful utilization of AR tools that will support in-field road workers. ○ Achieve an improvement in the management of maintenance works. ○ Improve safety conditions during the interventions. 2. Successful Connection of tools to (WP2) V2X module. ○ Provide workers with road information from V2X communications. ○ Provide workers with step-by-step instructions on maintenance operations. ○ Enhance workers' awareness of the surrounding environment.

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3.6 UC6. Digital Twin and Predictive maintenance

3.6.1 UC6.1. Road digital twin

3.6.1.1 State of the art

The current digital twin platform uses optimisation algorithms, artificial intelligent schemes and mathematical programming to automatically generate the 3D models and data integration of BIM models with sensor data and condition data. OMICRON will develop a high-level digital twin platform, which will combine with a decision-making system to reduce the human effort in planning tasks and road maintenance management in case of unexpected events.

Currently, advanced tools such as mobile scanners, Geospatial Artificial Intelligence, Unmanned Aerial Vehicles, Geospatial Augmented Reality apps, Light Detection, and Ranging are widely used in road digital twins [173]. Two sides are focused on: (i) the development of advanced tools such as miniaturization of sensors and mobile scanners, geospatial AI, Unmanned Aerial Vehicles (UAVs), geospatial AR apps, and Light Detection and Ranging (Lidar); as well as (ii) applications of the tools in cities and products such as Self-Driving Vehicles and Smart Cities.

In the OMICRON project, apart from these technologies, the developments focus on the development of a digital twin platform with bi-directional information connection for decision support tools. Our project would be able to provide a new road maintenance system using the concept of a Digital Twin. This digital model is a platform that allows to collect, organize and share the maintenance history of this important road infrastructure. OMICRON project introduces “Dynamic Laser Scanning”, Data Acquisition and Processing for Road modelling, and Cloud Point Post Processing [174].

Certain studies have been done to automatically generate road digital twins or railway geometric digital twins. Ariyachandra and Brilakis (2021) [175] proposed a framework that exploited the potential of railway topology to perform better when detecting and modelling the geometry of railway elements in railway point clouds with varying geometric patterns. They also studied the automated generation of railway track geometric digital twins (RailGDT) from airborne LiDAR data [176]. In addition, Agapaki & Brilakis (2021) [177] studied an automated benchmark framework for generating geometric digital twins of industrial facilities. They study, implement and benchmark a novel framework, named CLOI, that can accurately generate individual labelled point clusters of the most important shapes of existing industrial facilities with minimal manual effort in a generic point-level format. CLOI employs a combination of deep learning and geometric methods to segment the points into classes and individual instances. The project can continue to work on the direction to propose an automated benchmark framework for generating geometric digital twins of the road for the OMICRON project to quickly build a 3D model and digital twin platform.

Using the inputs from the inspection process and innovative sensor technologies, the digital twin platform will be developed in OMICRON and be able to interact with the decision support tool for road maintenance, to enhance the planning of maintenance interventions.

3.6.1.2 Summary of technical requirements

3.6.1.2.1 Brief introduction

UC 6.1 includes the actions to be performed with the objectives of road digital twins. The definition of the UC contains different activities to ensure the whole operative.

- The on-site operator will make use of the road digital twin and decision support system.
- The road digital twin system will provide the function of road inspection and condition checking.
- Road digital twin systems include BIM-oriented platform, legacy systems data and digital inspection data. The road digital twin models will be stored in a master PC, which will handle

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the visualization functions and automatic analysis to support the decision making for operations and maintenance.
- When there is a need for the maintenance inspection and operation, the operator will view the condition of each road section to check the status and decide whether it needs maintenance.

3.6.1.2.2 Target problem to be solved by the Use Case

Concerning the list of KPIs collected in the OMICRON project, it is possible to match the tasks involved in the use case with a subset of the main targets of the project.

- Reduction of major intervention actions by 10% due to a better maintenance planning.
- 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.

3.6.1.2.3 Methodology

The Use Case requirements are collected following the template based on IEC PAS 62559 (Annex C). A summary of this definition is presented in the following table.

Table 27. Summary of UC6.1

Title	Road Digital Twin
Short Narrative	In this use case, the on-site operator will use a road digital twin system to support the decision making on their road operations and maintenance.
Cluster Use Case	Detailed Use Case
Connection to other Use Cases	There is a relation to UC6.2: Road decision support tool
Actors	Operator; Road contractor; Road concessionaire; Digital twin; Historic records; Existing sensors, processes and measuring systems; OMICRON Digital Inspection Technologies; Communication system
Scope	The scope of this use case is the implementation of digital twin technology in road operation and maintenance management to support maintenance activities and decision making.
Objectives	a. Successful utilization of digital twin technology that will support the visualization of the road system. ○ Implementation of the digital twin technology, such as laser scanning, image processing, etc., to generate the 3D models of road. b. Successful integration of virtual model and physical models in road decision-making platform to support operation and maintenance. ○ Provide users with virtual models of the road system to support visualization. ○ Provide users with integration of virtual model and physical model. ○ Provide users with data integration of virtual models and real-time sensing data.

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3.6.2 UC6.2. Road decision support tool

3.6.2.1 State of the art

Current decision-support tools use optimisation algorithms based, for instance, on metaheuristics, AI schemes and mathematical programming to schedule maintenance interventions [178]. Current works focused on decision-making in the road sector cover aspects such as the prioritisation of interventions according to the criticality of road sections, thereby assessing safety [179]; the impact of traffic [180]; road infrastructure [181] or the optimisation of resources [182], but these concepts are usually addressed separately. Moreover, the management of uncertainties related to asset status prediction and real environments is often neglected. Furthermore, previous projects such as INFRALERT, IN2SMART or FORESEE have paved the ground to combine some of the above-mentioned planning requirements.

Decision Support tools have been improved by their connection to other technologies such as Digital Twins [183]. They can also combine big data frameworks to optimize vehicle routing problems [184], perform real-time crash predictions based on vehicle kinematics, driver inputs, roadway geometric features and real-time weather data [185] or evaluate different alternatives from economic, qualitative and environment perspectives. An example is the road weather information system Decision Support Tool developed by state highway agencies, which also includes a prioritization model to help determine and document which potential sites are the most crucial [186]. Decision support system for optimal maintenance decisions by multi-objective approach have also been formulated for a road network by considering functional condition [187].

During winter, the use of a decision support system for road-maintenance can be crucial. The FHWA Office of Transportation Operations Road Weather Management Program developed a winter road-maintenance decision-support system (MDSS) which is a unique data-fusion system designed to provide real-time treatment guidance [188]. The MeteoTrassa system combines data to present integrated road weather observations and predictions for the road network and generates recommendations on road treatment strategies based on standard practices for effective winter road maintenance [189].

All in all, Decision Support tools of different types and extents are broadly used in industry. IBM Maximo Application Suite is an intelligent asset management, unifying monitoring, predictive maintenance, computer vision, safety and reliability in a single platform which allows technicians to manage assets. On a different front, Siemens has developed the Railigent platform for rail services, which optimises the whole life-cycle cost through digital asset management, as well as the maintenance and operation planning lowering costs, decreasing downtimes and reducing unnecessary transfers to maintenance. Another German company, LocLab, develops digital twins to develop simulations, resources and planning optimisations and help in the decision-making of different fields like transport, energy, manufacturing and cities and communities. INTUENDI uses machine learning technology to effectively optimise inventory. AMBOSS helps clinicians to make effective clinical decisions guided by evidence-based recommendations. Powernoodle helps leaders engage their stakeholder and make quality decisions. These and many more decision support tools are starting to be commercially used across different sectors.

OMICRON will develop a high-level DST for decision-making which will aim at reducing the human role in planning tasks also in case of unexpected events. The uncertainty of the infrastructure status prediction will be considered as well as the criticality of road sections. The impact on the performance of the overall network and the impact on road users will be also carefully considered. Using the inputs from inspection and from the DT, the DST to be developed in OMICRON will be able to combine all of these needs and requirements from the infrastructure to enhance the planning of maintenance interventions.

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The proposed DSTs will be able to plan maintenance intervention activities at different planning levels, which will be assessed according to the KPIs set by the infrastructure manager.

3.6.2.2 Summary of technical requirements

OMICRON will develop a decision support tool for roads. The DST system will combine methodologies and models for optimal planning of interventions and resources towards predictive maintenance. This system will analyse and predict infrastructure condition, assess infrastructure degradation risk and define optimal road intervention planning depending on road asset state, intervention level and term planning.

In order to achieve these objectives, the DST will process data from different sources, including:

1. Already existing systems.
2. Digital inspection systems from OMICRON's WP2.
3. Road intervention information from WP3 and WP4.

These sources will integrate information such as historical records, real-time data recorded by sensors, digital twin simulations, etc.

The DST has two main features, the first one is the **infrastructure condition analysis**, where AI techniques, advanced models for asset status computation and decision-making and clustering methods for road sectioning according to condition state, safety risk and accessibility are used to process the data from the digital twin, assess infrastructure degradation risk and analyse and predict infrastructure condition. The second feature is the **asset management plan optimisation** which develops the maintenance planning functionality to improve the availability and reliability of the infrastructure, maintaining the levels of service and the safety of the road infrastructure. It also enables higher level of automation in decision-making through advanced optimisation techniques.

The maintenance plans will adapt to short, medium and long-term planning procedures; emergency, routine and extraordinary intervention levels; and different road assets. The prioritisation of interventions considers the previous results from the infrastructure condition analysis, as well as road section in terms of safety and impact on traffic and the optimisation of resources. The DST will use advanced optimisation techniques, maintenance plan simulation and comparison via what-if scenarios. All this information generated by the DST will be provided to the road concessionaire, to develop the work orders that must be applied to the road network.

As stated earlier, this Use Case is supported by the information and the technologies developed in previous Use Cases: UC1.1 (UAVs: Management Tool), UC1.2 (Inspection Vehicle) and UC6.1 (Road Digital Twin). This means the UAV inspection technologies, the vehicle inspection technologies, the data acquisition platform and the digital twin are required for the DST implementation. Before the DST can start working, all the previous digital inspection technologies which provide information to the Digital Twin must be complete and the DT must be correctly developed and tuned to provide adequate information to the platform.

Finally, a summary of the main information from the use case is presented in the following table.

Table 28. Summary of UC6.2

Title	UC6.2 Road decision support tool
Short Narrative	The decision support system to be developed in OMICRON will combine methodologies and models for optimal planning of interventions and resources towards predictive maintenance. This system will analyse and predict infrastructure condition, assess infrastructure degradation risk and define optimal road intervention planning.

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Title	UC6.2 Road decision support tool
Cluster Use Case	UC6: DT and Predictive maintenance
Connection to other Use Cases	UC6.2 is supported by UC1.1 UAVs: Management Tool, UC1.2 Inspection Vehicle and UC6.1 Road Digital Twin
Actors	Decision support tool, Digital twin, Historic records, OMICRON digital inspection technologies, road contractor, road concessionaire, communication system and Existing sensors, processes and measuring systems
Scope	The scope of this Use Case is the development and implementation of OMICRON's Decision Support Tool (DST) for roads. The DST will use information previously gathered or obtained through different technologies to assess and predict the infrastructure condition and infrastructure degradation risk, so as to generate optimal road intervention planning. Therefore, this tool provides decision-making support reducing human effort and helping in the case of unexpected events and develops maintenance plans depending on road asset state, intervention level and term planning.
Objectives	Through the implementation of the DST the Use Case aims to: • Improve availability and reliability of the infrastructure. • Optimise maintenance times and use of resources. • Implement improved maintenance plans.

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4 Project Key Performance Indicators

OMICRON has a solid Key Performance Indicator (KPI) system with the objective of monitoring and evaluating the results of the project. This is based on the KPI definition provided in OMICRON's Grant Agreement, although it is refined and elaborated in Task 1.1 (reported in this deliverable) and Task 6.1 (reported in D6.1).

The list of KPIs in OMICRON is presented in Table 29, including their overall target values and the link to the overall objectives of the project (referring to deliverable D8.1), divided in Specific Objectives (SO), Socio-Economic Objectives (SEO) and Environmental Objectives (EO).

Table 29. OMICRON indicators and target reductions, including the connection to the project objectives (from D8.1 and GA) and Project Expected Impacts (PEI)

Ref.	Key Performance Indicator	Target	Objectives	PEI
KPI 1	Exposure time of road workers and users to hazardous situations derived from inspection tasks	- 65%	SO: 2,3; SEO: 2,3	1
KPI 2	Emergency, ordinary and extraordinary maintenance intervention times	- 15%	SO 5; EO 2,3	1
KPI 3	Volume of people in dangerous zones in road maintenance areas	- 30%	SO 3,5	1
KPI 4	Volume of major intervention actions	- 10%	SO 4,6; SEO 1	1
KPI 5	Traffic disruptions due to inspection tasks	- 50%	SO 2	2
KPI 6	Traffic disruptions due to maintenance interventions	- 10%	SO 3,4,5	2
KPI 7	Bridge retrofitting traffic disturbances	- 30%	SO 5	2
KPI 8	Congestion due to traffic disturbances	- 10%	SO 3	2
KPI 9	Maintenance and inspection activity costs	- 10%	SO 2,3,5	3
KPI 10	Reduction of carbon footprint in the life cycle of bridges (1)	- 30%	SO 5; EO1	3
KPI 11	Road infrastructure maintenance costs	- 12%	SO 4,6	3
KPI 12	Road Hazard Index	- 58%	SO 2,4,5,7	4
KPI 13	Availability of the network. Impact of a reduced number of disruptions due to accidents and interventions	+ 15%	SO 2,4,5	4
KPI 14	Availability of the network. Impact of the reduction of traffic disruptions due to maintenance	+ 8%	SO 4,5,6,7	4

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(1) KPI 10 is the only indicator that has changed from the initial GA description of actions. Due to the high maintenance costs of the steel parts of the proposed hybrid bridge solution (UC4), which need to be repainted every 15 years, it would not be possible to reduce maintenance costs when compared to a conventional concrete solution (which is the baseline selected for this Use Case). Therefore, the KPI has been replaced with another one following objective EO1 (supporting the road transport sector in the transition set by the European Green Deal): reduction of the carbon footprint in the life cycle of bridges. This new KPI is based on the fact that the new hybrid reinforced concrete and steel solution will increase the amount of material that can be recycled at deconstruction and reused in new constructions.

The project KPIs in Table 29 above contribute to a set of four general Project Expected Impacts (PEIs), focused on the main road asset management impact areas that are tackled in OMICRON. These impacts are shown in Table 30.

Table 30. Project Expected Impacts

Ref.	Description	Target	Objs.
PEI 1	Fatal accidents of road users and deployed personnel due to maintenance works	> - 50%	All
PEI 2	Traffic disruptions due to maintenance works	> - 20%	
PEI 3	Routine maintenance costs	> - 20%	
PEI 4	Network capacity, based on the levels measured at the beginning of the project	> 20%	

The relations drawn by the contributions of the project KPIs to the overall project PEIs are shown in Table 31, where the estimated contributions are also collected.

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Table 31. Contributions of project KPIs to overall project impacts (PEIs)

	PEI 1	PEI 2	PEI 3	PEI 4
KPI 1	- 65%			
KPI 2	- 15%			
KPI 3	- 30%			
KPI 4	- 10%	- 10%		
KPI 5		- 50%		
KPI 6		- 10%		
KPI 7		- 30%		
KPI 8		- 10%		
KPI 9			- 10%	
KPI 10			- 30% (1)	
KPI 11			- 12%	
KPI 12				- 50%
KPI 13				+ 15%
KPI 14				+ 8%

Once the relation between the Project Expected Impacts and the Key Performance Indicators has been drawn, the next step is to present the connection and the contributions of the Use Cases to the project KPIs. This connection is summarised in Table 32, where the percentage contribution of each of the Use Cases is presented. The following general notes apply to certain KPIs of the table, following the numbering.

(1) The high-level use cases represent the overall impacts from certain technologies such as the UAV inspection platform tool, the terrestrial inspection vehicle or the modular robotic platform. These percentages are calculated as the mean of the contributions of each detailed use case.

(2) KPIs 12, 13 and 14 will be computed as an overall improvement from the joint impact of all project technologies, targeting percentage changes of at least -50%, +15% and +5% respectively.

(3) As stated in Table 29, KPI 10 is the only one that has been redefined due to the baseline for comparison used to compute the KPI. It is not focused on life cycle costs of bridges but on their life cycle carbon footprint, as explained above and in the description of UC4 in Annex C.

The details addressing the project KPIs and their effects in OMICRON's use cases are presented in the requirements forms presented in Annex C. In this context, the following subsection provides a preliminary description of how the PEIs will be computed in the project.

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Table 32. Contributions of project UCs to project KPIs

Use Case		Name	PEI 1			P1-2	PEI 2				PEI 3			PEI 4 (2)		
			KPI1	KPI2	KPI3	KPI4	KPI5	KPI6	KPI7	KPI8	KPI9	KPI10	KPI11	KPI12	KPI13	KPI14
UC1	UC1.1	UAVs: Management Tools (1)	-65%				-50%				-10%			-50%	15%	5%
	UC1.1.1	Long Range inspections	-65%				-50%				-10%					
	UC1.1.2	Multi-UAV	-65%				-50%				-10%					
	UC1.2	Inspection vehicle (1)	-65%			-10%	-50%				-10%			-50%	15%	5%
	UC1.2.1	Innovative sensor combination	-65%				-50%				-10%					
	UC1.2.2	Automatic computation of road index	-65%				-50%				-10%					
	UC1.3	V2X communications						-10%		-10%					15%	5%
UC2	UC2.1	Robotic Modular Platform (1)		-8%	-64%			-8%			-22%			-50%	15%	5%
	UC2.1.1	Installation of safety barriers		-10%	-25%			-10%			-10%					
	UC2.1.2	Installation of cones		-10%	-40%			-10%			-20%					
	UC2.1.3	Road assets cleaning		-20%	-90%			-20%			-45%					
UC3	UC3.1	Signalling during construction works		-15%	-30%			-10%			-10%					
	UC3.2	Sealing of surface pavement cracks		0%	-75%			0%			-13%					
	UC3.3	Removal of lane markings with laser		0%	-90%			0%			-26%					
	UC3.4	Rehabilitation of pavement		-20%				-30%			-25%			-50%	15%	5%
UC4	UC4	Modular construction for bridges (3)			-5%				-30%			-30%				
UC5	UC5.1	VR platform		-15%	-50%											
	UC5.2	AR tool		-15%	-50%											
UC6	UC6.1	Road digital twin				-10%							-12%			
	UC6.2	Decision support tool				-10%							-12%	-50%	15%	5%

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4.1 Computation of Project Expected Impact points

4.1.1 PEI 1. Reduction of fatal accidents due to maintenance works of road users and deployed personnel by 50%

OMICRON addresses a variety of asset management processes that lead to a direct reduction in the number of road accidents and, hence, related fatalities. These aspects include the fields presented in Table 33, following the values in Table 32.

Table 33. Fields used in the computation of PEI 1, following the values on Table 32

Ref.	Symbol	Description	Expected Value
1	ΔKPI_1	Reduction of the exposure due to intervention actions	- 65%
2	ΔKPI_2	Reduction of maintenance intervention times	- 15%
3	-	Reduction in the number of people in dangerous situations via the use of robotics	- 25%
4	-	Reduction in the number of people in dangerous situations via the use of AR and VR tools	- 50%
5	ΔKPI_4	Reduction of the number of major intervention actions due to enhanced planning	- 10%

Considering fields 3 and 4 in the table above, the reduction of people in dangerous zones during maintenance interventions (KPI 3) can be estimated as:

$$\Delta KPI_3 \sim - \ 30\%$$

Furthermore, the reduction in the probability of accidents during the course of intervention actions can be estimated as:

$$\Delta PEI_1(interventions) = \Delta KPI_2 + \Delta KPI_3 - \Delta KPI_2 \cdot \Delta KPI_3 \sim - \ 40\%$$

Likewise, the reduction in the probability of accidents during the course of maintenance actions and inspections (inspection and maintenance, I&M) can be estimated as:

$$\Delta PEI_1(I\&M) \sim - \ 53\%$$

Finally, the overall PEI on the reduction of fatal accidents can be computed as shown in equation (1).

$$\begin{aligned} \Delta PEI_1 &= \Delta KPI_4 + g\big(\Delta KPI_1, f(\Delta KPI_2, \Delta KPI_3)\big) - \Delta KPI_4 \cdot g\big(\Delta KPI_1, f(\Delta KPI_2, \Delta KPI_3)\big) \\ &= \Delta KPI_4 + \Delta PEI_1(I\&M) - \Delta KPI_4 \cdot \Delta PEI_1(I\&M) \sim - \ 58\% \end{aligned} \tag{1}$$

4.1.2 PEI 2. Reduction of traffic disruptions due to maintenance works by 20%

OMICRON's Intelligent Platform has the objective of improving the service provided to road users via PEI 2. There are several areas in which OMICRON's technologies could improve mobility, as presented in Table 34.

Table 34. Fields used in the computation of PEI 2, following the values on Table 32

Ref.	Symbol	Description	Expected Value
1	ΔKPI_5	Reduction of disruptions due to inspection tasks	- 50%

2	ΔKPI_6	Reduction of disruptions due to maintenance tasks	- 10%
3	ΔKPI_7	Reduction of disruptions due to bridge retrofitting	- 30%
4	ΔKPI_8	Reduction of disruptions applying V2X communications	- 10%

Following the values in the table above, the overall reduction of disruptions due to interventions via the joint action of ΔKPI_6 and ΔKPI_7 can be estimated as:

$$\Delta PEI_2(Interventions) \sim -\ 11\%$$

Furthermore, the overall reduction via enhanced digitalisation applying V2X (ΔKPI_8) and the intelligent platform technologies (ΔKPI_4) may be estimated as follows:

$$\Delta PEI_2(V2X\ \&\ DT) = \Delta KPI_4 + \Delta KPI_8 - \Delta KPI_4 \cdot \Delta KPI_8 \sim -\ 19\%$$

Likewise, the combined action of inspection and intervention technologies can be estimated as follows:

$$\Delta PEI_2(I\&M) \sim -\ 15\%$$

Finally, the overall PEI on traffic disruptions can be computed by taking into account the above technologies as shown in equation (2).

$$\begin{aligned}\Delta PEI_2 = {} & \mathrm{f}(\Delta KPI_4, \Delta KPI_8) + g\big(\Delta KPI_5, f(\Delta KPI_6, \Delta KPI_7)\big) - \mathrm{f}(\Delta KPI_4, \Delta KPI_8) \\ & \cdot g\big(\Delta KPI_5, f(\Delta KPI_6, \Delta KPI_7)\big) \\ & = \Delta PEI_2(V2X\ \&\ DT) + \Delta PEI_2(I\&M) - \Delta PEI_2(V2X\ \&\ DT) \\ & \cdot \Delta PEI_2(I\&M) \sim -\ 31\%\end{aligned} \quad (2)$$

4.1.3 PEI 3. Reduction of routine maintenance costs by 20%

OMICRON establishes an innovative framework for the maintenance guidelines of roads in which a definitive step forward towards industrialisation and robotisation will be taken. The main specific impacts are presented as follows.

Table 35. Fields used in the computation of PEI 3, following the values on Table 32

Ref.	Symbol	Description	Expected Value
1	ΔKPI_9	Reduction of costs related to inspection and maintenance tasks	- 10%
2	ΔKPI_{11}	Reduction of costs due to enhanced planning via the DST	- 12%

The overall reduction of infrastructure costs can be computed by considering the above technologies as shown in equation (3).

$$\Delta PEI_3 = \Delta KPI_{11} + \Delta KPI_9 - \Delta KPI_{11} \cdot \Delta KPI_9 \sim -\ 20\% \quad (3)$$

4.1.4 PEI 4. Improvement of network capacity by 20%

OMICRON's Intelligent Platform has the objective of contributing to the optimisation of the use of road networks via the application of enabling technologies in the whole road asset management pipeline, including digitalised inspection, enhanced and robotised maintenance interventions, improved retrofitting methodologies, improved evaluation methodologies using DTs and improved intervention planning using OMICRON's DST. Therefore, the improvement of network capacity will be given through the combined achievement of PEI points 1 to 3.

In this respect, the Road Hazard Index (KPI_{12}) is computed as presented in equation (4).

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$$RHI = \frac{Number\ of\ accidents\ with\ fatalities \cdot 10^8}{Mean\ Daily\ Traffic\ Intensity \cdot 365 \cdot Length\ (km)} \quad (4)$$

Using this equation, the values in Table 36 can be used to simulate the current and future status of the RHI for a road stretch of 100 km in the final demonstrator.

Table 36. Fields used in the computation of the RHI

Ref.	Symbol	Description	Current estimated value
1	-	Number of accidents with fatalities	140
2	-	Mean Daily Intensity (High Demand Scenario)	50000
3	-	Road Longitude (km)	100
4	ΔPEI_1	Reduction in the number of fatalities using OMICRON technologies	- 58%
5	ΔPEI_2	Reduction of traffic disruptions	- 31%

The computation before and after the project yields an estimated reduction in the Road Hazard Index of:

$$\Delta KPI_{12} \sim -\ 58\%$$

Besides, the availability of the infrastructure can be calculated as the uptime over the whole operating cycle of the infrastructure. A high demand ratio of 0.3 can be assumed for a potential 100 km stretch in the final demonstrator. Considering the enhancements related to the reduction of the number of accidents and the reduction of traffic disruptions in Table 36, the increase in availability due to these two instances may be calculated as shown in Table 37.

Table 37. Improvements in availability

Ref.	Symbol	Description	Current estimated value
1	$\Delta PEI_4(Accidents)$	Increase of availability following a reduced number of traffic disruptions caused by accidents and interventions	+ 15%
2	$\Delta PEI_4(Maintenance)$	Increase of availability following a reduced number of traffic disruptions caused by maintenance	+ 8%

Following the availability improvements in Table 37, the overall increase in network capacity can be computed as shown in equation (5).

$$\Delta PEI_4 = \Delta PEI_4(Accidents) + \Delta PEI_4(Maintenance) - \Delta PEI_4(Accidents) \cdot \Delta PEI_4(Maintenance) \sim +22\% \quad (5)$$

Section 4 shows a **preliminary assessment of project KPIs and PEIs**, as well as an initial computation of project expected impact points. It is important to note that the numbers and predictions shown in this section will have to be refined and may vary throughout the project, according to the real results. The revision of the KPIs and PEIs will be performed in WP6.

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5 Conclusion

This document has presented the main outcomes of two key tasks within OMICRON: T1.1, focused on the definition of the functional requirements of the Intelligent Platform; and task T1.2, focused on the analysis of the standards and legislation environment of all of OMICRON technologies. Precisely, deliverable D1.1 has covered the following topics:

1. The description of the methodology applied to define the requirements of the various technologies in OMICRON, following the IEC PAS 62559 standard, structured in technology Use Cases and commercial Business Cases.
2. The assessment of the current standards and legislation applicable to the OMICRON use cases, covering five main relevant umbrellas, i.e. drones, road inspection, robotics, machinery and maintenance, and data treatment.
3. The state of the art related to each of the use cases defined in OMICRON.
4. A summary of the requirements of each of the use cases, including the problem to be solved, a short narrative, the actors involved, the scope and the overall objectives of the use case.
5. A further definition of the project indicators and impacts, following the description provided in the Grant Agreement and deliverable D8.1, and preceding the definition of the evaluation methodology to be presented in D6.1.
6. The detailed description of each of the use cases (provided in Annexes A to C), following the IEC PAS 62559 template so as to define the technology requirements in detail.

The objective is to leave the requirement forms in Annex C as open documents that can be adapted throughout the project.

In this context, the progress in tasks T1.1 and T1.2 reported in this deliverable has established the link among:

- ✓ The project’s Business Cases.
- ✓ The technologies, clustered into use cases.
- ✓ The current level of development in each of these technologies or processes.
- ✓ The context legislation and standards.
- ✓ The requirements set for a successful deployment of the project, resulting in project KPIs and overall impact points (PEIs).

The work presented in this report is to be continued in tasks T1.3, addressing the final demonstrator, and T1.4, addressing the definition of the testing and demonstration procedures in OMICRON. The objectives will be to adapt the project technologies to real world scenarios (represented by the demonstrators) following the baseline of the project requirements in D1.1. This will require to further deepen in the preliminary testing, the four technical demonstrators and the final project demonstrator to present a detailed definition of OMICRON’s evaluation methodology.

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Annex A. List of Actor Subcategories

This Annex presents the corrected list of actor subcategories that was used in the definition of requirements for the OMICRON UCs following IEC PAS 62559.

Category	Type	Subcategory	Definition	Example
Actors	Role	Infrastructure owner	Owner and, depending on the specific case, manager of the infrastructure	Dirección General de Carreteras (Spain) Highways England
Actors	Role	Road concessionaire	Manager of the infrastructure	Abertis Cintra
Actors	Role	Road contractor	Provider of services to road infrastructures	Strukton Civil
Actors	Role	Road constructor	Builder of road infrastructures	Acciona
Actors	Role	Civil engineering contractor	Design, quality control or health and safety provider among others, generally addressing specific projects	Arup Laing O'Rourke
Actors	Role	Industrial partner	All industrial partners involved in a project	
Actors	Role	University and research partner	All university or research partners involved in a project	
Actors	Role	Retailer	Licensed supplier in any area of the project	
Actors	Role	User	A physical user that is involved at any area of the project	

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Category	Type	Subcategory	Definition	Example
Actors	System	Robotic element	Any robotic system involved in the project	
Actor	System	Road machinery	Any device used in the process of road management and intervention	Inspection vehicle
Actors	System	Communication infrastructure	All the infrastructure that are used for communication at all levels	Modems Routers
Actors	System	Interactive communication device	All devices used to interact with customers in the project	Web portal Display used for communication
Actors	System	Network element	All systems in the roadway network. It also includes the IS associated	Signalling Bridges Sensors
Actors	System	IS IT	All the hardware and software in the network in order to control or monitor it, among others	SCADA Central database Control center
Actors	System	Laboratory	All the equipment necessary to perform the monitoring campaign scaled model lab-testing	

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Annex B. List of Information Subcategories

This Annex presents the corrected list of information subcategories that was used in the definition of requirements following IEC PAS 62559.

Category	Type	Subcategory	Definition	Example
Data	Document	Internal document	All the documentation used to run operation, to monitor and conduct the project's good development	Meeting minutes Report on the cost's impact on selected design plans
Data	Document	Project deliverable	All the deliverables to be produced during the project's time as agreed in the DOW	Documentation on KPI Detailed Use Case Report on technical demonstration
Data	Document	Communication material	All the documentation that describes the project to the public and can be put on the future website	Purpose of the demonstration (leaflet) Brief description of Use Case Location of Use Case
Data	Financial data	Project financial data	All the financial data that is produced during the project and that is used to make financial report for European Commission and internal report	Invoices Cost and time imputation
Data	Financial data	Solution cost and selling price	All the financial data that can be made concerning estimation prices of solution for replication	Unit product cost of hardware developed by demonstrator Sell price of the developed solution (software, etc.)
Data	Parameter	Condition parameter	All the external parameters that may influence the success of the Use Case	Weather Time of day Day of week

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Category	Type	Subcategory	Definition	Example
Data	Parameter	Scenario assumption	All the stated parameters that are necessary to determinate a scenario for the Use Case	Experiment's location State of the road
Data	Parameter	Electrical parameter	All electrical parameters used	Intensity Voltage Frequency
Data	Parameter	Mechanical parameter	All mechanical parameters used	Force Torque
Data	Parameter	Algorithm, formula, rule, specific model	All the intellectual data that is created during the project to make software's contents	Vision algorithm Road condition state algorithm
Data	Parameter	Optimised value	Values of parameters that optimised the Use Case or the demonstration's performance	Optimisation of road maintenance planning
Data	Parameter	Forecast data	All the data used to forecast any relevant information	Forecast of traffic Estimated Time of Arrival
Data	Parameter	Historic data	All data taken from historic data bases.	Weather information Usage data
Data	Infrastructure data	Network topology	All information on network devices and their location and interactions	Map of the network Data found in a GIS system (Geographical Information System)

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Category	Type	Subcategory	Definition	Example
Data	Infrastructure data	Network state	All information concerning the road network's status (global or local) at a precise moment useful to monitor the network	Situation in road section State of network Location of congestion
Data	Infrastructure data	User information	All the information concerning the road user	Traffic flows
Data	Infrastructure data	Operator information	All the information concerning the road operator, maintainer, contractor, etc.	Maintenance action state
Data	Parameter	Information exchanged between IS or sent to device	All data sent between facilities/devices to recover information	Order sent to road operators Information on local network status coming from sensors Order and roadmap sent to network devices
Data	Parameter	Detailed specification on devices	All detailed information (reference components, specification, process, etc.) useful to build an element	Detailed specification of the telecommunication infrastructure Detailed specification of sensor network
Data	KPI	Data for KPI (input raw data)	All raw data that are used to calculate the final KPI	Duration of demonstrator Electro-mechanical parameter used for a KPI
Data	KPI	KPI (KPI values)	All the KPI values and the way to calculate them	Economic KPI System Efficiency KPI

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Annex C. Use Case Requirement Forms

Use Case 1.1. UAVs management tool

Use Case 1.1.1. Long range inspections

Use Case 1.1.2. Multi-UAV

Use Case 1.2. Inspection vehicle

Use Case 1.2.1. Innovative sensor combination

Use Case 1.2.2. Automatic computation of road index

Use Case 1.3. V2X communications

Use Case 2.1. Robotic Modular Platform

Use Case 2.1.1. Installation of safety barriers

Use Case 2.1.2. Installation of cones

Use Case 2.1.3. Road assets cleaning

Use Case 3.1. Signalling during construction works

Use Case 3.2. Sealing of surface pavement cracks

Use Case 3.3. Removal of lane markings with laser

Use Case 3.4. Rehabilitation of surface pavement layers

Use Case 4. Modular construction for bridges

Use Case 5.1. VR platform

Use Case 5.2. AR tools

Use Case 6.1. Road digital twin

Use Case 6.2. Road decision support tool

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OMI((RON

Intelligent Road Asset Management Platform

UAVs Management Tool

Definition of Requirements

Publish Date: 30.07.2021

Use Case Number: UC1.1

Use Case Title: UAVs Management Tool

Use Case Responsible Partner: USE

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 955269

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1 Description of the Use Case

1.1 Use Case Identification

ID	Domain(s)	Name of Use Case	Level of Use Case
UC1.1	UC1: Inspection, V2X communications and user support	UAVs: Management Tool	High Level Use Case

1.2 Scope and Objectives

Scope and Objectives of the Use Case	
Scope	The scope of the use case is the validation of the UAVs Management Tool that will allow to define and execute long-range and multi-UAV inspection. After the inspection is performed the data will be gathered. The UAVs Management Tool allows to define the locations and images that should be obtained for two different types of inspection: long-range inspection and multi-UAV inspection. If there is an unexpected event or failure, a safety pilot can command the UAV lo land immediately or return to the landing area. This safety pilot is needed due to the current regulation. The images obtained during the inspection flight will be recorded onboard and they will be transferred to the Management Tool after the UAV has landed. Later, the inspector can retrieve the data using the Management Tool.
Objective	The objectives are the following: • Definition and configuration of multi-UAV and long-range inspection missions • Execution and monitoring of multi-UAV and long-range inspection operation • Retrieval of data collected
Related Business Case	*BC2, Digitalization and Automation of road inspection procedure*

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1.3 Narrative of Use Case

Short description – max 3 sentences
The inspector will use the UAVs Management Tool to define the inspection operation and the UAV operator will execute the inspection when required. Moreover, the inspector will also be able to retrieve the data gathered after the inspection is performed.
Complete description
The inspector responsible for the road assessment will define the inspection mission. The definition includes the locations (e.g., geographic coordinates), the kind of images (e.g., lateral view or overhead), and the image quality (e.g., GSD – ground sample distance). Then, with this information, the Management Tool plans the inspection and calculates the UAV trajectory. If the Management Tool finds a solution, an inspection mission is deemed feasible, it is stored, and the inspector receives a *successful definition* notification. If the Management Tool doesn't find a solution, the inspector receives an *unsuccessful definition* notification. After an inspection mission has been successfully defined, the UAV operator can execute it. First, the UAVs are powered on by the safety pilots. Due to current regulations, there will be a safety pilot with a valid license making sure that the UAV carries out the specified mission. If something unexpected happens, this pilot will take remote control of the aerial platform and perform a safe landing. Then, the UAV operator establishes the Management Tool – UAV communications, and he selects a inspection mission from a list. After showing the planned inspection details, the UAV trajectories are uploaded, and the inspection starts. If everything goes as planned, the UAVs land after completing the inspection, the data are stored in the Management Tool, and the UAVs are powered off. In case an unexpected event happens, or an unfeasible inspection is estimated, the safety pilot commands the UAV to land or return home, and the inspection is deemed unsuccessful. After an inspection has been successfully completed, the inspector will be able to retrieve all the data generated during the mission.

1.4 KPIs

Key performance indicators description for the Use Case:

ID	Name	Description	Target	Reference to mentioned Use Case objectives
UC1.1	KPI 1	Exposure time of road workers and users to hazardous situations derived from inspection tasks	Reduction of the exposure time by 65% due to the use of automated UAV and terrestrial inspection vehicles	Development of advance inspection modules

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UC1.1	KPI 5	Traffic disruptions due to inspection tasks	The automation and robotization of inspection tasks in OMICRON should reduce traffic disruptions by at least 50%	Development of digital inspection modules
UC1.1	KPI 9	Maintenance and inspection activity costs	The enhancements in inspection and intervention tasks in OMICRON will reduce costs by at least 10%	Development of automated inspection
UC1.1	KPI 12	Road Hazard Index	The RHI will be reduced by 50% due to the implementation of OMICRON's Intelligent Platform	Development of UAVs Management Tool
UC1.1	KPI 13	Availability of the network. Impact of a reduced number of disruptions due to accidents and interventions	The availability of road infrastructures will increase by 15% due to a reduced number of traffic disruptions caused by accidents and interventions	Development of UAVs Management Tool
UC1.1	KPI 14	Availability of the network. Impact of the reduction of traffic disruptions due to maintenance	The availability of road infrastructures will increase by 5% at least due to a reduced number of traffic disruptions caused by maintenance	Development of UAVs Management Tool

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1.5 Use Case Conditions

Actor	Triggering Event	Pre-conditions	Assumption
Describe which Actor(s) trigger(s) this Use Case	Describe what event(s) trigger(s) this Use Case	Describe what condition(s) should have been met before this Use Case happens	Describe the assumptions about conditions or system configurations.
Inspector UAV operator	Inspection needs	In case of *Configuration* • Management Tool is running • Definition of inspection resources • Site map In case of *Execution* • UAVs in the landing area • Management Tool is running • Inspection defined • Inspection resources available and ready to fly • Site map • Flight permits granted In case of *Retrieve data* • Management Tool is running • Inspection performed	In case of *Execution* • UAVs are properly located inside the landing area • The communication range is enough for the inspection mission

1.6 Classification Information

Relation to Other Use Cases in the same project or area
Includes UC1.1.1 and UC1.1.2
Level of Depth - the degree of specialization of the Use Case
High Level Use Case

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Further Keywords for Classification
Visual inspection, inspection definition, multi-UAV, long-range, data gathering
Maturity of Use Case
- In preparation.

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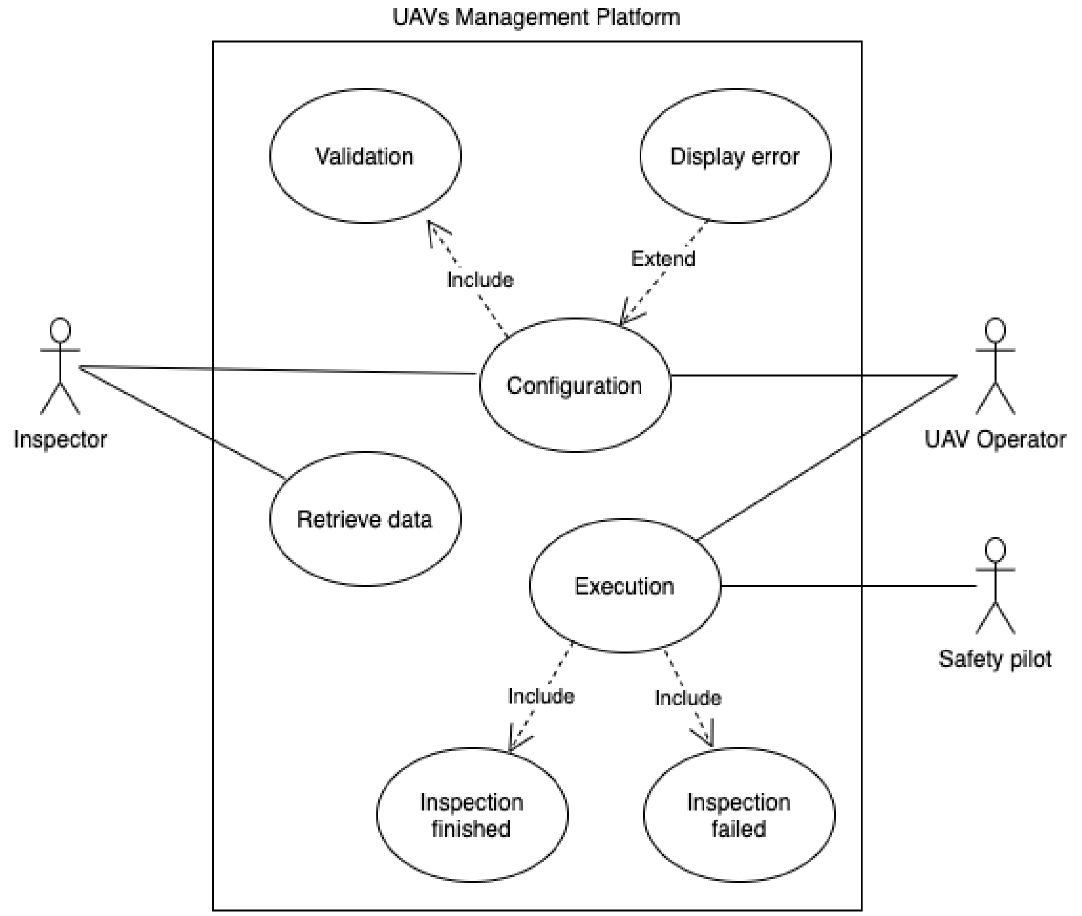
2 Diagrams of the Use Case

Context Diagram



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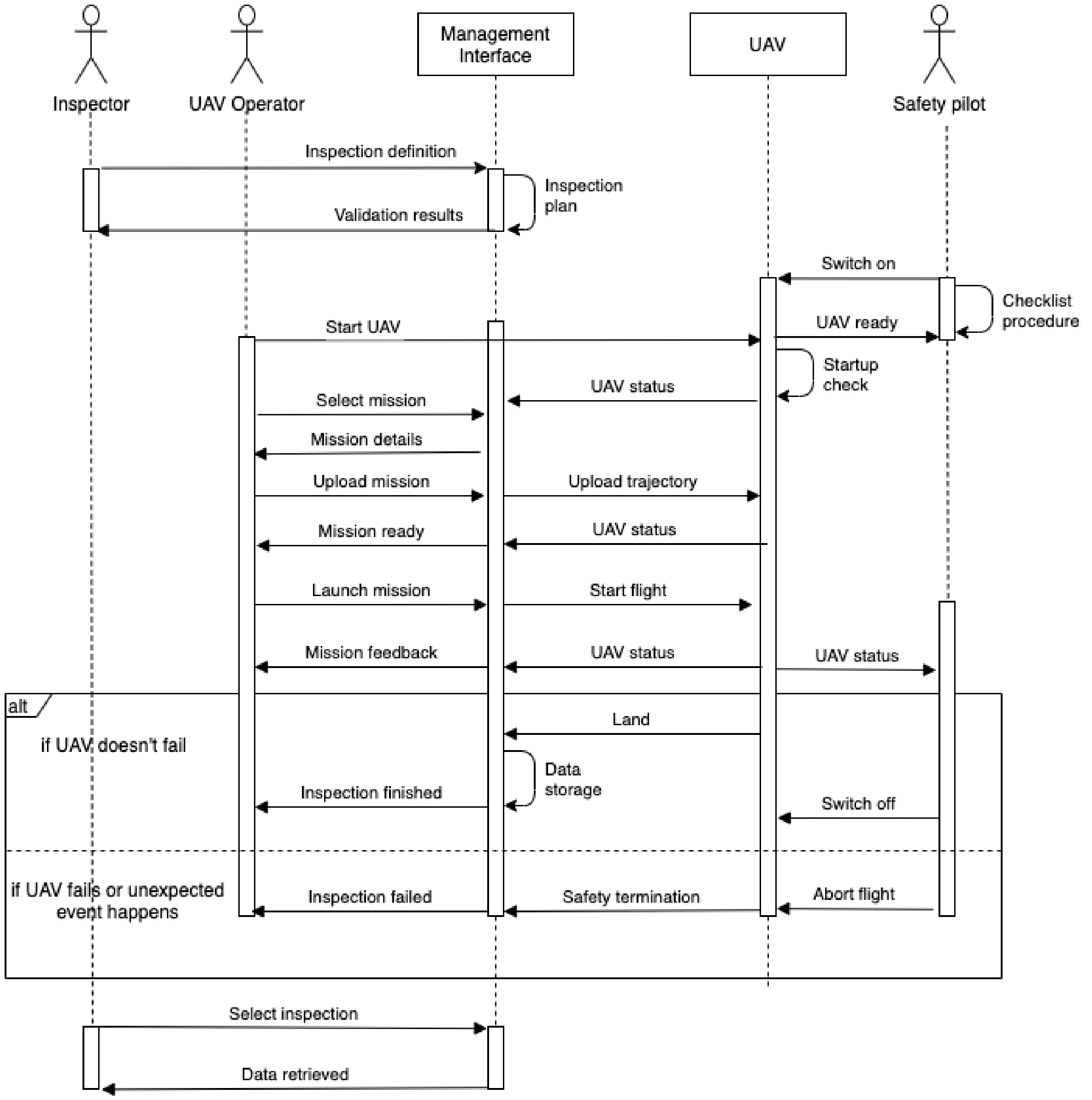
Sequence Diagram



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3 Technical details of the Use Case - Actors

Actor Name	Actor Type	Actor Subcategories	Actor description	Further information specific to this Use Case	Equipment Manufacturer	Requirement(s) of the actor	Reference Standards/Legislation
Inspector	Role	User	Person in charge of defining the inspection needs	The inspector defines the locations to be inspected, the data		Knowledge of the construction site and inspection resources (number of UAVs, inspection sensors, …)	
UAV operator	Role	User	Person that executes and supervises a UAV inspection	The UAV operator loads and executes the inspection tasks. He also monitors the progress of the task, including the UAV state and its trajectory.		Knowledge of the construction site and inspection resources, knowledge of UAV technology and performance	
Safety pilot	Role	User	Safety pilot in case of unexpected events	A safety pilot is required due to current regulation. In case of unexpected events the safety pilot could take control of an UAV to terminate the flight.		Defined by national or European regulation as detailed in task T1.2	To complete from task T1.2
Management Tool	System	IS IT	Management Tool hardware and software	The Management Tool includes the application (visual interface, database access, communications with UAVs, …) and the equipment required to work.			
UAV	System	Robotic element	UAV that can perform an inspection task	The UAV will perform autonomous inspections using an onboard camera. The UAV will follow a		Some requirements could apply from national or European regulation as detailed in task T1.2	To complete from task T1.2

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				planned trajectory to provide the images required.			

3.1 Other requirements

Provide any further requirements (technical or of other kind) which were not provided in section 3 or 5.

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4 Step by Step Analysis of the Use Case

4.1 List of scenarios

See Section 4.1 in UC1.1.1 and UC1.1.2.

4.2 Steps - Primary Scenario

See Section 4.2 in UC1.1.1 and UC1.1.2.

4.3 Steps – Alternative, Error Management, and/or Maintenance/Backup Scenario

See Section 4.3 in UC1.1.1 and UC1.1.2.

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5 Information Exchanged

This section provides detailed information about the information exchanged within the Use case (in the scenario steps).

See Section 5 in UC1.1.1 and UC1.1.2.

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OMI((RON

Intelligent Road Asset Management Platform

Long Range inspection

Definition of Requirements

Publish Date: 31.08.2021

Use Case Number: UC1.1.1

Use Case Title: Long Range inspection

Use Case Responsible Partner: CATEC

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1 Description of the Use Case

1.1 Use Case Identification

ID	Domain(s)	Name of Use Case	Level of Use Case
UC1.1.1	UC1: Inspection, V2X communications and user support UC1.1: UAV inspection	Long Range inspection	Detailed Use Case

1.2 Scope and Objectives

Scope and Objectives of the Use Case	
Scope	The scope of the use case is the validation of a UAV-based solution for the long range inspection of road infrastructure, with the highest levels of safety during the flight.
Objective	• Definition and configuration of long range inspection mission. • Execution and monitoring of long range inspection operations. • Develop Detect&Avoid technologies for the UAV, allowing both the sharing of airspace with other aircrafts and the achievement of remote long range and low altitude inspection flights. • Retrieval of data collected.
Related Business Case	*BC2, Digitalization and Automation of road inspection procedure*

1.3 Narrative of Use Case

Short description – max 3 sentences
The inspector will make use of a UAV-based solution to examine a specific section of a road. After specifying the required information, the UAV operator will plan the mission accordingly, and the UAV will autonomously cover the desired area to acquire high-quality images for building a precise 3D map afterwards, while ensuring the safety of the full mission making use of automatic obstacle detection and avoidance capabilities.
Complete description

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The inspector responsible for the road assessment will define the inspection mission. The definition includes at least the area of interest (e.g. geographic coordinates) and the image quality (e.g. Ground Sample Distance, GSD). Then, with this information, the Management Tool calculates a trajectory (e.g. list of waypoints) for the UAV to cover the area to inspect with the required image quality. If the Management Tool finds a solution, an inspection mission is deemed feasible, it is stored, and the inspector receives a *successful definition* notification. If the Management Tool doesn't find a solution, the inspector receives an *unsuccessful definition* notification.

After an inspection mission has been successfully defined, the UAV operator can execute it. First, the UAV is powered on by the safety pilot. Due to current regulations, there will be a safety pilot with a valid license making sure that the UAV carries out the specified mission. If something unexpected happens, this pilot will take remote control of the aerial platform and perform a safe landing.

Then, the UAV operator establishes the Management Tool – UAV communications, and selects an inspection mission from a list. After showing the planned inspection details, the UAV trajectory is uploaded, and the inspection can start. The UAV will autonomously take-off and start navigating sequentially to each of the waypoints of the mission. During the flight, the camera onboard the UAV will be acquiring high-quality images with the required overlap to be able to build a precise 3D map after the mission has finished. If everything goes as planned, after reaching the last uploaded waypoint, the UAV will land autonomously.

If an alarm is raised by the UAV system, such as low battery or communication loss, the UAV will autonomously go back to the take-off location and land safely. If an obstacle is detected, such as static elements or non-cooperative aircraft, which could interfere with the planned mission, the UAV will automatically send an alarm to the UAV operator, and autonomously compute and execute a new trajectory in order to avoid such obstacle.

In case an unexpected event happens, or an unfeasible inspection is estimated, the safety pilot commands the UAV to land or return home, and the inspection is deemed unsuccessful.

After the inspection has been successfully completed, the inspector will be able to retrieve all the data generated during the mission.

1.4 KPIs

Key performance indicators description for the Use Case:

ID	Name	Description	Target	Reference to mentioned Use Case objectives
UC1.1	KPI 1	Exposure time of road workers and users to hazardous situations derived from inspection tasks	Reduction of the exposure time by 65% due to the use of automated UAV and terrestrial inspection vehicles	Development of advance inspection modules
UC1.1	KPI 5	Traffic disruptions due to	The automation and robotisation of inspection	Development of digital inspection

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		inspection tasks	tasks in OMICRON should reduce traffic disruptions by at least 50%	modules
UC1.1	KPI 9	Maintenance and inspection activity costs	The enhancements in inspection and intervention tasks in OMICRON will reduce costs by at least 10%	Development of automated inspection

1.5 Use Case Conditions

Actor	Triggering Event	Pre-conditions	Assumption
Describe which Actor(s) trigger(s) this Use Case	Describe what event(s) trigger(s) this Use Case	Describe what condition(s) should have been met before this Use Case happens	Describe the assumptions about conditions or system configurations.
Inspector UAV operator	Inspection needs	In case of *Configuration* • Management Tool is running Definition of inspection resources • Site map In case of *Execution* • UAV in the take-off area • Management Tool is running • Inspection defined • Inspection resources available and ready to fly • Site map • Flight permits granted In case of *Retrieve data* • Management Tool is running • Inspection performed	In case of *Execution* • The inspection has been defined and validated • The communication range is enough for the inspection mission

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1.6 Classification Information

Relation to Other Use Cases in the same project or area
Extends UC1.1
Level of Depth - the degree of specialization of the Use Case
Detailed Use Case
Further Keywords for Classification
Visual inspection, long range operation, Detect & Avoid, data gathering
Maturity of Use Case
In preparation

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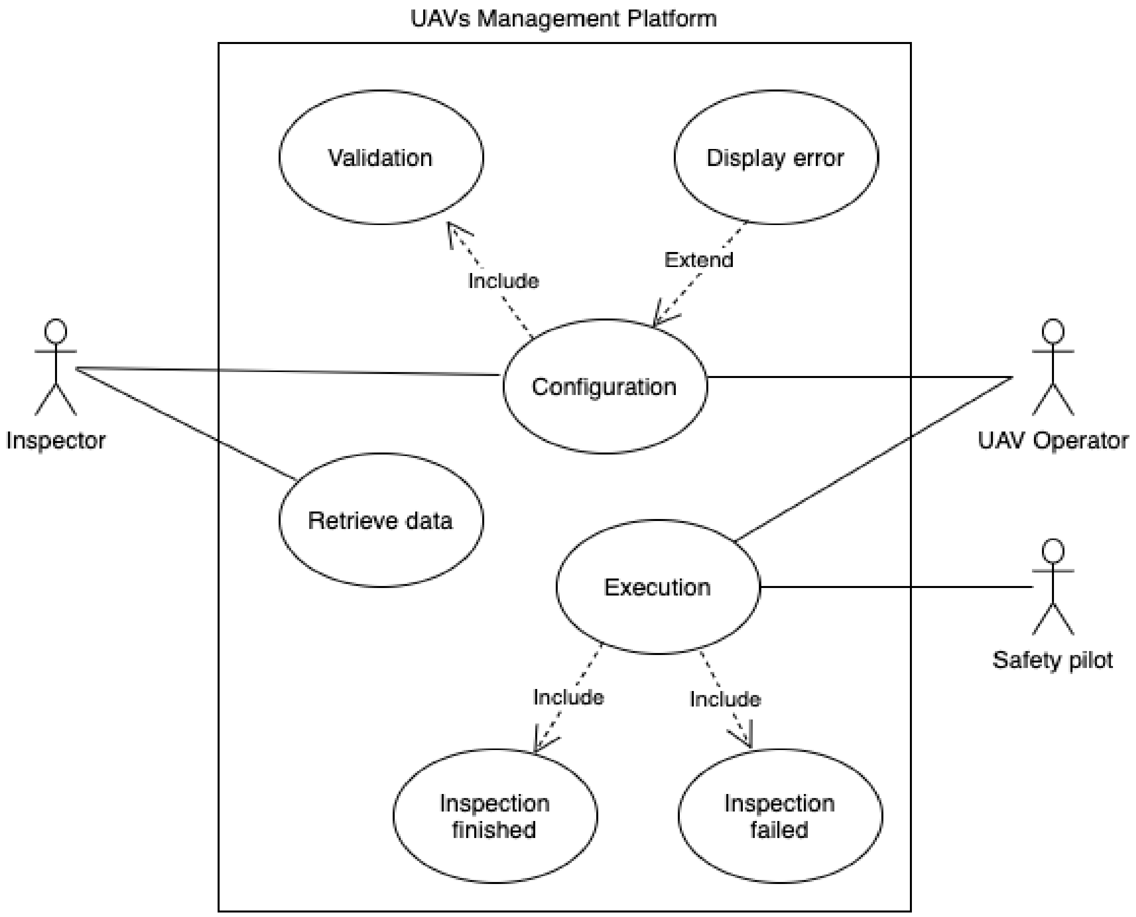
2 Diagrams of the Use Case

Context Diagram
It is shared by both detailed use cases from UC1.1



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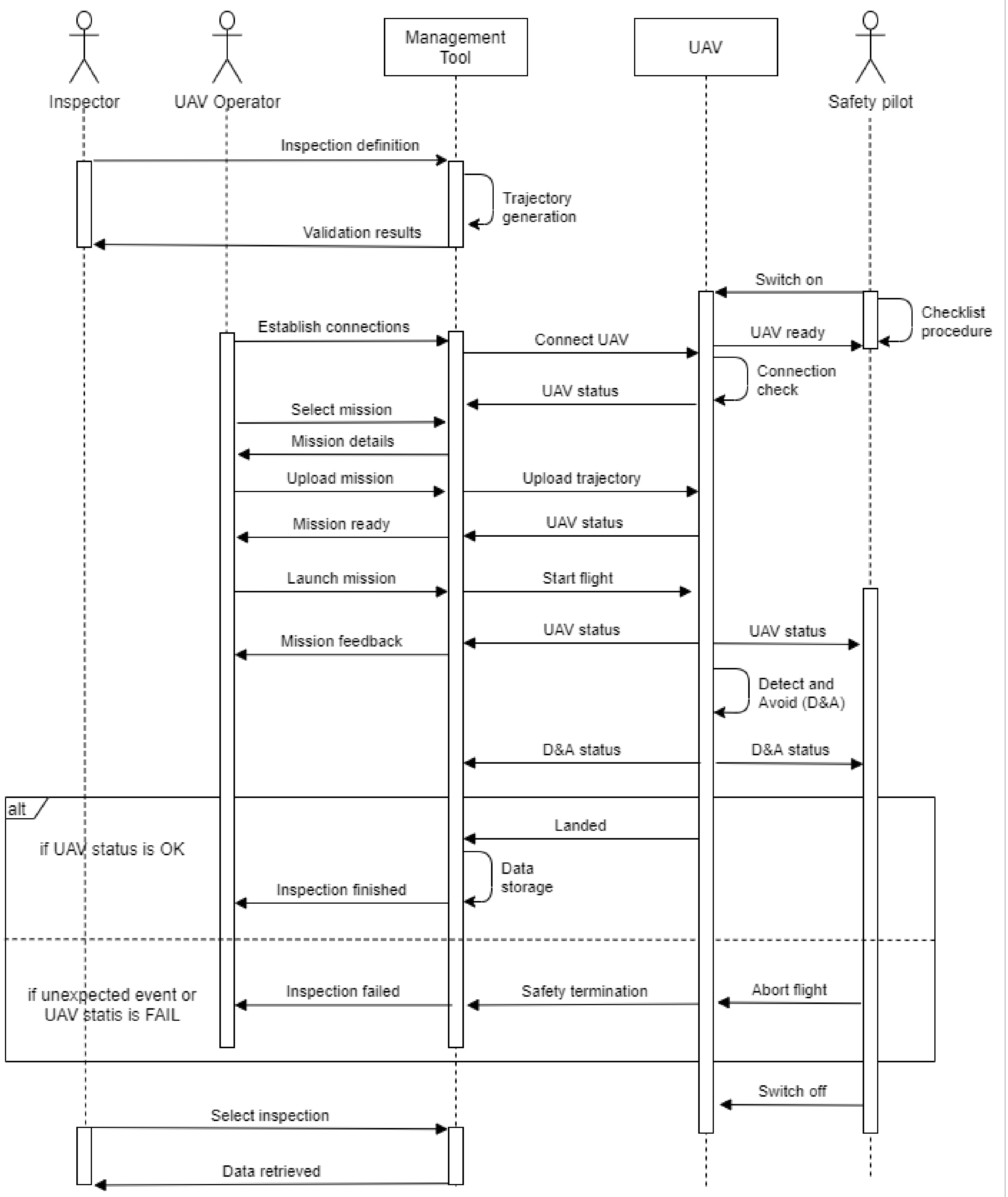
Sequence Diagram



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3 Technical details of the Use Case - Actors

Actor Name	Actor Type	Actor Subcategories	Actor description	Further information specific to this Use Case	Equipment Manufacturer	Requirement(s) of the actor	Reference Standards/Legislation
Inspector	Role	User	Person in charge of defining the inspection needs	The inspector defines the locations to be inspected, the data		Knowledge of the construction site and inspection resources (number of UAVs, inspection sensors, …)	
UAV operator	Role	User	Person that executes and supervises a UAV inspection	The UAV operator loads and executes the inspection tasks. He also monitors the progress of the task, including the UAV state and its trajectory.		Knowledge of the construction site and inspection resources, knowledge of UAV technology and performance	To complete from task T1.2
Safety pilot	Role	User	Safety pilot in case of unexpected events	A safety pilot is required due to current regulation. In case of unexpected events the safety pilot could take control of an UAV to terminate the flight.		Defined by national or European regulation as detailed in task T1.2	To complete from task T1.2
Management Tool	System	IS IT	Management Tool hardware and software	The Management Tool includes the application (visual interface, database access, communications with UAVs,…) and the equipment required to work.			

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UAV	System	Robotic element	UAV that can perform an inspection task	The UAV will perform an autonomous inspection using onboard sensors as planned from the Management Tool. The UAV will follow a planned trajectory to provide the images required. The UAV will autonomously detect and avoid obstacles.		Some requirements could apply from national or European regulation as detailed in task T1.2	To complete from task T1.2

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4 Step by Step Analysis of the Use Case

4.1 List of scenarios

S.No	Scenario Name	Scenario Description	Primary Actor	Triggering Event	Pre-Condition	Post-Condition
PS1	Inspection is configured	The inspector creates an inspection mission defining the data needed and the locations. The Management Tool tries to calculate the trajectory needed. The Management Tool estimates that the inspection mission is feasible.	Inspector	UAV Inspection is needed	Site map and inspection resources available in UAVs Management Tool	An inspection mission is successfully defined.
PS2	Inspection is executed	The Safety Pilot switches on the UAV and the UAV Operator establishes communication. After the UAV status and startup procedure are validated, the UAV Operator selects an inspection mission previously defined. The Management Tool provides the details and visual feedback of the inspection mission. Then the inspection mission is uploaded to the UAV. After the UAV Operator receives a mission ready notification, the inspection mission is launched and the UAV starts to fly. The UAV sends status messages periodically, also including information from the Detect&Avoid system. After the UAV lands, the data gathered are stored and the inspection finishes successfully. Finally, the Safety Pilot switches off the UAV.	UAV Operator	UAV Inspection is needed	Site map Inspection is defined Resources are available and ready to fly Flight permits granted	An inspection mission is successfully executed.
PS3	Data are gathered	The inspector selects an inspection mission previously executed in the Management Tool. Data from that inspection mission is retrieved successfully.	Inspector	UAV Inspection is needed	Site map and inspection resources available in UAVs Management Tool	Data from an inspection mission is successfully retrieved.

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AS1	Inspection definition fails	The inspector creates an inspection mission defining the data needed and the locations. The Management Tool tries to calculate the trajectory needed. The Management Tool estimates that the inspection mission is not feasible.	Inspector	UAV Inspection is needed	Site map and inspection resources available in UAVs Management Tool	The definition of the inspection mission fails
AS2	Inspection fails	The Safety Pilot switches on the UAV and the UAV Operator establishes communication. After the UAV status and startup procedure are validated, the UAV Operator selects an inspection mission previously defined. The Management Tool provides the details and visual feedback of the inspection mission. Then the inspection mission is uploaded to the UAV. After the UAV Operator receives a mission ready notification, the inspection mission is launched and the UAV starts to fly. During the flight, an unexpected event happens and the Safety pilot takes control of the UAV and terminates the flight. Then, the inspection is deemed unsuccessful. Finally, the Safety pilot switches off the UAV.	Safety pilot	UAV Inspection is needed	Site map Inspection is defined Inspection resources available and ready to fly Flight permits granted	The safety pilot remotely pilots the UAV and performs a safe landing in a controlled area. The inspection mission fails.

4.2 Steps - Primary Scenario

Scenario Name: Inspection is configured									
St No.	**Event**	**Description of Process/Activity**	**Information Producer**	**Information Receiver**	**Information Exchanged**	**Service**	**Requirements**	**Communication Media**	**Communication Means**
1	Inspector sends mission definition	Trajectory planning	Inspector	Management Tool	I-1.01	Create			GUI
2	Inspection is validated	Trajectory planning	Management Tool	Inspector	I-1.02	Report			GUI

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Scenario Name: Inspection is executed									
St No.	**Event**	**Description of Process/Activity**	**Information Producer**	**Information Receiver**	**Information Exchanged**	**Service**	**Requirements**	**Communication Media**	**Communication Means**
1	Safety Pilot powers on UAV	UAV startup	Safety Pilot	Active UAV Spare UAV	I-2.01	Change		Electrical switch	Power on switch
2	UAV ready	UAV startup	UAV	Safety Pilot	I-2.02	Report	Quality service Security	Wireless link	GCS RC transmitter
3	Establish connection	UAV connection	UAV Operator	Management Tool	I-2.03	Create			GUI
4	Connect UAV	UAV connection	UAV Management Tool	UAV	I-2.04	Change		Wireless link	Wireless modem
5	UAV status	UAV connection	UAV	Management Tool	I-2.05	Repeat	Quality service Security	Wireless link	Wireless modem
6	Select mission	Mission management	UAV Operator	Management Tool	I-2.06	Get			GUI
7	Mission selected	Mission management	Management Tool	UAV Operator	I-2.07	Report			GUI
8	Upload mission	Mission management	UAV Operator	Management Tool	I-2.08	Create			GUI

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9	Upload trajectory	Mission management	Management Tool	UAV	I-2.09	Create	Quality service Security	Wireless link	Wireless modem
10	Trajectory loaded	Mission management	Active UAV	Management Tool	I-2.10	Report	Quality service Security	Wireless link	Wireless modem
11	Mission ready	Mission management	Management Tool	UAV Operator	I-2.11	Report			GUI
12	Launch mission	Mission execution	UAV Operator	Management Tool	I-2.12	Change			GUI
13	Start flight	Mission execution	Management Tool	UAV	I-2.13	Change			
14	Mission feedback	Mission execution	Management Tool	UAV Operator	I-2.14	Report			
15	Trajectory update	Mission execution	Management Tool	UAV	I-2.15	Change	Quality service Security	Wireless link	Wireless modem
16	Landed	Mission execution	Active UAV	Management Tool	I-2.16	Report	Quality service Security	Wireless link	Wireless modem
17	Inspection finished	Mission execution	Management Tool	UAV Operator	I-2.17	Report			
18	Switch off	UAV power off	Safety Pilot	UAV	I-2.01	Change		Electrical switch	Power on switch

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Scenario Name: Data are gathered									
St No.	**Event**	**Description of Process/Activity**	**Information Producer**	**Information Receiver**	**Information Exchanged**	**Service**	**Requirements**	**Communication Media**	**Communication Means**
1	Inspection is selected	Data management	Inspector	Management Tool	I-3.01	Get			GUI
2	Data are retrieved	Data management	Management Tool	Inspector	I-3.02	Report			GUI

4.3 Steps – Alternative, Error Management, and/or Maintenance/Backup Scenario

Scenario Name: Inspection definition fails									
St No.	**Event**	**Description of Process/Activity**	**Information Producer**	**Information Receiver**	**Information Exchanged**	**Service**	**Requirements**	**Communication Media**	**Communication Means**
1	Inspector sends mission definition	Trajectory planning	Inspector	Management Tool	I-1.01	Create			GUI
2	Inspection is not feasible	Trajectory planning	Management Tool	Inspector	I-1.02	Report			GUI

Scenario Name: Inspection fails

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St No.	Event	Description of Process/Activity	Information Producer	Information Receiver	Information Exchanged	Service	Requirements	Communication Media	Communication Means
1	Safety Pilot power on UAV	UAV startup	Safety Pilot	Active UAV Spare UAV	I-2.01	Change		Electrical switch	Power on switch
2	UAV ready	UAV startup	UAV	Safety Pilot	I-2.02	Report	Quality service Security	Wireless link	GCS RC transmitter
3	Establish connection	UAV connection	UAV Operator	Management Tool	I-2.03	Create			GUI
4	Connect UAV	UAV connection	UAV Management Tool	Active UAV Spare UAV	I-2.04	Change		Wireless link	Wireless modem
5	UAV status	UAV connection	UAV	Management Tool	I-2.05	Repeat	Quality service Security	Wireless link	Wireless modem
6	Select mission	Mission management	UAV Operator	Management Tool	I-2.06	Get			GUI
7	Mission selected	Mission management	Management Tool	UAV Operator	I-2.07	Report			GUI
8	Upload mission	Mission management	UAV Operator	Management Tool	I-2.08	Create			GUI
9	Upload trajectory	Mission management	Management Tool	Active UAV	I-2.09	Create	Quality service	Wireless link	Wireless modem

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							Security		
10	Trajectory loaded	Mission management	Active UAV	Management Tool	I-2.10	Report	Quality service Security	Wireless link	Wireless modem
11	Mission ready	Mission management	Management Tool	UAV Operator	I-2.11	Report			GUI
12	Launch mission	Mission execution	UAV Operator	Management Tool	I-2.12	Change			GUI
13	Start flight	Mission execution	Management Tool	UAV	I-2.13	Change			
14	Mission feedback	Mission execution	Management Tool	UAV Operator	I-2.14	Report			
15	Trajectory update	Mission execution	Management Tool	UAV	I-2.15	Change	Quality service Security	Wireless link	Wireless modem
16	Abort flight	Mission execution	Safety Pilot	Active UAV	I-2.19	Change	Quality service Security	Wireless link	GCS RC transmitter
17	Safety termination	Mission execution	Active UAV	Management Tool	I-2.20	Report	Quality service Security	Wireless link	Wireless modem
18	Inspection failed	Mission execution	Management Tool	UAV Operator	I-2.17	Report			

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19	Switch off	UAV power off	Safety Pilot	UAV	I-2.01	Change		Electrical switch	Power on switch

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5 Information Exchanged

Inf. ID	Name of information exchanged	Description of information exchanged	Information Subcategories	Requirements
I-1.01	Inspection definition	This information contains the inspection resources available, the inspection data required (views, locations), take-off and landing spots	Algorithm	
I-1.02	Validation results	If the inspection defined is feasible, it contains the inspection plan calculated by the Management Platform, including the planned trajectory. If the inspection defined is not feasible, a failure is reported.	Algorithm	
I-2.01	UAV switch on	Electrical signal to power on UAV	Electrical parameter	
I-2.02	UAV ready	UAV status information including batteries, GNSS, navigation filter, failure flags, safety switch, motors, and onboard sensors	Electrical parameter Algorithm	
I-2.03	Establish connections	This information contains the UAV list and the data required for connection like IP address.		
I-2.04	Connect UAV	Protocol message that establishes the connection between the Management Tool and an UAV	Network topology	
I-2.05	UAV status	UAV status information including batteries, GNSS, navigation filter, failure flags, motors, onboard sensors, and mission progress	Electrical parameter Algorithm	
I-2.06	Select mission	Identifier of the inspection mission	Algorithm	

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I-2.07	Mission selected	It contains the details of an inspection mission: UAV, data required (views, locations), landing spot, UAV planned trajectory.	Algorithm	
I-2.08	Upload mission	Identifier of the inspection mission to be executed	Algorithm	
I-2.09	Upload trajectory	List of waypoints to follow	Algorithm	
I-2.10	Trajectory loaded	Acknowledgement that the list of waypoints has been successfully loaded	Algorithm	
I-2.11	Mission ready	Acknowledgement that the UAV in the mission has uploaded their trajectories	Algorithm	
I-2.12	Launch mission	Trigger to start the execution of the selected inspection	Algorithm	
I-2.13	Start flight	Command to take-off and waypoint navigation	Algorithm	
I-2.14	Mission feedback	It contains the UAV status, the tasks being executed, and the real trajectories.	Algorithm	
I-2.15	Trajectory update	Updated list of waypoints and speed	Algorithm	
I-2.16	Landed	Acknowledgement after the UAV has landed	Algorithm	
I-2.17	Inspection results	Reports if the inspection has been successfully completed or if it has failed		
I-2.18	Switch off	Electrical signal to power off UAV	Electrical parameter	

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I-2.19	Abort flight	Command from the safety pilot to land the UAV immediately, return home or manual control		
I-2.20	Safety termination	A safety termination flag and the ID of the UAV		
I-2.21	Stop flight	Land immediately or go home command to the UAV		
I-3.01	Select inspection	Identifier of the inspection mission	Algorithm	
I-3.02	Data retrieved	Inspection data (images, sensors, …) processed and retrieved from the Management Tool	Algorithm	

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OMICRON

Intelligent Road Asset Management Platform

Multi-UAV

Definition of Requirements

Publish Date: 29.07.2021

Use Case Number: UC1.1.2

Use Case Title: Multi-UAV

Use Case Responsible Partner: USE

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1 Description of the Use Case

1.1 Use Case Identification

ID	Domain(s)	Name of Use Case	Level of Use Case
UC1.1.2	UC1: Inspection, V2X communications and user support	Multi-UAV	Detailed Use Case

1.2 Scope and Objectives

Scope and Objectives of the Use Case	
Scope	The scope of the use case is the validation of the UAVs Management Tool that will allow to define and execute an inspection operation by a team of UAVs. After the inspection is performed the data will be gathered. The UAVs Management Tool allows to have active UAVs and backup UAVs. In case of failure of an active UAV, the Management Tool autonomously reconfigure the inspection mission, activating a backup UAV to complete the inspection. If there is an unexpected event or failure, a safety pilot can command a UAV lo land immediately or return to the landing area. This safety pilot is needed due to the current regulation. The images obtained during the inspection flights will be recorded onboard and they will be transferred to the Management Tool after the UAVs have landed. Later, the inspector can retrieve the data using the Management Tool.
Objective	The objectives are the following: • Definition and configuration of multi-UAV inspection missions • Execution and monitoring of multi-UAV inspection operations • Reconfiguration in case of UAV failure if a backup UAV is available • Retrieval of data collected
Related Business Case	*BC2, Digitalization and Automation of road inspection procedure*

1.3 Narrative of Use Case

Short description – max 3 sentences

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The inspector will use the UAVs Management Tool to define a multi-UAV inspection operation and the UAV operator will execute the inspection when required. Moreover, the inspector will also be able to retrieve the data gathered after the inspection is performed.
Complete description
The inspector responsible for the road assessment will define the inspection mission. The definition includes the number of active UAVs, number of spare UAVs (as backup in case of failure), the locations (e.g., geographic coordinates), the kind of images (e.g., lateral view or overhead), and the image quality (e.g., GSD – ground sample distance). Then, with this information, the Management Tool creates tasks, tries to allocate them among the active UAVs, and calculates a trajectory for each UAV. If the Management Tool finds a solution, an inspection mission is deemed feasible, it is stored, and the inspector receives a *successful definition* notification. If the Management Tool doesn't find a solution, the inspector receives an *unsuccessful definition* notification. After an inspection mission has been successfully defined, the UAV operator can execute it. First, the UAVs are powered on by the safety pilots. Due to current regulations, there will be a safety pilot with a valid license making sure that the UAV carries out the specified mission. If something unexpected happens, this pilot will take remote control of the aerial platform and perform a safe landing. Then, the UAV operator establishes the Management Tool – UAV communications, and he selects a inspection mission from a list. After showing the planned inspection details, the UAV trajectories are uploaded, and the inspection starts. If everything goes as planned, the UAVs land after completing the inspection, the data are stored in the Management Tool, and the UAVs are powered off. In case a UAV cannot complete its planned trajectory (e.g., due to lack of battery or a motor failure), the Management Tool calculates if the inspection can be completed with a spare (backup) UAV. If it is feasible, the tasks are re-allocated, new trajectories are calculated and the backup UAV starts flying. After landing, the data are stored in the Management Tool, and the UAVs are powered off. In case an unexpected event happens, or an unfeasible inspection is estimated, the safety pilot commands the UAV to land or return home, and the inspection is deemed unsuccessful. After an inspection has been successfully completed, the inspector will be able to retrieve all the data generated during the mission.

1.4 KPIs

Key performance indicators description for the Use Case:

ID	Name	Description	Target	Reference to mentioned Use Case objectives
UC1.1	KPI 1	Exposure time of road workers, and users to hazardous situations derived from inspection tasks	Reduction of the exposure time by 65% due to the use of automated UAV and terrestrial inspection vehicles	Development of advance inspection modules

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UC1.1	KPI 5	Traffic disruptions due to inspection tasks	The automation and robotization of inspection tasks in OMICRON should reduce traffic disruptions by at least 50%	Development of digital inspection modules
UC1.1	KPI 9	Maintenance and inspection activity costs	The enhancements in inspection and intervention tasks in OMICRON will reduce costs by at least 10%	Development of automated inspection

1.5 Use Case Conditions

Actor	Triggering Event	Pre-conditions	Assumption
Describe which Actor(s) trigger(s) this Use Case	Describe what event(s) trigger(s) this Use Case	Describe what condition(s) should have been met before this Use Case happens	Describe the assumptions about conditions or system configurations.
Inspector UAV operator	Inspection needs	In case of *Configuration* • Management Tool is running • Definition of inspection resources • Site map In case of *Execution* • UAVs in the landing area • Management Tool is running • Inspection defined • Inspection resources available and ready to fly • Site map • Flight permits granted In case of *Retrieve data*	In case of *Execution* • UAVs are properly separated inside the landing area (no less than 3 meters) • Number of UAVs are enough for the inspection mission • The communication range is enough for the inspection mission

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		• Management Tool is running • Inspection performed	

1.6 Classification Information

Relation to Other Use Cases in the same project or area
Extends UC1.1
Level of Depth - the degree of specialization of the Use Case
Detailed Use Case
Further Keywords for Classification
Visual inspection, inspection definition, multi-UAV, task allocation, trajectory planning, data gathering
Maturity of Use Case
- In preparation.

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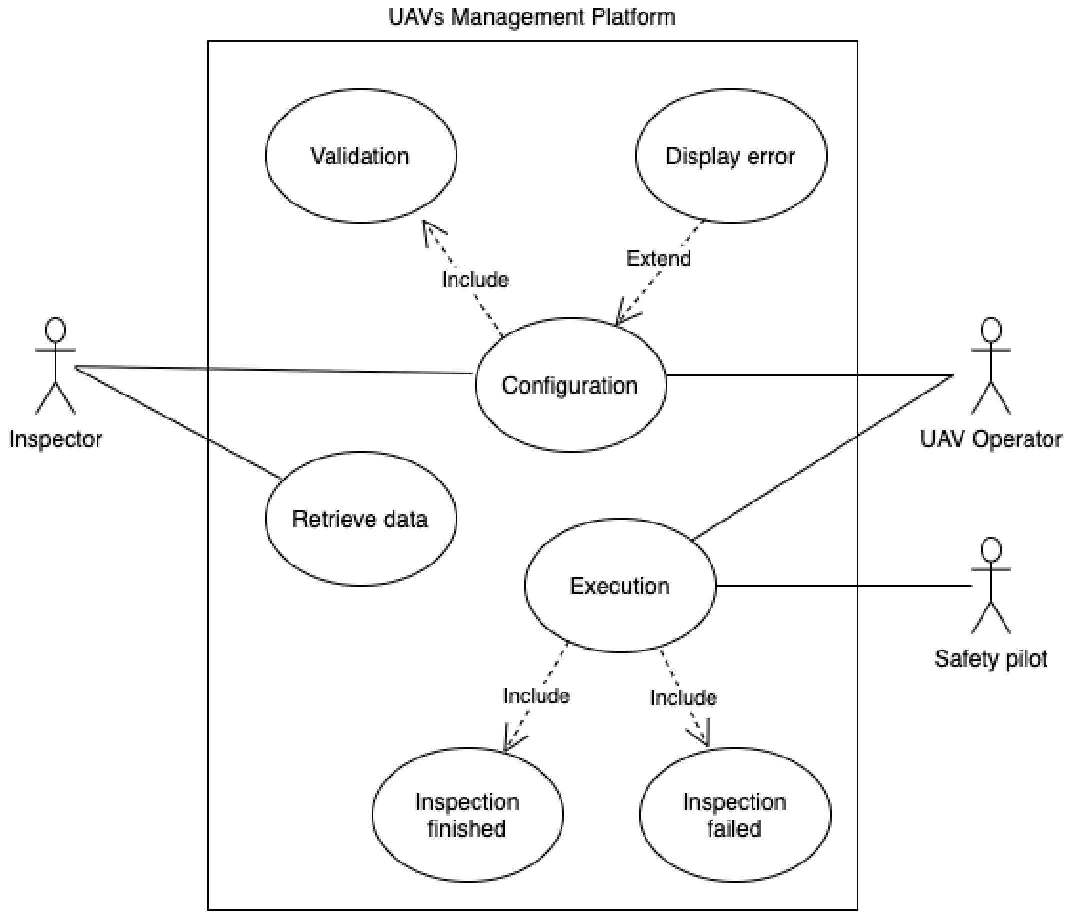
2 Diagrams of the Use Case

Context Diagram



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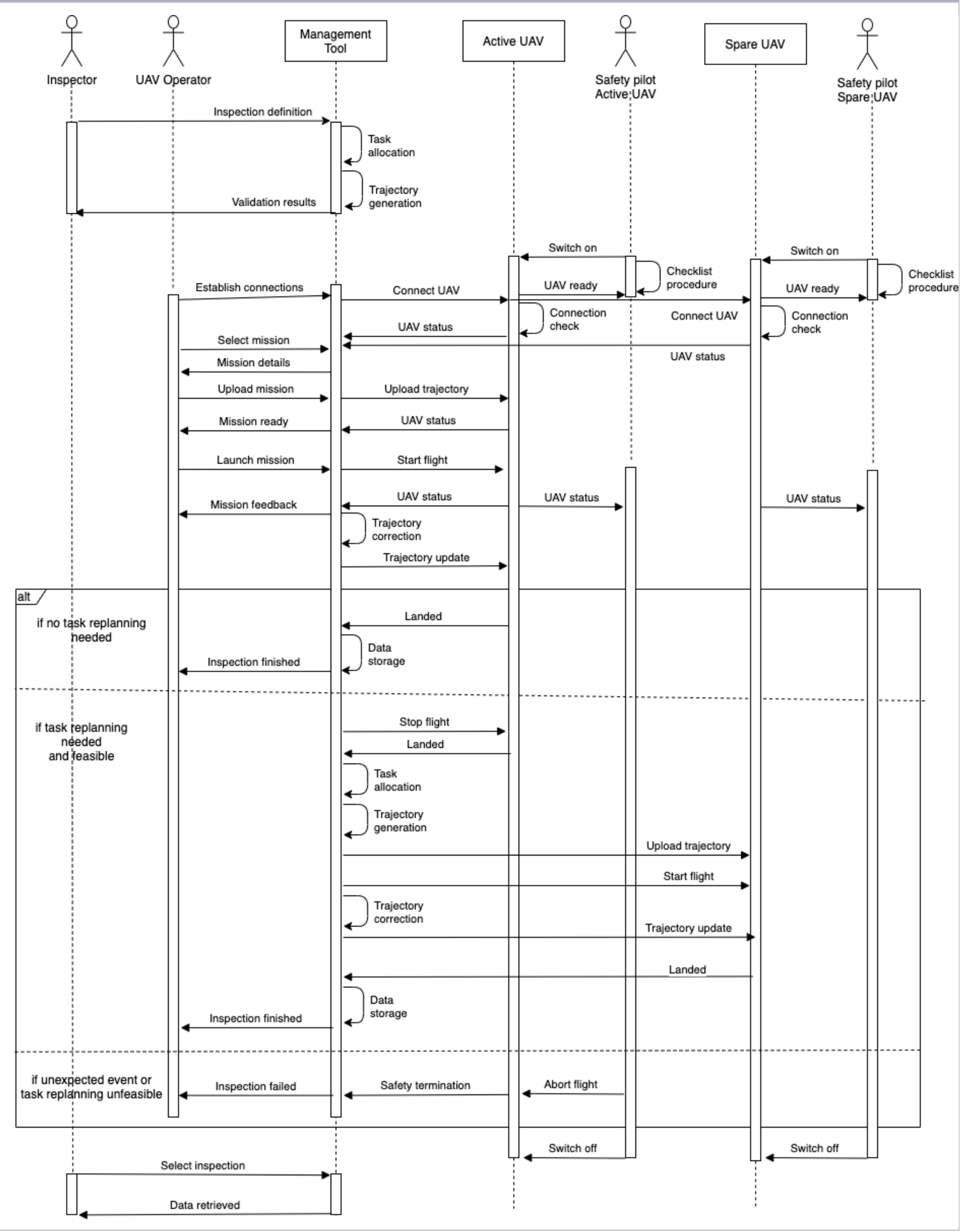
Sequence Diagram



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3 Technical details of the Use Case - Actors

Actor Name	Actor Type	Actor Subcategories	Actor description	Further information specific to this Use Case	Equipment Manufacturer	Requirement(s) of the actor	Reference Standards/Legislation
Inspector	Role	User	Person in charge of defining the inspection needs	The inspector defines the locations to be inspected, the data		Knowledge of the construction site and inspection resources (number of UAVs, inspection sensors, …)	
UAV operator	Role	User	Person that executes and supervises a UAV inspection	The UAV operator loads and executes the inspection tasks. He also monitors the progress of the task, including the UAV state and its trajectory.		Knowledge of the construction site and inspection resources, knowledge of UAV technology and performance	
Safety pilot	Role	User	Safety pilot in case of unexpected events	A safety pilot is required due to current regulation. In case of unexpected events the safety pilot could take control of an UAV to terminate the flight.		Defined by national or European regulation as detailed in task T1.2	To complete from task T1.2
Management Tool	System	IS IT	Management Tool hardware and software	The Management Tool includes the application (visual interface, database access, communications with UAVs, …) and the equipment required to work.			

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Active UAV	System	Robotic element	UAV that can perform an inspection task	This UAV will perform an autonomous inspection using onboard sensors as planned from the UAVs Management Tool. The UAV will follow a planned trajectory to provide the images required.		Some requirements could apply from national or European regulation as detailed in task T1.2	To complete from task T1.2
Spare UAV	System	Robotic element	UAV that can perform an inspection task	This UAV will be ready to fly but it will not perform an inspection task unless an Active UAV fails. In this case the UAV Management Tool will activate the Spare UAV to replace the failed UAV.		Some requirements could apply from national or European regulation as detailed in task T1.2	To complete from task T1.2

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and innovation programme under grant agreement N° 955269

4 Step by Step Analysis of the Use Case

4.1 List of scenarios

S.No	Scenario Name	Scenario Description	Primary Actor	Triggering Event	Pre-Condition	Post-Condition
PS1	Inspection is configured	The inspector creates an inspection mission defining the resources (UAVs), the data needed (views) and the locations. The Management Tool try to allocate the tasks among the UAVs and calculate the trajectories needed. The Management Tool estimates that the inspection mission is feasible.	Inspector	UAV Inspection is needed	Site map and inspection resources available in UAVs Management Tool	An inspection mission is successfully defined.
PS2	Inspection is executed	The Safety Pilot switches on the Active or Spare UAV and the UAV Operator establishes communication. After the UAV status and startup procedure are validated, the UAV Operator selects an inspection mission previously defined. The Management Tool provides the details and visual feedback of the inspection mission. Then the inspection mission is uploaded to each Active UAV. After the UAV Operator receives a mission ready notification, the inspection mission is launched, and the Active UAVs start to flight. Active UAVs send status messages periodically and the Management Tool compares the planned and real trajectories in order to correct them if necessary. After the Active UAV lands, the data gathered are stored and the inspection finishes successfully. Finally, the Safety Pilot switch off the UAVs.	UAV Operator	UAV Inspection is needed	Site map Inspection is defined Resources are available and ready to fly Flight permits granted	An inspection mission is successfully executed.
PS3	Data are gathered	The inspector selects an inspection mission previously executed in the Management Tool. Data from that inspection mission is retrieved successfully.	Inspector	UAV Inspection is needed	Site map and inspection resources available in UAVs Management Tool	Data from an inspection mission is successfully retrieved.

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AS1	Inspection definition fails	The inspector creates an inspection mission defining the resources (UAVs), the data needed (views) and the locations. The Management Tool try to allocate the tasks among the UAVs and calculate the trajectories needed. The Management Tool estimates that the inspection mission is not feasible.	Inspector	UAV Inspection is needed	Site map and inspection resources available in UAVs Management Tool	The definition of the inspection mission fails
AS2	Inspection is replanned	The Safety Pilot switches on the Active or Spare UAV and the UAV Operator establishes communication. After the UAV status and startup procedure are validated, the UAV Operator selects an inspection mission previously defined. The Management Tool provides the details and visual feedback of the inspection mission. Then the inspection mission is uploaded to each Active UAV. After the UAV Operator receives a mission ready notification, the inspection mission is launched, and the Active UAVs start to flight. Active UAVs send status messages periodically and the Management Tool compares the planned and real trajectories in order to correct them if necessary. If there is a failure in an Active UAV, the Management Tool replans the mission, reallocating the tasks and generating a new trajectory for a Spare UAV. After uploading the new trajectory to the Spare UAV, it starts flying to complete the mission. After the UAVs land, the data gathered are stored and the inspection finishes successfully. Finally, the Safety Pilot switch off the UAV.	UAV Operator	UAV Inspection is needed	Site map Inspection is defined Resources are available and ready to fly Flight permits granted	An inspection mission is successful after being replanned
AS3	Inspection fails	The Safety Pilot switches on the Active or Spare UAV and the UAV Operator establishes communication. After the UAV status and startup procedure are validated, the UAV Operator selects an inspection mission previously defined. The Management Tool provides the details and visual feedback of the inspection mission. Then the inspection mission is uploaded to each Active UAV. After the UAV Operator receives a mission ready notification, the inspection mission is launched, and the Active UAVs start to flight. Active UAVs send status messages periodically and the Management Tool compares the planned and real trajectories in order to correct them if necessary. If an unexpected event happens or the Management Tool considers that the inspection cannot be completed, the Safety Pilot takes control of the failing UAV and terminates the flight. Then, the inspection is deemed unsuccessful. Finally, the Safety Pilot switch off the UAV.	UAV Operator	UAV Inspection is needed	Site map Inspection is defined Resources are available and ready to fly Flight permits granted	An inspection mission fails.

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4.2 Steps - Primary Scenarios

Scenario Name: Inspection is configured									
St No.	Event	Description of Process/Activity	Information Producer	Information Receiver	Information Exchanged	Service	Requirements	Communication Media	Communication Means
1	Inspector sends mission definition	Task and trajectory planning	Inspector	Management Tool	I-1.01	Create			GUI
2	Inspection is validated	Task and trajectory planning	Management Tool	Inspector	I-1.02	Report			GUI

Scenario Name: Inspection is executed									
St No.	Event	Description of Process/Activity	Information Producer	Information Receiver	Information Exchanged	Service	Requirements	Communication Media	Communication Means
1	Safety Pilot power on UAV	UAV startup	Safety Pilot	Active UAV Spare UAV	I-2.01	Change		Electrical switch	Power on switch
2	UAV ready	UAV startup	Active UAV Spare UAV	Safety Pilot	I-2.02	Report	Quality service Security	Wireless link	GCS RC transmitter
3	Establish connections	UAVs connection	UAV Operator	Management Tool	I-2.03	Create			GUI

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4	Connect UAV	UAVs connection	UAV Management Tool	Active UAV Spare UAV	I-2.04	Change		Wireless link	Wireless modem
5	UAV status	UAVs connection	Active UAV SPARE UAV	Management Tool	I-2.05	Repeat	Quality service Security	Wireless link	Wireless modem
6	Select mission	Mission management	UAV Operator	Management Tool	I-2.06	Get			GUI
7	Mission selected	Mission management	Management Tool	UAV Operator	I-2.07	Report			GUI
8	Upload mission	Mission management	UAV Operator	Management Tool	I-2.08	Create			GUI
9	Upload trajectory	Mission management	Management Tool	Active UAV	I-2.09	Create	Quality service Security	Wireless link	Wireless modem
10	Trajectory loaded	Mission management	Active UAV	Management Tool	I-2.10	Report	Quality service Security	Wireless link	Wireless modem
11	Mission ready	Mission management	Management Tool	UAV Operator	I-2.11	Report			GUI
12	Launch mission	Mission execution	UAV Operator	Management Tool	I-2.12	Change			GUI

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13	Start flight	Mission execution	Management Tool	Active UAV	I-2.13	Change			
14	Mission feedback	Mission execution	Management Tool	UAV Operator	I-2.14	Report			
15	Trajectory update	Mission execution	Management Tool	Active UAV	I-2.15	Change	Quality service Security	Wireless link	Wireless modem
16	Landed	Mission execution	Active UAV	Management Tool	I-2.16	Report	Quality service Security	Wireless link	Wireless modem
17	Inspection finished	Mission execution	Management Tool	UAV Operator	I-2.17	Report			
18	Switch off	UAV power off	Safety Pilot	Active UAV Spare UAV	I-2.01	Change		Electrical switch	Power on switch

Scenario Name: Data are gathered									
St No.	**Event**	**Description of Process/Activity**	**Information Producer**	**Information Receiver**	**Information Exchanged**	**Service**	**Requirements**	**Communication Media**	**Communication Means**
1	Inspection is selected	Data management	Inspector	Management Tool	I-3.01	Get			GUI
2	Data are retrieved	Data management	Management Tool	Inspector	I-3.02	Report			GUI

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4.3 Steps – Alternative, Error Management, and/or Maintenance/Backup Scenario

Scenario Name: Inspection definition fails									
St No.	Event	Description of Process/Activity	Information Producer	Information Receiver	Information Exchanged	Service	Requirements	Communication Media	Communication Means
1	Inspector sends mission definition	Task and trajectory planning	Inspector	Management Tool	I-1.01	Create			GUI
2	Inspection is not feasible	Task and trajectory planning	Management Tool	Inspector	I-1.02	Report			GUI

Scenario Name: Inspection is replanned									
St No.	Event	Description of Process/Activity	Information Producer	Information Receiver	Information Exchanged	Service	Requirements	Communication Media	Communication Means
1	Safety Pilot power on UAV	UAV startup	Safety Pilot	Active UAV Spare UAV	I-2.01	Change		Electrical switch	Power on switch
2	UAV ready	UAV startup	Active UAV Spare UAV	Safety Pilot	I-2.02	Report	Quality service Security	Wireless link	GCS RC transmitter
3	Establish connections	UAVs connection	UAV Operator	Management Tool	I-2.03	Create			GUI

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4	Connect UAV	UAVs connection	UAV Management Tool	Active UAV Spare UAV	I-2.04	Change		Wireless link	Wireless modem
5	UAV status	UAVs connection	Active UAV SPARE UAV	Management Tool	I-2.05	Repeat	Quality service Security	Wireless link	Wireless modem
6	Select mission	Mission management	UAV Operator	Management Tool	I-2.06	Get			GUI
7	Mission selected	Mission management	Management Tool	UAV Operator	I-2.07	Report			GUI
8	Upload mission	Mission management	UAV Operator	Management Tool	I-2.08	Create			GUI
9	Upload trajectory	Mission management	Management Tool	Active UAV	I-2.09	Create	Quality service Security	Wireless link	Wireless modem
10	Trajectory loaded	Mission management	Active UAV	Management Tool	I-2.10	Report	Quality service Security	Wireless link	Wireless modem
11	Mission ready	Mission management	Management Tool	UAV Operator	I-2.11	Report			GUI
12	Launch mission	Mission execution	UAV Operator	Management Tool	I-2.12	Change			GUI

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13	Start flight	Mission execution	Management Tool	Active UAV	I-2.13	Change			
14	Mission feedback	Mission execution	Management Tool	UAV Operator	I-2.14	Report			
15	Trajectory update	Mission execution	Management Tool	Active UAV	I-2.15	Change	Quality service Security	Wireless link	Wireless modem
16	Stop flight	Mission execution	Management Tool	Active UAV	I-2.21	Change	Quality service Security	Wireless link	Wireless modem
17	Landed	Mission execution	Active UAV	Management Tool	I-2.16	Report	Quality service Security	Wireless link	Wireless modem
18	Upload trajectory	Mission management	Management Tool	Spare UAV	I-2.09	Create	Quality service Security	Wireless link	Wireless modem
19	Start flight	Mission execution	Management Tool	Spare UAV	I-2.13	Change			
20	Trajectory update	Mission execution	Management Tool	Spare UAV	I-2.15	Change	Quality service Security	Wireless link	Wireless modem
21	Landed	Mission execution	Spare UAV	Management Tool	I-2.16	Report	Quality service	Wireless link	Wireless modem

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							Security		
22	Inspection finished	Mission execution	Management Tool	UAV Operator	I-2.17	Report			
23	Switch off	UAV power off	Safety Pilot	Active UAV Spare UAV	I-2.01	Change		Electrical switch	Power on switch

Scenario Name: Inspection fails									
St No.	**Event**	**Description of Process/Activity**	**Information Producer**	**Information Receiver**	**Information Exchanged**	**Service**	**Requirements**	**Communication Media**	**Communication Means**
1	Safety Pilot power on UAV	UAV startup	Safety Pilot	Active UAV Spare UAV	I-2.01	Change		Electrical switch	Power on switch
2	UAV ready	UAV startup	Active UAV Spare UAV	Safety Pilot	I-2.02	Report	Quality service Security	Wireless link	GCS RC transmitter
3	Establish connections	UAVs connection	UAV Operator	Management Tool	I-2.03	Create			GUI
4	Connect UAV	UAVs connection	UAV Management Tool	Active UAV Spare UAV	I-2.04	Change		Wireless link	Wireless modem

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5	UAV status	UAVs connection	Active UAV SPARE UAV	Management Tool	I-2.05	Repeat	Quality service Security	Wireless link	Wireless modem
6	Select mission	Mission management	UAV Operator	Management Tool	I-2.06	Get			GUI
7	Mission selected	Mission management	Management Tool	UAV Operator	I-2.07	Report			GUI
8	Upload mission	Mission management	UAV Operator	Management Tool	I-2.08	Create			GUI
9	Upload trajectory	Mission management	Management Tool	Active UAV	I-2.09	Create	Quality service Security	Wireless link	Wireless modem
10	Trajectory loaded	Mission management	Active UAV	Management Tool	I-2.10	Report	Quality service Security	Wireless link	Wireless modem
11	Mission ready	Mission management	Management Tool	UAV Operator	I-2.11	Report			GUI
12	Launch mission	Mission execution	UAV Operator	Management Tool	I-2.12	Change			GUI
13	Start flight	Mission execution	Management Tool	Active UAV	I-2.13	Change			
14	Mission feedback	Mission execution	Management Tool	UAV Operator	I-2.14	Report			

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15	Trajectory update	Mission execution	Management Tool	Active UAV	I-2.15	Change	Quality service Security	Wireless link	Wireless modem
16	Abort flight	Mission execution	Safety Pilot	Active UAV	I-2.19	Change	Quality service Security	Wireless link	GCS RC transmitter
17	Safety termination	Mission execution	Active UAV	Management Tool	I-2.20	Report	Quality service Security	Wireless link	Wireless modem
18	Inspection failed	Mission execution	Management Tool	UAV Operator	I-2.17	Report			
19	Switch off	UAV power off	Safety Pilot	Active UAV Spare UAV	I-2.01	Change		Electrical switch	Power on switch

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5 Information Exchanged

Inf. ID	Name of information exchanged	Description of information exchanged	Information Subcategories	Requirements
I-1.01	Inspection definition	This information contains the inspection resources available (number of active UAVs, number of spare UAVs), the inspection data required (views, locations, simultaneous or not), take-off and landing spots	Algorithm	
I-1.02	Validation results	If the inspection defined is feasible, it contains the inspection plan calculated by the Management Tool, including the task allocated to each UAV and their planned trajectory. If the inspection defined is not feasible, a failure is reported.	Algorithm	
I-2.01	UAV switch on	Electrical signal to power on UAV	Electrical parameter	
I-2.02	UAV ready	UAV status information including batteries, GNSS, navigation filter, failure flags, safety switch, motors, and onboard sensors	Electrical parameter Algorithm	
I-2.03	Establish connections	This information contains the UAV list and the data required for connection like IP address.		
I-2.04	Connect UAV	Protocol message that establishes the connection between the Management Tool and an UAV	Network topology	
I-2.05	UAV status	UAV status information including batteries, GNSS, navigation filter, failure flags, motors, onboard sensors, and mission progress	Electrical parameter Algorithm	

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I-2.06	Select mission	Identifier of the inspection mission	Algorithm	
I-2.07	Mission selected	It contains the details of an inspection mission: active UAVs, spare UAVs, data required (views, locations, simultaneous or not), landing spot, tasks allocated to each UAV and their planned trajectory.	Algorithm	
I-2.08	Upload mission	Identifier of the inspection mission to be executed	Algorithm	
I-2.09	Upload trajectory	List of waypoints to follow	Algorithm	
I-2.10	Trajectory loaded	Acknowledgement that the list of waypoints has been successfully loaded	Algorithm	
I-2.11	Mission ready	Acknowledgement that all active UAVs in a mission have uploaded their trajectories	Algorithm	
I-2.12	Launch mission	Trigger to start the execution of the selected inspection	Algorithm	
I-2.13	Start flight	Command to take-off and waypoint navigation	Algorithm	
I-2.14	Mission feedback	It contains the UAVs status, the tasks being executed, and the real trajectories.	Algorithm	
I-2.15	Trajectory update	Updated list of waypoints and speed	Algorithm	
I-2.16	Landed	Acknowledgement after a UAV has landed	Algorithm	
I-2.17	Inspection results	Reports if the inspection has been successfully completed or if it has failed		

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I-2.18	Switch off	Electrical signal to power off UAV	Electrical parameter	
I-2.19	Abort flight	Command from the safety pilot to land the UAV immediately, return home or manual control		
I-2.20	Safety termination	A safety termination flag and the ID of the UAV involved		
I-2.21	Stop flight	Land immediately or go home command to the UAV		
I-3.01	Select inspection	Identifier of the inspection mission	Algorithm	
I-3.02	Data retrieved	Inspection data (images, sensors, ...) processed and retrieved from the Management Tool	Algorithm	

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Intelligent Road Asset Management Platform

Inspection Vehicle

Definition of Requirements

Publish Date: 24.09.2021

Use Case Number: UC1.2

Use Case Title: Inspection vehicle

Use Case Responsible Partner: INDRA

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1 Description of the Use Case

1.1 Use Case Identification

ID	Domain(s)	Name of Use Case	Level of Use Case
UC1.2	UC1: Inspection, V2X communications and user support.	Inspection vehicle	High Level Use Case

1.2 Scope and Objectives

Scope and Objectives of the Use Case	
Scope	The scope of this use case is the development of in-vehicle inspection and auscultation technologies to improve current road surface inspection systems, through the automatic detection of the most relevant parameters for analyzing the condition of the road.
Objective	• Investigate new pavement monitoring technologies to improve traditional methods. • Establish the points where it is necessary to carry out rehabilitation actions at an early stage to extend the useful life of existing roads. • Recognize the points where there are elements in poor condition that hinder the circulation of vehicles and can cause incidents. • Successful implementation of innovative sensors that will support the road inspection • Successful development of innovative sensors that will perform data acquisition and data analysis, to support road inspection
Related Business Case	BC2: Digitalization and Automation of road inspection procedure.

1.3 Narrative of Use Case

Short description – max 3 sentences
Within this use case, various pavement inspection technologies will be tested on board a vehicle that, driving at normal road speed, can collect pavement information in an automated way. Subsequently, by applying machine learning and artificial intelligence, it is expected to obtain a value of the classic parameters of road auscultation calculation, such as the IRI (International Roughness

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Index) or deflection, and thus establish an effective preventive maintenance plan, which reduces the long-term cost and improves the safety and service life of road infrastructures.

Complete description

In the management of road condition monitoring in any country, it is necessary to have a series of parameters that make it possible to determine the real condition of the infrastructure, with a unified criterion, throughout the entire road network. In the case of roads, we are talking about infrastructures that interact enormously with users, to the point that sometimes they leave their lives on them, so these parameters are even more important.

In this sense, two lines of analysis of the surface condition of roads are established. On the one hand, visual inspection is the review performed by a competent technician to a structure in which he observes its properties visually to characterize its functional and service condition. On the other hand, auscultation is the evaluation of the functional and structural condition of an infrastructure with high-performance equipment; in the case of pavements, it is done almost continuously, very quickly and without significantly affecting the circulation of vehicles.

This use case will try to evolve and digitize the current auscultation systems using new technologies, still under research. The use of two different solutions will be studied, although both on-board the inspection vehicle.

Both functional and structural evaluation of the pavement will be performed with the use of these technologies. In the functional evaluation some properties will be measured such as:

- **Macrotexture:** it facilitates road-tire contact in the presence of water and maintain this adherence at high speeds, observing that the minimum macrotexture is observed according to the road category.

- **Surface evenness:** it determines the rolling quality of vehicles on the road surface, preventing sliding and avoiding vibrations and oscillations. It is calculated through the IRI (International Roughness Index), currently calculated using response type vehicles or vehicles with laser equipment such as those used in texture measurement as well.

In the structural evaluation, studies will focus on:

- **Deflection:** it measures the response of the pavement to traffic loads over time. It is currently measured with deflectographs, curviameters or impact deflectometers.

These parameters will be detected through the images collected in two different ways. First, a sensor combination consisting of three cameras of different technologies, such as LiDAR's point cloud, monocular cameras, stereo cameras, GPS devices, and IMUs will be tested. These sensors support the inspector to quickly obtain the information and road features, which will enable them to find the maintenance parts. When there is a need for an inspection task, the inspector will perform road inspection using the inspection vehicles and get the required maintenance road sections. Secondly, the creation of artificial intelligence algorithms for the analysis of the traditional parameters for pavement condition classification will be researched and developed. This analysis will detect pavement cracks and their behavior over time.

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These technologies include the creation of artificial intelligence algorithms and the use of machine learning for the analysis of the information collected, as well as an analysis based on the knowledge of experts in road maintenance. In this way, the aim is to reduce the costs associated with corrective maintenance, transforming trends towards preventive maintenance, which will improve road safety and contribute to the reduction of accidents.

1.4 KPIs

Key performance indicators description for the Use Case:

ID	Name	Description	Target	Objectives
KPI 1	Exposure time of road workers and users to hazardous situations derived from inspection tasks.	Reduction of the exposure time due to the use of terrestrial inspection vehicles.	-65%	Safety
KPI 4	Volume of major intervention actions.	Reduction of major intervention actions due to a better maintenance planning.	- 10%	Reduction of costs
KPI 5	Traffic disruptions due to inspection tasks.	The automation of inspection tasks should reduce traffic disruptions.	-50%	Safety
KPI 9	Maintenance and inspection activity costs.	Enhancement of maintenance operations with innovative sensor combinations.	- 10%	Reduction of costs
KPI 12	Road Hazard Index.	The RHI will be reduced due to the implementation of OMICRON's Intelligent Platform.	-50% (overall for the whole project)	Safety
KPI 13	Availability of the network. Impact of a reduced number of disruptions due to accidents and interventions.	The availability of road infrastructures will increase due to a reduced number of traffic disruptions caused by accidents and interventions.	15% (overall for the whole project)	Safety

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KPI 14	Availability of the network. Impact of the reduction of traffic disruptions due to maintenance.	The availability of road infrastructures will increase due to a reduced number of traffic disruptions caused by maintenance.	5% (overall for the whole project)	Safety

1.5 Use Case Conditions

Actor	Triggering Event	Pre-conditions	Assumption
Describe which Actor(s) trigger(s) this Use Case	Describe what event(s) trigger(s) this Use Case	Describe what condition(s) should have been met before this Use Case happens	Describe the assumptions about conditions or system configurations.
Inspector Vehicle operator	Maintenance inspection	• Innovative sensor combination developed. • Inspection Vehicle established.	• Proper function of innovative sensor combinations • Proper function of inspection vehicles • Proper function of ML and AI technology

1.6 Classification Information

Relation to Other Use Cases in the same project or area
Includes UC1.2.1 and UC1.2.2 Relation with UC6.1
Level of Depth - the degree of specialization of the Use Case
High Level Use Case.
Further Keywords for Classification
Road inspection, inspection vehicle, innovative sensors, automatic computation, road parameters.
Maturity of Use Case
In preparation.

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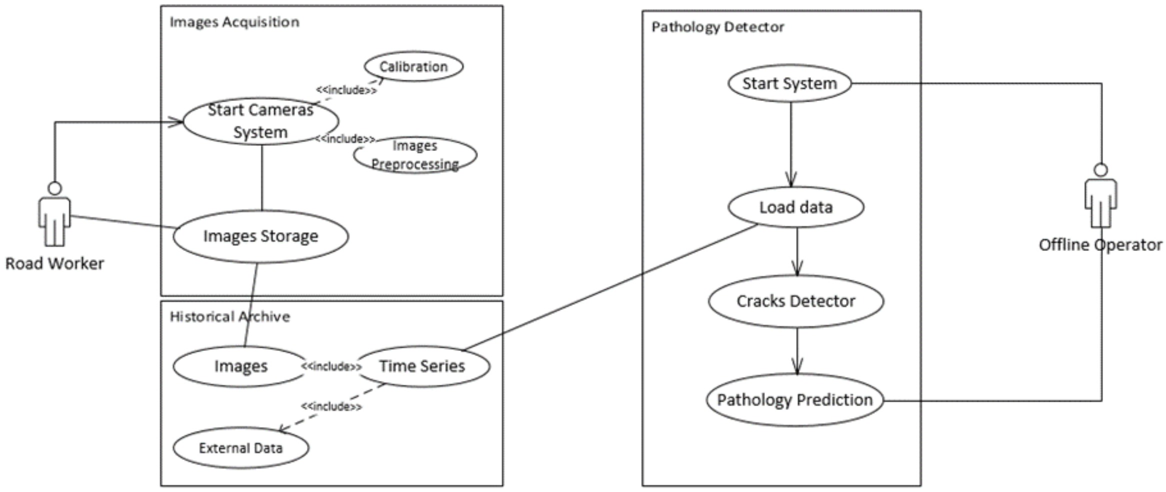
2 Diagrams of the Use Case

Context Diagram



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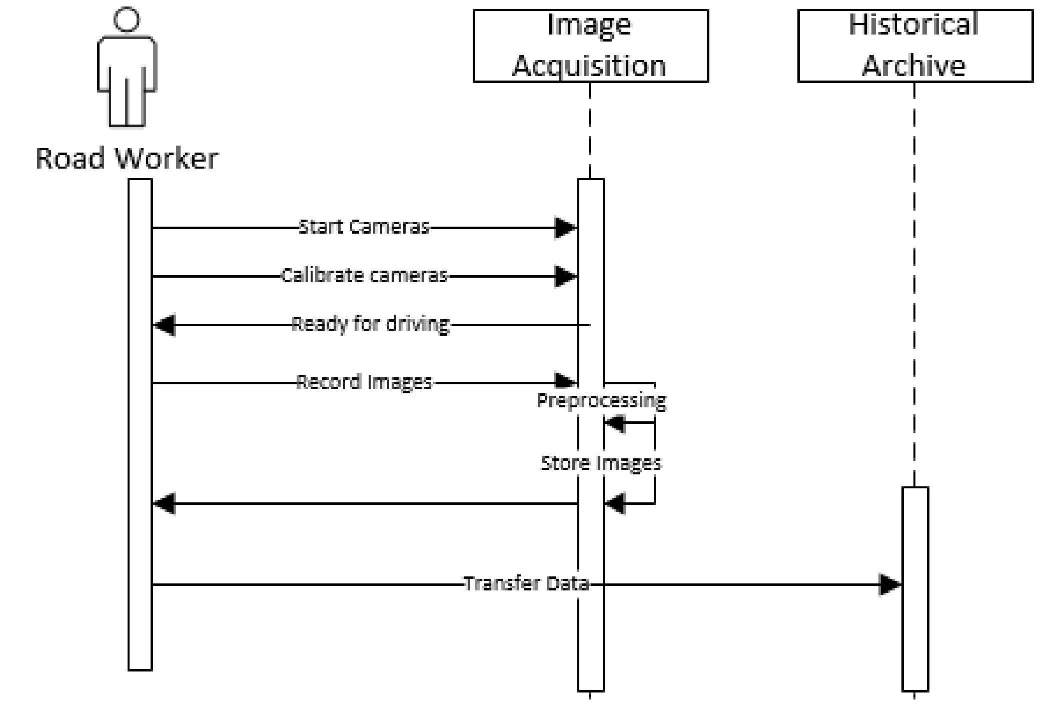
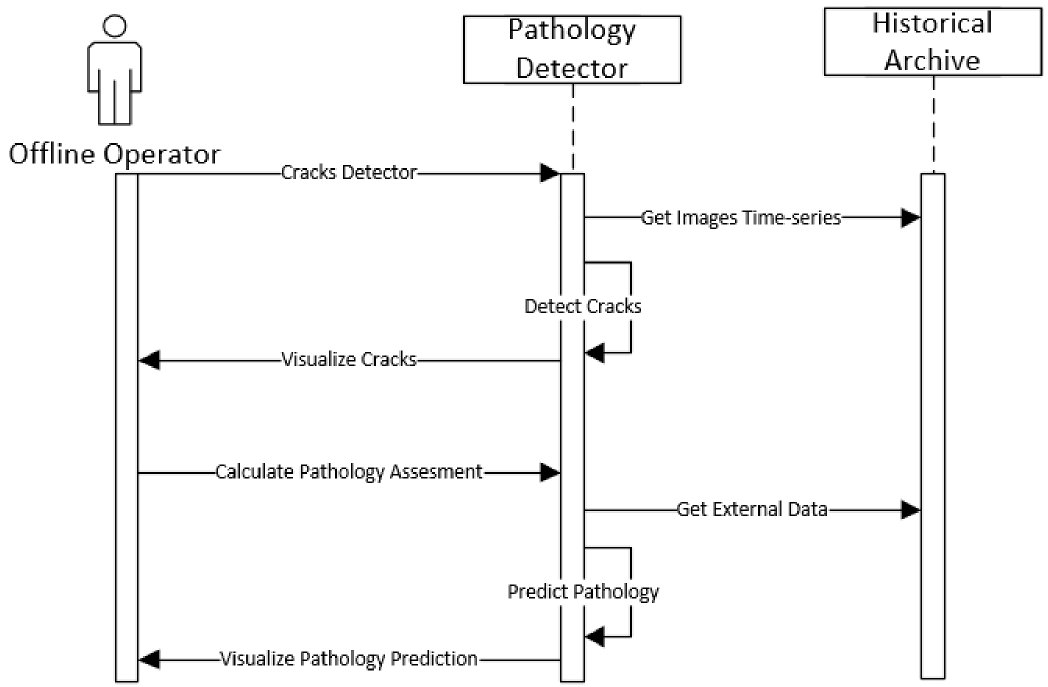
Sequence Diagram

Acquisition of the data



Crack detection and pathology prediction sequence diagram



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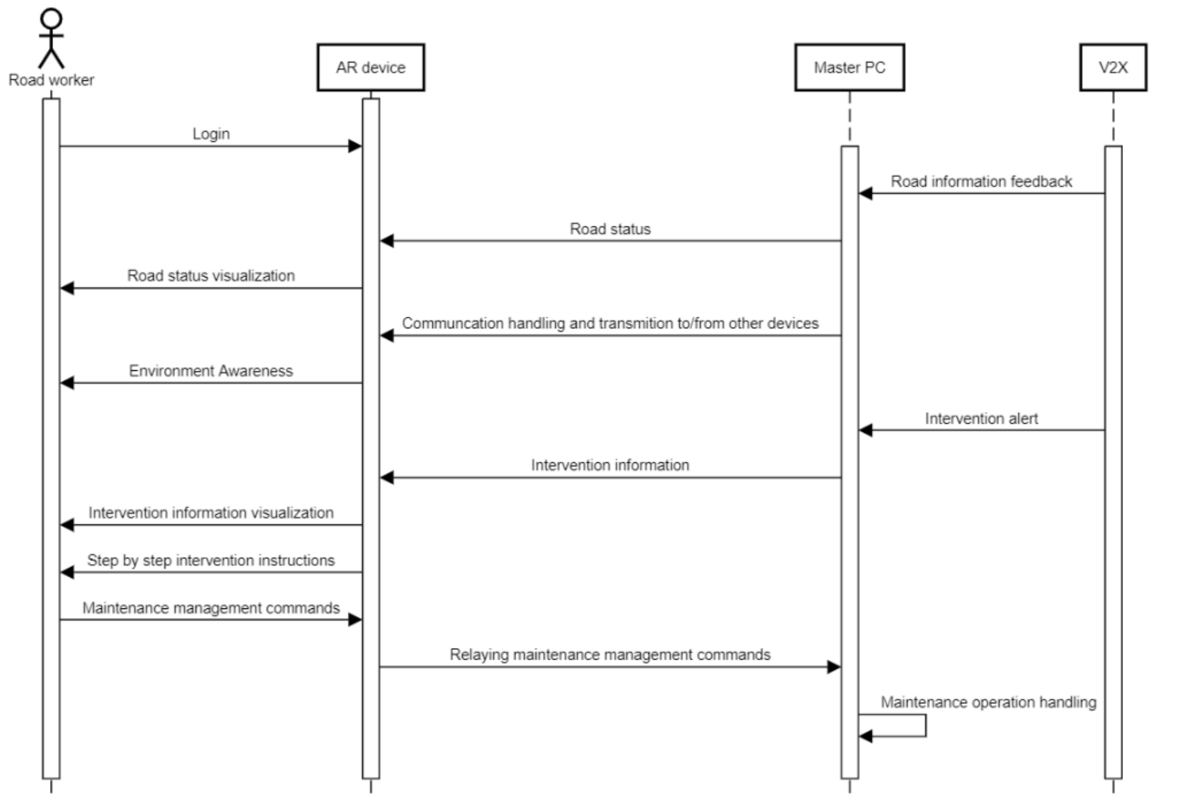
AR sequence diagram



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3 Technical details of the Use Case - Actors

Actor Name	Actor Type	Actor Subcategories	Actor description	Further information specific to this Use Case	Equipment Manufacturer	Requirement(s) of the actor	Reference Standards/Legislation
Inspector	Role	User	Inspector in maintenance and operations	Inspector will use the inspection vehicle to detect the road condition and collect the road information.		Usage of inspection vehicle	
Master PC	System	Implementation system	Master PC to handle communications	The master PC will handle communications for multiple sensor connection; solve the automatic computation of road parameters. A different PC may also be used for road information collection before deploying the inspection vehicle.	Master PC	System	Implementation system

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4 Step by Step Analysis of the Use Case

4.1 List of scenarios

Scenarios provided in section 4.1 of UC1.2.1 and UC1.2.2.

4.2 Steps - Primary Scenario

Scenarios provided in section 4.1 of UC1.2.1 and UC1.2.2.

4.3 Steps – Alternative, Error Management, and/or Maintenance/Backup Scenario

Scenarios provided in section 4.1 of UC1.2.1 and UC1.2.2.

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5 Information Exchanged

This section provides detailed information about the information exchanged within the Use case (in the scenario steps).

Scenarios provided in section 4.1 of UC1.2.1 and UC1.2.2.

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OMICRON

Intelligent Road Asset Management Platform

Innovative Sensor Combination

Definition of Requirements

Publish Date: 17.10.2021

Use Case Number: UC1.2.1

Use Case Title: Innovative sensor combination

Use Case Responsible Partner: UOC

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1 Description of the Use Case

1.1 Use Case Identification

ID	Domain(s)	Name of Use Case	Level of Use Case
UC1.2.1	UC1.2： Inspection vehicle and automatic computation of road parameters	Innovative Sensor Combination.	Detailed Use Case

1.2 Scope and Objectives

Scope and Objectives of the Use Case	
Scope	The scope of this use case is the application of innovative sensor combinations in road information and parameter acquisition and road detection, as well as the application of machine learning and artificial intelligence technology to automatically calculate road parameters.
Objective	• Successful implementation of innovative sensors that will support the road inspection ○ Achieve an improvement in the inspection management of road maintenance worker ○ Improve the inspection efficiency during the road maintenance • Successful development of innovative sensors that will perform data acquisition and data analysis, to support road inspection. ○ Provide the data acquisition, including image data collection and laser scanning data acquisition. ○ Provide the data analysis to identify the road detection and road inspection.
Related Business Case	*Digitalization and Automation of road inspection procedure*

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1.3 Narrative of Use Case

Short description – max 3 sentences
In this use case, the on-site inspector will use innovative sensors to obtain the information of road surface and analysis the information to support their road operations and maintenance.
Complete description
The on-site road inspector will make use of the innovative sensors and devices to inspect the road. The innovative sensors, such as LiDAR's point cloud, monocular cameras, stereo cameras, GPS devices, and IMUs will be installed into the inspection vehicles. These sensors support the inspector to quickly obtain the information and road features, which will enable them to find the maintenance parts. When there is a need for an inspection task, the inspector will perform road inspection using the inspection vehicles and get the required maintenance road sections.

1.4 KPIs

The key performance indicators description for the Use Case is shown in the following table.

ID	Name	Description	Target	Reference to mentioned Use Case objectives
1	KPI 1	Exposure time of road workers and users to hazardous situations derived from inspection tasks	Reduction of the exposure time by 65% due to the use of automated UAV and terrestrial inspection vehicles	Development of advance inspection modules (WP2) and assessment of results (WP6)
1	KPI 5	Traffic disruptions due to inspection tasks	The automation and robotisation of inspection tasks in OMICRON should reduce traffic disruptions by at least 50%	Development of digital inspection modules (WP2) and integration to the rest of the tool (WP5, WP6)
1	KPI9	Maintenance and inspection activity costs	The enhancements in inspection and intervention tasks in OMICRON will reduce costs by at least 10%	Enhancement of maintenance operations with innovative sensor combinations.

1.5 Use Case Conditions

Actor	Triggering Event	Pre-conditions	Assumption

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Describe which Actor(s) trigger(s) this Use Case	Describe what event(s) trigger(s) this Use Case	Describe what condition(s) should have been met before this Use Case happens	Describe the assumptions about conditions or system configurations.
Inspector	Maintenance inspection	• Innovative sensor combination developed. • Inspection Vehicle established.	• Proper function of innovative sensor combinations • Proper function of inspection vehicles • Proper function of ML and AI technology

1.6 Classification Information

Relation to Other Use Cases in the same project or area
There is a relation to UC6.1: Road Digital Twin
Level of Depth - the degree of specialization of the Use Case
Detailed Use Case
Further Keywords for Classification
Road Inspection, Innovative sensors, Inspection vehicle, automatic computation, road parameters
Maturity of Use Case
By the end of the project, UC1.2 will have been executed in the demonstration level

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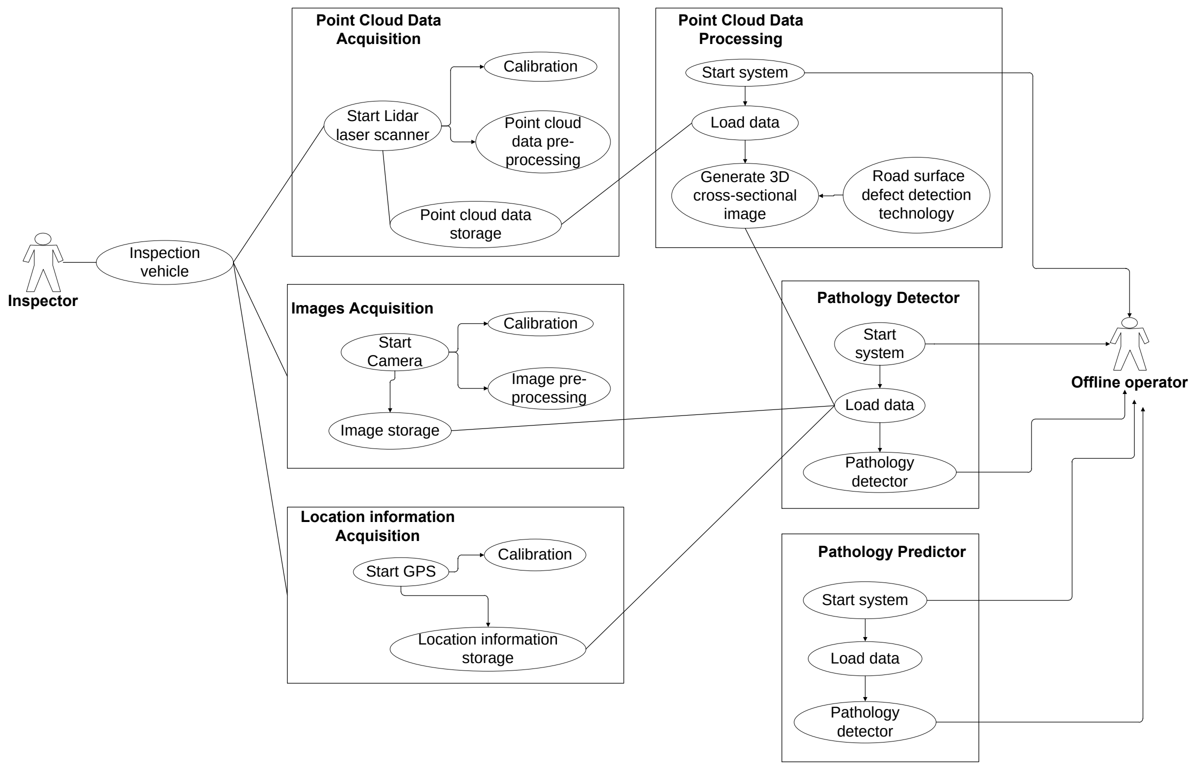
2 Diagrams of the Use Case

Context Diagram



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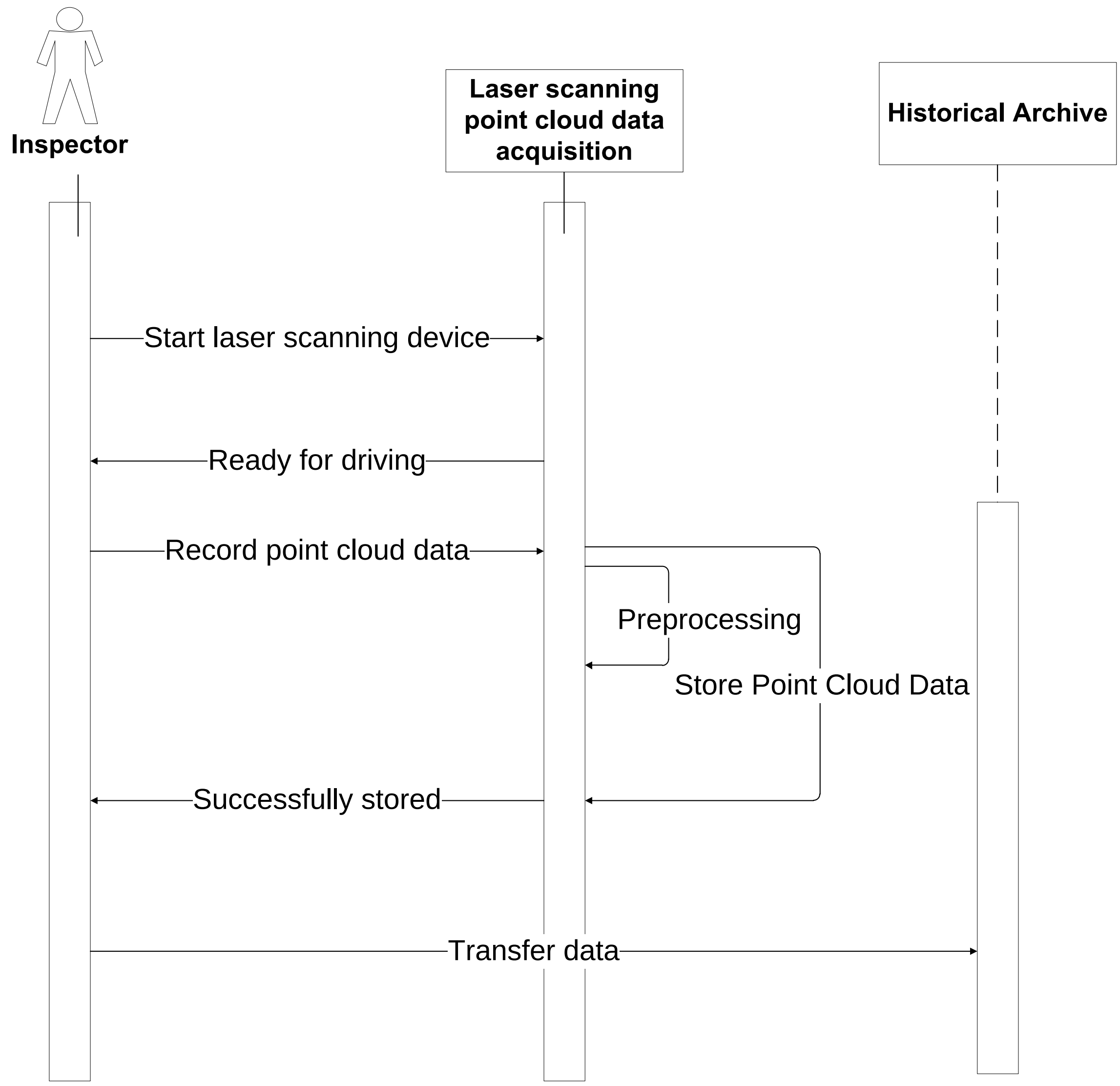
Sequence Diagram



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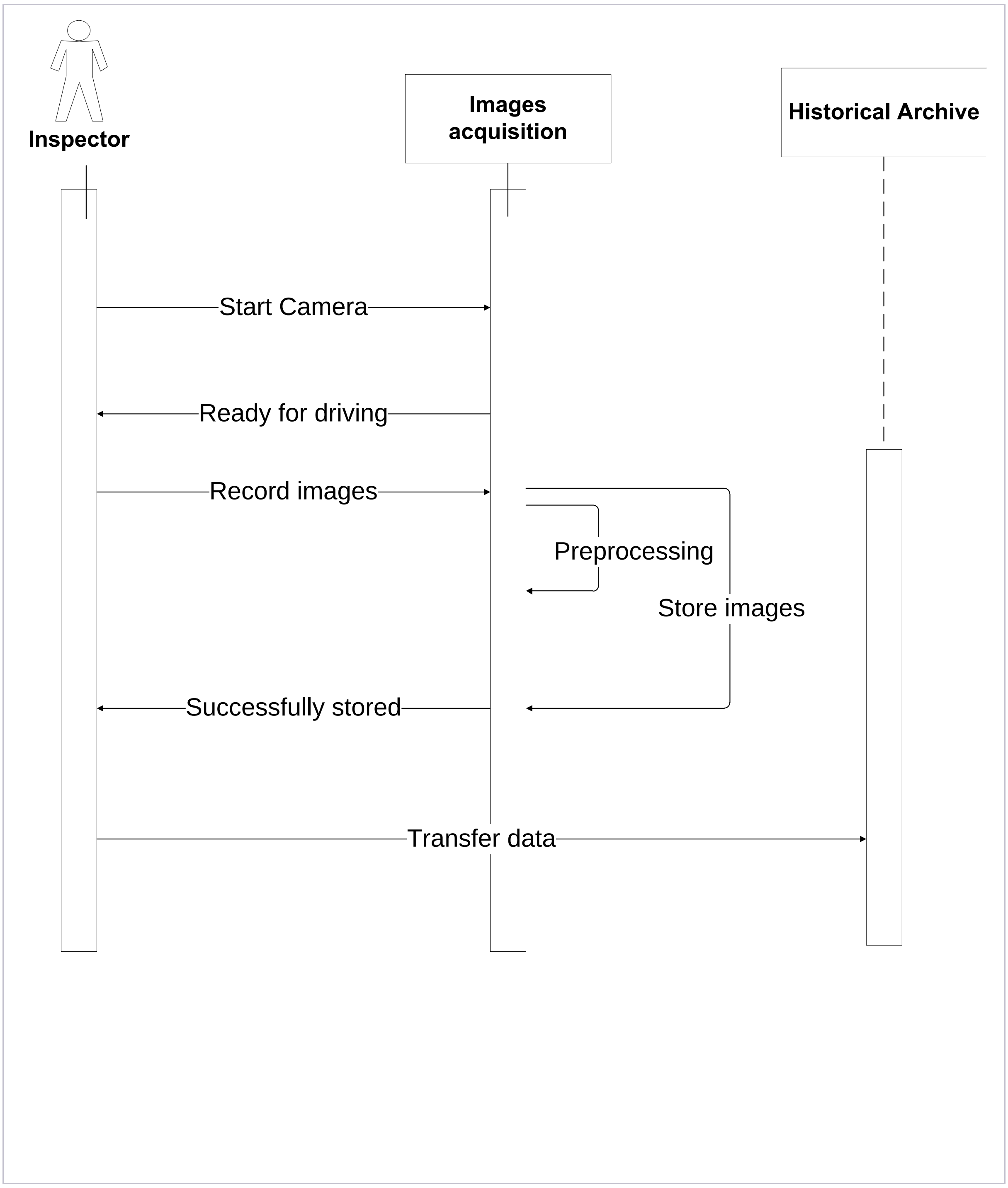

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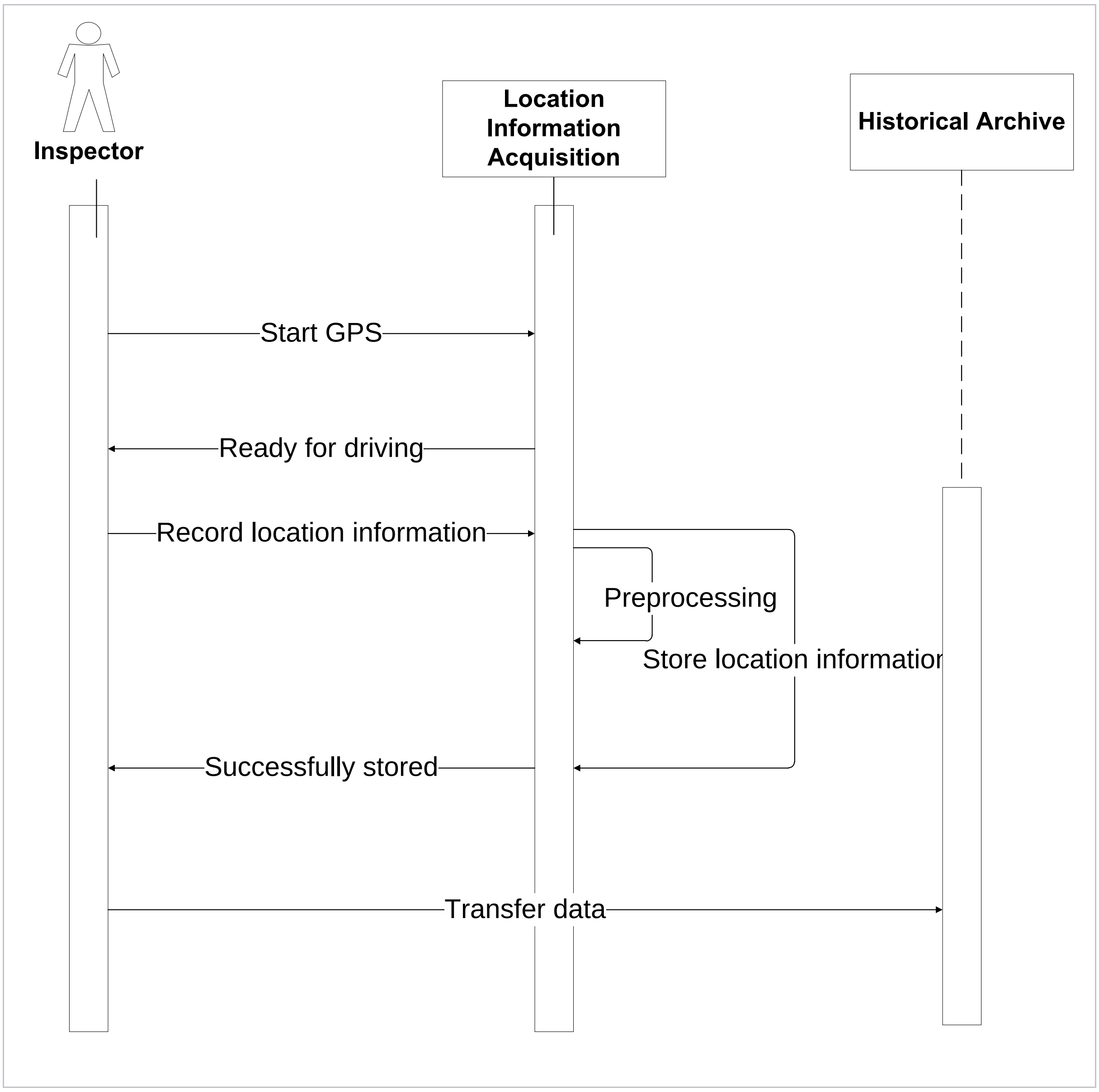

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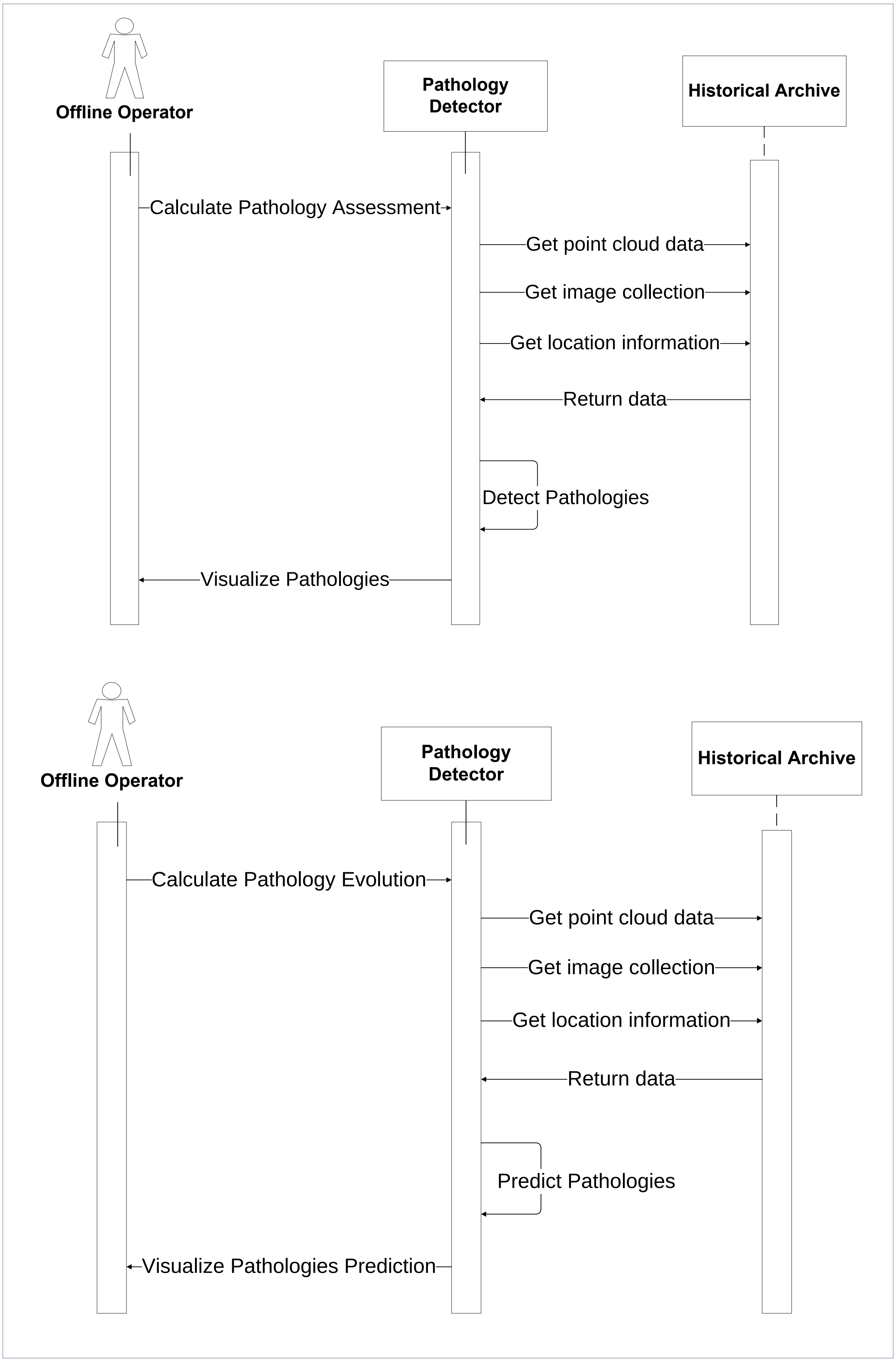

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3 Technical details of the Use Case - Actors

Actor Name	Actor Type	Actor Subcategories	Actor description	Further information specific to this Use Case	Equipment Manufacturer	Requirement(s) of the actor	Reference Standards/Legislation
Inspector	Role	User	Inspector in maintenance and operations	The inspector will use the inspection vehicle to detect the road condition and collect the road information.	Inspection vehicle with the appropriate cameras, laser scanning devices, GPS devices and data storage system	Usage of inspection vehicle	
Offline operator	Role	User	Operator	The operator will use the collected data to calculate the defect and analyze the pathology detection and pathology prediction.	AI and machine learning technology for image processing and 3D point cloud data processing	Usage of inspection vehicle	
Master PC	System	Implementation system	Master PC to handle communications	The master PC will handle communications for multiple sensor connection, solve the automatic computation of road parameters. A different PC may also be used for road information collection before deploying the inspection vehicle.	Suggested requirements: • Intel i7 4+ core CPU (or AMD equivalent) • 16GB RAM • Nvidia 1060 or better graphics (or AMD equivalent)		

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4 Step by Step Analysis of the Use Case

4.1 List of scenarios

S.No	Scenario Name	Scenario Description	Primary Actor	Triggering Event	Pre-Condition	Post-Condition
PS1	Laser scanning data acquisition	During a regular maintenance drive, the laser scanning data are captured together with metadata for geo-localization	Inspector	Maintenance is needed and road point cloud data and 3D images are required.	The appropriate hardware is installed and configured	A series of laser scanning data for a given date is acquired and stored in the Historical Archive
PS2	Image Acquisition	During a regular maintenance drive, a series of images are captured together with metadata for geo-localization	Inspector	Maintenance is needed and road images are required.	The appropriate hardware is installed and configured	A series of images for a given date is acquired and stored in the Historical Archive
PS3	Location information acquisition	During a regular maintenance drive, a series of images are captured together with metadata for geo-localization	Inspector	Maintenance is needed and road geo-location information is required.	The appropriate hardware is installed and configured	A series of geo-location information for a given date is acquired and stored in the Historical Archive
PS4	Road Pathology Detection	Given a set of images acquired during a drive, the pathologies are detected and georeferenced	Offline Operator	Detection of pathologies	The set of images, laser scanning data and geo-location information acquired during a drive has sufficient quality and precision as expected	The pathologies are detected and georeferenced

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PS5	Road Pathology Prediction	Given a time series set of images acquired during several drives a prediction of the pathologies is performed	Offline Operator	Prediction of pathologies	The historical archive contains sufficient time series so the prediction is possible	The evolution of pathologies is resolved

4.2 Steps - Primary Scenario

Scenario Name: Laser Scanning Data Acquisition									
St No.	**Event**	**Description of Process/Activity**	**Information Producer**	**Information Receiver**	**Information Exchanged**	**Service**	**Requirements**	**Communication Media**	**Communication Means**
1	Start 3D laser scanning device	Turn on the laser scanning system	Inspector	Point cloud data Acquisition (module)	Device state	Execute	Configuration		Push button
2	Ready for driving	The system is turned on	3D Point cloud data acquisition (module)	Inspector	Device state	Report	Configuration	Visual	The camera green light is on
3	Record laser scanning data	The record of the 3D point cloud data starts	Inspector	Point cloud data Acquisition (module)	System state	Execute	Data Management		Push button
4	Preprocessing	A bulk of 3D point cloud data is preprocessed with its corresponding meta date	3D Point cloud data Acquisition (module)	Point cloud data Acquisition (module)		Execute	Data Management		

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5	Store point cloud data	A bulk of 3D point cloud data is locally stored	3D Point cloud data Acquisition (module)	Point cloud data Acquisition (module)		Execute	Data Management		
6	Successfully stored	The 3D point cloud data are successfully stored in the local disk	3D Point cloud data Acquisition (module)	Inspector		Report	Data Management		
7	Transfer Data	The data shall be transferred to the archive	Road Worker	Historical Archive		Execute	Data Management		

Scenario Name: Images Acquisition

St No.	Event	Description of Process/Activity	Information Producer	Information Receiver	Information Exchanged	Service	Requirements	Communication Media	Communication Means
1	Start cameras	Turn on the images acquisition system	Inspector	Image Acquisition (module)	Cameras state	Execute	Configuration		Push button
2	Ready for driving	The system is turned on	Image acquisition (module)	Inspector	Camera state	Report	Configuration	Visual	Camera green light is on
3	Record images	The record of the images starts	Road Worker	Image Acquisition (module)	System state	Execute	Data Management		Push button
4	Preprocessing	A bulk of images is preprocessed with their corresponding metadata	Image Acquisition (module)	Image Acquisition (module)		Execute	Data Management		

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5	Store images	A bulk of images is locally stored	Image Acquisition (module)	Image Acquisition (module)		Execute	Data Management		
6	Successfully stored	The images are successfully stored in the local disk	Image Acquisition (module)	Inspector		Report	Data Management		
7	Transfer Data	The data shall be transferred to the archive	Road Worker	Historical Archive		Execute	Data Management		

Scenario Name: Geo-location information acquisition									
St No.	**Event**	**Description of Process/Activity**	**Information Producer**	**Information Receiver**	**Information Exchanged**	**Service**	**Requirements**	**Communication Media**	**Communication Means**
1	Start GPS	Turn on the geo-location acquisition system	Inspector	Geo-location information Acquisition (module)	GPS state	Execute	Configuration		Push button
2	Ready for driving	The system is turned on	Geo-location information acquisition (module)	Inspector	GPS state	Report	Configuration	Visual	Camera green light is on
3	Record geo-location information	The record of the geo-location information starts	Inspector	Geo-location information Acquisition (module)	System state	Execute	Data Management		Push button

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4	Preprocessing	Geo-location information is preprocessed with its corresponding meta date	Geo-location information Acquisition (module)	Geo-location information Acquisition (module)		Execute	Data Management		
5	Store images	Geo-location information is locally stored	Geo-location information Acquisition (module)	Geo-location information Acquisition (module)		Execute	Data Management		
6	Successfully stored	The geo-location information is successfully stored in the local disk	Geo-location information Acquisition (module)	Inspector		Report	Data Management		
7	Transfer Data	The data shall be transferred to the archive	Inspector	Historical Archive		Execute	Data Management		

Scenario Name: Pathology Detector									
St No.	**Event**	**Description of Process/Activity**	**Information Producer**	**Information Receiver**	**Information Exchanged**	**Service**	**Requirements**	**Communication Media**	**Communication Means**
1	Calculate Pathology Assessment	Execute the pathology detection module for a given date	Offline Operator	Pathology Detector Module	Given data of the 3D point cloud data, images, and geo-location information to be used as input for the pathologies detection	Execute	Data Management		GUI

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2	Get data of the 3D point cloud, images, and geo-location information	Request the selected set of 3D point cloud data, images, and geo-location information the Historical archive	Pathology Detector Module	Historical Archive	Given data of the 3D point cloud data, images, and geo-location information to be used as input for the pathologies detection	Execute	Data		GUI
3	Return data of the 3D point cloud, images, and geo-location information	The selected 3D point cloud data, images, and geo-location information are retrieved from the archive	Historical Archive	Pathology Detector Module	Successful retrieving of the 3D point cloud data, images, and geo-location information from the archive	Report	Management		GUI
4	Detect Pathologies	Execute the core module for pathologies detection	Pathology Detector Module	Pathology Detector Module	Order execution	Execute	Data		GUI
5	Visualize Pathologies	Depict the images with the pathologies highlighted	Pathology Detector Module	Offline Operator	Rendered information of the detected pathologies	Report	Management		GUI

Scenario Name: Pathology Predictor									
St No.	**Event**	**Description of Process/Activity**	**Information Producer**	**Information Receiver**	**Information Exchanged**	**Service**	**Requirements**	**Communication Media**	**Communication Means**
1	Calculate Pathology Evolution	Execute the pathology prediction module for a given date taking into account a time-series of the 3D point cloud data,	Offline Operator	Pathology Predictor Module	Given data of the 3D point cloud, images, and geo-location information to be used as input for the pathologies detection	Execute	Data Management		GUI

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		images, and geo-location information							
2	Get the 3D point cloud data, images, and geo-location information in Time-series	Request the selected set of the 3D point cloud data, images, and geo-location information to the Historical Archive	Pathology Predictor Module	Historical Archive	Given start and end time of the 3D point cloud data, images, and geo-location information to be used as input for the pathologies prediction	Execute	Data Management		GUI
3	Return set of the 3D point cloud data, images, and geo-location information	The selected 3D point cloud data, images, and geo-location information are retrieved from the archive	Historical Archive	Pathology Predictor Module	Successful retrieving of the 3D point cloud data, images, and geo-location information from the archive	Report	Data Management		GUI
4	Predict Pathology	Execute the core module for pathologies detection	Pathology Predictor Module	Pathology Predictor Module	Order execution	Execute	Data Management		GUI
5	Visualize Pathology Prediction	Depict the 3D point cloud data, images, and geo-location information with the evolution of the pathologies	Pathology Predictor Module	Offline Operator	Rendered information of the predicted pathologies	Report	Management		GUI

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4.3 Steps – Alternative, Error Management, and/or Maintenance/Backup Scenario

Scenario Name: AS1 Failure capture information									
St No.	Event	Description of Process/Activity	Information Producer	Information Receiver	Information Exchanged	Service	Requirements	Communication Media	Communication Means
1	Information acquisition failure	The device of innovative sensor combination is set up incorrectly	The 3D laser scanning device, camera, GPS.	Data system	N/A	Get		Communication means to be agreed with the rest of the partners	Communication means to be agreed with the rest of the partners

Scenario Name: AS2 Data acquisition failure									
St No.	Event	Description of Process/Activity	Information Producer	Information Receiver	Information Exchanged	Service	Requirements	Communication Media	Communication Means
1	Information acquisition	The device of innovative sensor combination is set up correctly	The 3D laser scanning device, camera, GPS.	Data system	N/A	Get		Communication means to be agreed with the rest of the partners	Communication means to be agreed with the rest of the partners
2	Failure on the information received	The device of innovative sensor combination is set up correctly, but the transmission of data is not correct	The 3D laser scanning device, camera, GPS.	Pathology detector	yes	Get	The setting up of devices of innovation system are correctly.	Communication means to be agreed with the rest of the partners	Communication means to be agreed with the rest of the partners

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Scenario Name: AS3 Data Processing Failure									
St No.	Event	Description of Process/Activity	Information Producer	Information Receiver	Information Exchanged	Service	Requirements	Communication Media	Communication Means
1	Information acquisition	The device of innovative sensor combination is set up correctly	The 3D laser scanning device, camera, GPS.	Data system	N/A	Get	The setting up of devices of innovation system are correctly.	Communication means to be agreed with the rest of the partners	Communication means to be agreed with the rest of the partners
2	information received	The device of innovative sensor combination is set up correctly, and the process of data transmission is correct	The 3D laser scanning device, camera, GPS.	Pathology detector	yes	Get	The setting up of devices of innovation system are correctly.	Communication means to be agreed with the rest of the partners	Communication means to be agreed with the rest of the partners
3	Failure on the data processing	The device of innovative sensor combination is set up correctly, and the transmission of data is correct. But there are something wrong in point cloud data processing.	Point cloud data acquisition	Point cloud data processing	YES	Point cloud data acquisition	Point cloud data acquisition should be performed correctly	Communication means to be agreed with the rest of the partners	Communication means to be agreed with the rest of the partners

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5 Information Exchanged

Inf. ID	Name of information exchanged	Description of information exchanged	Information Subcategories	Requirements
I-01	3D laser scanning data	The LiDAR device shall provide the point cloud data in maximum resolution.	input	Set up well
I-02	Raw Images	The camera shall provide the images taken at maximum resolution.	input	
I-03	Geo-location information	The GPS shall provide the geo-location information in the maximum resolution	input	
I-04	Camera tracking information	The camera shall provide the taking parameters, such us the shutter speed, lens aperture, ISO value, etc.	Parameters	
I-05	Model	The database or repository shall provide the trained model.	Model	The training should have been carried out
I-06	Pathology assessment	The evaluation module shall provide the assessment for each one of the detected potential pathologies.	Algorithm	
I-07	Pathology location	The evaluation module shall provide the location for each one of the detected potential pathologies.	Algorithm	

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OMI((RON

Intelligent Road Asset Management Platform

Automatic Computation of Road Indexes

Definition of Requirements

Publish Date: 08.10.2021

Use Case Number: UC1.2.2

Use Case Title: Automatic computation of road indexes

Use Case Responsible Partner: INDRA

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1 Description of the Use Case

1.1 Use Case Identification

ID	Domain(s)	Name of Use Case	Level of Use Case
UC1.2.2	UC1: Inspection, V2X communications and user support	Automatic computation of road index	Detailed Use Case

1.2 Scope and Objectives

Scope and Objectives of the Use Case	
Scope	The scope of this use case is the development of in-vehicle inspection and auscultation technologies to improve current road surface inspection systems, through the automatic detection of the most relevant parameters for analyzing the condition of the road using optical images.
Objective	Development of innovative modules for detection and prediction of road pathologies • Design, implement and validate an algorithm for the detection of pathologies in the road pavement • Design, implement and validate an algorithm to predict the evolution of pathologies of the road pavement
Related Business Case	BC2: Digitalization and Automation of road inspection procedure.

1.3 Narrative of Use Case

Short description – max 3 sentences
In this use case, the operator will receive a video or a set of images acquired during a maintenance drive. The system will inform of the location of cracks in the road, and in the case the system already has previous drives stored in an archive of images, it will predict the evolution of the state of the road.
Complete description
In the management of road condition monitoring in any country, it is necessary to have a series of parameters that make it possible to determine the real condition of the infrastructure, with a unified criterion, throughout the entire road network. In the case of roads, we are talking about

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infrastructures that interact enormously with users, to the point that sometimes they leave their lives on them, so these parameters are even more important.

In this sense, two lines of analysis of the surface condition of roads are established. On the one hand, visual inspection is the review performed by a competent technician to a structure in which he observes its properties visually to characterize its functional and service condition. On the other hand, auscultation is the evaluation of the functional and structural condition of an infrastructure with high-performance equipment; in the case of pavements, it is done almost continuously, very quickly and without significantly affecting the circulation of vehicles.

This use case will try to evolve and digitize the current auscultation systems using new technologies, still under research. The use of two different solutions will be studied, although both on-board the inspection vehicle.

Both functional and structural evaluation of the pavement will be performed with the use of these technologies. In the functional evaluation some properties will be measured such as:

- **Macrotexture:** it facilitates road-tire contact in the presence of water and maintain this adherence at high speeds, observing that the minimum macrotexture is observed according to the road category.

- **Surface evenness:** it determines the rolling quality of vehicles on the road surface, preventing sliding and avoiding vibrations and oscillations. It is calculated through the IRI (International Roughness Index), currently calculated using response type vehicles or vehicles with laser equipment such as those used in texture measurement as well.

In the structural evaluation, studies will focus on:

- **Deflection:** it measures the response of the pavement to traffic loads over time. It is currently measured with deflectographs, curviameters or impact deflectometers.

To achieve the detection of these parameters, an operator will receive a set of georeferenced images acquired using a terrestrial vehicle. A deep learning model will be used to detect the anomalies in the road pavement.

To predict the evolution of the pathologies on the road, the software will use another algorithm that will take as input a time-series of images from an image archive. Other necessary inputs will be external factors as the weather, number and type of vehicles that drove between the maintenance sessions.

Both models will initially be trained with a dataset generated and labelled in an early stage. In addition, the model has the capability to improve its performance, by being retrained with new images collected during different drives.

The output that the operator will receive will be the location of the cracks in the images, and in the case images from previous drives and information of external factors are available how the cracks will evolve after certain time stamp.

1.4 KPIs

Key performance indicators description for the Use Case:

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ID	Name	Description	Target	Reference to mentioned Use Case objectives
KPI 1	Exposure time of road workers and users to hazardous situations derived from inspection tasks.	Reduction of the exposure time due to the use of terrestrial inspection vehicles.	- 65%	Development of innovative modules for detection and prediction of road pathologies
KPI 5	Traffic disruptions due to inspection tasks.	The automation of inspection tasks should reduce traffic disruptions.	- 50%	Development of innovative modules for detection and prediction of road pathologies
KPI 9	Maintenance and inspection activity costs.	Enhancement of maintenance operations with innovative sensor combinations.	- 10%	Development of innovative modules for detection and prediction of road pathologies

1.5 Use Case Conditions

Actor	Triggering Event	Pre-conditions	Assumption
Describe which Actor(s) trigger(s) this Use Case	Describe what event(s) trigger(s) this Use Case	Describe what condition(s) should have been met before this Use Case happens	Describe the assumptions about conditions or system configurations.
Road Worker	Data Acquisition	The appropriate hardware and software components are installed in the maintenance vehicle	The system is capable to acquire images and their metadata for a precise geo-localisation
Offline Operator	Offline execution of the detection and prediction modules	The appropriate hardware is available and configured The appropriate software modules are installed	The images archive is available in the system

1.6 Classification Information

Relation to Other Use Cases in the same project or area
It is included in UC1.2
Level of Depth - the degree of specialization of the Use Case

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Detailed Use Case
Further Keywords for Classification
Road Inspection, Road pathologies, Pavement state, Data acquisition
Maturity of Use Case
In preparation

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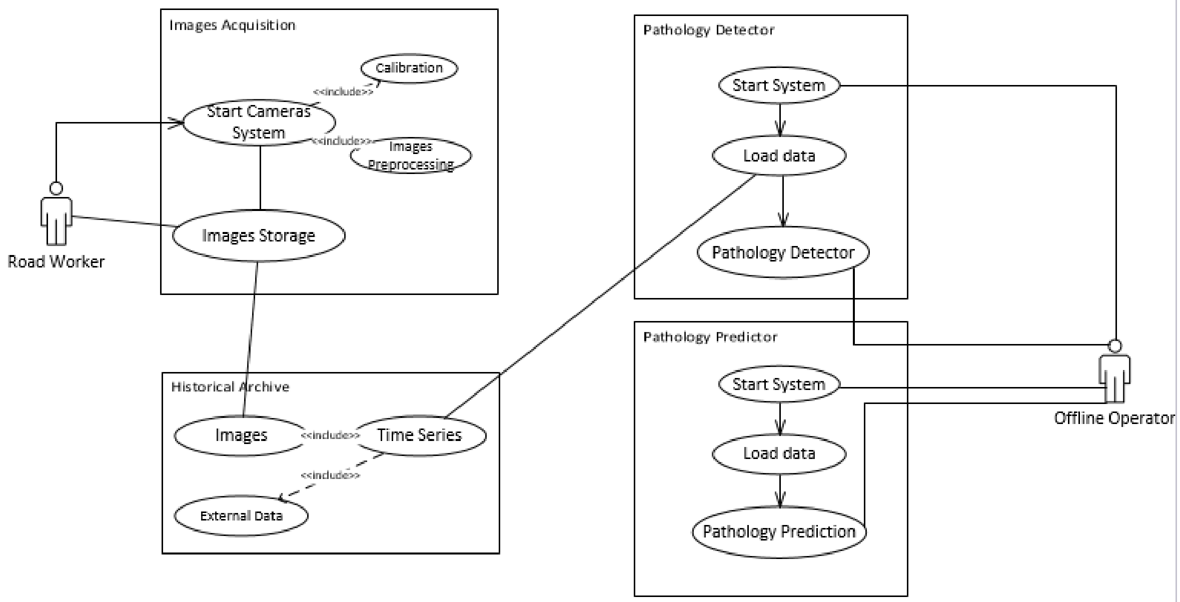
2 Diagrams of the Use Case

Context Diagram



Sequence Diagram

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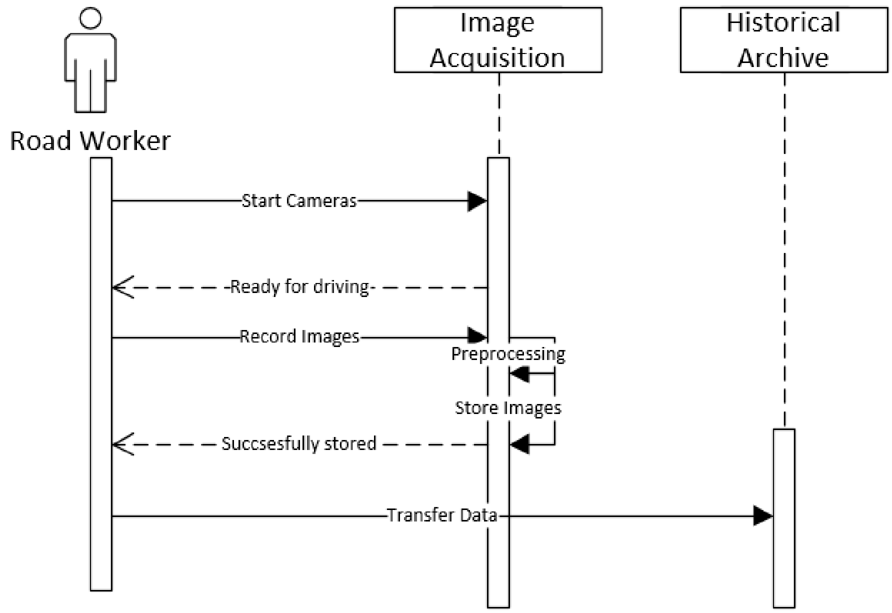
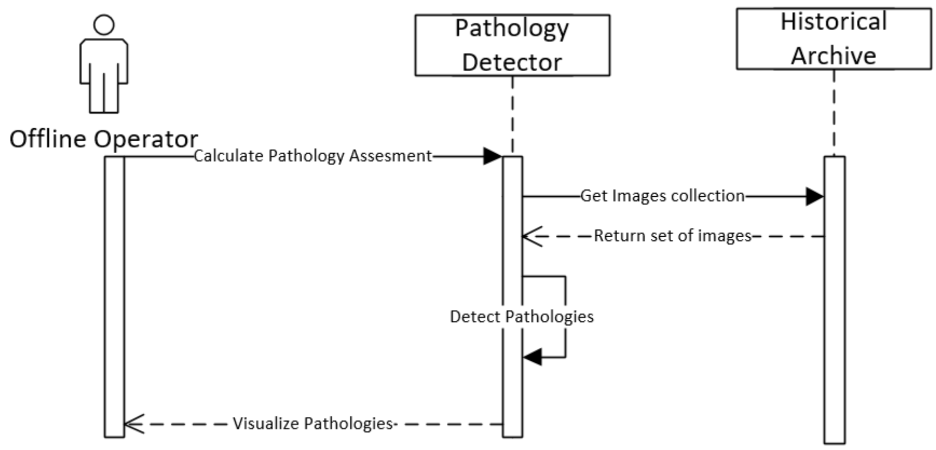
Acquisition of the data sequence diagram



Pathology Detection Sequence Diagram



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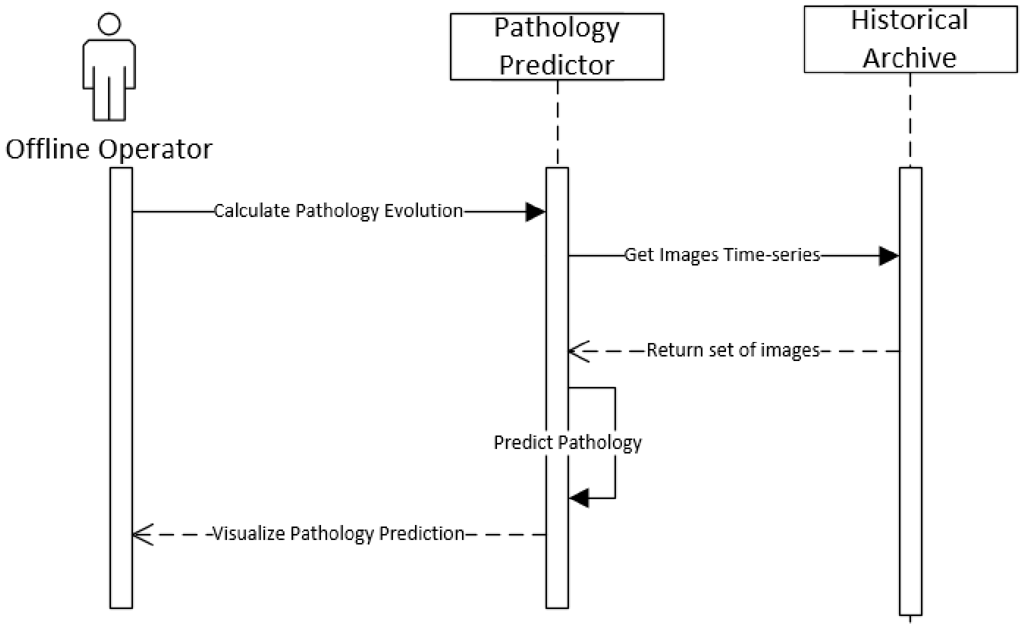
Prediction Sequence Diagram



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3 Technical details of the Use Case - Actors

Actor Name	Actor Type	Actor Subcategories	Actor description	Further information specific to this Use Case	Equipment Manufacturer	Requirement(s) of the actor	Reference Standards/Legislation
Road Worker	Role		Driver in charge with the inspection of the road	Actor in charge with the acquisition of the onsite data, e.g. images and videos of the road under inspection	Maintenance vehicle with the appropriate cameras and data storage system		
Offline Operator	Role		Operator				
Master PC	System	Implementation system	Master PC to handle communications	The master PC will handle communications for multiple sensor connection; solve the automatic computation of road parameters. A different PC may also be used for road information collection before deploying the inspection vehicle.	Master PC	System	Implementation system

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4 Step by Step Analysis of the Use Case

4.1 List of scenarios

S.No	Scenario Name	Scenario Description	Primary Actor	Triggering Event	Pre-Condition	Post-Condition
PS1	Image Acquisition	During a regular maintenance drive a series of images are captured together with metadata for geo-localization	Road Worker	Road Images series shall be acquired	The appropriate hardware is installed and configured	A series of images for a given date is acquired and stored in the Historical archive
PS2	Road Pathology Detection	Given a set of images acquired during a drive , the pathologies are detected and georeferenced	Offline Operator	Detection of pathologies	The set of images acquired during a drive has the sufficient quality and precision as expected	The pathologies are detected and georeferenced
PS3	Road Pathology Prediction	Given a time series set of images acquired during several drives a prediction of the pathologies is performed	Offline Operator	Prediction of pathologies	The historical archive contains sufficient time series so the prediction is possible	The evolution of pathologies is resolved

4.2 Steps - Primary Scenario

Scenario Name: Images Acquisition									
St No.	Event	Description of Process/Activity	Information Producer	Information Receiver	Information Exchanged	Service	Requirements	Communication Media	Communication Means
1	Start cameras	Turn on the images acquisition system	Road Worker	Image Acquisition (module)	Cameras state	Execute	Configuration		Push button

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2	Ready for driving	The system is turned on	Image acquisition (module)	Road Worker	Camera state	Report	Configuration	visual	Camera green light is on
3	Record images	The record of the images starts	Road Worker	Image Acquisition (module)	System state	Execute	Data Management		Push button
4	Preprocessing	A bulk of images is preprocessed with its corresponding metadate	Image Acquisition (module)	Image Acquisition (module)		Execute	Data Management		
5	Store images	A bulk of images is locally stored	Image Acquisition (module)	Image Acquisition (module)		Execute	Data Management		
6	Successfully stored	The images are successfully stored in the local disk	Image Acquisition (module)	Road Worker		Report	Data Management		
7	Transfer Data	The data shall be transferred to the archive	Road Worker	Historical Archive		Execute	Data Management		

Scenario Name: Pathology Detector									
St No.	**Event**	**Description of Process/Activity**	**Information Producer**	**Information Receiver**	**Information Exchanged**	**Service**	**Requirements**	**Communication Media**	**Communication Means**
1	Calculate Pathology Assessment	Execute the pathology detection module for a given date	Offline Operator	Pathology Detector Module	Given date of the images collection to be used as	Execute	Data Management		GUI

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					input for the pathologies detection				
2	Get Images Collection	Request the selected set of images to the Historical archive	Pathology Detector Module	Historical Archive	Given date of the images collection to be used as input for the pathologies detection	Execute	Data		GUI
3	Return set of images	The selected images are retrieved from the archive	Historical Archive	Pathology Detector Module	Successful retrieving of the images from the archive	Report	Management		GUI
4	Detect Pathologies	Execute the core module for pathologies detection	Pathology Detector Module	Pathology Detector Module	Order execution	Execute	Data		GUI
5	Visualize Pathologies	Depict the images with the pathologies highlighted	Pathology Detector Module	Offline Operator	Rendered information of the detected pathologies	Report	Management		GUI

Scenario Name: Pathology Preditor									
St No.	**Event**	**Description of Process/Activity**	**Information Producer**	**Information Receiver**	**Information Exchanged**	**Service**	**Requirements**	**Communication Media**	**Communication Means**
1	Calculate Pathology Evolution	Execute the pathology prediction module for a given date taking into account a time-series of images	Offline Operator	Pathology Predictor Module	Given date of the images collection to be used as input for the pathologies detection	Execute	Data Management		GUI

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2	Get Images Time-series	Request the selected set of images to the Historical archive	Pathology Predictor Module	Historical Archive	Given start and end time of the images collection to be used as input for the pathologies prediction	Execute	Data Management		GUI
3	Return set of images	The selected images are retrieved from the archive	Historical Archive	Pathology Predictor Module	Successful retrieving of the images from the archive	Report	Data Management		GUI
4	Predict Pathology	Execute the core module for pathologies detection	Pathology Predictor Module	Pathology Predictor Module	Order execution	Execute	Data Management		GUI
5	Visualize Pathology Prediction	Depict the images with the evolution of the pathologies	Pathology Predictor Module	Offline Operator	Rendered information of the predicted pathologies	Report	Management		GUI

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5 Information Exchanged

Inf. ID	Name of information exchanged	Description of information exchanged	Information Subcategories	Requirements
1	Camera taking configuration/information	The camera shall provide the taking parameters, such us the shutter speed, lens aperture, ISO value, etc.	Parameters	
2	Raw images	The camera shall provide the images taken at maximum resolution.	Input	
3	Preprocessed images	The preprocessing module shall share the images after being prepared for the evaluation.		
4	Model	The database or repository shall provide the trained model.	Model	The training should have been carried out
5	Pathology assessment	The evaluation module shall provide the assessment for each one of the detected potential pathologies.	Algorithm	
6	Pathology location	The evaluation module shall provide the location for each one of the detected potential pathologies.	Algorithm	

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OMI((RON

Intelligent Road Asset Management Platform

V2X Communications

Definition of Requirements

Publish Date: 24.09.2021

Use Case Number: UC1.3

Use Case Title: V2X communications

Use Case Responsible Partner: INDRA

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1 Description of the Use Case

1.1 Use Case Identification

ID	Domain(s)	Name of Use Case	Level of Use Case
UC1.3	UC1: Inspection, V2X communications and user support	V2X communications	Detailed Use Case

1.2 Scope and Objectives

Scope and Objectives of the Use Case	
Scope	Exploit the capabilities of V2X communications in the field of road maintenance and road user support in order to Ensure road safety and driving efficient conditions during maintenance activities.
Objective	• Demonstrate the usability of V2X communication for reducing dangerous situations during maintenance activities on the road. • Provide key information to vehicles regarding road maintenance reducing the time of the travel. • Contribute to the development of the Ten-T Corridor from Madrid
Related Business Case	BC2

1.3 Narrative of Use Case

Short description – max 3 sentences
V2X communications allow the exchange of key information between vehicles and infrastructure, in relation to events occurring on the road, such as the presence of traffic, accidents, lane closures due to road works or adverse weather. In this use case, the capabilities of ETSI ITS-G5 standardized short-range communication will be exploited to improve safety conditions during maintenance works, through the deployment of sensorization on the road and the deployment of on-board modules in vehicles.
Complete description
During the last decade, the European Commission has promoted the development of C-ITS systems for connected vehicles, in order to accelerate the widespread deployment of highly automated vehicles and, in the future, autonomous vehicles. To this end, the development of communications between infrastructure and vehicles is essential, especially at critical points or in dangerous

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situations for road infrastructure users. This pilot will address the development of V2X communications to improve the safety conditions of maintenance workers on the road.

For this purpose, there is a C-ITS Hub that act as a control center where all the necessary and key information for communication with the sensors deployed on the road is collected. This information comes from traffic authorities, maintenance managers, weather agencies, road operators, etc., and is integrated in different standardized formats such as DATEX II, ECO-AT, ETSI and BSM, as well as allowing integration with other environments and C-ITS modules and gateways. The C-ITS Hub, thanks to this information, develops the so-called C-ITS services, which are classified according to the information they share:

- C-ITS "Day 1 service - Safety Priority" C-ITS "Day 1
- C-ITS "Day 1.5" service - Traffic management
- C-ITS "Day 2" service - Services for Automated
- C-ITS "Day 3" service - Services for cooperation

Currently, only “Day 1” services have been standardized by the European Commission, but work is already underway to standardize “Day 2” services. In this use case, only “Day 1” and “Day 1.5” services will be addressed. These services will be generated in the C-ITS Hub and will be sent to the vehicles through the sensorization deployed on the road. A Roadworks warning service will be generated to indicate the presence of maintenance vehicles and personnel in the field. The detailed information sent includes geographical information about the roadwork, lanes affected, speed recommendations, affection and information distance, detailed road history incident, and trace.

The sensorization consists of the Road Side Units (RSU) and the equipment and connections necessary for their operation. These units are short-range communication antennas that operate under the ETSI ITS-G5 standard, and are located at the map interface of the C-ITS HUB. The RSUs receive the services generated by the C-ITS HUB and transmit it to the vehicles passing through the section where the information regarding road maintenance conditions is effective.

The connected vehicles that incorporate the on-board module will receive the information related to the maintenance area, so that they can avoid it and ensure the safety conditions of the maintenance operators.

1.4 KPIs

Key performance indicators description for the Use Case:

ID	Name	Description	Target	Reference to mentioned Use Case objectives
KPI 6	Traffic disruptions due to maintenance interventions	The automation and robotisation of maintenance tasks in OMICRON should reduce traffic disruptions	-10%	Development of automatic management and inform V2X module

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KPI 8	Congestion due to traffic disturbances	The implementation of V2X communications will reduce the congestion due to traffic disruptions	-10%	Development of automatic management and inform V2X module
KPI 13	Availability of the network. Impact of a reduced number of disruptions due to accidents and interventions	The availability of road infrastructures will increase due to a reduced number of traffic disruptions caused by accidents and interventions	15% (overall for the whole project)	Development of V2X communications system.
KPI 14	Availability of the network. Impact of the reduction of traffic disruptions due to maintenance	The availability of road infrastructures will increase to a reduced number of traffic disruptions caused by maintenance	5% (overall for the whole project)	Development of V2X management system module.

1.5 Use Case Conditions

Actor	Triggering Event	Pre-conditions	Assumption
Describe which Actor(s) trigger(s) this Use Case	Describe what event(s) trigger(s) this Use Case	Describe what condition(s) should have been met before this Use Case happens	Describe the assumptions about conditions or system configurations.
System Operator	Ongoing Roadworks	In case of *Configuration* • Management events Tool is running • Definition of roadworks message type and resources • Site map In case of *Execution* • RSU in the area • Management Tool is running • Roadwork Event is	In case of *Execution* • V2X message are properly located and configure. • The communication range is enough for send the V2X information.

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		defined • Site map • V2X message is sent	
System Triggering by third-party	Ongoing Roadworks	In case of *Execution* • RSU in the area • Management Tool is running • Roadwork Event defined • Site map • V2X message is sent	In case of *Execution* • V2X message are properly located and configure. • The communication range is enough for send the V2X information.

1.6 Classification Information

Relation to Other Use Cases in the same project or area
Related to UC5 and UC6
Level of Depth - the degree of specialization of the Use Case
Detailed Level Use Case
Further Keywords for Classification
V2X communications, safety communications, short range communications, C-ITS European Standards, C-ITS services.
Maturity of Use Case
In preparation.

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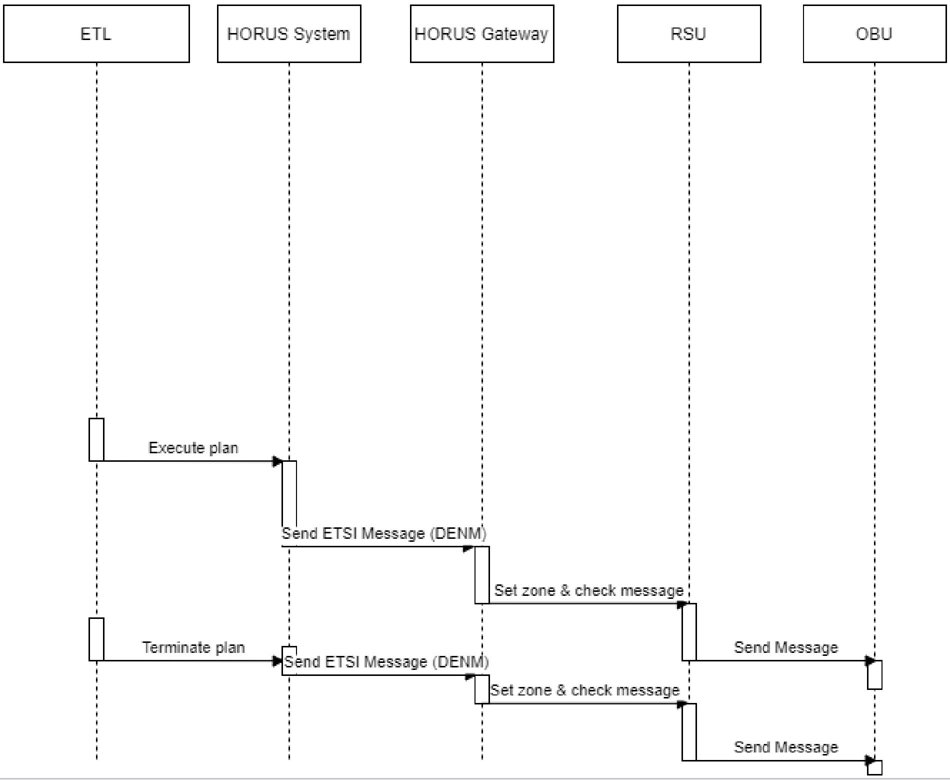
2 Diagrams of the Use Case

Context Diagram



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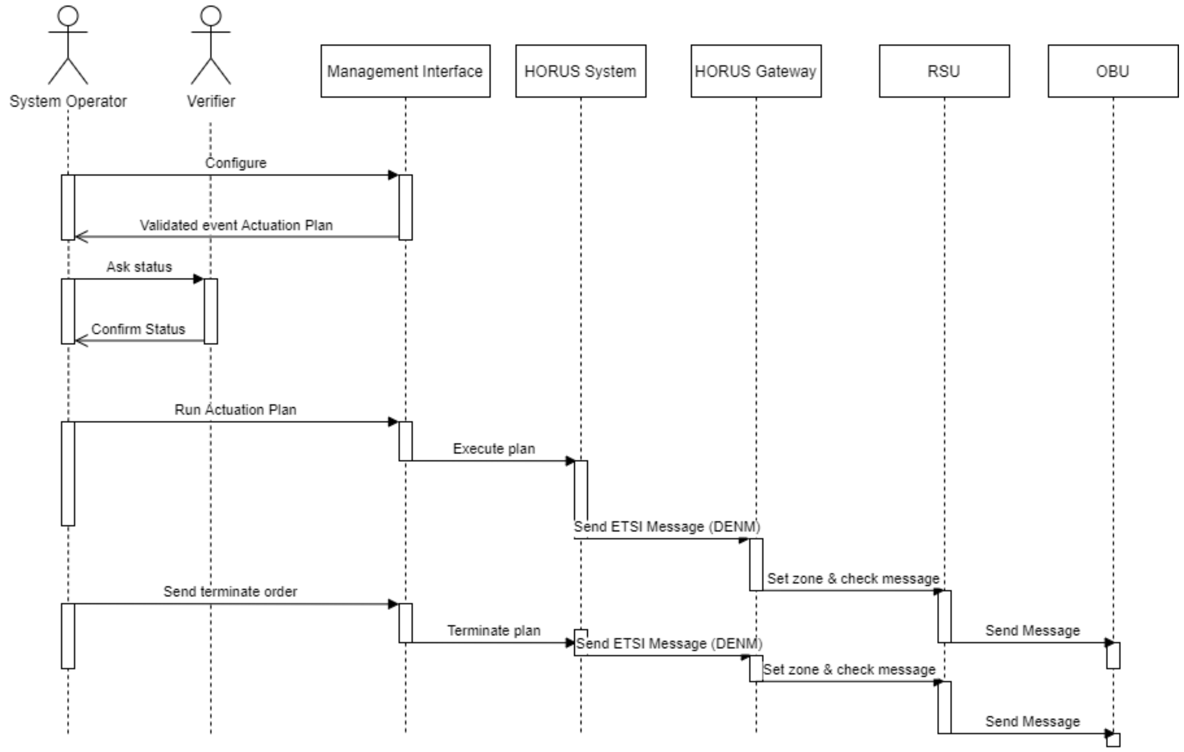
Sequence Diagram

Diagram of manual launch case



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3 Technical details of the Use Case - Actors

Actor Name	Actor Type	Actor Subcategories	Actor description	Further information specific to this Use Case	Equipment Manufacturer	Requirement(s) of the actor	Reference Standards/Legislation
System Operator	Role	User	Person in charge of control the system	The system operator manages the information to send it to vehicles and infrastructure		Knowledge of Horus system and traffic management.	
Verifier	Role	User	Person in charge of inform the real status of the roadworks	The verifier confirms real status of Roadworks message			
ETL	System	IS IT	System in charge to transform the roadwork information in message knowing by system	ETL continuous know the status of roadworks and transform information in Horus system messages			
HORUS System	System	IS IT	System in charge to manage all road information	Main System to manage all road information			
Horus Gateway	System	IS IT	System in charge to manage all V2X information	Dedicated Horus Module to manage V2X messages.			ETSI V2X C-ITS

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RSU	System		System in charge to connect HORUS information, roadwork information in message knowing by system	Road equipment to receive and send info between Horus system and OBU			ETSI V2X RSU
OBU	System		System in charge	Vehicle module to connect with RSU, and manage information relative V2X			ETSI V2X OBU

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4 Step by Step Analysis of the Use Case

4.1 List of scenarios

S.No	Scenario Name	Scenario Description	Primary Actor	Triggering Event	Pre-Condition	Post-Condition
PS1	Roadwork in progress	The system operator launch a Roadworks message plan to inform vehicles that a particular zone of the road is under roadworks	System operator	The system operator confirms with the verifier that a roadworks is ongoing	Place on map the roadworks warning message and declare a roadworks plan in the system	Send information through messages to the vehicles
PS2	Roadwork in progress (automatic)	The ETL launch a Roadworks message plan to inform vehicles that a particular zone of the road is under roadworks	ETL	The ETL was informed that a roadworks is ongoing	Declare a roadworks message plan in the system	Send information through messages to the vehicles
AS1	Roadwork in progress	Roadworks message is ongoing	HORUS System	The roadworks message continues active	Launch roadworks message plan	Continue sending information through messages to the vehicles
AS2	Roadwork Terminate	Roadworks message ends and informs the system or the operator	System operator / HORUS System	Roadworks message ends	Roadwork is ongoing	Send final Roadworks message

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4.2 Steps - Primary Scenario

Scenario Name:									
St No.	Event	Description of Process/Activity	Information Producer	Information Receiver	Information Exchanged	Service	Requirements	Communication Media	Communication Means
1	Operator configure plan	Message configure	Operator		ID or description	create	Configuration,		GUI
2	Operator Launch plan	Active Plan	verifier	operator		execute	Configuration		Voice, GUI
2	ETL Launch Plan	Active Plan	ETL	HORUS system		execute	Configuration	Communication protocol	Communication protocol
3	Connect Gateway	Gateway connection	Gateway Management Tool	Active Gateway	I-2.04	Send		Communication protocol	Communication protocol
4	Connect RSU	RSU connection	HORUS system	RSU	I-2.04	Send		Communication protocol	Communication protocol
5	Send message to RSU	RSU receive message from gateway	Gateway	RSU	I-2.04	Send	Active RSU	Communication protocol	Communication protocol
6	RSU Send message	RSU send message to vehicles	RSU	Vehicles -OBU		Send	Active OBU	Communication protocol	Communication protocol
7	OBU receive message	OBU receive message	RSU	OBU		Receive	Active OBU	Communication protocol	Communication protocol

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8	Operator Terminate plan	Terminate Plan	verifier	operator		Terminate	Launch		Voice, GUI
8	ETL Terminate Plan	Terminate Plan	ETL	HORUS system		Terminate	Launch	Communication protocol	Communication protocol

4.3 Steps – Alternative, Error Management, and/or Maintenance/Backup Scenario

Scenario Name:									
St No.	**Event**	**Description of Process/Activity**	**Information Producer**	**Information Receiver**	**Information Exchanged**	**Service**	**Requirements**	**Communication Media**	**Communication Means**
2	Operator Launch plan	Active Plan	verifier	operator		execute	Configuration		Voice, GUI
2	ETL Launch Plan	Active Plan	ETL	HORUS system		execute	Configuration	Communication protocol	Communication protocol
3	Connect Gateway	Gateway connection	Gateway Management Tool	Active Gateway	I-2.04	Send		Communication protocol	Communication protocol
4	Gateway unavailable	Gateway doesn't work	Horus System			Report	Management	Communication protocol	Communication protocol

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5 Information Exchanged

Inf. ID	Name of information exchanged	Description of information exchanged	Information Subcategories[1]	Requirements
1	protocolVersion	ITS PDU header from C-ITS/RSU and Constant, “currentVersion” = 1, ITS G5 is overwritten by RSU.	protocol parameter	
2	messageID	ITS PDU header from C-ITS/RSU and Constant, DENM = 1, ITS G5 is overwritten by RSU.	protocol parameter	
13	stationID	ITS PDU header from C-ITS/RSU and Variable in the registry, ITS G5 is overwritten by the RSU.	protocol parameter	
4	actionID	Management from C-ITS and IdPlan+stationID. If ITS G5 calculates internally. IdPlan only allows one order per sequence.	protocol parameter	
5	detectionTime	Management from C-ITS and It‘s calculated when the C-ITS conforms the message.	Algorithm	
6	referenceTime	Management from C-ITS/RSU and It is calculated when the C-ITS forms the message, ITS G5 is overwritten by the RSU.	Algorithm	
7	Termination	Management from C-ITS/RSU and Value set in form editor sequences, ITS G5 is overwritten by the RSU after the terminate function. and Only use if = isCancellation (0).	protocol parameter	
8	eventPosition	Management from C-ITS/RSU and Form Order interface. If eventPosition = (0, 0, 0) then RSU uses its own position.	protocol parameter	
9	relevanceDistance	Management from C-ITS/RSU and Form Order interface. and Although DE is optional, it is necessary to define it, because ITS G5 RSU uses it to calculate the destination area (GN Data). If it is undefined the messages still are correct, but a default value (1 = <100m) must be used. It is possible to get out the zoom on the sequence.	protocol parameter	
10	relevanceTrafficDirection	Management from C-ITS/RSU and Form Order interface. RSUs always uses it, if C-ITS does not determine it the default value is 1 (upstream).	protocol parameter	
11	validityDuration	Management from C-ITS and Time from registry value	protocol parameter	
12	transmissionInterval	Management from and Not used	protocol parameter	

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13	stationType	Management from C-ITS/RSU and RSU overwrites roadSideUnit (15) in ITS G5.It is necessary to define a value for C-ITS, when this value is not overwritten, under cellular connections (16).	protocol parameter	
14	informationQuality	Situation from C-ITS/RSU and Constant, lowest(1) , ITS G5 is overwritten by RSU	protocol parameter	
15	eventType	Situation from C-ITS and Form Order interface.	protocol parameter	
16	linkedCause	Situation from and Not used	protocol parameter	
17	eventHistory EventHistory	Situation from C-ITS and Form Order interface.	protocol parameter	
18	eventSpeed	Location from RSU and IF subCauseCode = slowMovingRoadMaintenace, then its own velocity is used, otherwise, it is not sent.	protocol parameter	
19	eventPositionHeading	Location from C-ITS and Form Order interface.	protocol parameter	
20	Traces	Location from C-ITS and Form Order interface.	protocol parameter	
21	roadType	Location from and Not used	protocol parameter	
22	lanePosition	alacarte from C-ITS and Form Order interface.	protocol parameter	
23	impactReduction	alacarte from and Not used	protocol parameter	
24	externalTemperature	alacarte from and Not used	protocol parameter	
25	roadWorks	alacarte from C-ITS/ RSU and If causeCode = roadWork	protocol parameter	
26	positioningSolution	alacarte from and Not used	protocol parameter	
27	stationaryVehicle	alacarte from and Not used	protocol parameter	
28	heightLonCarrLeft	ImpactReductionContainer from and Not used	protocol parameter	
29	heightLonCarrRight	ImpactReductionContainer from and Not used	protocol parameter	
30	posLonCarrLeft	ImpactReductionContainer from and Not used	protocol parameter	
31	posLonCarrRight	ImpactReductionContainer from and Not used	protocol parameter	
32	positionOfPillars	ImpactReductionContainer from and Not used	protocol parameter	
33	posCentMass	ImpactReductionContainer from and Not used	protocol parameter	
34	wheelBaseVehicle	ImpactReductionContainer from and Not used	protocol parameter	
35	turningRadius	ImpactReductionContainer from and Not used	protocol parameter	
36	posFrontAx	ImpactReductionContainer from and Not used	protocol parameter	
37	positionOfOccupant	ImpactReductionContainer from and Not used	protocol parameter	
38	vehicleMass	ImpactReductionContainer from and Not used	protocol parameter	
39	requestResponseIndication	ImpactReductionContainer from and Not used	protocol parameter	
40	lightBarSirenInUse	RoadWorksContainerExtended from and Not used	protocol parameter	

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41	closedLanes	RoadWorksContainerExtended from C-ITS and Form Order interface.	protocol parameter	
42	Restriction	RoadWorksContainerExtended from and Not used	protocol parameter	
43	speedLimit	RoadWorksContainerExtended from C-ITS and Form Order interface.	protocol parameter	
44	incidentIndication	RoadWorksContainerExtended from and Not used	protocol parameter	
45	recommendedPath	RoadWorksContainerExtended from C-ITS and Depends of RSU & C-ITS. Form Order interface.	protocol parameter	
46	startingPointSpeedLimit	RoadWorksContainerExtended from C-ITS and Form Order interface.	protocol parameter	
47	trafficFlowRule	RoadWorksContainerExtended from and Not used	protocol parameter	
48	referenceDenms	RoadWorksContainerExtended from and Not used	protocol parameter	
49	stationarySince	StationaryVehicleContainer from and Not used	protocol parameter	
50	stationaryCause	StationaryVehicleContainer from and Not used	protocol parameter	
51	carryingDangerousGoods	StationaryVehicleContainer from and Not used	protocol parameter	
52	numberOfOccupants	StationaryVehicleContainer from and Not used	protocol parameter	
53	vehicleIdentification	StationaryVehicleContainer from and Not used	protocol parameter	
54	energyStorageType	StationaryVehicleContainer from and Not used	protocol parameter	

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OMI((RON

Intelligent Road Asset Management Platform

Robotic Modular Platform

Definition of Requirements

Publish Date: 2021.09.15

Use Case Number: UC2.1

Use Case Title: Robotic Modular Platform

Use Case Responsible Partner: TEKNIKER

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1 Description of the Use Case

1.1 Use Case Identification

ID	Domain(s)	Name of Use Case	Level of Use Case
UC2.1	UC2: Routine and emergency maintenance interventions	Implementing a Robotic Modular platform for road maintenance interventions	Detailed Use Case

1.2 Scope and Objectives

Scope and Objectives of the Use Case	
Scope	Road maintenance workers shall be supported in their intervention activities. These activities comprise among others, placing and removing traffic signals and cones, installing safety barriers or cleaning road assets. For these activities, operators need to walk along the road with traffic, even cross it, and carry large loads. These activities force the operators to constantly take very high risks, both from the ergonomic and safety points of view. Additionally, the use of a modular robotic platform should reduce the execution times and the corresponding workforce needed, resulting in a remarkable reduction in maintenance costs.
Objective	• Daily work support: Aim of the use case is to assist operators improving their working conditions. • Operator safety: A modular robotic platform reduces the exposure of workers to construction sites and also reduces intervention times, thereby reducing the probability of an accident. • Saving costs: The robotic solution has as a direct result the reduction of execution times and the corresponding workforce needed. This will result in a reduction in maintenance costs. • Road safety: The robotised interventions with the modular robotic platform in are executed more effectively and efficiently, thus ensuring the proper functioning of the traffic flow and preventing road users from being killed or seriously injured. • Availability of the network: The effective and efficient robotised interventions reduce the traffic disruptions.
Related Business Case	*Automation and robotisation of maintenance operations*

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1.3 Narrative of the Use Case

Short description – max 3 sentences
A robotic modular platform for road maintenance operations shall support road workers in their maintenance activities, like placing / removing signals and cones, installing safety barriers or cleaning road assets. For these activities, a perception system that combines Artificial Vision and AI tools is needed, which allows the robotic system to detect the elements of interest and to adapt autonomously the motions of the robot arm according to the status of the road and the elements to be manipulated. Additionally, a set of interchangeable tools shall be designed to tailor the system to a set of maintenance and renewal processes.
Complete description
Road maintenance workers need support in their daily intervention activities, since current methods for those activities are labour intensive and as such are slow, unsafe and costly to the economy and environment. Many maintenance activities are not or cannot be fully automated at a reasonable cost due to technical issues. Therefore, human-robot cooperation may be the most cost-efficient and productive solution avoiding complex automation and increasing process efficiency. A robotic modular platform shall be able to operate in conjunction with workers in multiple maintenance interventions, taking over higher risk operations from works, and minimizing workers' exposure to live traffic. The robotic modular platform is comprised of a robotic arm, a perception module and a set of tools to assist in several emergency, ordinary and extraordinary maintenance interventions. For example, the installation or replacement of safety barriers is a key emergency operation. This process comprises the manual handling of high loads, particularly in the elevation and support of the fence while it is being adjusted to the post. The robotic modular arm shall focus on the placement and adjustment of the barrier on the post. The robot arm shall provide a way for the worker to easily adjust the position with respect the vertical posts. The worker shall be able to move manually the robot to adjust the position, while the robot maintains the weight of the guardrail. Another application of the robotic platform is the installation and removal of safety cones. The robotic arm automatically manipulates the cones. To this end, a vision camera shall be used, so the perception algorithm identifies the position of the elements, by combining AI techniques with surface matching algorithms. The robot tool shall be adapted to handle cones reliably. During the operation, the operators shall not need to leave the vehicle to perform the task. The cleaning of signalling and lighting is an extremely repetitive task, currently performed manually. The modular elements integrated in the robotic platform shall allow cleaning lights and vertical signals located on the sides of the roads and at the reach of the robot, while ensuring both safety and quality in the results. The robot shall use a vision system to identify the presence of signals and estimate the relative position with respect to the robot. Then, a control logic shall generate the trajectories and activate the water spraying cleaning tool (through digital signals). In addition to these routine interventions, the robotic modular platform shall assist also in extraordinary interventions, like installing signals during construction works, removing horizontal markings and sealing pavement cracks. The layout of signalling construction works is regulated according to Member States legislation, and generally includes the use of traffic signals (reduction of speed, narrowing signals, etc.) and signalling cones. The robotic platform shall use a perception system to identify the position of signals and cones, along with a tool to handle both cones and signals reliably.

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Painting removal is a common task in road maintenance, being the most common approach painting over with black paint. The main drawbacks of this approach are the presence of brightness and the creation of a slippery area due to an additional painting layer. The robotic modular platform shall use a laser-based innovative concept for paint removal and provide specific texture to surface to avoid reduction in the friction. For this task, a laser head shall shall be mounted on the flange of the robotic arm. Besides, the platform shall use a perception system to identify and characterise the painting signal and generates the trajectory of the laser head.

Road crack sealing is an important step to take for the maintenance of the asphalt surface, because it helps to prevent larger maintenance projects down the road. The sealing of cracks in surface pavement layers is performed using a dedicated machine that heats up the sealing material. A robotic arm shall assume the operation of the pipes of the machine and the application of the sealing material over the cracks, minimizing the exposure of workers to the manipulation of the material and, hence, preventing accidents, like severe burns on workers. Crack sealing operations includes two basic steps: first, the application of hot air flow on the crack, so as to remove any material inside and prepare the surface for the sealing material; second, the application of the sealing material. The modular robotic platform shall automate this process by using a special tool that combines the application of hot air flow and the sealing material.

1.4 KPIs

ID	Name	Description	Target	Reference to mentioned Use Case objectives
KPI2*	Emergency, ordinary and extraordinary maintenance intervention times	The use of a modular robotic platform shall reduce the intervention times of some maintenance tasks.	9%	Reduction of time
KPI3*	Volume of people in dangerous zones in road maintenance areas	The use of a modular robotic platform shall reduce the need of workers' exposure to live traffic and dangerous zones.	58%	Operator safety
KPI6*	Traffic disruptions due to inspection tasks	The automation and robotisation of maintenance tasks should reduce traffic disruptions.	8%	Operator safety Road safety

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KPI9*	Maintenance and inspection activity costs	The use of a modular robotic platform shall reduce the number of operators needed for some maintenance tasks, as well as intervention times, thereby reducing costs.	21%	Saving costs
KPI12	Road Hazard Index	Hazard index attempts to explain the degree of danger and exposure to the risk of accidents. The robotised interventions in road will be executed more effectively and efficiently, thus reducing this index.	Overall 50% (including all project technologies)	Road safety
KPI13	Availability of the network. Impact of a reduced number of disruptions due to accidents and interventions	The availability of road infrastructures should increase due to a reduced number of traffic disruptions caused by accidents and interventions.	Overall 15% (including all project technologies)	Road safety
KPI14	Availability of the network. Impact of the reduction of traffic disruptions due to maintenance	The availability of road infrastructures should increase due to a reduced number of traffic disruptions caused by maintenance	Overall 5% (including all project technologies)	

* The target values have been calculated as the average value of the use cases UC2.1.1, UC2.1.2, UC2.1.3, UC3.1, UC3.2 and UC3.3.

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1.5 Use Case Conditions

Actor	Triggering Event	Pre-conditions	Assumption
Describe which Actor(s) trigger(s) this Use Case	Describe what event(s) trigger(s) this Use Case	Describe what condition(s) should have been met before this Use Case happens	Describe the assumptions about conditions or system configurations.

Road administration	The road administration contacts the road workers to notify that they need to provide a service	The kilometre points in which the service need to be performed.	• The vehicle has enough fuel
			• The system works properly, including:
			  ○ Robot arm
			  ○ Perception system
			  ○ Tooling

1.6 Classification Information

Relation to Other Use Cases in the same project or area
UC2.1.1 Installation of safety barriers UC2.1.2 Installation of cones UC2.1.3 Road assets cleaning UC3.1 Signalling during construction works UC3.2 Sealing of surface pavement cracks UC3.3 Removal of lane markings with laser
Level of Depth - the degree of specialization of the Use Case
Detailed Use Case
Further Keywords for Classification
Modular robotic arm, road maintenance
Maturity of Use Case
Visionary

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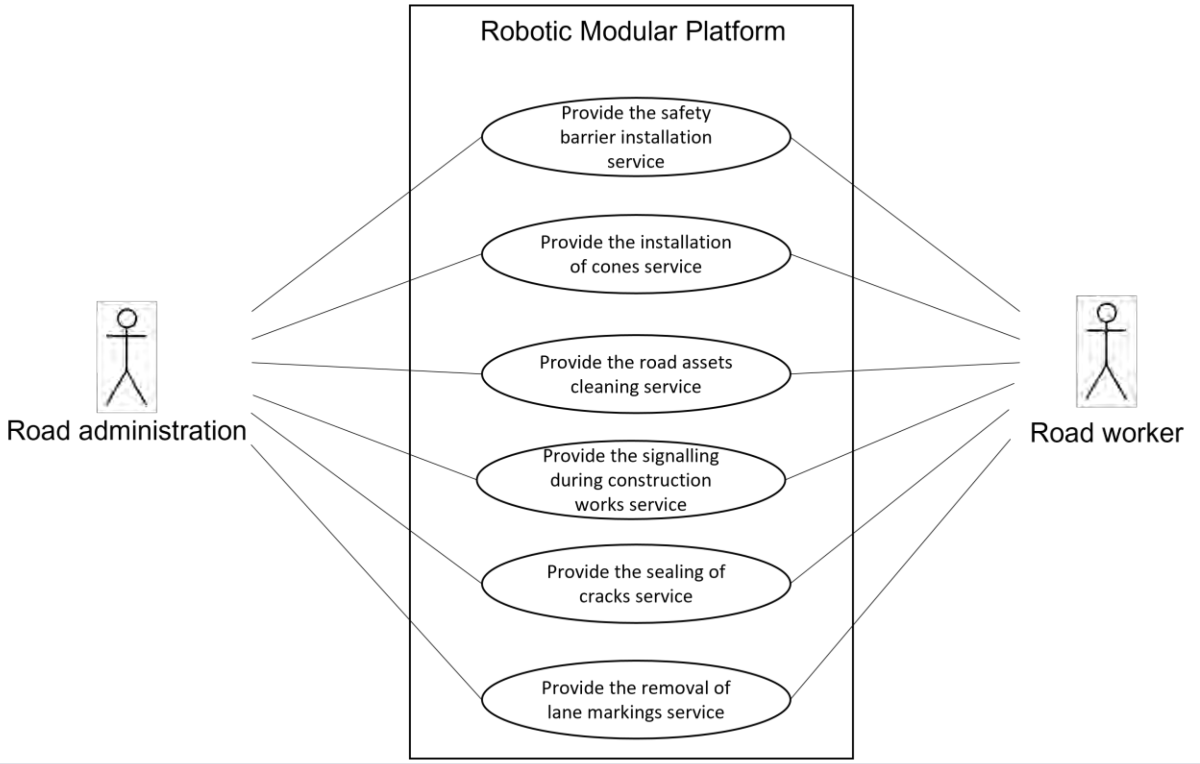
2 Diagrams of the Use Case

Context Diagram



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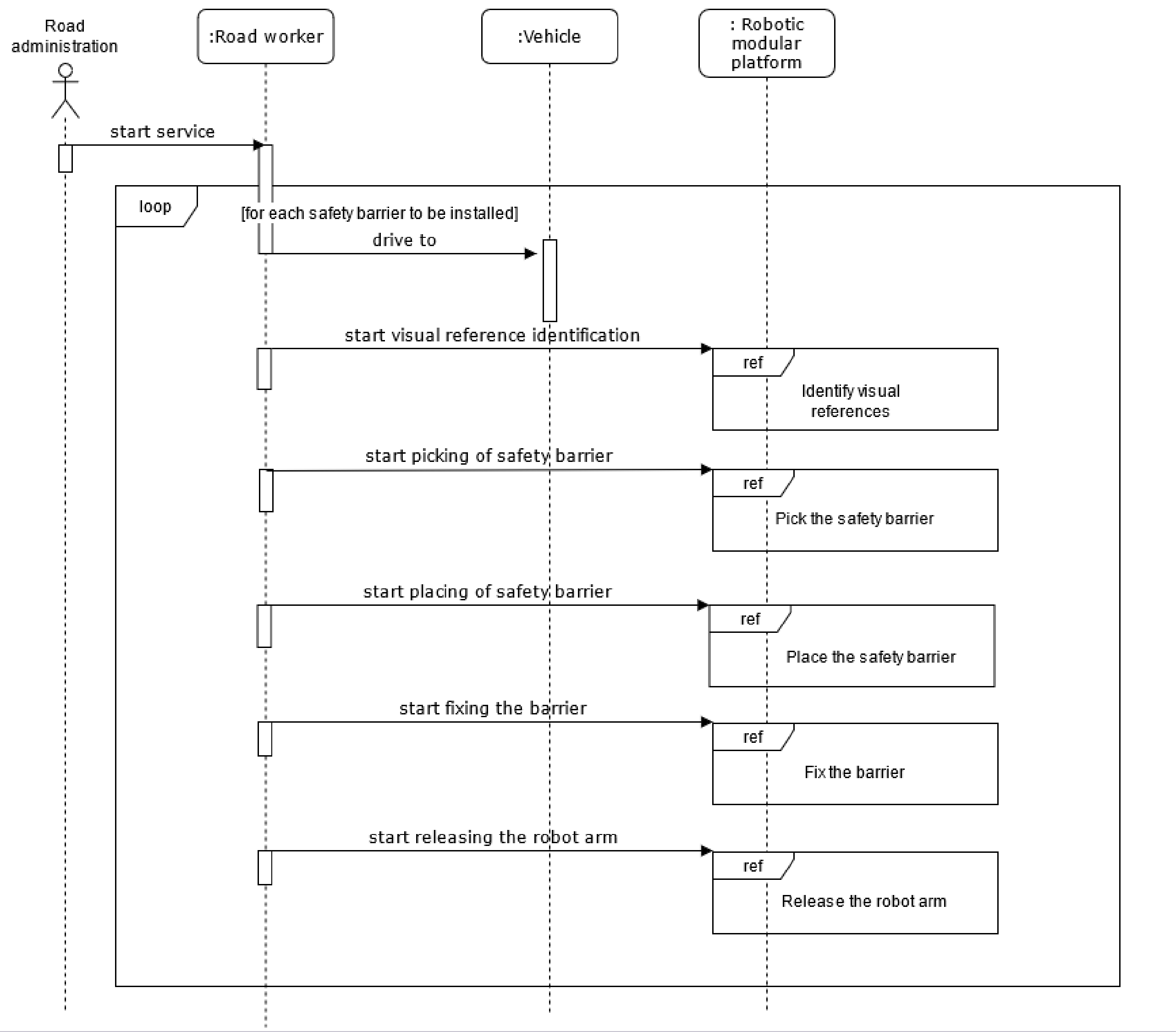
Sequence Diagram: Provide the safety barrier installation service



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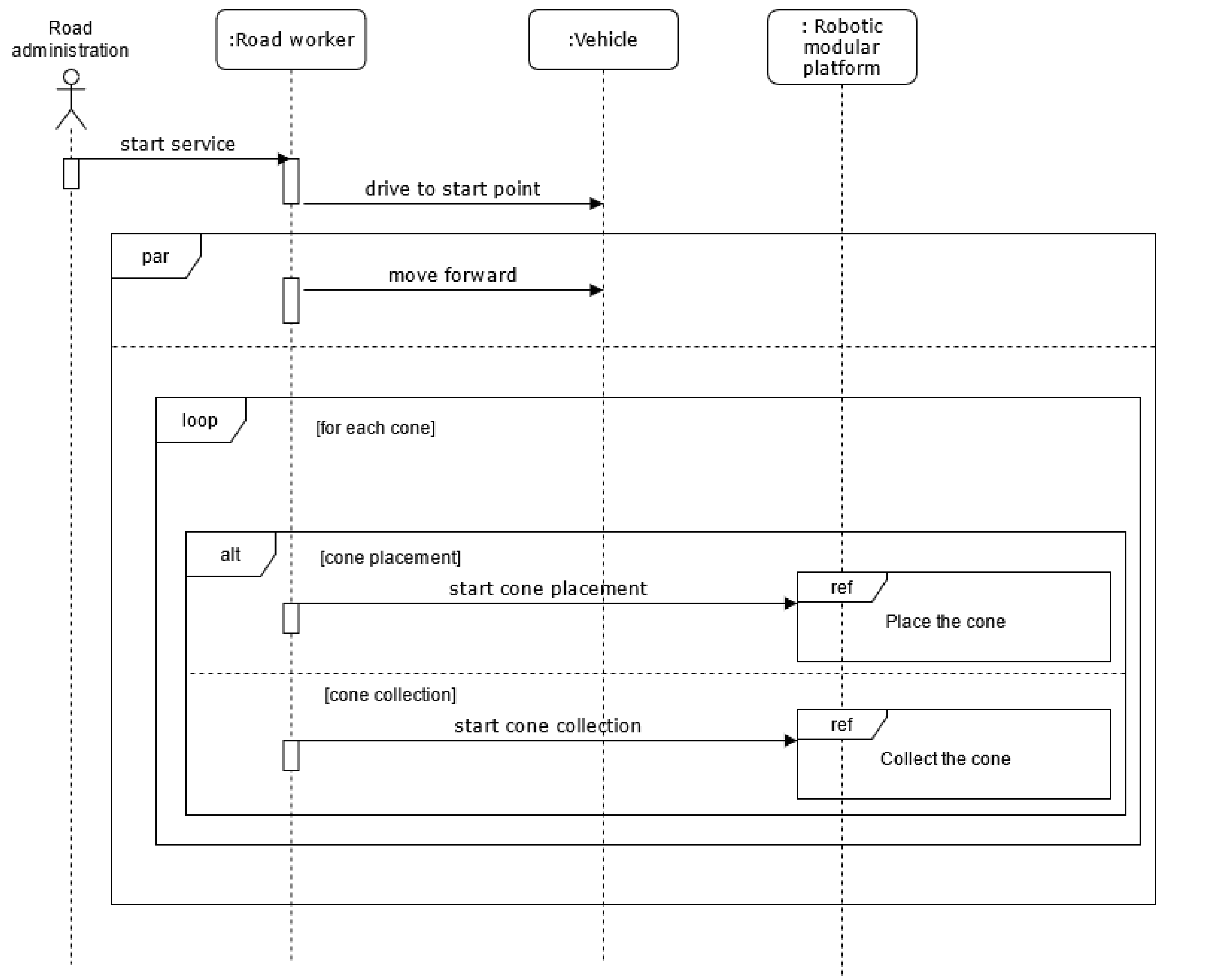
Sequence Diagram: Provide the installation of cones service



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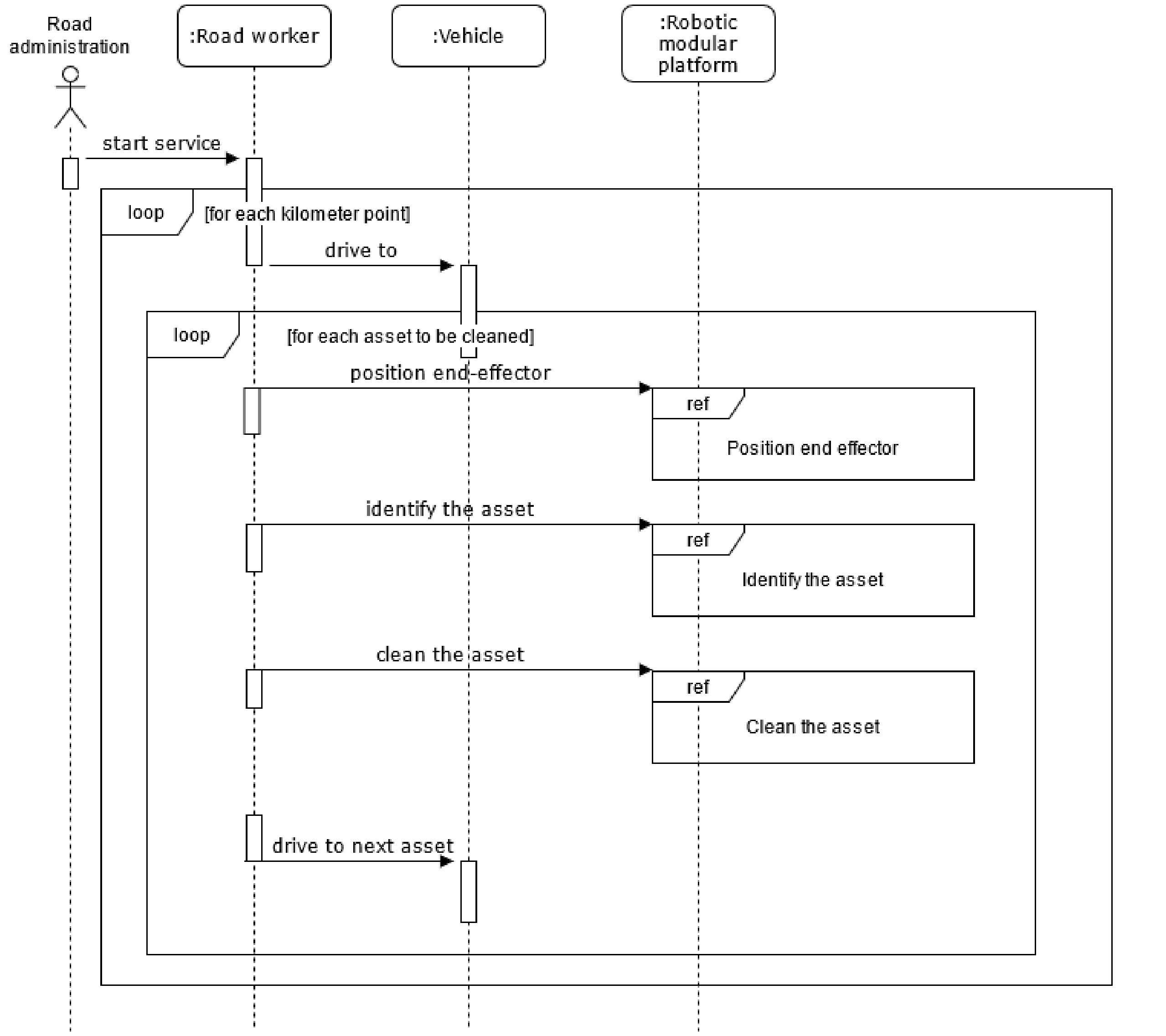
Sequence Diagram: Provide the road assets cleaning service



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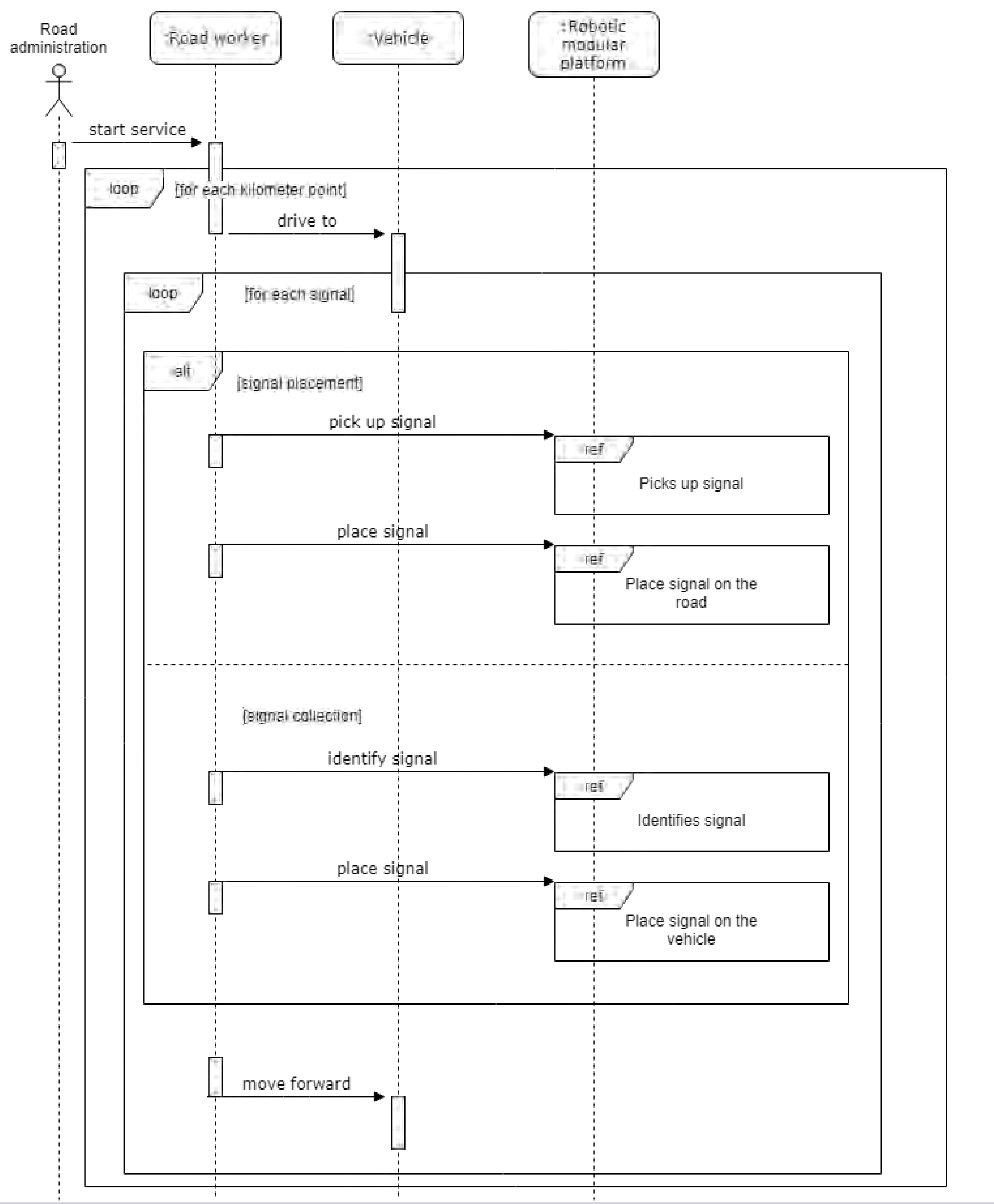
Sequence Diagram: Provide the signalling during construction works service



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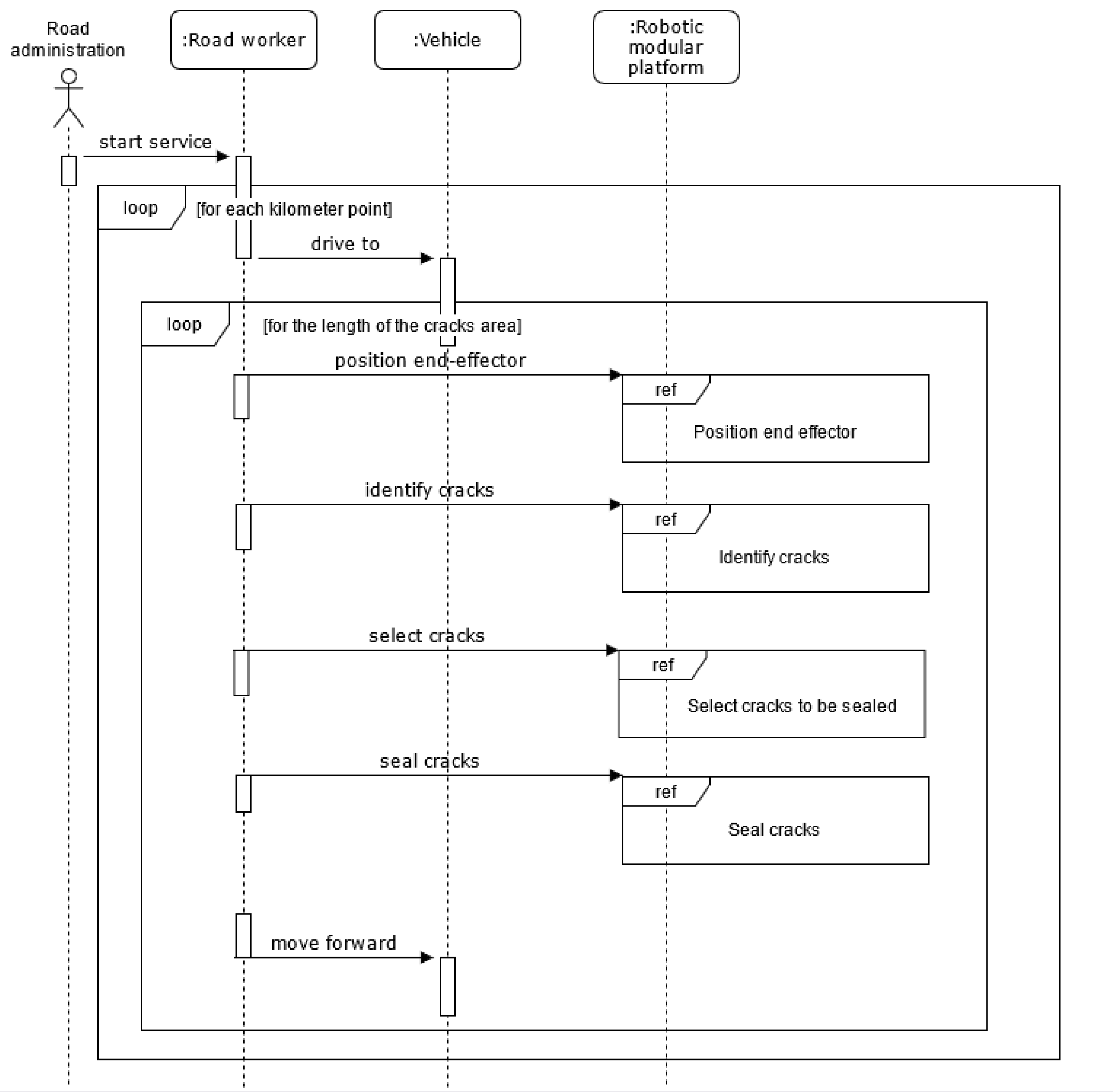
Sequence Diagram: Provide the sealing of cracks service



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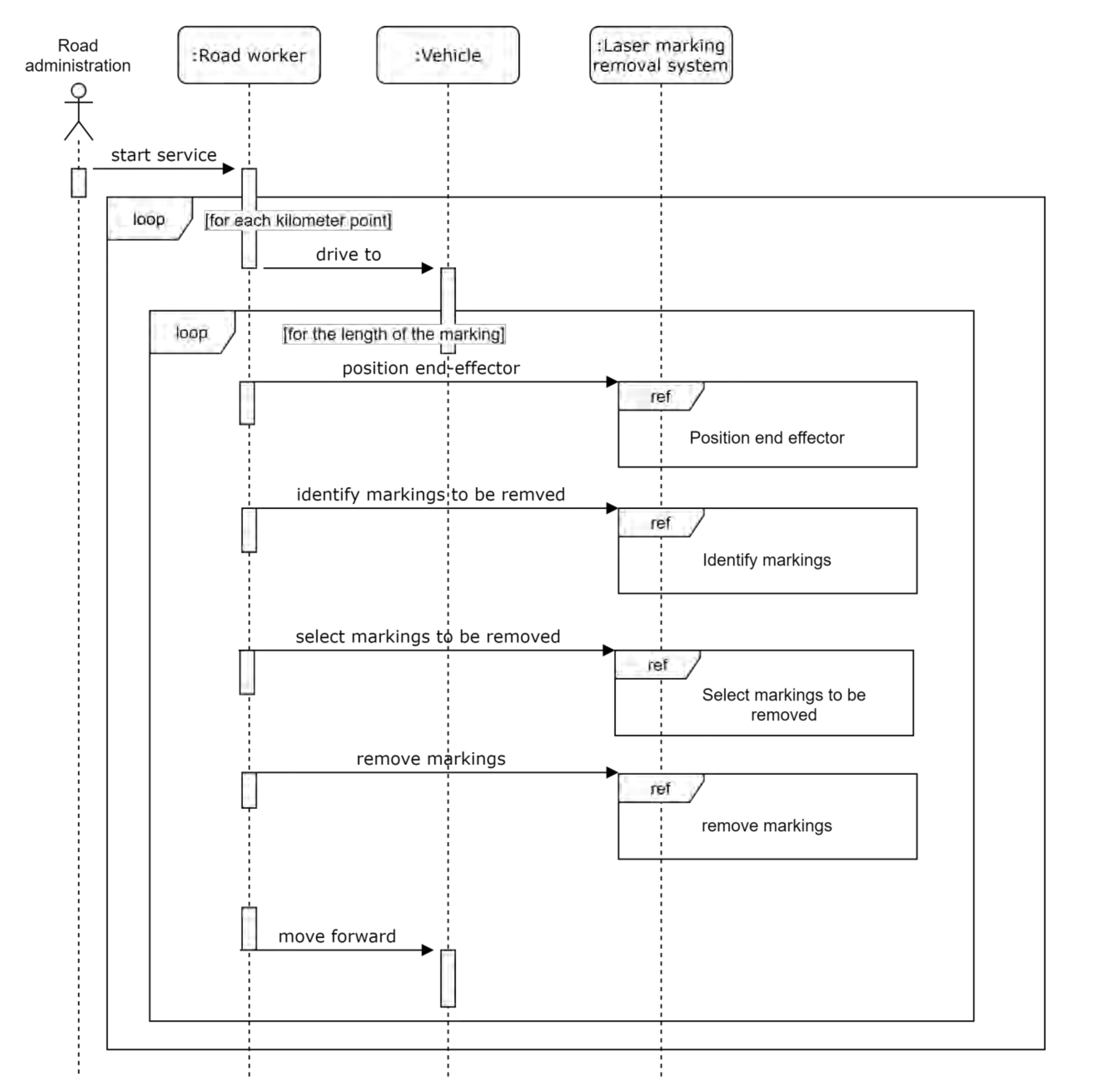
Sequence Diagram: Provide the removal of lane markings service



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3 Technical details of the Use Case - Actors

Actor Name	Actor Type	Actor Subcategories	Actor description	Further information specific to this Use Case	Equipment Manufacturer	Requirement(s) of the actor	Reference Standards/Legislation
Road administration	Role	Road contractor	The administration that notifies the road workers to perform a service	The administration manages roads inspection data and, based on that, decides when a service need to be started.		Shall have knowledge of the roads and service resources	
Road worker	Role	Road contractor	The operator that performs the service	The operator directly uses the modular robotic platform to perform the service		Shall have knowledge of the modular robotic platform technology and operation	
Vehicle	System	Road machinery	The vehicle that carries the modular robotic platform	The vehicle carries the modular robotic platform, which is hooked up to the back of it.		Shall contain enough space to storage the assets Shall be able to tow the whole robotic system Shall be able to move at a very low speed	

4 Step by Step Analysis of the Use Case

4.1 List of scenarios

S.No	Scenario Name	Scenario Description	Primary Actor	Triggering Event	Pre-Condition	Post-Condition

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PS1	Provide the safety barrier installation service	The road worker drives the vehicle pushing the modular robotic platform to the first place where a safety barrier needs to be fixed to the posts that were already installed. The worker positions the vehicle in such a way that the robotic platform is close enough to perform the operation. After that, the road worker starts the identification of visual references process. When the post is identified, the road worker starts the safety barrier picking process. After that, the robot places the safety barrier in the right position, next to the. Then, the robot enters in sensitive mode, so the worker can easily move the robot to adjust the position with respect the vertical posts and fix the safety barrier. Finally, the road worker starts the release process to move the robot to the start position. This process is repeated for all the safety barriers that need to be installed. This scenario is described in detail in use case UC2.1.1 Installation of Safety Barriers	Road administration	Road administration notifies the start of the service	Safety barriers installation points have been identified and notified (at kilometre point level).	All safety barriers are fixed to the posts.
PS2	Provide the installation cones service	The road administration notifies the road workers that the cones placement service needs to be started. The road administration provides a kilometre point where the cones need to be placed. Then, the road workers drive to the kilometre point. When they arrive, they start moving slowly forward. For	Road administration	Road administration notifies the start of the service	The necessity of temporary signalling using cones has been identified and located (at kilometre point level).	All cones are placed (or collected).

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		each cone that need to be installed, the road worker manually starts the placement service. The same process applies for the collection of cones. This scenario is described in detail in use case UC2.1.2 Installation of Cones.				
PS3	Provide the road assets cleaning service	The road administration notifies the road workers that a road assets service needs to be started. The road administration provides a set of the kilometre points where there are assets that need to be cleaned. Then, the road workers drive to the first kilometre point in the list. When they arrive, they stop at the location of the first asset. After that, the road worker positions the end-effector of the robotic arm. Once positioned, the road worker starts the asset identification. When the asset is identified, the road worker selects manually the asset cleaning process. Once, finished the cleaning, the road worker moves forward to the next asset. This process is repeated for all the kilometre points where assets need to be cleaned. This scenario is described in detail in use case UC2.1.3 Road Assets Cleaning.	Road administration	Road administration notifies the start of the service	Assets to be cleaned have been identified and located (at kilometre point level).	All the assets are clean.
PS4	Provide the signalling during	The road administration notifies the road workers that the signalling placement service needs to be started.	Road administration	Road administration notifies the start of the service	The necessity of temporary signalling in a construction area	All signals are placed (or collected).

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	construction works service	The road administration provides a kilometre point where the signals need to be placed. Then, the road workers drive to the kilometre point. When they arrive, they stop at the beginning of the construction works. After that, the robot picks up the signal and places on the road. Once the signal is placed, the road worker moves forward to the next point in which a signal need to be placed. For the collection of the signals, the process is similar. In this case, the signal is identified by the perception system, and the robot picks up the signal and places on the vehicle. This scenario is described in detail in use case UC3.1 Signalling during Construction Works.			has been identified and located (at kilometre point level).	
PS5	Provide the crack sealing service	The road administration notifies the road workers that a crack sealing service need to be started. The road administration provides a set of the kilometre points where there are cracks that need to be sealed. Then, the road workers drive to the first kilometre point in the list. When they arrive, they stop at the beginning of the cracks. After that, the road worker positions the end-effector of the robotic. Once positioned, the road worker starts the crack identification. When the cracks are identified, the road worker selects manually the cracks to be sealed. Then, the road worker starts the crack sealing	Road administration	Road administration notifies the start of the service	Cracks on the road have been identified and located (at kilometre point level).	All the cracks are sealed.

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		process. Once, finished the sealing, the road worker moves forward a small distance using the vehicle to repeat the process again until the crack area is covered. This process is repeated for all the kilometre points where cracks need to be sealed. This scenario is described in detail in use case UC3.2 Sealing of Surface Pavement Cracks.				
PS6	Provide the removal of lane markings service	The road administration notifies the road workers that a marking removal service need to be started. The road administration provides a set of the kilometre points where there are markings that need to be removed. Then, the road workers drive to the first kilometre point in the list. When they arrive, they stop at the position of the first marking to be removed. After that, the road worker positions the end-effector of the robotic arm. Once positioned, the road worker starts the marking identification. When the markings are identified, the road worker selects manually the markings to be removed. Then, the road worker starts the marking removal process. Once the removal is completed, the road worker moves forward a small distance using the vehicle to repeat the process again until the markings are removed.	Road administration	Road administration notifies the start of the service	Improvement or maintenance works completed Ghost markings the road have been identified and located (at kilometre point level).	All the markings are removed

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		This process is repeated for all the kilometre points where markings need to be removed. This scenario is described in detail in use case UC3.3 Removal of Lane Markings with Laser.				
AS1	The road administration provides a set of incorrect kilometre points	The road worker reaches the kilometre point according to the information supplied by the road administration, but the place is not the right place perform the operation	Road worker	The worker drives to the kilometre point	The kilometre point was wrongly communicated.	The road workers get the right position.

4.2 Steps - Primary Scenario

Scenario Name: PS1.Provide the safety barrier installation service									
St No.	**Event**	**Description of Process/Activity**	**Information Producer**	**Information Receiver**	**Information Exchanged**	**Service**	**Requirements**	**Communication Media**	**Communication Means**
PS1.1	The road administration notifies the road worker	The road administration calls the road workers to notify that they need to provide a safety barriers installation service	Road administration	Road worker	I-01	REPORT		Phone call	Voice

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Scenario Name: PS1.Provide the safety barrier installation service									
St No.	**Event**	**Description of Process/Activity**	**Information Producer**	**Information Receiver**	**Information Exchanged**	**Service**	**Requirements**	**Communication Media**	**Communication Means**
PS1.2	The road worker drives to the installation point	The road worker drives the vehicle to the point where a safety barrier needs to be fixed.	Road worker	Vehicle					
PS1.3	The road worker starts the visual reference identification	(Defined in use case UC2.1.1 Installation of Safety Barriers)							
PS1.4	The road worker starts the picking of the safety barrier	(Defined in use case UC2.1.1 Installation of Safety Barriers)							
PS1.5	The road worker starts the placing of the safety barrier	(Defined in use case UC2.1.1 Installation of Safety Barriers)							
PS1.6	The road worker fixes the safety barrier to the posts	(Defined in use case UC2.1.1 Installation of Safety Barriers)							

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Scenario Name: PS1.Provide the safety barrier installation service									
St No.	Event	Description of Process/Activity	Information Producer	Information Receiver	Information Exchanged	Service	Requirements	Communication Media	Communication Means
PS1.7	The road worker starts the releasing of robot arm	(Defined in use case UC2.1.1 Installation of Safety Barriers)							
PS1.8	All safety barriers are fixed	Previous steps are repeated until all safety barriers are fixed.				REPEAT (2-7)			

Scenario Name: PS2.Provide the installation of cones service									
St No.	Event	Description of Process/Activity	Information Producer	Informatio n Receiver	Informatio n Exchanged	Service	Requirement s	Communicatio n Media	Communicatio n Means
PS2.1	The road administrati on notifies the road worker	The road administration calls the road workers to notify that they need to provide a cones installation service	Road administratio n	Road worker	I-01	REPOR T		Phone call	Voice
PS2.2	The road worker drives to the installation point	The road worker drives the vehicle to the point where cones need to be placed	Road worker	Vehicle					

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Scenario Name: PS2.Provide the installation of cones service										
St No.	**Event**	**Description of Process/Activity**	**Information Producer**	**Information Receiver**	**Information Exchanged**	**Service**	**Requirements**	**Communication Media**	**Communication Means**
PS2.3	The road worker decides to start moving forward	The road worker drives slowly the vehicle							
PS2.4	The road worker starts the picking of the cone	(Defined in use case UC2.1.2 Installation of Cones)							
PS2.5	All cones are picked	Previous steps are repeated until all cones are picked.				REPEAT (3-4)			

Scenario Name: PS3.Provide the road assets cleaning service									
St No.	**Event**	**Description of Process/Activity**	**Information Producer**	**Information Receiver**	**Information Exchanged**	**Service**	**Requirements**	**Communication Media**	**Communication Means**
PS3.1	The road administration	The road administration calls the road workers to notify that they need to provide a crack sealing service	Road administration	Road worker	I-01	REPORT		Phone call	Voice

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Scenario Name: PS3.Provide the road assets cleaning service									
St No.	**Event**	**Description of Process/Activity**	**Information Producer**	**Information Receiver**	**Information Exchanged**	**Service**	**Requirements**	**Communication Media**	**Communication Means**
	notifies the road worker								
PS3.2	The road worker drives to kilometre point	The road worker drives the vehicle to the kilometre point where assets need to be cleaned	Road worker	Vehicle					
PS3.3	The road worker positions the end-effector	(Defined in use case UC2.1.3 Road Assets Cleaning)							
PS3.4	The road worker starts the asset identification	(Defined in use case UC2.1.3 Road Assets Cleaning)							
PS3.5	The road worker starts the asset cleaning process	(Defined in use case UC2.1.3 Road Assets Cleaning)							
PS3.6	The road worker moves forward the vehicle	The road worker drives the vehicle to move forward to the next asset to be cleaned.	Road worker	Vehicle					

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Scenario Name: PS3.Provide the road assets cleaning service									
St No.	Event	Description of Process/Activity	Information Producer	Information Receiver	Information Exchanged	Service	Requirements	Communication Media	Communication Means
PS3.7	Assets are cleaned	Previous steps are repeated until all assets in the area are cleaned				REPEAT (3-6)			
PS3.8	All kilometre points are covered	Previous steps are repeated until all provided Kilometre points are covered				REPEAT (2-7)			

Scenario Name: PS4.Provide the signalling during construction works service									
St No.	Event	Description of Process/Activity	Information Producer	Information Receiver	Information Exchanged	Service	Requirements	Communication Media	Communication Means
PS4.1	The road administration notifies the road worker	The road administration calls the road workers to notify that they need to provide a signalling during constructions works service	Road administration	Road worker	I-01	REPORT		Phone call	Voice
PS4.2	The road worker drives to kilometre point	The road worker drives the vehicle to the kilometre point where signals need to be placed	Road worker	Vehicle					

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Scenario Name: PS4.Provide the signalling during construction works service									
St No.	Event	Description of Process/Activity	Information Producer	Information Receiver	Information Exchanged	Service	Requirements	Communication Media	Communication Means
PS4.3	The road worker starts the signal pick up process	(Defined in use case UC3.1 Signalling During Construction Works)							
PS4.4	The road worker starts the signal placing process	(Defined in use case UC3.1 Signalling During Construction Works)							
PS4.5	The road worker moves forward the vehicle	The road worker drives the vehicle to move forward a little bit to continue the signalling process	Road worker	Vehicle					
PS4.6	Signals are placed	Previous steps are repeated until all signals are placed				REPEAT (3-5)			
PS4.7	All kilometre	Previous steps are repeated until all provided Kilometre points are covered				REPEAT (2-6)			

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Scenario Name: PS4.Provide the signalling during construction works service									
St No.	Event	Description of Process/Activity	Information Producer	Information Receiver	Information Exchanged	Service	Requirements	Communication Media	Communication Means
	points are covered								

Scenario Name: PS5.Provide the crack sealing service									
St No.	Event	Description of Process/Activity	Information Producer	Information Receiver	Information Exchanged	Service	Requirements	Communication Media	Communication Means
PS5.1	The road administration notifies the road worker	The road administration calls the road workers to notify that they need to provide a crack sealing service	Road administration	Road worker	I-01	REPORT		Phone call	Voice
PS5.2	The road worker drives to kilometre point	The road worker drives the vehicle to the kilometre point where cracks need to be sealed	Road worker	Vehicle					

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Scenario Name: PS5.Provide the crack sealing service									
St No.	Event	Description of Process/Activity	Information Producer	Information Receiver	Information Exchanged	Service	Requirements	Communication Media	Communication Means
PS5.3	The road worker positions the end-effector	(Defined in use case UC3.2 Sealing of Surface Pavement Cracks)							
PS5.4	The road worker starts the crack identification	(Defined in use case UC3.2 Sealing of Surface Pavement Cracks)							
PS5.5	The road worker selects the cracks	(Defined in use case UC3.2 Sealing of Surface Pavement Cracks)							
PS5.6	The road worker starts the crack sealing process	(Defined in use case UC3.2 Sealing of Surface Pavement Cracks)							

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Scenario Name: PS5.Provide the crack sealing service									
St No.	**Event**	**Description of Process/Activity**	**Information Producer**	**Information Receiver**	**Information Exchanged**	**Service**	**Requirements**	**Communication Media**	**Communication Means**
PS5.7	The road worker moves forward the vehicle	The road worker drives the vehicle to move forward a little bit to continue the sealing of cracks	Road worker	Vehicle					
PS5.8	cracks are sealed	Previous steps are repeated until all cracks in the area are sealed				REPEAT (3-7)			
PS5.9	All kilometre points are covered	Previous steps are repeated until all provided Kilometre points are covered				REPEAT (2-8)			

Scenario Name: PS6.Provide the removal of lane markings service									
St No.	**Event**	**Description of Process/Activity**	**Information Producer**	**Information Receiver**	**Information Exchanged**	**Service**	**Requirements**	**Communication Media**	**Communication Means**
PS6.1	The road administration notifies	The road administration calls the road workers to notify that they need to provide a marking removal service	Road administration	Road worker	I-01	REPORT		Phone call	Voice

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Scenario Name: PS6.Provide the removal of lane markings service										
St No.	**Event**	**Description of Process/Activity**	**Information Producer**	**Information Receiver**	**Information Exchanged**	**Service**	**Requirements**	**Communication Media**	**Communication Means**
	the road worker								
PS6.2	The road worker drives to kilometre point	The road worker drives the vehicle to the kilometre point where markings need to be removed	Road worker	Vehicle					
PS6.3	The road worker positions the end-effector	(Defined in OMICRON_UC3.3_Removal_of_lane_markings_with_laser.docx)							
PS6.4	The road worker starts the marking identification	(Defined in use case UC3.3 Removal of Lane Markings with Laser)							
PS6.5	The road worker selects the markings	(Defined in use case UC3.3 Removal of Lane Markings with Laser)							
PS6.6	The road worker	(Defined in use case UC3.3 Removal of Lane Markings with Laser)							

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Scenario Name: PS6.Provide the removal of lane markings service									
St No.	Event	Description of Process/Activity	Information Producer	Information Receiver	Information Exchanged	Service	Requirements	Communication Media	Communication Means
	starts the marking removal process								
PS6.7	The road worker moves forward the vehicle	The road worker drives the vehicle to move forward a little bit to continue the removal of markings	Road worker	Vehicle					
PS6.8	markings are removed	Previous steps are repeated until all markings in the area are removed				REPEAT (3-7)			
PS6.9	All kilometre points are covered	Previous steps are repeated until all provided Kilometre points are covered				REPEAT (2-8)			

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4.3 Steps – Alternative, Error Management, and/or Maintenance/Backup Scenario

Scenario Name: AS1.The road administration provides a set of incorrect kilometre points									
St No.	Event	Description of Process/Activity	Information Producer	Information Receiver	Information Exchanged	Service	Requirements	Communication Media	Communication Means
AS1.1	Kilometre point is incorrect.	The road workers notices that the kilometre point is incorrect. Therefore, they contact to road administration to get the right position.	Road administration	Road worker	I-01	CHANGE		Phone	Voice

5 Information Exchanged

Inf. ID	Name of information exchanged	Description of information exchanged	Information Subcategories[1]	Requirements
I-01	Kilometre points data	The road administration provides a set of kilometre points codes where the service needs to be provided.	Network state	

[1] Select from the Subcategories listed in Annex B or in case of a new subcategory, please introduce it in the structure given in Annex B (insertion of new row in the Annex B).

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OMI((RON

Intelligent Road Asset Management Platform

Installation of Safety Barriers

Definition of Requirements

Publish Date: 2021.09.15

Use Case Number: UC2.1.1

Use Case Title: Installation of Safety Barriers

Use Case Responsible Partner: TEKNIKER

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1 Description of the Use Case

1.1 Use Case Identification

ID	Domain(s)	Name of Use Case	Level of Use Case
UC2.1.1	UC2: Routine and emergency maintenance interventions	Implementing a robotic system for the installation of safety barriers.	Detailed Use Case

1.2 Scope and Objectives

Scope and Objectives of the Use Case	
Scope	A robotic system shall support road maintenance workers in the process of installing safety barriers. This process comprises the manual handling of high loads, including the elevation and support of the fence while it is being adjusted to the post, and certain types of forced postures. All this leads to frequent injuries to the workers. Additionally, the use of a robotic arm for the positioning and support of the fence should reduce the installation time, resulting in a reduction in maintenance costs.
Objective	• Daily work support: Aim of the use case is to assist operators improving their working conditions. • Operator safety: The robotic system reduces the exposure of workers to the handling of high loads and certain types of forced postures, thereby reducing the probability of injury. • Saving costs: The robotic solution has as a direct result in the reduction of the corresponding workforce needed. This will result in a reduction in maintenance costs.
Related Business Case	*Automation and robotisation of maintenance operations*

1.3 Narrative of the Use Case

Short description – max 3 sentences
A robotic modular arm shall support road workers in the process of installing safety barriers in roads. For this process, a perception system is needed which allows the robotic arm to locate the visual references (posts and/or workers) and place the barriers in the right position. Then, the robot shall offer a way for the worker to easily adjust the position of the barrier with respect to the vertical posts. Additionally, a specific tool shall be designed to manipulate the metal barriers.
Complete description

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Road maintenance workers need support in the safety barriers installation process, particularly in the elevation and support of the fence while it is being adjusted to the post. A robotic arm shall assume the operation of positioning the metal safety barrier, minimizing manual handling of loads and forced postures of the workers.

A standard barrier is basically composed of three elements: the guardrail, the post, and the distance piece/spacer.

- **Guardrail**: it is the element that comes into contact with the vehicle, absorbing part of its kinetic energy through plastic deformation, and redirecting it to circulation in a smooth way. These are double wave metal profiles.
- **Post**: It is the element of support and insertion in the field. For its manufacture, metal profiles with different shapes are used (tubular, type C or CPN, etc.).
- **Distance piece/spacer**: It is the connecting element between the post and the fence. Its mission is to prevent vehicles from reaching the post, also keeping the height of the fence constant during the impact. Not all barriers have this element.

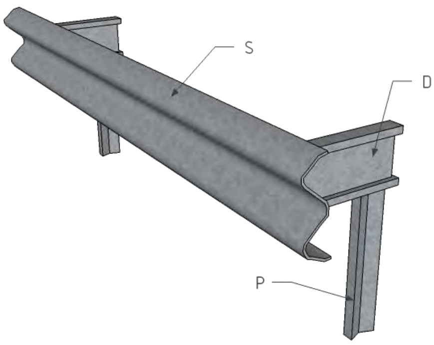


Figure 1 Parts that make up a common barrier with separator. S – guardrail, P – post, D – distance piece/spacer

In addition to these three main elements, there are the fixing elements (screws and nuts), the reflectors and in some cases, the exposed post under the fence is covered with a protection element for motorcyclists.

In addition, there are other types of simple metal barriers such as the simple fence without separator, the double fence, the overlapping fences, and the overlapping double fences, as well as double metal barriers.

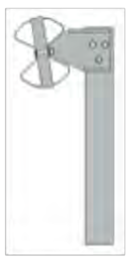
With distance piece / spacer				Reduced
Simple barrier	Double barrier	Overlaying barriers	Overlaying double barriers	Simple barrier
				

Figure 2 Types of metallic barriers

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The task of installing a W-beam metal barrier on the road vary depending on the type of barrier, as well as the terrain conditions, the type of road, the weather conditions, etc. In general, the barrier installation includes the following tasks:

- Installing the signalling of the zone of work.
- Supply of materials (fences, posts, spacers, screws, washers and nuts, reflectors), equipment (driver, welding machine, etc.) and tools (keys, hammer, etc.).
- Distribution of the elements and setting out of the location of the posts.
- Positioning of the W-beam barriers in their location.
- Marking and driving posts.
- Post cutting (if applicable).
- Distance piece/spacer attachment (if applicable).
- Placement and adjustment of the barrier or fence on the post.
- Screwing and fixing the barrier or fence to the post.
- Placement of the reflector (on alternate posts).
- Levelling the section and final tightening.
- Removing the signalling of the zone of work.

Regarding the repair, the order of the tasks is the same but with a previous phase of removal of the damaged or old elements.

Out of all the installation steps, the robotic modular arm shall focus on the placement and adjustment of the barrier on the post. More specifically, the robotic modular arm shall focus on the installation of simple barriers (see Figure 2). The robot arm shall provide a way for the worker to easily adjust the position with respect the vertical posts. The worker shall be able to move manually the robot to adjust the position, while the robot maintains the weight of the guardrail.

1.4 KPIs.

ID	Name	Description	Target	Reference to mentioned Use Case objectives
KPI2	Emergency, ordinary and extraordinary maintenance intervention times	The robot is in charge of positioning the guardrail. This process should reduce a little bit the intervention time	10%	Reduction of time
KPI3	Volume of people in dangerous zones in road	The use of a modular robotic platform shall reduce the need	25%	Operatory safety

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	maintenance areas	of workers to manipulate the guardrails during the fixing with the posts.		
KPI6	Traffic disruptions due to maintenance interventions	The reduction of time in positioning the guardrail shall reduce the traffic disruption	10%	
KPI9	Maintenance and inspection activity costs		10%	Saving costs

1.5 Use Case Conditions

Actor	Triggering Event	Pre-conditions	Assumption
Describe which Actor(s) trigger(s) this Use Case	Describe what event(s) trigger(s) this Use Case	Describe what condition(s) should have been met before this Use Case happens	Describe the assumptions about conditions or system configurations.
Road administration	The road administration contacts the road workers to notify that they need to provide an installation of safety barriers service	The kilometre points in which the safety barriers need to be installed have been identified. Posts have been already installed.	• The vehicle has enough fuel • The system works properly, including: ○ Robot arm ○ Camera

1.6 Classification Information

Relation to Other Use Cases in the same project or area
UC2.1 Robotic Modular Platform UC2.1.2 Installation of cones UC2.1.3 Road assets cleaning UC3.1 Signalling during construction works

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UC3.2 Sealing of surface pavement cracks UC3.3 Removal of lane markings with laser
Level of Depth - the degree of specialization of the Use Case
Detailed Use Case
Further Keywords for Classification
Modular robotic arm, installation of safety barriers, automatic detection of vertical pillars, automatic positioning of safety barrier
Maturity of Use Case
Visionary

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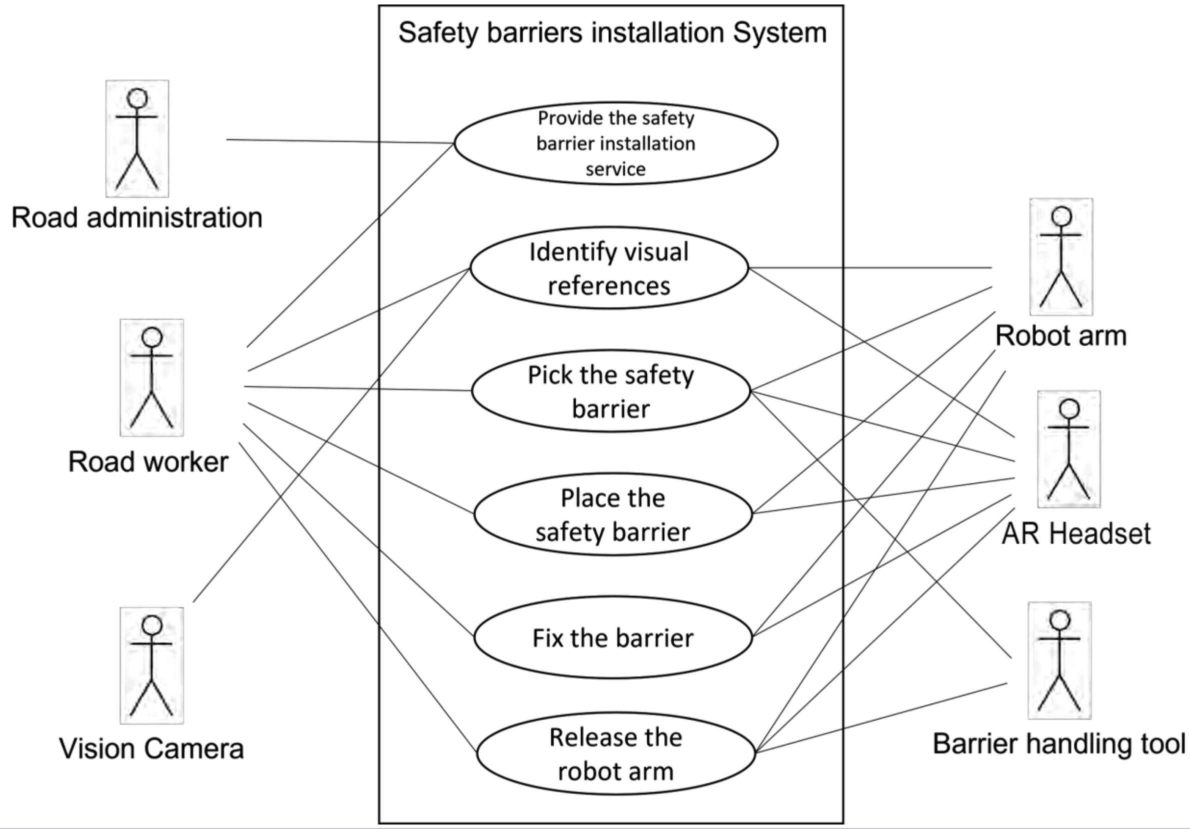
2 Diagrams of the Use Case

Context Diagram


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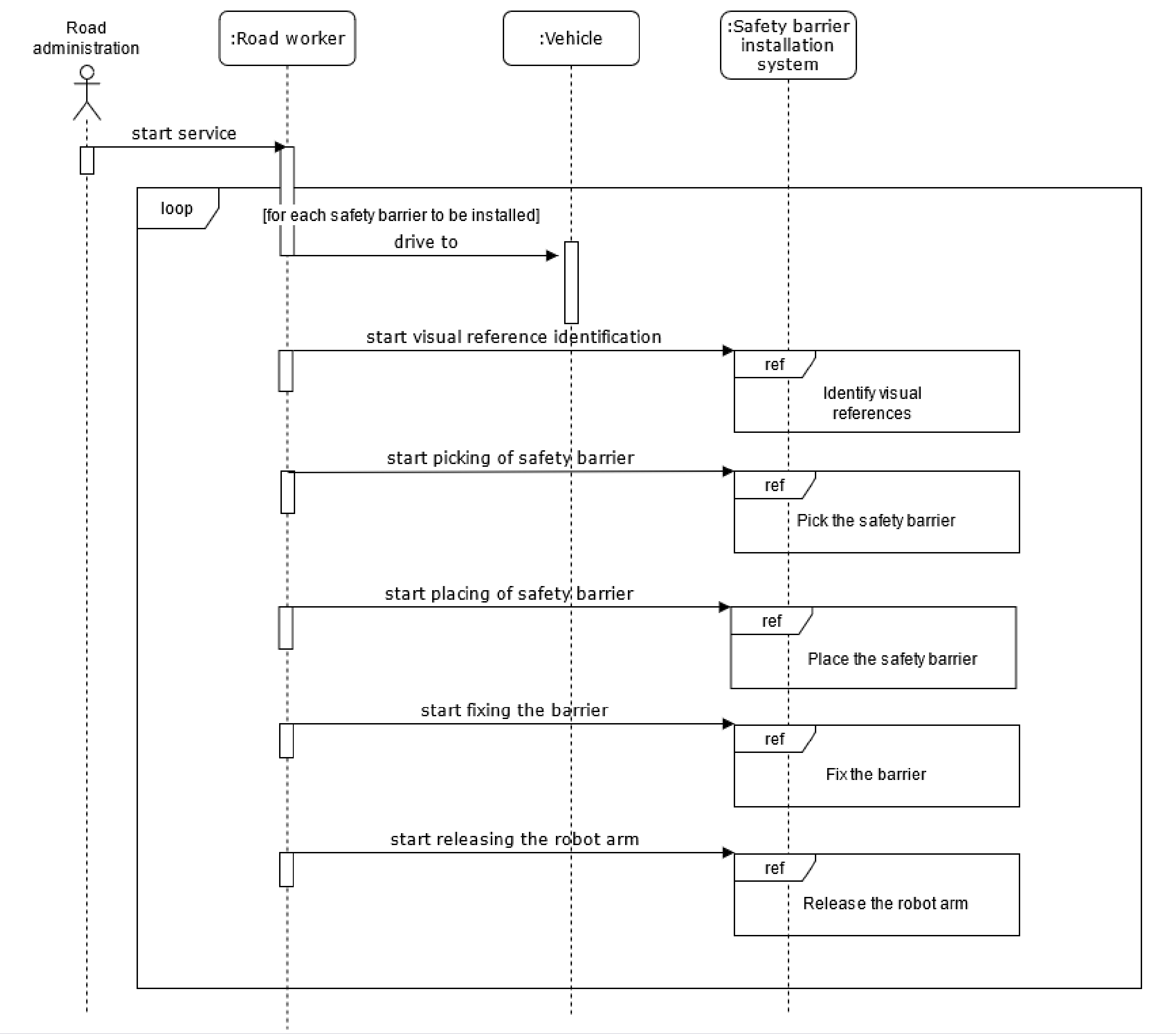
Sequence Diagram: Provide the safety barrier installation



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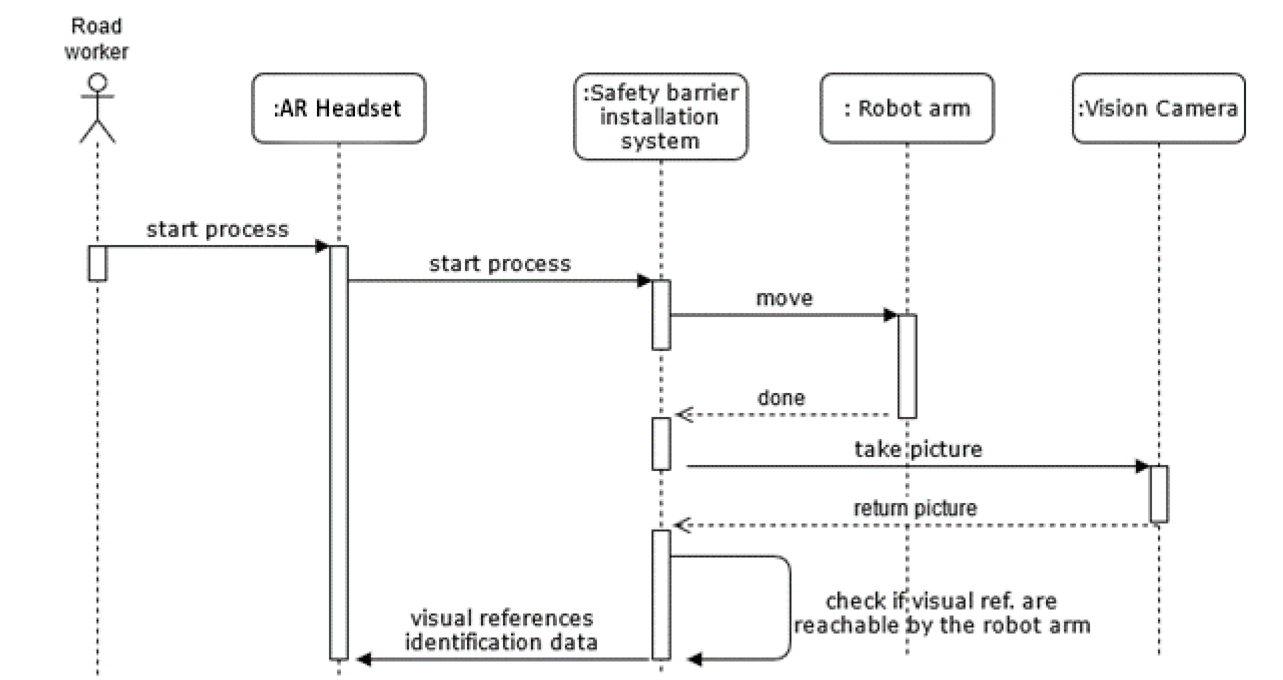
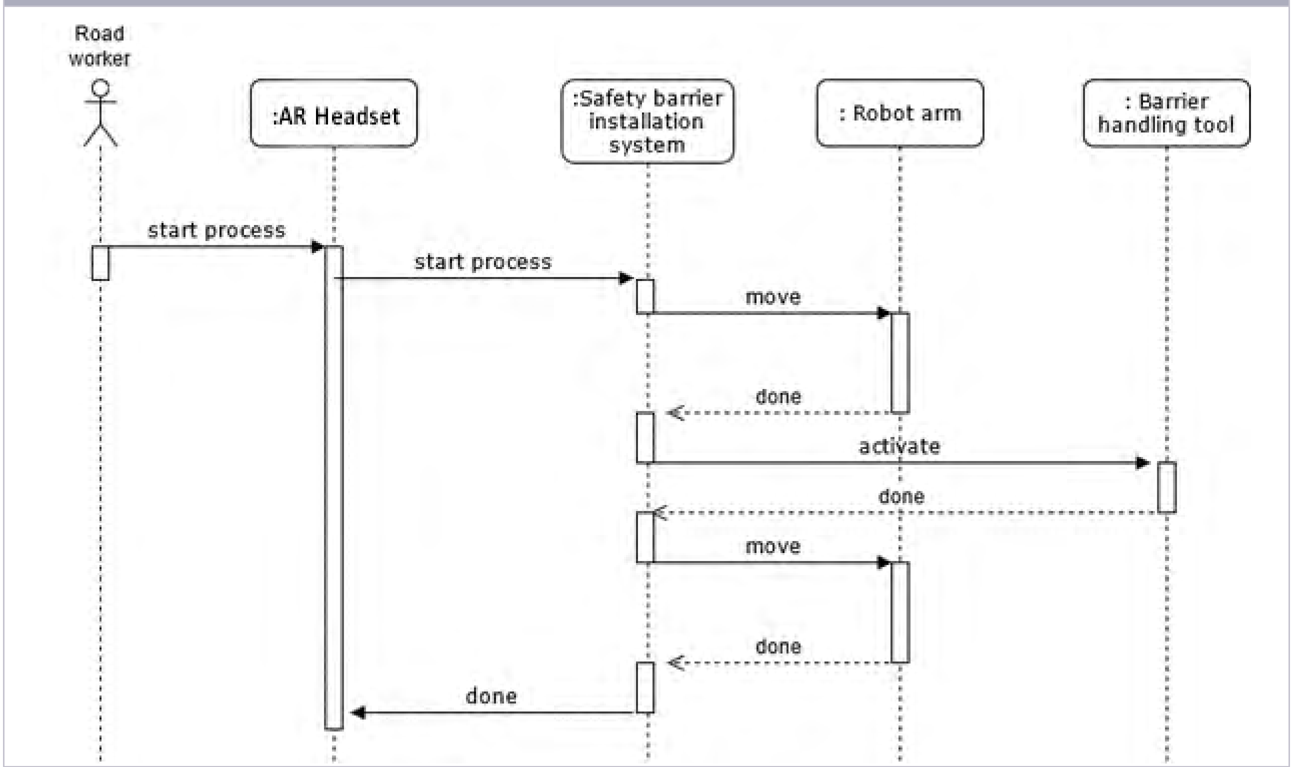
Sequence Diagram: Identify visual references



Sequence Diagram: Pick the safety barrier



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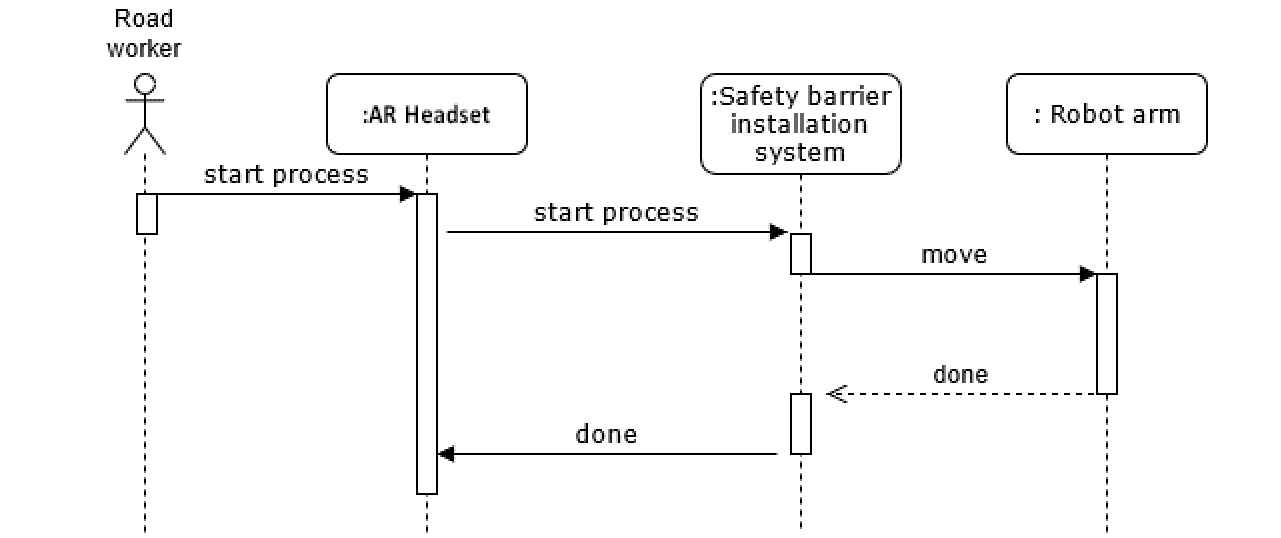
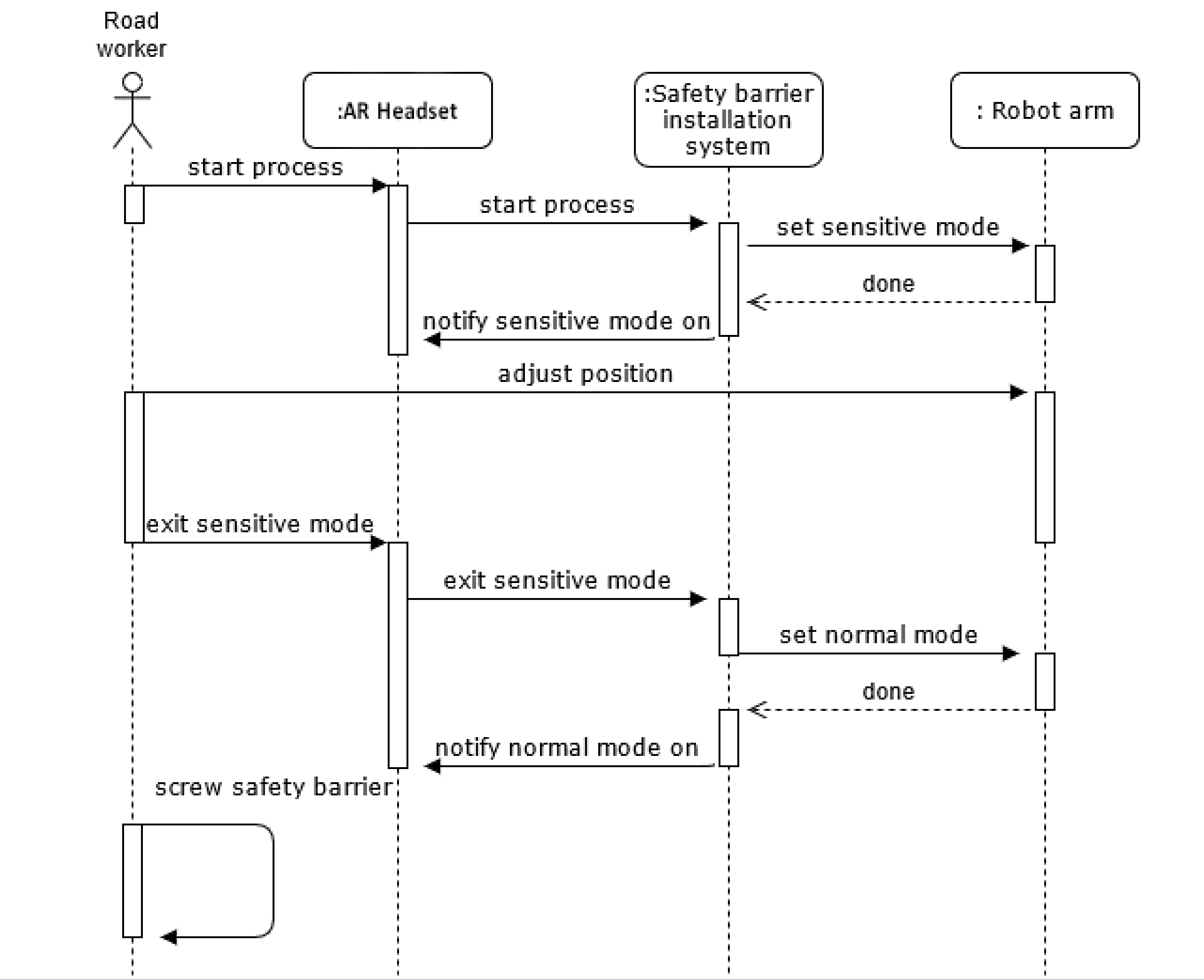
Sequence Diagram: Place the safety barrier



Sequence Diagram: Fix the barrier



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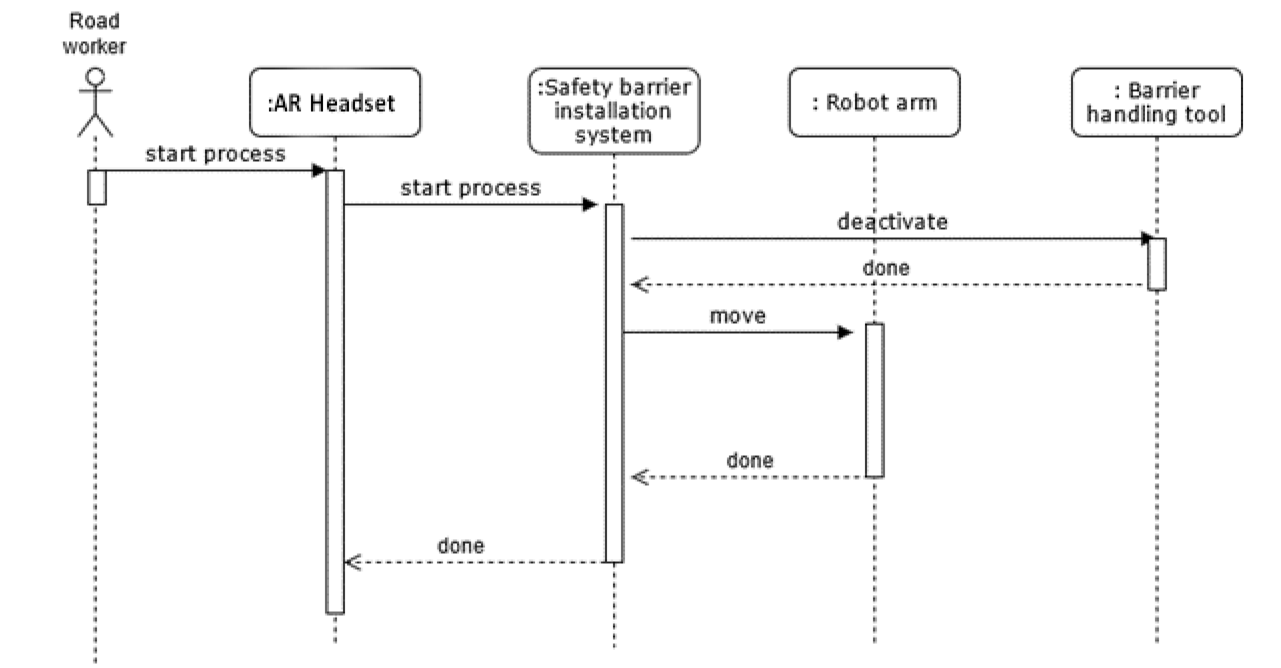
Sequence Diagram: Release the robot arm


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3 Technical details of the Use Case - Actors

Actor Name	Actor Type	Actor Subcategories	Actor description	Further information specific to this Use Case	Equipment Manufacturer	Requirement(s) of the actor	Reference Standards/Legislation
Road administration	Role	Road contractor	The administration that notifies the road workers to perform a safety barriers installation service	The administration manages roads inspection data and bases on that, decides when a safety barriers installation service need to be started.		Shall have knowledge of the roads and service resources	
Road worker	Role	Road contractor	The operator that performs the task of installing safety barriers	The operator directly uses the safety barriers installation robotic system to place and adjust the barrier on the posts		Shall have knowledge of the modular robotic platform technology and operation	
Vehicle	System	Road machinery	The vehicle that carries the safety barriers installation robotic system	The vehicle carries the safety barriers installation robotic system, which is hooked up to the back of it.		Shall contain enough space to storage the assets Shall be able to tow the whole robotic system Shall be able to move at a very low speed	
Vision camera	System	Robotic element	RGB-D camera for the perception of visual references (vertical posts, humans).	The camera is mounted on the robot arm to take images that will serve to the system to identify the visual references (vertical posts and/or humans).		Shall be able to operate under low light conditions (night operations)	
Robot arm	System	Robotic element	An anthropomorphic industrial robotic arm	The robot arm will handle the safety barriers		Shall be able to move loads of around 40 kilos. Shall provide a sensitive mode for the operator to move it by hand (e.g.,	ISO 10218, ISO12100, ISO 13849.

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						gravity compensation function).	
Barrier handling tool	System	Road machinery	A tool that allows to hold safety barriers	The barrier handling tool is mounted on the robotic arm flange		Shall allow to grab and release the barrier (eg. Electromagnetic), ensuring that it will not come loose during the process	ISO 20218
AR Headset	System	Interactive communication device	The AR headset used by the road worker	The operator uses the headset to facilitate support in communications, safety and maintenance operations. In particular, it is used by the road worker to start/stop operations and configure the gravity compensation while the safety barrier is being adjusted with respect to vertical posts.	e.g. Hololens, Google		UL 8400, IEEE P2048

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4 Step by Step Analysis of the Use Case

4.1 List of scenarios

S.No	Scenario Name	Scenario Description	Primary Actor	Triggering Event	Pre-Condition	Post-Condition
PS1	Provide the safety barrier installation service	The road worker drives the vehicle pushing the modular robotic platform to the first place where a safety barrier needs to be fixed to the posts that were already installed. The worker positions the vehicle in such a way that the robotic platform is close enough to perform the operation. After that, the road worker starts the identification of visual references process (cf. Identify visual references). When the post is identified, the road worker starts the safety barrier picking process (cf. Pick the safety barrier). After that, the robot places the safety barrier in the right position, next to the post (cf. Pick the safety barrier). Then, the robot enters in sensitive mode, so the worker can easily move the robot to adjust the position with respect the vertical posts and fix the safety barrier (cf. Fix the barrier with respect the vertical posts). Finally, the road worker starts the release process to move the robot to the start position (cf. Release the robot arm). This process is repeated for all the safety barriers that need to be installed.	Road administration	Road administration notifies the start of the service	Safety barriers installation points have been identified and notified (at kilometre point level).	All safety barriers are fixed to the posts.

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S.No	Scenario Name	Scenario Description	Primary Actor	Triggering Event	Pre-Condition	Post-Condition
PS2	Identify visual references	The road worker uses the display to manually start the visual references identification process. These visual references could be the vertical posts or the road workers (still to be decided). Therefore, a vision camera provides data to the safety barriers installation system for identifying the visual references. After this identification, the system checks that the robot is near enough to reach the destination. Finally, the information is sent to the display to be shown to the road worker.	Vision camera	Road worker starts the visual reference identification process	The visual references are inside the working envelope of the robot.	The road worker has received the data of the identification of the visual references.
PS3	Pick the safety barrier	The road worker uses the display to manually start the picking of the safety barrier. The robot arm executes a specific program to pick the safety barrier that is placed next to it, on the platform. The barrier handling tool is used to pick the safety barrier.	Robot arm	Road worker starts the picking process	The safety barrier to be picked is on the platform.	The safety barrier is picked.
PS4	Place the safety barrier	The road worker uses the display to manually start the placing of the safety barrier. Therefore, the visual reference identification data are used by the barriers installation system to calculate the trajectory that the robot arm needs to execute. The robot arm then executes the trajectory.	Robot arm	Road worker starts the placing process	The safety barrier is picked.	The safety barrier is placed in the right position, next to the visual reference.

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S.No	Scenario Name	Scenario Description	Primary Actor	Triggering Event	Pre-Condition	Post-Condition
PS5	Fix the barrier with respect the vertical posts	The road worker uses the display to change the robot state to a sensitive mode in which the robot can be easily moved by applying an external force. In this mode, the road worker adjusts the position of the safety barrier with respect to the vertical posts. After that, the road worker deactivates the sensitive mode to finally screw the safety barrier to the posts.	Road worker	Road worker starts the fixing process	The safety barrier is placed in the right position, next to the visual reference.	The safety barrier is fixed to the posts.
PS6	Release the robot arm	The road worker uses the display to start the release process. The robot tool releases the safety barrier, and the robot arm moves to an initial pose.	Robot arm	Road worker starts the fixing process	The safety barrier is fixed to the posts.	The robot is in the initial pose.
AS1	The road administration provides a set of incorrect kilo metre points	The road worker reaches the kilometre point according to the information supplied by the road administration, but the place is not the right place to install the safety barriers.	Road worker	The worker drives to the kilometre point	The kilometre point was wrongly communicated.	The road workers get the right position.
AS2	Visual references are not identified	The system in charge of identifying the references is not able to identify the vertical post.	Safety barriers installation system	The deep learning system is not able to find the references.	Picture is not enough good to identify the asset (illumination, so far away from the references)	The safety barrier is placed in the right position, next to the vertical posts.

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4.2 Steps - Primary Scenario

Scenario Name: PS1.Provide the safety barrier installation service									
St No.	Event	Description of Process/Activity	Information Producer	Information Receiver	Information Exchanged	Service	Requirements	Communication Media	Communication Means
PS1.1	The road administration notifies the road worker	The road administration calls the road workers to notify that they need to provide a safety barriers installation service	Road administration	Road worker	I-01	REPORT		Phone call	Voice
PS1.2	The road worker drives to the installation point	The road worker drives the vehicle to the point where a safety barrier needs to be fixed.	Road worker	Vehicle					
PS1.3	The road worker starts the visual reference identification	(cf. PS2)							
PS1.4	The road worker starts the picking of the safety barrier	(cf. PS3)							
PS1.5	The road worker starts	(cf. PS4)							

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Scenario Name: PS1.Provide the safety barrier installation service									
St No.	Event	Description of Process/Activity	Information Producer	Information Receiver	Information Exchanged	Service	Requirements	Communication Media	Communication Means
	the placing of the safety barrier								
PS1.6	The road worker fixes the safety barrier to the posts	(cf. PS5)							
PS1.7	The road worker starts the releasing of robot arm	(cf. PS6)							
PS1.8	All safety barriers are fixed	Previous steps are repeated until all safety barriers are fixed.				REPEAT (2-7)			

Scenario Name: PS2.Identify visual references									
St No.	Event	Description of Process/Activity	Information Producer	Information Receiver	Information Exchanged	Service	Requirements	Communication Media	Communication Means
PS2.1	The road worker starts the service	The road worker uses the display to push the start process button. The display	Display	Safety barrier installation system	I-02	REPORT		Ethernet	Protocol

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Scenario Name: PS2.Identify visual references									
St No.	**Event**	**Description of Process/Activity**	**Information Producer**	**Information Receiver**	**Information Exchanged**	**Service**	**Requirements**	**Communication Media**	**Communication Means**
		sends a signal to the safety barrier installation system.							
PS2.2	Safety barrier installation system is notified	After receiving a signal from display, the safety barrier installation system requests the robot arm to move to a specific position.	Safety barrier installation system	Robot arm	I-03	GET		Ethernet	Protocol
PS2.3	Robot arm is addressed	The robot arm moves to the specified position.	Robot arm	Robot arm	I-03	EXECUTE			
PS2.4	Robot arm finishes its motion	The robot arm sends a notification to the safety barrier installation system.	Robot arm	Safety barrier installation system	I-04	GET		Ethernet	Protocol
PS2.5	Safety barrier installation system is notified	After receiving a notification from the robot arm, the safety barrier installation system requests an image from the vision camera.	Safety barrier installation system	Vision camera	I-05	GET		Ethernet	Protocol
PS2.6	Vision Camera is addressed	The vision camera takes a picture. The data is sent to the safety barrier installation system.	Vision camera	Safety barrier installation system	I-06	CREATE		Ethernet	Protocol

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Scenario Name: PS2.Identify visual references									
St No.	Event	Description of Process/Activity	Information Producer	Information Receiver	Information Exchanged	Service	Requirements	Communication Media	Communication Means
PS2.7	Safety barrier installation system receives picture data	The safety barrier installation system receives the picture data from the vision camera. Based on this, computer vision methods are applied to identify the visual references in the picture.	Safety barrier installation system	Safety barrier installation system	I-07	CREATE		Ethernet	Protocol
PS2.8	Visual references are identified	The safety barrier installation system checks whether the visual references are inside the working envelope of the robot arm.	Safety barrier installation system	Safety barrier installation system	I-07	EXECUTE		Ethernet	Protocol
PS2.9	Visual references are inside the working envelope of the robot	The safety barrier installation system sends the visual references identification data that will be shown to the road worker in the display	Safety barrier installation system	Display	I-07	GET		Ethernet	Protocol
PS2.10	Display receives visual references identification data	The display shows to the road worker the information of the visual references	Display	Road worker	I-07	EXECUTE		Screen	GUI

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Scenario Name: PS3.Pick the safety barrier									
St No.	Event	Description of Process/Activity	Information Producer	Information Receiver	Information Exchanged	Service	Requirements	Communication Media	Communication Means
PS3.1	The road worker manually starts the picking process	The road worker pushes a button in the display that starts the safety barrier picking process.	Display	Safety barrier installation system	I-02	REPORT		Ethernet	Protocol
PS3.2	Safety barrier installation system is notified	After receiving a signal from display, the safety barrier installation system requests the robot arm to move to a specific position.	Safety barrier installation system	Robot arm	I-03	GET		Ethernet	Protocol
PS3.3	Robot arm is addressed	The robot arm moves to the specified position.	Robot arm	Robot arm	I-03	EXECUTE		Ethernet	Protocol
PS3.4	Robot motion is finished	The robot arm sends a notification to the safety barrier installation system.	Robot arm	Safety barrier installation system	I-04	GET		Ethernet	Protocol
PS3.5	Safety barrier installation system has the signal	After receiving a notification from the robot arm, the safety barrier installation system requests the barrier handling tool to activate	Safety barrier installation system	Barrier handling tool	I-08	REPORT		Ethernet	Protocol

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Scenario Name: PS3.Pick the safety barrier									
St No.	Event	Description of Process/Activity	Information Producer	Information Receiver	Information Exchanged	Service	Requirements	Communication Media	Communication Means
PS3.6	The barrier handling tool is addressed	The barrier handling tool activates (electromagnetic system)	Barrier handling tool	Barrier handling tool	I-08	EXECUTE		Ethernet	Protocol
PS3.7	The tool is on	The barrier handling tool sends a signal to the safety barrier installation system	Barrier handling tool	Safety barrier installation system	I-09	GET		Ethernet	Protocol
PS3.8	Safety barrier installation system has the signal	The safety barrier installation system sends a signal to the robot arm to start moving to a specific position.	Safety barrier installation system	Robot arm	I-03	GET		Ethernet	Protocol
PS3.9	Robot arm is addressed	The robot arm executes the motion.	Robot arm	Robot arm	I-03	EXECUTE		Ethernet	Protocol
PS3.10	Robot motion is finished	The robot arm sends a signal to the safety barrier installation system	Robot arm	Safety barrier installation system	I-04	GET		Ethernet	Protocol
PS3.11	Safety barrier installation system has the signal	The safety barrier installation system sends a signal to the	Safety barrier installation system	Display	I-10	GET		Ethernet	Protocol

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Scenario Name: PS3.Pick the safety barrier									
St No.	Event	Description of Process/Activity	Information Producer	Information Receiver	Information Exchanged	Service	Requirements	Communication Media	Communication Means
		display, to notify the result of the process							
PS3.12	Display receives the signal	The display shows the notification to the road worker	Display	Display	I-10	EXECUTE		Screen	GUI

Scenario Name: PS4.Place the safety barrier									
St No.	Event	Description of Process/Activity	Information Producer	Information Receiver	Information Exchanged	Service	Requirements	Communication Media	Communication Means
PS4.1	The road worker manually starts the placing process	The road worker pushes a button in the display that starts the safety barrier placing process.	Display	Safety barrier installation system	I-02	REPORT		Ethernet	Protocol
PS4.2	Safety barrier installation system is notified	After receiving a signal from display, the safety barrier installation system requests the robot arm to move to a position next to the visual reference that was previously identified.	Safety barrier installation system	Robot arm	I-03			Ethernet	Protocol

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Scenario Name: PS4.Place the safety barrier									
St No.	Event	Description of Process/Activity	Information Producer	Information Receiver	Information Exchanged	Service	Requirements	Communication Media	Communication Means
PS4.3	Robot arm is addressed	The robot arm moves to the specified position.	Robot arm	Robot arm	I-03	EXECUTE		Ethernet	Protocol
PS4.4	Robot motion is finished	The robot arm sends a notification to the safety barrier installation system.	Robot arm	Safety barrier installation system	I-04	GET		Ethernet	Protocol
PS4.5	Safety barrier installation system has the signal	After receiving a notification from the robot arm, the safety barrier installation system sends a signal to the display	Safety barrier installation system	Display	I-10	GET		Ethernet	Protocol
PS4.7	Display receives the signal	The display shows the notification that the process has successfully finished to the road worker	Display	Display	I-10	EXECUTE		Screen	GUI

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Scenario Name: PS5.Fix the barrier with respect the vertical posts									
St No.	Event	Description of Process/Activity	Information Producer	Information Receiver	Information Exchanged	Service	Requirements	Communication Media	Communication Means
PS5.1	The road worker manually starts the sensitive mode	The road worker pushes a button in the display that requests to change the robot arm to the sensitive mode	Display	Safety barrier installation system	I-02	REPORT		Ethernet	Protocol
PS5.2	Safety barrier installation system is notified	After receiving a signal from display, the safety barrier installation system requests the robot arm to change to the sensitive mode	Safety barrier installation system	Robot arm	I-11	REPORT		Ethernet	Protocol
PS5.3	Robot arm is addressed	The robot arm changes its status to the sensitive mode	Robot arm	Robot arm	I-11	EXECUTE		Ethernet	Protocol
PS5.4	Robot arm changes mode	The robot arm notifies the safety barrier installation system that the mode has changed.	Robot arm	Safety barrier installation system	I-12	GET		Ethernet	Protocol
PS5.5	Safety barrier installation system is notified	The safety barrier installation system notifies the display that the mode has changed.	Safety barrier installation system	Display	I-10	GET		Ethernet	Protocol

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Scenario Name: PS5.Fix the barrier with respect the vertical posts									
St No.	Event	Description of Process/Activity	Information Producer	Information Receiver	Information Exchanged	Service	Requirements	Communication Media	Communication Means
PS5.6	Display is notified	The display shows a notification to the road worker	Display	Road worker				Screen	GUI
PS5.7	The road worker manually adjusts the position	The road worker manually adjusts the position of the safety barrier with respect the vertical posts, by moving the arm with their hands.	Road worker	Robot arm		EXECUTE			
PS5.8	The road worker exits the sensitive mode	The road worker pushes a button in the display to exit the sensitive mode. The display sends a signal to the safety barrier installation system	Display	Safety barrier installation system	I-02	REPORT		Ethernet	Protocol
PS5.9	Safety barrier installation system is notified	The safety barrier installation system sends a signal to the robot arm to exit the sensitive mode	Safety barrier installation system	Robot arm	I-11	REPORT		Ethernet	Protocol
PS5.10	Robot arm is addressed	The robot arm changes its status to the normal	Robot arm	Robot arm	I-11	EXECUTE		Ethernet	Protocol

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Scenario Name: PS5.Fix the barrier with respect the vertical posts									
St No.	**Event**	**Description of Process/Activity**	**Information Producer**	**Information Receiver**	**Information Exchanged**	**Service**	**Requirements**	**Communication Media**	**Communication Means**
		mode, exiting from the previous sensitive mode							
PS5.11	Robot arm changes mode	The robot arm notifies the safety barrier installation system that the mode has changed.	Robot arm	Safety barrier installation system	I-12	GET		Ethernet	Protocol
PS5.12	Safety barrier installation system is notified	The safety barrier installation system notifies the display that the mode has changed.	Safety barrier installation system	Display	I-12	GET		Ethernet	Protocol
PS5.13	Display is notified	The display shows a notification to the road worker	Display	Road worker	I-10	GET		Screen	GUI
PS5.14	The worker screws the safety barrier	The road worker manually screws the safety barrier to the posts	Road worker	Road worker		EXECUTE			

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Scenario Name: PS6.Release the robot arm									
St No.	**Event**	**Description of Process/Activity**	**Information Producer**	**Information Receiver**	**Information Exchanged**	**Service**	**Requirements**	**Communication Media**	**Communication Means**
PS6.1	The road worker manually starts the robot arm release process	The road worker pushes a button in the display that starts the robot arm release process.	Display	Safety barrier installation system	I-02	REPORT		Ethernet	Protocol
PS6.2	Safety barrier installation system is notified	After receiving a signal from display, the safety barrier installation system requests the barrier handling tool to deactivate	Safety barrier installation system	Barrier handling tool	I-08	REPORT		Ethernet	Protocol
PS6.3	The barrier handling tool is addressed	The barrier handling tool is deactivated (electromagnetic system)	Barrier handling tool	Barrier handling tool	I-08	EXECUTE		Ethernet	Protocol
PS6.4	The tool is deactivated	The barrier handling tool sends a signal to the safety barrier installation system	Barrier handling tool	Safety barrier installation system	I-09	GET		Ethernet	Protocol
PS6.5	Safety barrier installation system has the signal	After receiving a signal from the tool, the safety barrier installation system requests the robot arm to move to a specific position.	Safety barrier installation system	Robot arm	I-10	GET		Ethernet	Protocol

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Scenario Name: PS6.Release the robot arm									
St No.	**Event**	**Description of Process/Activity**	**Information Producer**	**Information Receiver**	**Information Exchanged**	**Service**	**Requirements**	**Communication Media**	**Communication Means**
PS6.6	Robot arm is addressed	The robot arm executes the fixed motion	Robot arm	Robot arm	I-03	EXECUTE		Ethernet	Protocol
PS6.7	Robot motion is finished	The robot arm sends a signal to the safety barrier installation system	Robot arm	Safety barrier installation system	I-04	GET		Ethernet	Protocol
PS6.8	Safety barrier installation system has the signal	The safety barrier installation system sends a signal to the display	Safety barrier installation system	Display	I-10	GET		Ethernet	Protocol
PS6.9	Display receives the signal	The display shows the notification to the road worker	Display	Road worker	I-10	EXECUTE		Screen	GUI

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4.3 Steps – Alternative, Error Management, and/or Maintenance/Backup Scenario

Scenario Name: AS1.The road administration provides a set of incorrect kilometre points									
St No.	Event	Description of Process/Activity	Information Producer	Information Receiver	Information Exchanged	Service	Requirements	Communication Media	Communication Means
AS1.1	Kilometre point is incorrect.	The road workers notices that the kilometre point is incorrect. Therefore, they contact to road administration to get the right position.	Road administration	Road worker	I-01	CHANGE		Phone	Voice

Scenario Name: AS2.Visual references are not identified									
St No.	Event	Description of Process/Activity	Information Producer	Information Receiver	Information Exchanged	Service	Requirements	Communication Media	Communication Means
AS2.1	The system in charge of identifying the references is not able to identify the vertical post.	The safety barriers installation system alerts that it is not able to find the reference.	Safety barrier installation system	Display	I-10	CANCEL		Ethernet	Protocol

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Scenario Name: AS2.Visual references are not identified									
St No.	Event	Description of Process/Activity	Information Producer	Information Receiver	Information Exchanged	Service	Requirements	Communication Media	Communication Means
AS2.2	The road worker manually starts the picking process	The road worker pushes a button in the display that starts the safety barrier picking process.	Display	Safety barrier installation system	I-02	REPORT		Ethernet	Protocol
AS2.3	Safety barrier installation system is notified	After receiving a signal from display, the safety barrier installation system requests the robot arm to move to a specific position.	Safety barrier installation system	Robot arm	I-03	GET		Ethernet	Protocol
AS2.4	Robot arm is addressed	The robot arm moves to the specified position.	Robot arm	Robot arm	I-03	EXECUTE		Ethernet	Protocol
AS2.5	Robot motion is finished	The robot arm sends a notification to the safety barrier installation system.	Robot arm	Safety barrier installation system	I-04	GET		Ethernet	Protocol
AS2.6	Safety barrier installation system has the signal	After receiving a notification from the robot arm, the safety barrier installation system requests the	Safety barrier installation system	Barrier handling tool	I-08	REPORT		Ethernet	Protocol

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Scenario Name: AS2.Visual references are not identified									
St No.	Event	Description of Process/Activity	Information Producer	Information Receiver	Information Exchanged	Service	Requirements	Communication Media	Communication Means
		barrier handling tool to activate							
AS2.7	The barrier handling tool is addressed	The barrier handling tool activates (electromagnetic system)	Barrier handling tool	Barrier handling tool	I-08	EXECUTE		Ethernet	Protocol
AS2.8	The tool is on	The barrier handling tool sends a signal to the safety barrier installation system	Barrier handling tool		I-09	GET		Ethernet	Protocol
AS2.9	Request to robot in manual mode	The robotic system sends to the display the necessity to change its mode to manual. The road worker is ready to move the robot manually. In this way, the safety barrier can be moved to the target position.	Safety barrier installation system	Display	I-10	EXECUTE		Ethernet	Protocol
AS2.10	Start the movement of the robot manually	The road worker moves the robot manually	Road worker	Robot arm					

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Scenario Name: AS2.Visual references are not identified									
St No.	**Event**	**Description of Process/Activity**	**Information Producer**	**Information Receiver**	**Information Exchanged**	**Service**	**Requirements**	**Communication Media**	**Communication Means**
AS2.11	The robot reaches the target position	The robot reaches the position. Then the road worker uses the display to confirm that the safety barrier is placed in the right position, next to the vertical posts. The process can follow as usual.	Road worker	Display				Tactile	GUI

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5 Information Exchanged

Inf. ID	Name of information exchanged	Description of information exchanged	Information Subcategories[1]	Requirements
I-01	Kilometer points data	The road administration provides a set of kilometer points codes where safety barriers need to be installed.	Network state	
I-02	Signal from the display	The display sends a signal to the safety barrier installation system to notify that the a process must start	Information exchanged between IS or sent to device	
I-03	Robot movement goal	The message contains the pose of the robot end-effector.	Information exchanged between IS or sent to device	
I-04	Result of movement operation	Message to signal that robot movement finished. It contains the result of the movement process.	Information exchanged between IS or sent to device	
I-05	Signal from the safety barrier installation system for picture	The safety barrier installation system sends a signal to vision camera to get a picture.	Information exchanged between IS or sent to device	
I-06	Picture data	The picture data contains RGB and depth values	Information exchanged between IS or sent to device	
I-07	Visual references information	The message contains the information about the detected visual references.	Information exchanged between IS or sent to device	
I-08	Signal to the barrier handling tool	The safety barrier installation system sends a signal to the barrier handling tool. The signal is binary, i.e.,	Information exchanged between IS or sent to device	

[1] Select from the Subcategories listed in Annex B or in case of a new subcategory, please introduce it in the structure given in Annex B (insertion of new row in the Annex B).

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		only the values 0 and 1 exist (0 = activate, 1 = deactivate)		
I-09	Signal from the barrier handling tool	The barrier handling tool sends a signal to the safety barrier installation system.	Information exchanged between IS or sent to device	
I-10	Signal to the display	The safety barrier installation system sends a message containing the result of the operation	Information exchanged between IS or sent to device	
I-11	Signal to change robot arm mode	The safety barrier installation system sends a signal to the robot arm to change the mode (0=Normal, 1=Sensitive).	Information exchanged between IS or sent to device	
I-12	Signal from the robot to notify mode change	Message to signal that robot arm changed its mode.	Information exchanged between IS or sent to device	

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OMI((RON

Intelligent Road Asset Management Platform

Installation of Cones

Definition of Requirements

Publish Date: 2021.09.15

Use Case Number: UC2.1.2

Use Case Title: Installation of Cones

Use Case Responsible Partner: TEKNIKER

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1 Description of the Use Case

1.1 Use Case Identification

ID	Domain(s)	Name of Use Case	Level of Use Case
UC2.1.2	UC2: Routine and emergency maintenance interventions	Installation of temporary signalling of cones	Detailed Use Case

1.2 Scope and Objectives

Scope and Objectives of the Use Case	
Scope	Currently the road maintenance workers are in charge of placing and collecting the temporary signalling such as cones. Usually, the cones are placed and collected manually by road workers. The road worker hangs from the vehicle a heavy cone in their hands. This is very demanding from the point of view of physical health. Moreover, the operation of dropping the cones demands expertise and concentration from the worker in order to avoid that the cones not be placed in incorrect way. It might produce that the cone invades the opposite traffic lane with the corresponding hazard to drivers. The use of a modular robotic arm should reduce the corresponding workforce needed, resulting in a reduction in maintenance costs.
Objective	• Daily work support: Aim of the use case is to assist operators improving their working conditions. • Operator safety: The robotic system reduces the exposure of workers in the placement and collection of the cones, thereby reducing the probability of an accident. • Driver safety: The robotic system reduces the possibility of cones not placed in the right position, thereby reducing the probability of an accident for drivers. • Saving costs: The robotic solution has as a direct result the reduction of the corresponding workforce needed. This will result in a reduction in maintenance costs. • Equivalent quality to worker: The installation of cones by means of robotics system should be even better that the worker quality, as it would avoid fallen cones when they are being placed, as it happens sometimes in the case of cones set from a truck in movement.
Related Business Case	*Automation and robotisation of maintenance operations*

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1.3 Narrative of the Use Case

Short description – max 3 sentences
A robotic modular arm shall support road workers in the maintenance process of placing and collecting cones. For this process, a perception system that combines Artificial Vision and Artificial Intelligence is needed, which allows to the robotic system to locate the cones regarding robotic arm. Additionally, a specific tool shall be designed to: (1) place the cones on the road (2) collect the cones from the road.
Complete description
Within the tasks of temporary signalling the installation of cones is one of the most common activities. The objective of this task is alert the users of there has been an accident, works on the road, liquids on the pavement and so on. This is fundamental in order to avoid accidents that affect both the safety of workers who are carrying out tasks on the road as well as the people who circulate in vehicles, in order to prevent run over, collisions with machines in movement or swerves off the road. In this type of work, operators are exposed to the risk of being run over due to usually the cones are placed and collect while the traffic continues. The main tasks are to place provisional signs, cones, and its subsequent collection at the end of the necessity. These main tasks could be slightly different depending on regulations of each country. An example of the whole process is detailed bellow. - ***Placement*** This task includes different stages, which also depends on the type of signalling. An example of a turnout mounting is described below: One kilometre before the car traffic congestion sign is placed. At 100 m the works sign is placed At 100 m the sign of overtaking prohibited At 100 m the sign of speed limited to 100 km / h Next are the sign of lane loss. At 100 m the speed sign limited to 80 km / h All the above signs are placed on both sides of the road. For the 100 meters, the road surface markings on the road are taken as a reference. At 100 m the directional panels (3 in total are placed along the lane) The cones are placed in a wedged shape (approximately one cone every 5 steps). The wedge is about 200 meters. Once the wedge is finished, a cone is placed every 2 lane stripes 20 cm roughly within the lane that is cut. And finally, 50 m from the end of the work zone, the sign of end of all restrictions.

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- *Collection*

The collection of the signage will generally be carried out in the reverse order of its placement, and whenever possible from the area closed to traffic or from the shoulder. This must remain for the time strictly necessary for the work to last and be withdrawn after they are finished.

The type of signals used and, therefore, manipulated influences the physical load to which the workers are subjected, since their weight and the way of mounting can be different in each case, depending on the type of track and whether they are on tripod or with base and pole.

The robot arm shall perform the task of placing and collecting the cones while the traction element is moving. The robotic modular platform is composed of a robotic arm, a perception module which it helps to locate the cones and a specific tool to place and collect ones. The system is mounted on a trailer that can be easily hooked up to the back of a vehicle (e.g., a truck) as shown in Figure 1. The perception system will be placed in such a way that allows to detect the cones with enough time to carried out the movements of the robot to grasp it.

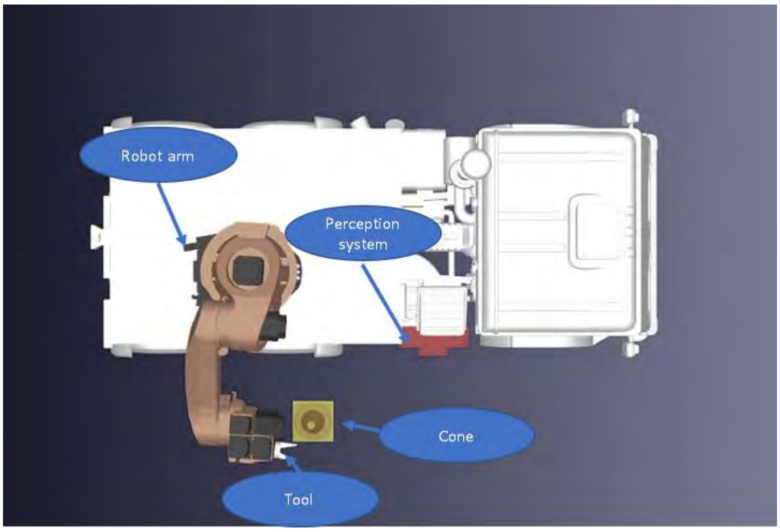

Figure 1: Robotic solution for placing and collecting cones

The perception system will allow to know the localisation of the cone. The system will consist in a RGB-D sensor which provides a RGB image and the point cloud, a computation system based on a powerful GPU and a deep learning algorithm to detect the cone from the data.

Figure 2: Examples of GPU (NVIDIA Xavier) and RGB-D camera

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1.4 KPIs

ID	Name	Description	Target	Reference to mentioned Use Case objectives
KPI2	Emergency, ordinary and extraordinary maintenance intervention times	The robot will do it faster in those cases in which the process is done manually	10%	Reduction of time
KPI 3	Volume of people in dangerous zones in road maintenance areas	There is no need for manual intervention, expect when the cones are not reachable by the robot (cones displaced to distant locations, cones that are not in vertical position)	Reduction of the number of people in dangerous zones in maintenance areas by 40%, via the use of robotic platform.	Operator safety
KPI6	Traffic disruptions due to maintenance interventions	The reduction of time in installing the cones shall reduce the traffic disruption	10%	
KPI 9	Maintenance and inspection activity costs	The use of a modular robotic platform shall reduce the workforce needed for the installation of cones.	20%	Saving costs

1.5 Use Case Conditions

Actor	Triggering Event	Pre-conditions	Assumption
Describe which Actor(s) trigger(s) this Use Case	Describe what event(s) trigger(s) this Use Case	Describe what condition(s) should have been met before this Use Case happens	Describe the assumptions about conditions or system configurations.
Road administration	The road administration	There has been an accident, works on the	• The vehicle has

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Actor	Triggering Event	Pre-conditions	Assumption
	contacts the road workers to notify that they need to provide the cones installation service.	road are going to start in a short period of time, there is a liquid on the road due to a leak, etc. Thus, to sign the road with cones is necessary.	enough fuel • There are enough cones to carry out the work. • The system works properly, including: ○ Cone installation robotic system ○ Robot arm ○ Perception system

1.6 Classification Information

Relation to Other Use Cases in the same project or area
UC2.1 Robotic Modular Platform UC2.1.1 Installation of safety barriers UC2.1.3 Road assets cleaning UC3.1 Signalling during construction works UC3.2 Sealing of surface pavement cracks UC3.3 Removal of lane markings with laser
Level of Depth - the degree of specialization of the Use Case
Detailed Use Case
Further Keywords for Classification
Modular robotic arm, temporary signalling, placement of cones, collection of cones, incident sign installation.
Maturity of Use Case
Realized in R&D

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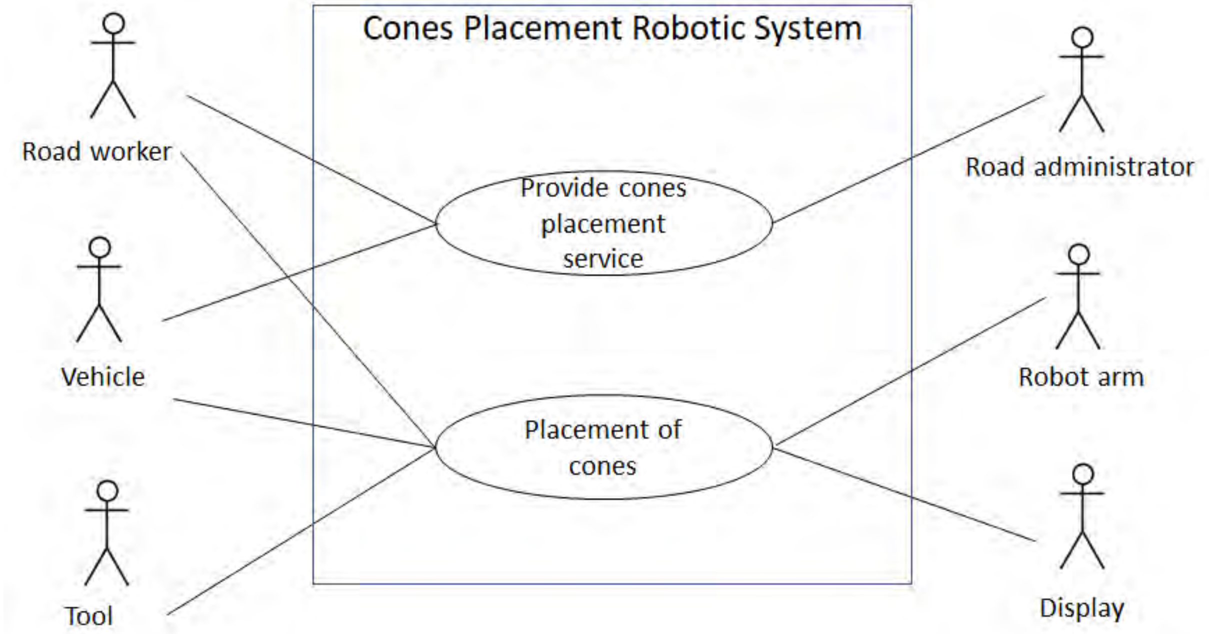
2 Diagrams of the Use Case

2.1 Placement of cones

Context Diagram: Placement of cones


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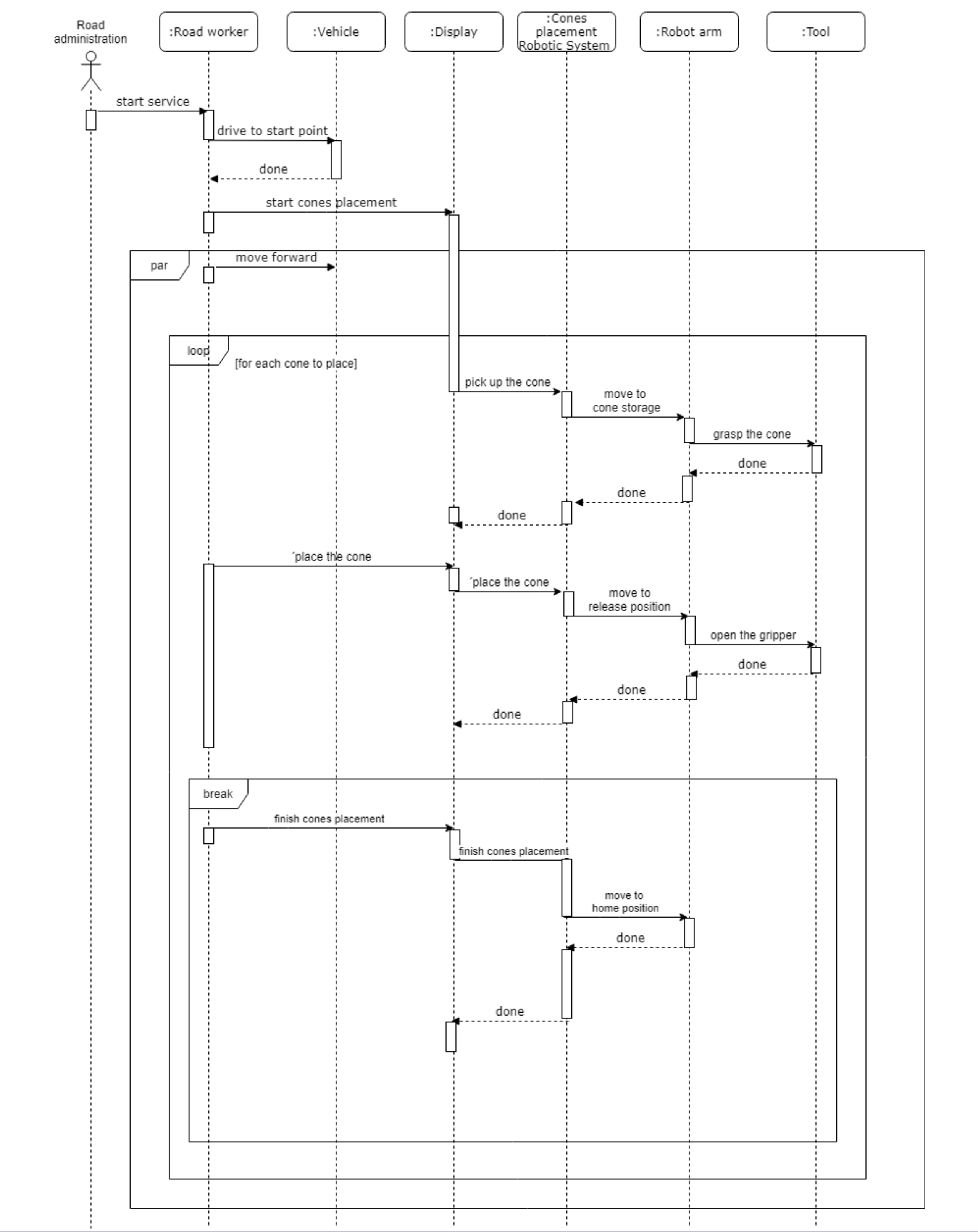
Sequence Diagram: Placement of cones



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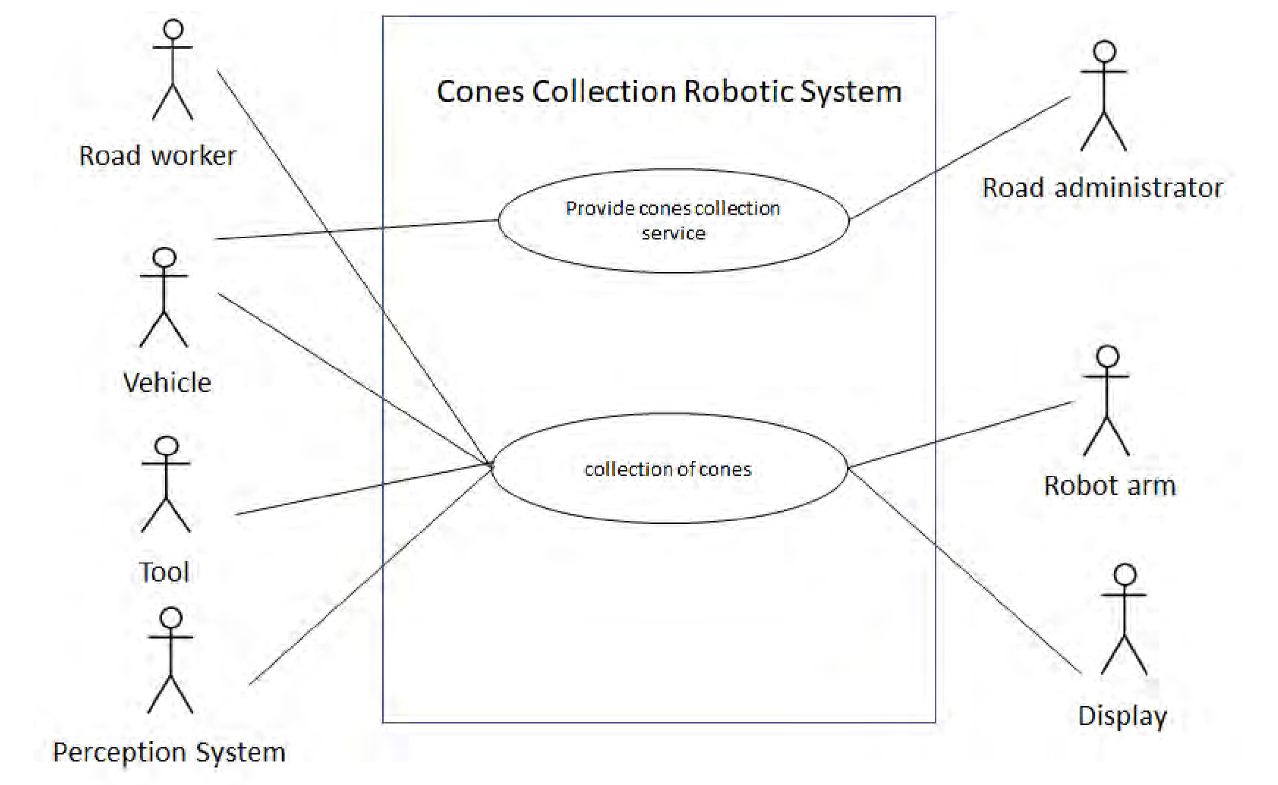
2.2 Collection of cones

Context Diagram: Collection of cones



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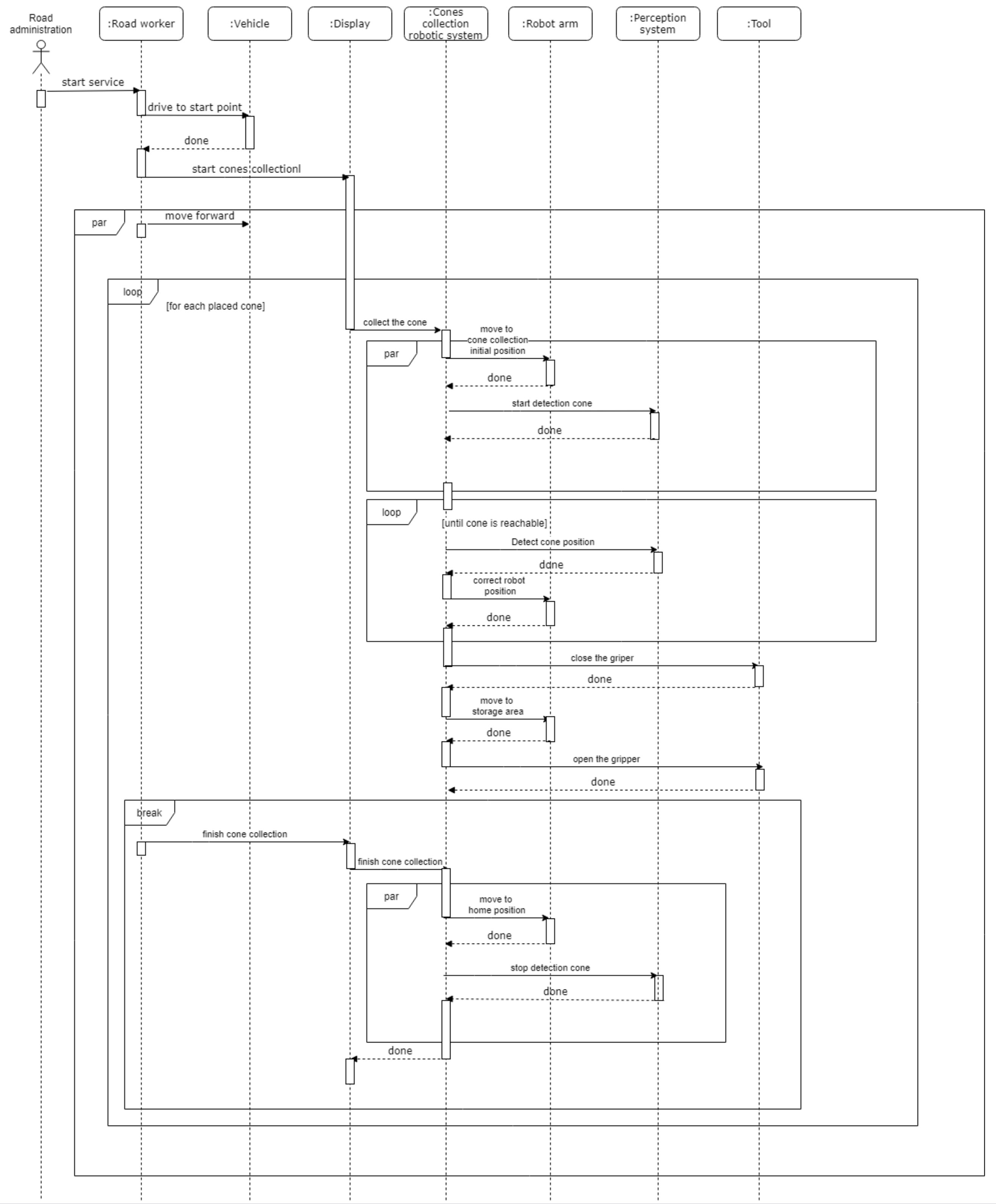
Sequence Diagram: Collection of cones



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3 Technical details of the Use Case - Actors

Actor Name	Actor Type	Actor Subcategories	Actor description	Further information specific to this Use Case	Equipment Manufacturer	Requirement(s) of the actor	Reference Standards/Legislation
Road administration	Role	Road contractor	The administration that notifies the road workers to perform the installation of cones service.	The administration manages roads inspection data and bases on that, decides when the cone installation service need to be started.		Shall have knowledge of the roads and service resources	
Road worker	Role	Road contractor	The operator that performs the task of installation of cones.	The operator directly uses the cone installation robotic system to start/stop the process of placement or collection of cones.		Shall have knowledge of the modular robotic platform technology and operation	
Vehicle	System	Road machinery	The vehicle that carries the cones, the robotic system and the perception system.	The vehicle houses the cones and the whole cone installation robotic system including the perception system.		Shall contain enough space to storage the assets Shall be able to tow the whole robotic system Shall be able to move at a very low speed	

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Actor Name	Actor Type	Actor Subcategories	Actor description	Further information specific to this Use Case	Equipment Manufacturer	Requirement(s) of the actor	Reference Standards/Legislation
Perception system	System	Computer vision based on deep learning	RGB-D camera for cones perception.	The camera shall be mounted on the vehicle in a such way that allows to locate the cone with enough time to allow the movements of the robot for achieving the grasping of the cones.	e.g., Intel Realsense 435D RGB-D camera, NVIDIA Xavier for AI.	Shall be able to operate under low light conditions (night operations) Computation system shall be enough faster to calculate the position of the cones to allow to grasp them.	ISO 5469 (under development)
Robot arm	System	Robotic element	An anthropomorphic industrial robotic arm.	The robot arm will operate the specific tool to place and collect the cones.	e.g., Kuka, ABB, Universal robots	At least 6 degrees of freedom. The robot flange should be able to reach near the pavement for grasping and placing the cones. Thus, this must be considered when the robot be installed on the vehicle.	ISO 10218, ISO12100, ISO 13849.
Display	System	Interactive communication device	A device to provide input and show output of the system.	The operator makes use of the display to start/stop the placement and collection of the cones.		Tactile system, rugged display, sound	

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Actor Name	Actor Type	Actor Subcategories	Actor description	Further information specific to this Use Case	Equipment Manufacturer	Requirement(s) of the actor	Reference Standards/Legislation
Tool	System	Road machinery	A tool that combines the action to grasp the cone both from the storage area to place it on the road and grasp it from the road in the task of cones collection.	The grasping tool shall be mounted on the robot arm flange.	ad hoc design	Shall allow to grasp and place the cones without damaging them.	ISO 20218

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4 Step by Step Analysis of the Use Case - Placement of cones

4.1 List of scenarios for placement of cones

S.No	Scenario Name	Scenario Description	Primary Actor	Triggering Event	Pre-Condition	Post-Condition
PS1	Provide the placement of cones service	The road administration notifies the road workers that the cones placement service needs to be started. The road administration provides a kilometre point where the cones need to be placed. Then, the road workers drive to the kilometre point.	Road administration	Road administration notifies the start of the service.	The necessity of temporary signalling using cones has been identified and located (at kilometre point level).	The road worker has received the kilometre point where the cones must be placed and how long is the zone to signal.
PS2	Placement of cones	The road worker uses the display to manually start the cones placement process.	Road worker	The vehicle moves forward at slow speed.	The storage area has enough cones to carry out the order.	All the cones have been placed according to the work order.
AS1	The road administration provides a set of incorrect kilometre points	The road worker reaches the kilometre point according to the information supplied by the road administration, but the place does not need to be signalled.	Road worker	The worker drives to the kilometre point.	The kilometre point was wrongly communicated.	The road workers get the right position.
AS2	There is not cone ready for picking up from the pickup area	The robot arm reaches the pickup position of the cone but is not able to grasp the cone.	Robot arm	The robot arm moves to pick up the cone.	There is not cone.	A cone is placed in the pickup area.
AS3	The cone is not grasped by the robot	The robot arm tries to pick up the cone but this one is not grasped.	Robot arm	The robot arm moves to pick up the cone.	The cone is damaged.	A new cone is placed in the pickup area.

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S.No	Scenario Name	Scenario Description	Primary Actor	Triggering Event	Pre-Condition	Post-Condition
AS4	The cone is not placed correctly	The robot arm places the cone on the road but this one is not placed correctly (eventually, the cone ends up lying)	Robot arm	The robot arm releases the cone.	Vehicle speed higher than required by the system.	The cone is placed.
AS5	The cone is not placed correctly (case 2)	The robot arm places the cone on the road but this one is not placed correctly (eventually, the cone ends up lying)	Robot arm	The robot arm releases the cone.	Uneven state of the road.	The cone is placed.

4.2 Steps – Primary Scenario for placement of cones

Scenario Name: PS1 Provide the placement of cones service									
St No.	Event	Description of Process/Activity	Information Producer	Information Receiver	Information Exchanged	Service	Requirements	Communication Media	Communication Means
PS1.1	The road administration notifies the road worker.	The road administration calls the road workers to notify that they need to provide a cones placement service.	Road administration	Road worker	I-01	REPORT		Phone	Voice
PS1.2	The road worker drives to kilometre point.	The road worker drives the vehicle to the kilometre point where the cones need to be placed.	Road worker	Vehicle		EXECUTE			

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Scenario Name: PS2 Placement of cones									
St No.	Event	Description of Process/Activity	Information Producer	Information Receiver	Information Exchanged	Service	Requirements	Communication Media	Communication Means
PS2.1	The road worker moves forward the vehicle.	The road worker moves the vehicle at slow speed to allow the robotic system to place the cones.	Road worker	Vehicle		CHANGE			
PS2.2	The road worker starts the placement process.	The road worker uses the display to push the start process button.	Road worker	Display				Tactile	GUI
PS2.3	The display requests to the robotic system to start the task.	The robotic system receives the request from the display and starts the task of placement of the cones. Thus, the arm connection is initialised.	Display	Robotic system	I-03	CREATE		Ethernet	Protocol
PS2.4	The robotic system requests to the robot arm to move to storage area.	The robot carries out the movement to reach the storage area.	Robotic System	Robot arm	I-04	EXECUTE		Ethernet	Protocol
PS2.5	The robot arm requests to grasp the cone.	The robot arm closes the tool to grasp the cone from the storage area.	Robot arm	Tool	I-05	EXECUTE		Ethernet	Protocol
PS2.6	The road worker requests to place the cone.	The demarcation of the zone must start. The road worker uses the display to push the start process button.	Road worker	Display		CREATE		Tactile	GUI

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Scenario Name: PS2 Placement of cones									
St No.	**Event**	**Description of Process/Activity**	**Information Producer**	**Information Receiver**	**Information Exchanged**	**Service**	**Requirements**	**Communication Media**	**Communication Means**
PS2.7	The display requests to robotic system to place the cone	The display sends a signal to the robotic system to place the cone.	Display	Robotic system	I-06	CHANGE		Ethernet	Protocol
PS2.8	The robotic system requests to place the cone to the robot arm.	The robot carries out the movement to reach the release position.	Robotic system	Robot arm	I-04	EXECUTE		Ethernet	Protocol
PS2.9	The robot places the cone.	The robot arm opens the tool to place the cone.	Robot arm	Tool	I-07	EXECUTE		Ethernet	Protocol
PS2.10	Another cones to place.	The system is cyclic.				EXECUTE REPEAT [6-11]			
PS2.11	The road worker terminates the placement of cones.	The demarcation of the zone has been carried out. The road worker uses the display to push the stop process button.	Road worker	Display				Tactile	GUI
PS2.12	The display requests to robotic system to stop the placement task.	The robotic system receives the request from the display and stops the task of placement of the cones.	Display	Robotic system	I-08	CLOSE		Ethernet	Protocol

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Scenario Name: PS2 Placement of cones									
St No.	Event	Description of Process/Activity	Information Producer	Information Receiver	Information Exchanged	Service	Requirements	Communication Media	Communication Means
PS2.13	The robotic system notifies robot arm of the task of placement of cones has finished.	The robot arm moves to home position	Robotic system	Robot arm	I-09	EXECUTE		Ethernet	Protocol

4.3 Steps – Alternative, Error Management, and/or Maintenance/Backup Scenario

Scenario Name: AS1.The road administration provides a set of incorrect kilometre points									
St No.	Event	Description of Process/Activity	Information Producer	Information Receiver	Information Exchanged	Service	Requirements	Communication Media	Communication Means
AS1.1	Kilometre point is incorrect.	The road worker notices that the kilometre point is incorrect. Therefore, they contact to road administration to get the right position.	Road administration	Road worker	I-01	CHANGE		Phone	Voice

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Scenario Name: AS2.There is no cone to pick up form the storage area									
St No.	Event	Description of Process/Activity	Information Producer	Information Receiver	Information Exchanged	Service	Requirements	Communication Media	Communication Means
AS2.1	There is not cone ready to pick up form the pickup area	The robotic system perceives that there is not cone in the pickup area. The robotic system sends an alert to the display.	Robotic system	Display	I-17	CHANGE		Screen	GUI/Sound
AS2.2	Robotic system requests to pause the robot arm	The robotic system notifies to the robot arm that it must pause the execution of picking the cones from the pickup area.	Robotic system	Robot arm	I-18	EXECUTE		Ethernet	Protocol
A2.3	The display shows that the pickup area is empty.	The display shows that the pickup area is empty to the worker.	Display	Road worker	I-19	CHANGE		Screen	GUI
A2.4	The road worker requests to stop the vehicle	The driver stops the vehicle to manage the incident.	Road worker	Vehicle		CANCEL		Voice	Voice

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Scenario Name: AS2.There is no cone to pick up form the storage area									
St No.	Event	Description of Process/Activity	Information Producer	Information Receiver	Information Exchanged	Service	Requirements	Communication Media	Communication Means
A2.5	The road worker places a cone to the pickup area.	The road worker sends a request to the display indicating that the incident is repaired.	Road worker	Display	I-20	CREATE		Tactile	GUI
AS2.6	The display shows that the incident is repaired.	The driver restarts the movement of the vehicle	Display	Vehicle		EXECUTE		Screen	GUI
AS2.7	The display requests to restart the process to the robotic system	The robotic system receives the request from the display to restart the robot arm movement.	Display	Robotic system	I-21	EXECUTE		Ethernet	Protocol
AS2.8	The robotic system requests to restart the process to the robot arm	The robot arm moves to the pickup area to grasp the cone.	Robotic system	Robot arm	I-22	EXECUTE		Ethernet	Protocol

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Scenario Name: AS3.The cone is not grasped by the robot									
St No.	**Event**	**Description of Process/Activity**	**Information Producer**	**Information Receiver**	**Information Exchanged**	**Service**	**Requirements**	**Communication Media**	**Communication Means**
AS3.1	The cone is not grasped by the robot	The robotic system perceives that the cone is not grasped. As an example, the surface of the cone could be damaged, and this prevents the cone from being grasped.	Robotic system	Display	I-23	CHANGE		Screen	GUI
AS3.2	Robotic system requests to pause the robot arm	The robotic system notifies to the robot arm that it must pause the execution of placement the cone on the road.	Robotic system	Robot arm	I-24	CANCEL		Ethernet	Protocol
A3.3	The display shows that the pickup area is not empty.	The display shows that the cone was not grasped.	Display	Road worker	I-25	CHANGE		Screen	GUI
A3.4	The road worker requests to stop the vehicle	The driver stops the vehicle to manage the incident.	Road worker	Vehicle		EXECUTE		Voice	

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Scenario Name: AS3.The cone is not grasped by the robot									
St No.	**Event**	**Description of Process/Activity**	**Information Producer**	**Information Receiver**	**Information Exchanged**	**Service**	**Requirements**	**Communication Media**	**Communication Means**
A3.5	The road worker substitutes the cone in the pickup area.	The road worker sends a request to the display indicating that the incident is repaired.	Road worker	Display	I-20	CREATE		Tactile	GUI
AS3.6	The display shows that the incident is repaired.	The driver restarts the movement of the vehicle.	Display	Vehicle		EXECUTE		Screen	GUI
AS3.7	The display requests to restart the process to the robotic system	The robotic system receives the request from the display to restart the process.	Display	Robotic system	I-26	EXECUTE		Ethernet	Protocol
AS3.8	The robotic system request to restart the process to the robot arm	The robot arm moves to the pickup area to grasp the cone.	Robotic system	Robot arm	I-22	EXECUTE		Ethernet	Protocol

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Scenario Name: AS4.The cone is not placed correctly									
St No.	Event	Description of Process/Activity	Information Producer	Information Receiver	Information Exchanged	Service	Requirements	Communication Media	Communication Means
AS4.1	The cone is not placed correctly	The cone is not placed correctly since the speed of the vehicle is higher than the required for the process. The vehicle is stopped.	Road worker	Vehicle		CANCEL		Voice	Voice
AS4.2	The cone is not placed correctly	The road worker request to stops the process of placement of cones.	Road worker	Display		CANCEL		Tactile	GUI
AS4.3	The display sends the notification to stop the process to the robotic system	The robotic system receives the notification to stop the process.	Display	Robotic system	I-27	CANCEL		Ethernet	Protocol
AS4.4	The robotic system sends the order to stop the robot arm	The robot arm receives the order stop order.	Robotic system	Robot arm	I-24	CANCEL		Ethernet	Protocol

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Scenario Name: AS4.The cone is not placed correctly									
St No.	**Event**	**Description of Process/Activity**	**Information Producer**	**Information Receiver**	**Information Exchanged**	**Service**	**Requirements**	**Communication Media**	**Communication Means**
AS4.5	The cone was placed correctly.	The road worker places manually the cone and restart the system.	Road worker	Display		EXECUTE		Tactile	GUI
AS4.6	The display shows that the incident is repaired.	The driver restarts the movement of the vehicle.	Display	Vehicle		EXECUTE		Screen	GUI
AS4.7	The worker restarts the process by the display	The display sends the order to the robotic system to restart the process.	Display	Robotic system	I-26	EXECUTE		Ethernet	Protocol
AS4.8	The robotic system sends the order to the robot to restart.	The robotic system restarts the process of placement of cones	Robotic system	Robot arm	I-22	EXECUTE		Ethernet	Protocol

The cone is not placed correctly-2 alternative scenario follows the same steps as previous alternative scenario.

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5 Step by Step Analysis of the Use Case - Collection of cones

5.1 List of scenarios for collection of cones

S.No	Scenario Name	Scenario Description	Primary Actor	Triggering Event	Pre-Condition	Post-Condition
PS1	Provide the collection of cones service.	The road administration notifies the road workers that a cone collection service needs to be started. The road administration provides a kilometre point where the cones need to be placed. Then, the road workers drive to the kilometre point.	Road administration	Road administration notifies the start of the service.	The temporary signalling at kilometre point x should be collected.	The road worker has received the kilometre point where the cones must be collected.
PS2	Collection of cones.	The road worker starts the cones collection process.	Road worker	The road worker uses the display to start the process.	The vehicle moves at slow speed.	Road work demarcation has been finished.
AS1	The road administration provides a set of incorrect kilometre points	The road worker reaches the kilometre point according to the information supplied by the road administration, but the place does not need to be signalled.	Road worker	The worker drives to the kilometre point	The kilometre point was wrongly communicated.	The road workers get the right position.
AS2	The cone is not grasped from the road.	The robot tries to collect the cone from the road, but the system is not able to collect it.	Robot arm	The robot arm moves to collect the cone from the road guided by the perception system.	Vehicle speed higher than required by the system	The cone is collected.
AS3	The cone is not grasped from the road (case 2).	The robot tries to collect the cone from the road, but the system is not able to collect it.	Robot arm	The robot arm moves to collect the cone from the road guided by the perception system.	The perception system does not identify the cone	The cone is collected.

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S.No	Scenario Name	Scenario Description	Primary Actor	Triggering Event	Pre-Condition	Post-Condition
AS4	The cone is not grasped from the road (case 3).	The robot tries to collect the cone from the road, but the system is not able to collect it due to the fact that the reach of the robot is not enough to collect it.	Robot arm	The robot arm moves to collect the cone from the road guided by the perception system.	The trajectory of the vehicle prevents the cone from being collected.	The cone is collected.

5.2 Steps – Primary Scenario for collection of cones

Scenario Name: PS1. Provide the collection of cones service.									
St No.	Event	Description of Process/Activity	Information Producer	Information Receiver	Information Exchanged	Service	Requirements	Communication Media	Communication Means
PS1.1	The road administration notifies the road worker	The road administration calls the road workers to notify that they need to provide a cone collection service.	Road administration	Road worker	I-02	REPORT		Phone	Voice
PS1.2	The road worker drives to kilometre point.	The road worker drives the vehicle to the kilometre point where the cones need to be collected.	Road worker	Vehicle		EXECUTE			

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Scenario Name: PS2. Collection of cones.									
St No.	Event	Description of Process/Activity	Information Producer	Information Receiver	Information Exchanged	Service	Requirements	Communication Media	Communication Means
PS2.1	The road worker moves forward the vehicle	The road worker moves the vehicle at slow speed to allow the cones collection robotic system to collect the cones.	Road worker	Vehicle		CHANGE	The speed must be adjusted to the operative.		
PS2.2	The road worker starts the collection process.	The withdrawal of cones must start. The road worker uses the display to push the start process button.	Road worker	Display				Tactile	GUI
PS2.3	The display requests to robotic system to start the process of collection	The display sends a signal to the robotic system to start the process.	Display	Robotic system	I-10	CREATE		Ethernet	Protocol
PS2.4	The robotic system requests to the robot arm to start the process of collection	The robotic system requests to the robot arm to move the robot arm to the cone collection initial position.	Robotic System	Robot arm	I-03	EXECUTE		Ethernet	Protocol
PS2.5	The robotic system requests to start the cone detection	The robotic system sends a signal to the perception system. The perception system carries out all the process of initialization.	Robotic system	Perception system	I-11	CREATE		Ethernet	Protocol

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Scenario Name: PS2. Collection of cones.									
St No.	**Event**	**Description of Process/Activity**	**Information Producer**	**Information Receiver**	**Information Exchanged**	**Service**	**Requirements**	**Communication Media**	**Communication Means**
		System. (RGB camera, AI system)							
PS2.6	The perception system sends the localization of the cone	The perception system sends the position of the cone to the robotic system.	Perception system	Robotic system	I-12	GET		Ethernet	Protocol
PS2.7	The robotic system requests to move the robot arm	The robotic system requests to move the robot arm trying to reach the best position, minimize the distance between the cone and the tool according to the information of the perception system.	Robotic system	Robot arm	I-04	EXECUTE REPEAT [8-9] UNTIL CONE IS REACHEABLE		Ethernet	Protocol
PS2.8	The robotic system requests to close the gripper.	The robotic system has calculated that the cone can be grasped by the tool if a request is sent at this right moment.	Robotic system	Tool	I-13	EXECUTE		Ethernet	Protocol
PS2.9	The robotic system requests to robot arm to move to the storage area	Once the cone is grasped the robot must place the cone in the storage area.	Robotic system	Robot arm	I-14	EXECUTE		Ethernet	Protocol

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Scenario Name: PS2. Collection of cones.									
St No.	Event	Description of Process/Activity	Information Producer	Information Receiver	Information Exchanged	Service	Requirements	Communication Media	Communication Means
PS2.10	The robotic system requests to the tool that it opens the gripper.	The robotic system requests to the tool that it opens the gripper.	Robotic system	Tool	I-07	EXECUTE REPEAT [6-12] UNTIL CONE IS REACHEABLE		Ethernet	Protocol
PS2.11	The road worker terminates the collection of cones.	The withdrawal of cones has been carried out. The road worker uses the display to push the stop process button.	Road worker	Display				Tactile	GUI
PS2.12	The display requests to robotic system to stop the collection task.	The robotic system receives the request from the display and stops the task of collection of the cones.	Display	Robotic system	I-15	CANCEL		Ethernet	Protocol
PS2.13	The robotic system notifies robot arm that the task of collection has finished.	The robot arm moves to home position.	Robotic system	Robot arm	I-09	EXECUTE		Ethernet	Protocol
PS2.14	The robotic system notifies perception	The perception system stops the calculation of the position of the cones.	Robotic system	Perception system	I-16	CANCEL		Ethernet	Protocol

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Scenario Name: PS2. Collection of cones.									
St No.	Event	Description of Process/Activity	Information Producer	Information Receiver	Information Exchanged	Service	Requirements	Communication Media	Communication Means
	system that the task of collection has finished.								

5.3 Steps – Alternative, Error Management, and/or Maintenance/Backup Scenario

AS1 is not included. Please refer to “AS1.The road administration provides a set of incorrect kilometre points” in section 4.3 as the steps are the same.

Only AS2 is included, as the steps to be performed in AS3 and AS4 are the same as in AS2.

Scenario Name: AS2.The cone is not grasped from the road.									
St No.	Event	Description of Process/Activity	Information Producer	Information Receiver	Information Exchanged	Service	Requirements	Communication Media	Communication Means
AS2.1	The cone is not collected	The road worker alerts to the driver to stop the vehicle.	Road worker	Vehicle		CHANGE		Voice	Voice
AS2.2	The road worker indicates thru the display that the collection process must be stopped.	The road worker uses the display to push the stop the process.	Road worker	Display		EXECUTE		Tactile	GUI
AS2.3	The display sends to the robotic	The robotic system stops the task of collection of cones and	Display	Robotic system	I-15	EXECUTE		Ethernet	Protocol

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Scenario Name: AS2.The cone is not grasped from the road.									
St No.	Event	Description of Process/Activity	Information Producer	Information Receiver	Information Exchanged	Service	Requirements	Communication Media	Communication Means
	system the order to stop the process.	sends the order to stop the robotic arm. Perception system is not stopped.							
AS2.4	The robotic system sends the order to stop the task to the robot arm	The robot arm stops its movement	Robotic system	Robot arm	I-09	CANCEL		Ethernet	Protocol
AS2.5	The road worker collects the cone and stores it in the storage area.	The road worker restarts the process by the display.	Road worker	Display		EXECUTE		Tactile	GUI
AS2.6	The display shows that the incident is repaired.	The driver restarts the movement of the vehicle.	Display	Vehicle	The trajectory and speed must fit to the required by the system.	EXECUTE		Screen	GUI
AS2.7	The road worker collects the cone and stores it in the storage area.	The road worker uses the display to push the start the process of collecting cones.	Road worker	Display		EXECUTE		Ethernet	Protocol
AS2.8	The display sends the message to start the process.	The order to start the process is received by the robotic system. This prepares the perception system and the	Display	Robotic system	I-03	EXECUTE		Ethernet	Protocol

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Scenario Name: AS2.The cone is not grasped from the road.									
St No.	**Event**	**Description of Process/Activity**	**Information Producer**	**Information Receiver**	**Information Exchanged**	**Service**	**Requirements**	**Communication Media**	**Communication Means**
		communication channel with the robot.							
AS2.9	The robotic system sends the order to robot arm	The robot arm receives de order to start the process.	Robotic system	Robot arm	I-04	EXECUTE		Ethernet	Protocol

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6 Information Exchanged

This section provides detailed information about the information exchanged within the Use cases both placement of cones and collection of cones (in the scenario steps).

Inf. ID	Name of information exchanged	Description of information exchanged	Information Subcategories[1]	Requirements
I-01	Kilometre point data and distance	The road administration provides a kilometre point where the cones must be placed and the distance to placed.	Network state	
I-02	Kilometre point data and distance	The road administration provides a kilometre point where the cones must be collected	Network state	
I-03	Display sends an order to start the robotic system for placement.	The message contains information to start up the robotic system for placement.	Information exchanged between IS or sent to device	
I-04	Robot movement goal	The message contains the pose of the robot end-effector.	Information exchanged between IS or sent to device	
I-05	Close the tool	The message contains the order to close the tool	Information exchanged between IS or sent to device	
I-06	Place the cone	The message contains the order to place the cone	Information exchanged between IS or sent to device	

[1] Select from the Subcategories listed in Annex B or in case of a new subcategory, please introduce it in the structure given in Annex B (insertion of new row in the Annex B).

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Inf. ID	Name of information exchanged	Description of information exchanged	Information Subcategories[1]	Requirements
I-07	Open the tool	The message contains the order to open the tool	Information exchanged between IS or sent to device	
I-08	The display requests to the robotic system to stop the task of placement of cones	The message contains information to stop the robotic system.	Information exchanged between IS or sent to device	
I-09	Robot movement to home position	Message to the robot to move to home position.	Information exchanged between IS or sent to device	
I-10	Display sends an order to start the robotic system for the collection of cones.	The message contains information to start up the robotic system for the collection of cones.	Information exchanged between IS or sent to device	
I-11	The robotic system sends to the perception system to start locating cone position.	The message contains information to start up the perception system.	Information exchanged between IS or sent to device	
I-12	The perception system sends the position of the cone.	The message contains information about the position of the detected cone.	Information exchanged between IS or sent to device	
I-13	The robotic system estimates that the cone should be able to grasp.	The message sends the order to close the gripper	Information exchanged between IS or sent to device	
I-14	Robot movement to storage area.	The message contains information to move the robot to storage area.	Information exchanged between IS or sent to device	
I-15	The display requests to the robotic system to stop the task.	The message contains information to stop the robotic system.	Information exchanged between IS or sent to device	
I-16	The robotic system requests to the perception system to stop.	The message contains information to stop the perception system.	Information exchanged between IS or sent to device	

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Inf. ID	Name of information exchanged	Description of information exchanged	Information Subcategories[1]	Requirements
I-17	The robotic system sends an alert to the display showing the pickup area is empty	The message contains information to indicate that the pickup area is empty robot.	Information exchanged between IS or sent to device	
I-18	The robotic system sends to the robot arm the order to pause the execution of the movement.	The message contains information to pause the execution of the robot.	Information exchanged between IS or sent to device	
I-19	The display shows that the pickup area is empty.	The message contains human readable information about the pickup area.	Information exchanged between IS or sent to device	
I-20	The display shows that the pickup area has a cone.	The message contains human readable information about the pickup area.	Information exchanged between IS or sent to device	
I-21	The display sends to the robotic system the order to continue the execution of the movement.	The message contains information to continue the execution of the robot.	Information exchanged between IS or sent to device	
I-22	The robotic system sends to the robot arm the order to continue the execution of the movement.	The message contains information to continue the execution of the robot.	Information exchanged between IS or sent to device	
I-23	The robotic system sends to the display that the cone was nor grasped	The message contains information to notify that the display cone was not grasped	Information exchanged between IS or sent to device	
I-24	The robotic system sends to the robot arm the order to cancel the execution of the movement.	The message contains information to cancel the execution of the robot.	Information exchanged between IS or sent to device	
I-25	The displays shows that the cone was nor grasped	The message contains human readable information to show in the display.	Information exchanged between IS or sent to device	

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Inf. ID	Name of information exchanged	Description of information exchanged	Information Subcategories[1]	Requirements
I-26	The display sends to the robotic system to restart the placement process.	The message contains information to restart the process of placement of cones.	Information exchanged between IS or sent to device	
I-27	The display sends to the robotic system to stop the placement process	The message contains information to stop the process of placement of cones.	Information exchanged between IS or sent to device	

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OMICRON

Intelligent Road Asset Management Platform

Road Assets Cleaning

Definition of Requirements

Publish Date: 2021.09.15

Use Case Number: UC2.1.3

Use Case Title: Road Assets Cleaning

Use Case Responsible Partner: TEKNIKER

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1 Description of the Use Case

1.1 Use Case Identification

ID	Domain(s)	Name of Use Case	Level of Use Case
UC2.3.1	UC2: Routine and emergency maintenance interventions	Implementing a robotic system for road assets cleaning	Detailed Use Case

1.2 Scope and Objectives

Scope and Objectives of the Use Case	
Scope	A robotic system shall support road maintenance workers in the process of cleaning road assets. This process comprises the manual cleaning by the road workers, which entails an exposure of workers to traffic, with a high probability of suffering accidents. Additionally, the use of a robotic arm for the cleaning of road assets should reduce the cleaning time, resulting in a reduction in maintenance costs.
Objective	• Daily work support: Aim of the use case is to assist operators improving their working conditions. • Operator safety: The robotic system reduces the exposure of workers to the handling of high loads and certain types of forced postures, thereby reducing the probability of injury. • Saving costs: The robotic solution has as a direct result the reduction of the corresponding workforce needed. This will result in a reduction in maintenance costs.
Related Business Case	*Automation and robotisation of maintenance operations*

1.3 Narrative of the Use Case

Short description – max 3 sentences
A robotic modular arm shall support road workers in the process of cleaning road assets. For this process, a perception system is needed which allows the robotic arm to locate the road signs. Then, the robot shall calculate the trajectory to cover the surface of the road sign. Additionally, a specific tool shall be designed to clean the signs with pressurized water.

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Complete description

Signs are placed to help ensure the motoring public's safety. When signs are not legible, they cannot serve that purpose. To maintain maximum retro reflectivity, performance and acceptability, signs should be kept clean and free from dirt, road tar, oil and bituminous material. The cleaning of signalling and lightning elements is an extremely repetitive task which is currently performed manually by road workers using water spraying systems (see Figure 1).

Figure 1 Road worker manually cleaning road signals

A robotic arm shall assume the operation of cleaning the road assets, minimizing the exposure of road workers to traffic. The assets considered are traffic signals located on the sides of the road and the lighting that is at reach of the robot.

The robotic modular platform is composed of a robotic arm, a perception module and an integrated commercial water spraying system. The robot arm is mounted on a trailer that can be easily hooked up to the back of a vehicle (eg., a truck) that carries the water tank, as shown in Figure 2.

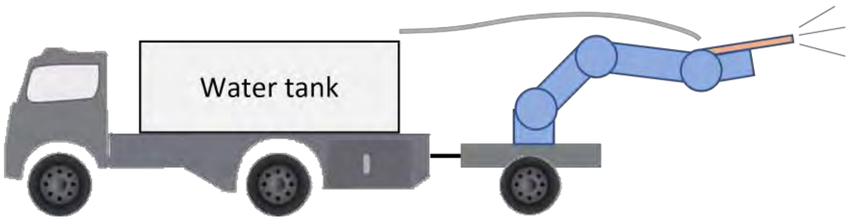

Figure 2 Robotic solution for road assets cleaning

The robot shall perform the cleaning of signals and lightning while the vehicle is stopped. Once the process is finished for the signal or lighting, the vehicle shall move to the next signal to be cleaned.

A vision system is needed to identify the presence of signals and estimate the relative position with respect to the robot and the control logic to generate the trajectories to cover the surface of the signals.

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1.4 KPIs.

ID	Name	Description	Target	Reference to mentioned Use Case objectives
KPI2	Emergency, ordinary and extraordinary maintenance intervention times	Although the cleaning itself could require the same time, the displacement between the signals and the preparation of the gun can be faster	20%	Reduction of time
KPI3	Volume of people in dangerous zones in road maintenance areas	The use of the robotic platform avoids the need of a worker being in the road	90%	Operator safety
KPI6	Traffic disruptions due to maintenance interventions	Traffic disruptions due to maintenance interventions	20%	
KPI9	Maintenance and inspection activity costs	The use of the robotic platform avoids the need of the worker handling the spraying gun	45%	Saving costs

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1.5 Use Case Conditions

Actor	Triggering Event	Pre-conditions	Assumption
Describe which Actor(s) trigger(s) this Use Case	Describe what event(s) trigger(s) this Use Case	Describe what condition(s) should have been met before this Use Case happens	Describe the assumptions about conditions or system configurations.

Road administration	The road administration calls the road workers to notify that they need to provide road assets cleaning service	The road assets that need to be cleaned have been identified and located (at kilometre point level).	• The vehicle has enough fuel
			• The water tank is full
			• The system works properly, including:
			  ○ Robot arm
			  ○ Camera
			  ○ VR headset
			  ○ AR headset

1.6 Classification Information

Relation to Other Use Cases in the same project or area
UC2.1 Robotic Modular Platform UC2.1.1 Installation of safety barriers UC2.1.2 Installation of cones UC3.1 Signalling during construction works UC3.2 Sealing of surface pavement cracks UC3.3 Removal of lane markings with laser
Level of Depth - the degree of specialization of the Use Case
Detailed Use Case
Further Keywords for Classification
Modular robotic arm, road assets cleaning, automatic detection of signals, automatic detection of lights, automatic cleaning
Maturity of Use Case
Visionary

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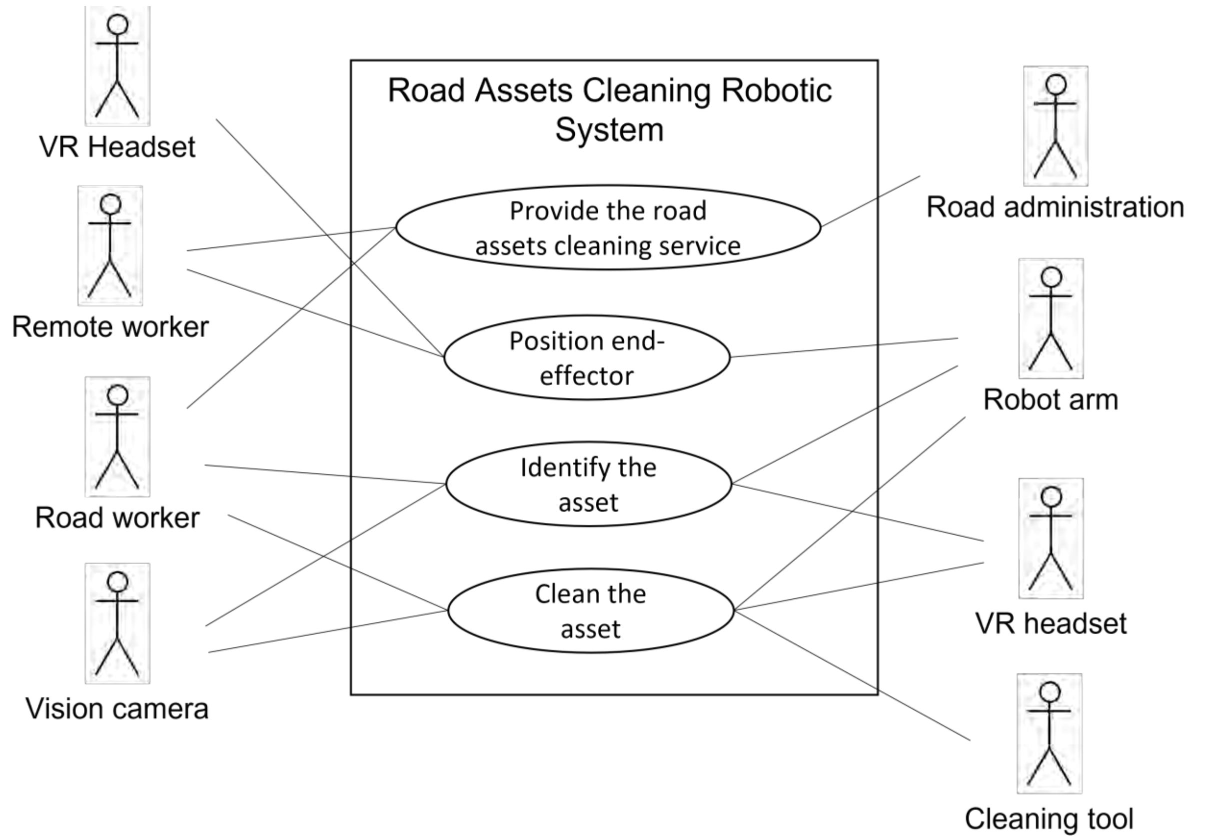
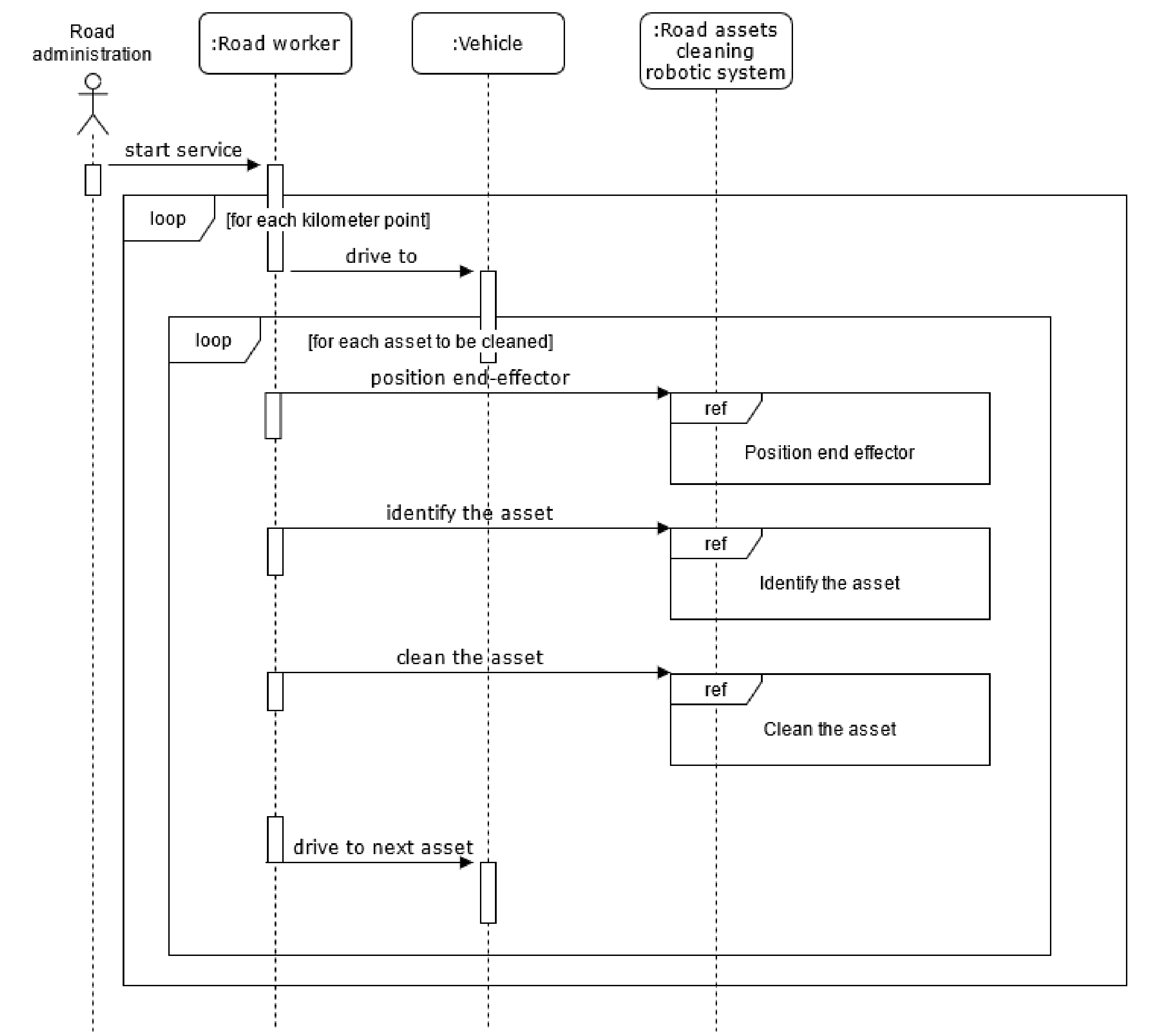
2 Diagrams of the Use Case

Context Diagram


Sequence Diagram: Provide the road assets cleaning service



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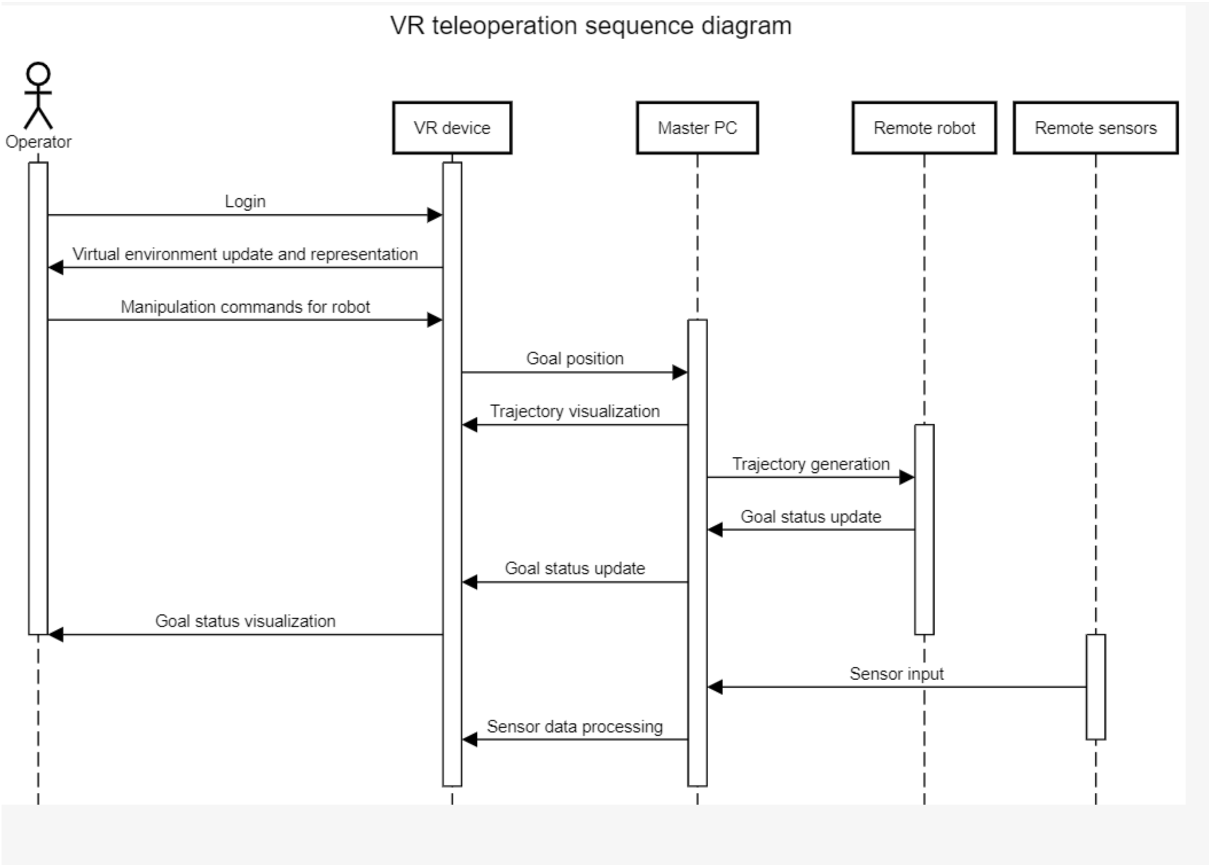
Sequence Diagram: Position end-effector



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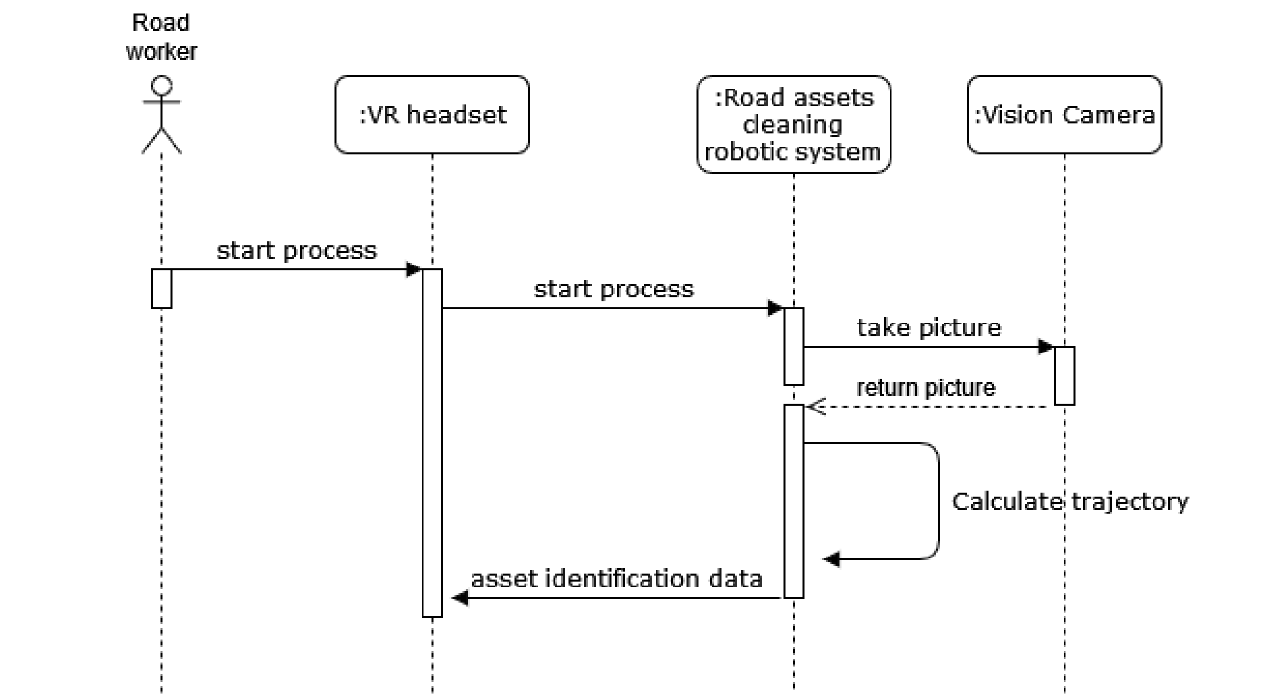
Sequence Diagram: Identify the asset



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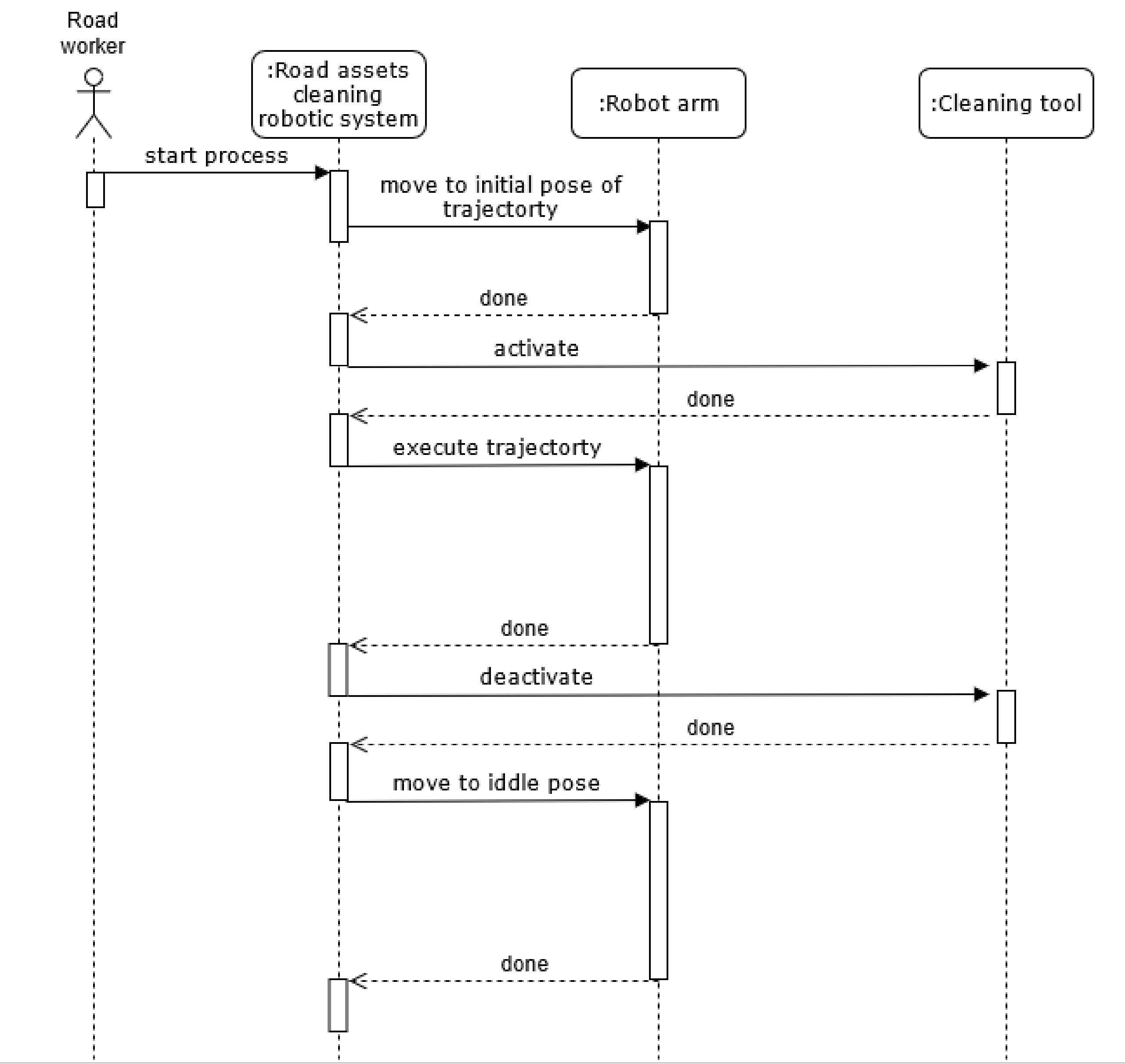
Sequence Diagram: Clean the asset



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3 Technical details of the Use Case - Actors

Actor Name	Actor Type	Actor Subcategories	Actor description	Further information specific to this Use Case	Equipment Manufacturer	Requirement(s) of the actor	Reference Standards/Legislation
Road administration	Role	Road contractor	The administration that notifies the road workers to perform a road assets cleaning service	The administration manages roads inspection data and based on that, decides when a road assets cleaning service need to be started.		Shall have knowledge of the roads and service resources	
Road worker	Role	Road contractor	The operator that performs the task cleaning the road assets	The operator directly uses the road assets cleaning robotic system to clean the traffic signs and lights		Shall have knowledge of the modular robotic platform technology and operation	
Vehicle	System	Road machinery	The vehicle that carries the robotic system for the cleaning of road assets	The vehicle carries the road assets cleaning robotic system, which is hooked up to the back of it.		Shall contain enough space to storage the assets Shall be able to tow the whole robotic system Shall be able to move at a very low speed	
Vision camera	System	Robotic element	RGB-D camera for the perception of traffic signs and lights	The camera is mounted on the robot arm to take images that will serve to the system to identify the traffic signs and lights		Shall be able to operate under low light conditions (night operations)	ISO 5469 (under development)
Robot arm	System	Robotic element	An anthropomorphic	The robot arm will manipulate the cleaning tool		At least 6 degrees of freedom.	ISO 10218, ISO12100, ISO 13849.

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Actor Name	Actor Type	Actor Subcategories	Actor description	Further information specific to this Use Case	Equipment Manufacturer	Requirement(s) of the actor	Reference Standards/Legislation
			industrial robotic arm			The robot flange should be able to reach near the assets. (Assets have a radius of 900 mm and a height of around 2000 mm) Thus, this must be considered when the robot be installed on the vehicle.	
Cleaning tool	System	Road machinery	A tool that allows to clean the road assets by spraying water	The cleaning tool is mounted on the robotic arm flange		Shall allow to clean the road assets.	
VR Headset	System	Interactive communication device	The VR headset used by the Remote Operator	The operator uses the headset to facilitate the remote operation of the robotic arm to position it over the track, and facilitate support in communications, safety and maintenance operations	e.g Oculus, Vive		UL 8400, IEEE P2048
Remote Operator	Role	Road Contractor	Operator that uses VR platform for teleoperation of robotic resources	Operator uses real -time feedback to be aware of the environment and uses modelled kinematics in VE in order to manipulate robotic resources remotely		Knowledge of VR operations, possession of VR device, construction of VE, awareness of remote environment	

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4 Step by Step Analysis of the Use Case

4.1 List of scenarios

S.No	Scenario Name	Scenario Description	Primary Actor	Triggering Event	Pre-Condition	Post-Condition
PS1	Provide the road assets cleaning service	The road administration notifies the road workers that a road assets service needs to be started. The road administration provides a set of the kilometre points where there are assets that need to be cleaned. Then, the road workers drive to the first kilometre point in the list. When they arrive, they stop at the location of the first asset. After that, the road worker positions the end-effector of the robotic arm (cf. Position end-effector use case). Once positioned, the road worker starts the asset identification (cf. Identify asset use case). When the asset is identified, the road worker selects manually the asset cleaning process (cf. Clean the asset use case). Once, finished the cleaning, the road worker moves forward to the next asset. This process is repeated for all the kilometre points where assets need to be cleaned.	Road administration	Road administration notifies the start of the service	Assets to be cleaned have been identified and located (at kilometre point level).	All the assets are clean.
PS2	Position end-effector	The remote operator uses a web-based VR platform to position the robotic arm end-effector near the road asset. The web-based VR platform allows remote operator to teleoperate the robotic arm in real time. The remote operator receives a video stream from the vision camera, facilitating the remote operation.	VR Headset	Road operator starts the positioning manoeuvre	The asset is inside the water spraying area of the robot.	The robot end-effector is positioned next to the asset and the asset is in the field of view of the vision camera.
PS3	Identify the asset	The road worker uses the display of the AR headset to manually start the asset identification process. Therefore, a vision camera provides data for the road asset cleaning robotic system for identifying and characterising the asset. After this identification	Vision camera	Road worker starts the asset identification process	The robotic arm end-effector is positioned next to the asset.	The road worker has received the data of the asset identification.

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S.No	Scenario Name	Scenario Description	Primary Actor	Triggering Event	Pre-Condition	Post-Condition
		and characterisation, the information is sent to the AR headset to be shown to the road worker.			The vision camera and the AR headset are connected with the road assets cleaning robotic system.	
PS4	Clean the asset	The road worker uses the AR headset to manually start the asset cleaning process. Therefore, the asset identification and characterisation data are used by the road assets cleaning robotics system to calculate the trajectory that the robot arm needs to execute to cover the surface of the asset. Then, the robot arm is positioned at the beginning of the trajectory. After this point, the road assets cleaning robotics system activates the tool to start spraying water. The robot arm will then execute the trajectory with a given constant speed. When the trajectory finishes, the road assets cleaning robotics system deactivates the tool.	Robot arm	Road worker starts the asset cleaning process	The asset cleaning system has the asset information.	The asset is clean.
AS1	The road administration provides a set of incorrect kilometre points	The road worker reaches the kilometre point according to the information supplied by the road administration, but the place does not need to be cleaned.	Road worker	The worker drives to the kilometre point	The kilometre point was wrongly communicated. t	The road workers get the right position.
AS2	Asset is not recognised	The road assets cleaning robotic system does not recognize the asset.	Road assets cleaning robotic system	The deep learning system does not recognise the asset	The quality picture is bad, (illumination, blur, perspective, vegetation). The	The asset is known and located by the robotic system.

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S.No	Scenario Name	Scenario Description	Primary Actor	Triggering Event	Pre-Condition	Post-Condition
					asset is dirty. Others ..	
AS3	The water jet does not reach the asset properly.	The water jet does not reach the asset properly.	Road assets cleaning robotic system	The trajectory of the robot arm is not calculated correctly.	The calculation of the position of the asset is wrong. The asset is not recognised correctly.	The cleaning task is finished.

4.2 Steps - Primary Scenario

Scenario Name: PS1.Provide the road assets cleaning service									
St No.	Event	Description of Process/Activity	Information Producer	Information Receiver	Information Exchanged	Service	Requirements	Communication Media	Communication Means
PS1.1	The road administration notifies the road worker	The road administration calls the road workers to notify that they need to provide a crack sealing service	Road administration	Road worker	I-11	REPORT		Phone call	Voice
PS1.2	The road worker drives to kilometre point	The road worker drives the vehicle to the kilometre point where assets need to be cleaned	Road worker	Vehicle					

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Scenario Name: PS1.Provide the road assets cleaning service									
St No.	**Event**	**Description of Process/Activity**	**Information Producer**	**Information Receiver**	**Information Exchanged**	**Service**	**Requirements**	**Communication Media**	**Communication Means**
PS1.3	The road worker positions the end-effector	(cf. PS2)							
PS1.4	The road worker starts the asset identification	(cf. PS3)							
PS1.5	The road worker starts the asset cleaning process	(cf. PS4)							
PS1.6	The road worker moves forward the vehicle	The road worker drives the vehicle to move forward to the next asset to be cleaned.	Road worker	Vehicle					
PS1.7	Assets are cleaned	Previous steps are repeated until all assets in the area are cleaned				REPEAT (3-6)			
PS1.8	All kilometre points are covered	Previous steps are repeated until all provided Kilometre points are covered				REPEAT (2-7)			

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Scenario Name: PS2.Position end-effector									
St No.	**Event**	**Description of Process/Activity**	**Information Producer**	**Information Receiver**	**Information Exchanged**	**Service**	**Requirements**	**Communication Media**	**Communication Means**
PS2.1	Feedback for the event is provided to the remote operator	Real-time data feedback is presented to the Operator	Remote sensors and communications	Virtual Device	I-02	GET	Data Management,	Web-based	protocol, e.g. TCP/IP
PS2.2	Successful	Manipulation commands sent from the operator to the PCthat solves the kinematics	Virtual Device	Master PC	I-09	CHANGE	Configuration, Constrains or other issues	Web-based	protocol, e.g. TCP/IP
PS2.3	Successful	Movement goal sent to robotic resources	Master PC	Remote robotic resources	I-09	CHANGE	Configuration, Constrains or other issues	Web-based	protocol, e.g. TCP/IP
PS2.4	Successful	Robotic resource completes movement and sends result back to VR headset	Remote robotic resources	Remote Resources	I-04	GET	Configuration, Constrains or other issues	Web-based	protocol, e.g. TCP/IP

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Scenario Name: PS3.Identify the asset									
St No.	**Event**	**Description of Process/Activity**	**Information Producer**	**Information Receiver**	**Information Exchanged**	**Service**	**Requirements**	**Communication Media**	**Communication Means**
PS3.1	The road worker starts the process	The road worker uses the AR Headset to push the start process button. The display sends a signal to the road assets cleaning robotic system.	AR Headset	Road assets cleaning robotic system	I-05	REPORT		Ethernet	GUI
PS3.2	Road assets cleaning robotic system is notified	After receiving a signal from AR Headset, the road assets robotic system requests an image from the vision camera.	Road assets cleaning robotic system	Vision camera	I-06	GET		Ethernet	protocol
PS3.3	Vision Camera is addressed	The vision camera takes a picture. The data is sent to the road assets cleaning robotic system.	Vision camera	Road assets cleaning robotic system	I-07	GET		Ethernet	Protocol
PS3.4	Road assets cleaning robotic system receives picture data	The road assets cleaning robotic system receives the picture data from the vision camera. Based on this, a traditional computer vision and Deep Learning methods are applied to identify and characterise the asset in the picture.	Road assets cleaning robotic system	Road assets cleaning robotic system	I-07	CREATE			
PS3.5	Asset has been identified and characterised	The road assets cleaning robotic system sends the asset identification and characterisation data that will be	Road assets cleaning robotic system	AR Headset	I-08	CHANGE		Wifi	Protocol

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Scenario Name: PS3.Identify the asset									
St No.	**Event**	**Description of Process/Activity**	**Information Producer**	**Information Receiver**	**Information Exchanged**	**Service**	**Requirements**	**Communication Media**	**Communication Means**
		shown to the road worker in the display.							
PS3.6	Display receives asset identification and characterisation data	The AR Headset shows to the road worker the information of the asset	AR Headset	AR Headset	I-08	REPORT			

Scenario Name: PS4.Clean the asset									
St No.	**Event**	**Description of Process/Activity**	**Information Producer**	**Information Receiver**	**Information Exchanged**	**Service**	**Requirements**	**Communication Media**	**Communication Means**
PS4.1	Road assets cleaning robotic system is notified	After receiving a signal from the AR headset, the road assets cleaning robotic system calculates the trajectory for the robot to cover the surface of the asset	Road assets cleaning robotic system	Road assets cleaning robotic system	I-08	CREATE			
PS4.2	Trajectory is calculated	The road assets cleaning robotic system sends a signal to the robotic arm to move to the initial pose of the calculated trajectory.	Road assets cleaning robotic system	Robot Arm	I-09	CHANGE		Ethernet	Protocol

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Scenario Name: PS4.Clean the asset									
St No.	Event	Description of Process/Activity	Information Producer	Information Receiver	Information Exchanged	Service	Requirements	Communication Media	Communication Means
PS4.3	Robot arm is notified	The robot arm positions the cleaning tool in the initial pose of the calculated trajectory.	Robot Arm	Robot Arm	I-09	EXECUTE			
PS4.4	Robot motion is finished	The robot arm sends a signal to the road assets cleaning robotic system.	Robot Arm	Road assets cleaning robotic system	I-04	GET		Ethernet	Protocol
PS4.5	Road assets cleaning robotic system has the signal	The road assets cleaning robotic system sends a signal to the cleaning tool to activate.	Road assets cleaning robotic system	Cleaning tool	I-10	CHANGE		Ethernet	Protocol
PS4.6	Cleaning tool is addressed	The cleaning tool switches on	Cleaning tool	Cleaning tool	I-10	EXECUTE			
PS4.7	Cleaning tool is on	The cleaning tool sends a signal to the road assets sealing robotic system.	Cleaning tool	Road assets cleaning robotic system	I-11	GET		Ethernet	Protocol
PS4.8	Road assets cleaning robotic system has the signal	The road assets cleaning robotic system sends a signal to the robot arm to execute the trajectory motion.	Road assets cleaning robotic system	Robot arm	I-09	CHANGE		Ethernet	Protocol
PS4.9	Robot arm is addressed	The robot arm executes the trajectory motion	Robot arm	Robot arm	I-09	EXECUTE			

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Scenario Name: PS4.Clean the asset									
St No.	Event	Description of Process/Activity	Information Producer	Information Receiver	Information Exchanged	Service	Requirements	Communication Media	Communication Means
PS4.10	Robot motion is finished	The robot arm sends a signal to the road assets cleaning robotic system.	Robot Arm	Road assets cleaning robotic system	I-04	GET		Ethernet	Protocol
PS4.11	Road assets cleaning robotic system has the signal	The road assets cleaning robotic system sends a signal to the cleaning tool to deactivate.	Road assets cleaning robotic system	Cleaning tool	I-10	CHANGE		Ethernet	Protocol
PS4.12	Cleaning tool is addressed	The cleaning tool switches off	Cleaning tool	Sealing tool	I-10	EXECUTE			
PS4.13	Cleaning tool is off	The cleaning tool sends a signal to the road assets cleaning robotic system.	Cleaning tool	Road assets cleaning robotic system	I-11	GET		Ethernet	Protocol
PS4.14	Road assets cleaning robotic system has the signal	The road assets cleaning robotic system sends a signal to the robot arm to move to the idle position	Road assets cleaning robotic system	Robot arm	I-03	CHANGE		Ethernet	Protocol
PS4.15	Robot arm is addressed	The robot arm moves to the idle position	Robot arm	Robot arm	I-03	EXECUTE			
PS4.16	Robot motion is finished	The robot arm sends a signal to the road assets cleaning robotic system.	Robot Arm	Road assets cleaning robotic system	I-04	GET		Ethernet	Protocol

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4.3 Steps – Alternative, Error Management, and/or Maintenance/Backup Scenario

Scenario Name: AS1.The road administration provides a set of incorrect kilometre points									
St No.	Event	Description of Process/Activity	Information Producer	Information Receiver	Information Exchanged	Service	Requirements	Communication Media	Communication Means
AS1.1	Kilometre point is incorrect.	The road workers notices that the kilometre point is incorrect. Therefore, they contact to road administration to get the right position.	Road administration	Road worker	I-01	CHANGE		Phone	Voice

Scenario Name: AS2.Assets is not recognised									
St No.	Event	Description of Process/Activity	Information Producer	Information Receiver	Information Exchanged	Service	Requirements	Communication Media	Communication Means
AS2.1	The robotic system does not recognise the asset	The robotic system stops the process and sends the picture to the display.	Road assets cleaning robotic system	Display	I-07	CHANGE		Ethernet	GUI

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Scenario Name: AS2.Assets is not recognised									
St No.	**Event**	**Description of Process/Activity**	**Information Producer**	**Information Receiver**	**Information Exchanged**	**Service**	**Requirements**	**Communication Media**	**Communication Means**
AS2.2	The display shows a set of assets	The display shows a set of assets to select the right asset.	Display	Road worker	I-12	CHANGE		Screen	GUI
AS2.3	The asset is chosen and located	The road worker selects the right asset and locates it in the picture.	Road worker	Display		EXECUTE		Tactile	GUI
AS2.4	The system restarts the process	The display sends the confirmation of the asset and the order to restart the process.	Display	Road assets cleaning robotic system	I-13	EXECUTE		Ethernet	Protocol

Scenario Name: AS3.The water jet does not reach the asset									
St No.	**Event**	**Description of Process/Activity**	**Information Producer**	**Information Receiver**	**Information Exchanged**	**Service**	**Requirements**	**Communication Media**	**Communication Means**
AS3.1	The water jet does not reach the asset	The water jet does not reach the asset. The road worker pushes the button in the	Road worker	Display		CHANGE		Ethernet	GUI

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Scenario Name: AS3.The water jet does not reach the asset									
St No.	Event	Description of Process/Activity	Information Producer	Information Receiver	Information Exchanged	Service	Requirements	Communication Media	Communication Means
		display to stop the process.							
AS3.2	The display sends the stop process message	The message is received by the robotic system. The robot arm and the water jet are stopped.	Display	Road assets cleaning robotic system	I-13	EXECUTE		Ethernet	Protocol
AS3.3	The road worker selects the manual process.	The road worker pushes the manual cleaning mode.	Road worker	Display		EXECUTE		Tactile	GUI
AS3.4	The display sends the manual selection to the robotic system	The robotic system changes the mode to manual mode allowing to the operator move the robot arm.	Display	Road assets cleaning robotic system	I-15	CHANGE		Ethernet	Protocol
AS3.5	The road worker starts the manual movement	The road worker moves the arm thru the display.	Display	Road assets cleaning robotic system	I-16	EXECUTE		Ethernet	Protocol

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Scenario Name: AS3.The water jet does not reach the asset									
St No.	Event	Description of Process/Activity	Information Producer	Information Receiver	Information Exchanged	Service	Requirements	Communication Media	Communication Means
	of the robot.								
AS3.6	The road worker requests to resume the task.	The display sends the confirmation to resume the task.	Road worker	Display		CHANGE		Tactile	GUI
AS3.7	The display sends the order to resume the task	The display sends the message to resume the task. The road assets cleaning robotic system is ready to carry out the next task.	Display	Road assets cleaning robotic system	I-14	CHANGE		Ethernet	Protocol

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5 Information Exchanged

Inf. ID	Name of information exchanged	Description of information exchanged	Information Subcategories	Requirements
I-01	Kilometre points data	The road administration provides a set of kilometre points codes where there are assets to be cleaned	Network state	
I-02	Data stream (visual)		Information exchanged between IS or sent to device	
I-03	Robot movement goal	The message contains the pose of the robot end-effector.	Information exchanged between IS or sent to device	
I-04	Result of movement operation	Message to signal that robot movement finished. It contains the result of the movement process.	Information exchanged between IS or sent to device	
I-05	Signal from the AR Headset	The AR Headset sends a signal to the road assets cleaning robotic system to notify that the cleaning process must start or stop. The signal is binary, i.e. only the values 0 and 1 exist (0 = start cleaning, 1 = stop cleaning).	Information exchanged between IS or sent to device	Correct communication establishment between AR headset and road assets cleaning robot
I-06	Signal from the Road assets cleaning robotic system for picture	The road assets cleaning robotic system sends a signal to vision camera to get a picture.	Information exchanged between IS or sent to device	
I-07	Picture data	The picture data contains RGB and depth values.	Information exchanged between IS or sent to device	
I-08	Asset's information	Message containing the identification and characterisation data of all the asset.	Information exchanged between IS or sent to device	

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Inf. ID	Name of information exchanged	Description of information exchanged	Information Subcategories	Requirements
I-09	Robot movement trajectory	The message contains the trajectory for the robot to execute.	Information exchanged between IS or sent to device	
I-10	Signal from the road assets cleaning robotic system to the cleaning tool	The signal specifies if the tool need to be activated or deactivated.	Information exchanged between IS or sent to device	
I-11	Signal from the cleaning tool	Message to signal that cleaning tool activation/deactivation process finished.	Information exchanged between IS or sent to device	
I-12	A set of assets	A GUI showing a set of assets	Information exchanged between IS or sent to device	
I-13	Stop the process	Message to stop the process	Information exchanged between IS or sent to device	
I-14	Restart the process	Message to restart the process	Information exchanged between IS or sent to device	
I-15	Change to manual mode	Message to change the cleaning process to manual mode	Information exchanged between IS or sent to device	
I-16	Manual trajectory	The message contains points of the trajectory of the robotic arm.	Information exchanged between IS or sent to device	

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OMI((RON

Intelligent Road Asset Management Platform

Safe signalling during construction works

Definition of Requirements

Publish Date:	15.09.2021
Use Case Number:	UC3.1
Use Case Title:	Safe signalling during construction works
Use Case Responsible Partner:	CEM

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1 Description of the Use Case

1.1 Use Case Identification

ID	Domain(s)	Name of Use Case	Level of Use Case
UC3.1	UC3: Large and extraordinary maintenance actions	Safe signaling during construction works	Detailed Use Case

1.2 Scope and Objectives

Scope and Objectives of the Use Case	
Scope	Previous to any road works, it is mandatory to place the required signaling on site in order (1) to inform users and (2) to order traffic along the section under works. This operation is currently done manually by the workers; hence, it is an extremely risky task since they have to perform this task while traffic is active, having to run across several lanes. The scope of the proposed Use Case is to implement the operation of placing and removing the temporary signs for maintenance works by means of the robotic arm to be developed in OMICRON.
Objective	The objectives of this Use Case are: • Daily work support: aim of the use case is to assist operators improving their working conditions. • Operator safety: aim of the use case is to increase the safety of operators when placing construction site signs. • Reduced traffic disruptions: another objective of this use case is to reduce the execution time of this task through the use of automated robotic systems. This will lead to shorter traffic disruptions. This will also have an effect in the overall costs.
Related Business Case	*BC4. Automation and robotization of maintenance operations*

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1.3 Narrative of Use Case

Short description – max 3 sentences
A robotic modular arm shall support the execution of different road maintenance interventions such as placing and removing temporary signals during works on the road. The use of robotic technologies for placing and removing temporary signals during road works will increase the safety of the operators who will no longer be exposed to doing this task manually while traffic is active, with the risks that this entails. In addition to increased safety, the automation of this task will lead to a reduction in execution times, which will increase the capacity of the network as there will be less disruptions to traffic.
Complete description
Previous to any road works, it is mandatory to place the required signalling on site in order to: (1) inform users and (2) order traffic along the section under works. This operation is currently done manually by the workers; hence, it is an extremely risky task since they have to perform this task while traffic is active, sometimes having to run across several lanes. This use case aims to use the robotic arm and the modular platform (to be developed in OMICRON) to place and remove signals during road works. The context of this use case is a road that is going to be partially closed due to maintenance works. An industrial robotic arm will be installed on a trailer attached to and carried by a truck or van that is driven by an operator. The different temporary signals that need to be placed during the execution of the works on the road will be positioned by the robotic arm installed on the trailer. Then, once the works on the road are finished, the robotic arm will remove the signals. Signals will be recognised by a perception module which will allow the robotic arm to identify the position of the elements to be removed. In the primary scenario, the worker drives the van or similar (with the trailer attached containing the robotic arm and the signs to be placed) to the position where the first sign is to be placed. There, the worker activates the robotic arm, and it picks up the sign and places it automatically in its final position. Then, the worker moves to the next position and repeat the process for the next signal. After finalising the works on the road, the temporary signs are to be removed. In this case, the robotic arm identifies the position of the elements to be removed through a perception module, moves to a position next to it, and picks it up. Then, it moves to the point where the truck with the trailer is placed (on the right-hand verge of the road) and place the signal on the trailer.

1.4 KPIs

Key performance indicators description for the Use Case:

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ID	Name	Description	Target	Reference to mentioned Use Case objectives
KPI 2	Emergency, ordinary and extraordinary maintenance intervention times	Reduction of the intervention times of the different robot-assisted maintenance tasks addressed in the project.	15%	Operator safety
KPI 3	Volume of people in dangerous zones in road maintenance areas	Reduction of the number of people in dangerous zones in maintenance areas using AR, VR and robotic platforms.	30%	Operator safety
KPI 6	Traffic disruptions due to maintenance interventions	The automation and robotisation of maintenance tasks in OMICRON will reduce traffic disruptions.	10%	Reduced traffic disruptions
KPI 9	Maintenance and inspection activity costs	The automation and robotisation of signalling tasks will reduce maintenance costs.	10%	Reduced traffic disruptions

1.5 Use Case Conditions

Actor	Triggering Event	Pre-conditions	Assumption
Road administration	The road administration contacts the road workers to notify that maintenance works are going to be carried out and therefore signalling during construction works is needed.	The affected road section is identified as well as the location of the different signals.	The system works properly.
Road worker		Training in the use of the robotic arm has to be	Operators' training is provided

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Actor	Triggering Event	Pre-conditions	Assumption
		integrated into existing training programs	
Road worker		Signals must be arranged on the trailer in the order in which they are going to be placed.	Information on the expected location of signs is provided.
Robotic arm		The robot arm is provided with the appropriate tool to hold the signals	The arm is configured with the corresponding tool to grab signals
Perception module		Lighting must be integrated to ensure good lighting at night	There is enough light for the perception system to see the signals

1.6 Classification Information

Relation to Other Use Cases in the same project or area
This use case is related to the use cases for routine and emergency maintenance interventions: • UC2.1 Robotic Modular platform • UC2.1.1 Installation of safety barriers • UC2.1.2 Installation of cones Use Cases for Large and extraordinary maintenance actions: • UC3.2 Sealing of surface pavement cracks • UC3.3 Removal of lane marking with laser
Level of Depth - the degree of specialization of the Use Case
Detailed Use Case
Further Keywords for Classification
Robotic arm, automatic placing and removing of road work signs.
Maturity of Use Case
Visionary

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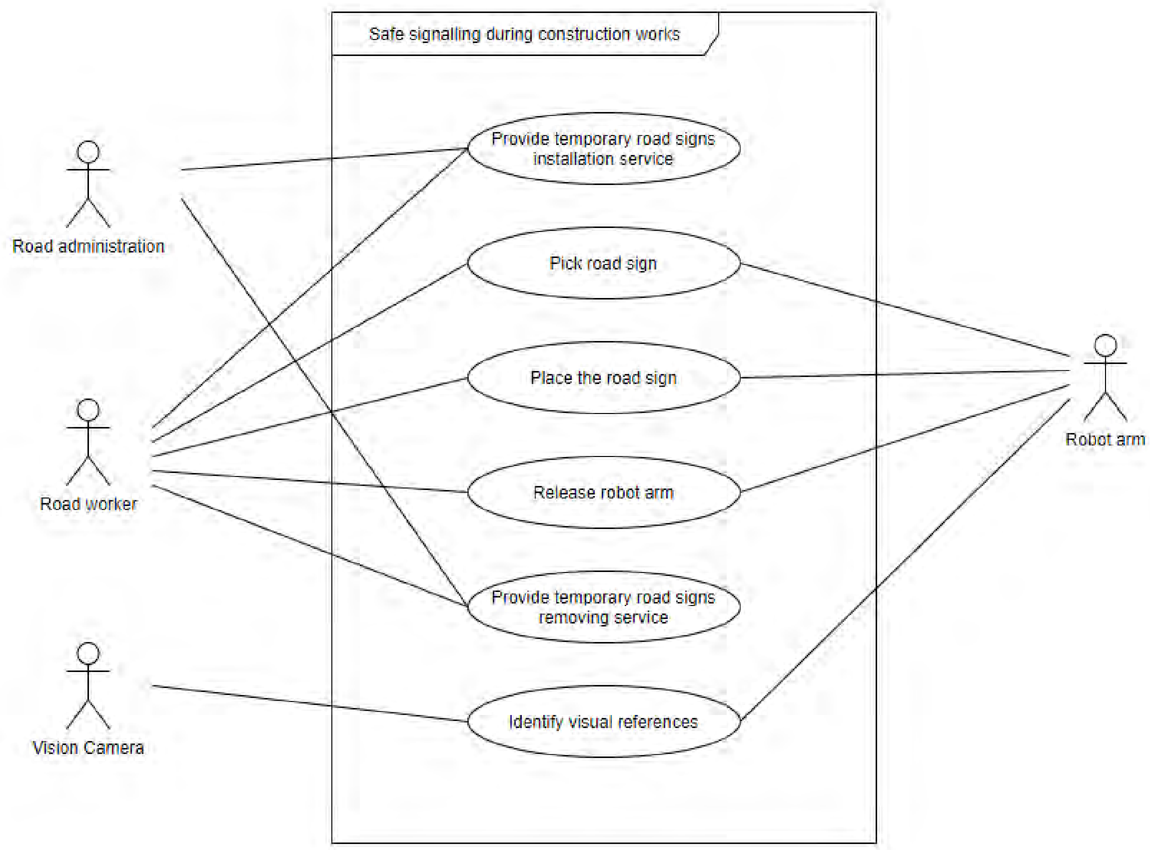
2 Diagrams of the Use Case

Context Diagram


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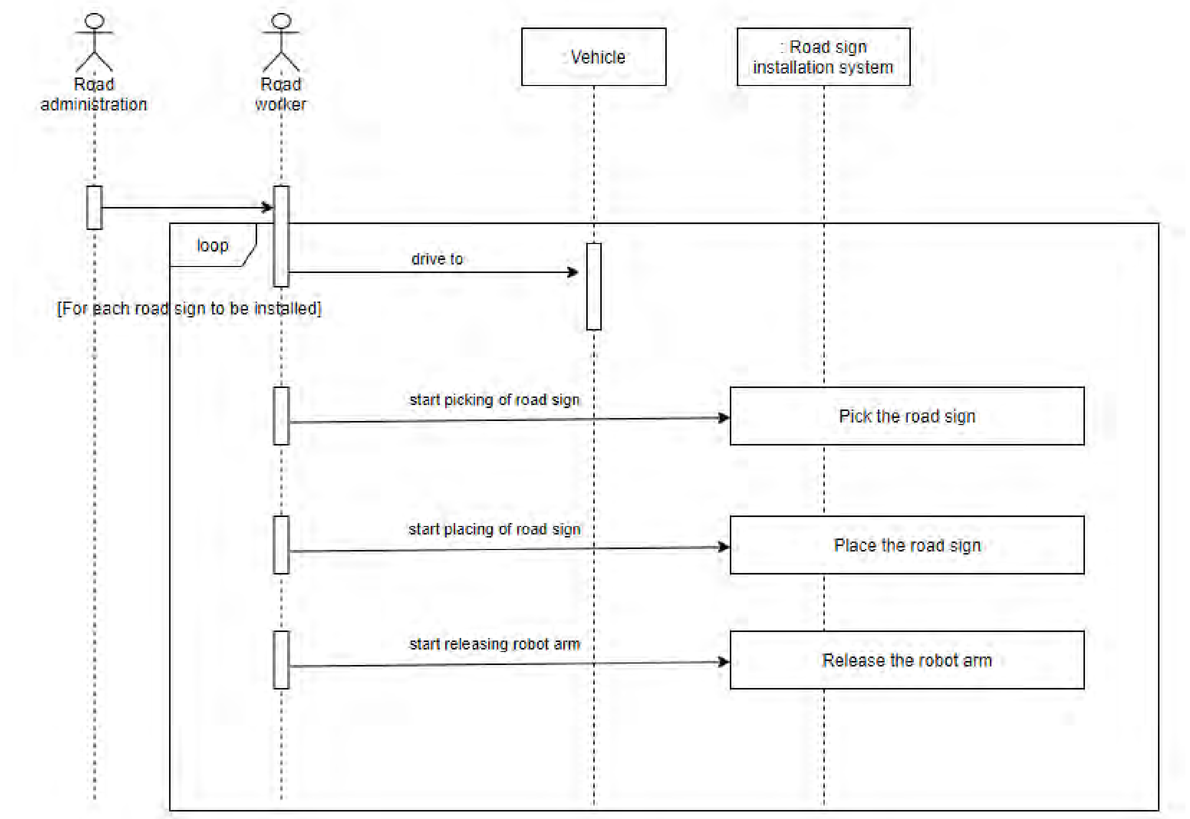
Sequence Diagram: Provide temporary road signs installation service



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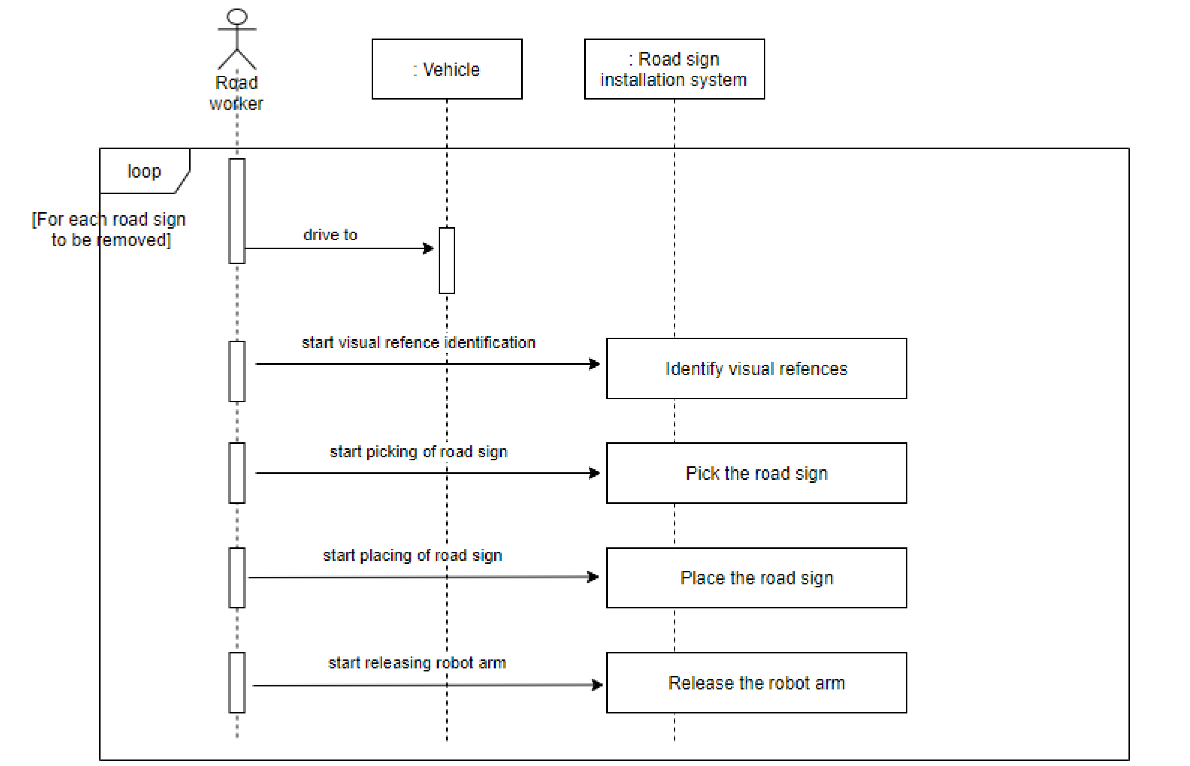
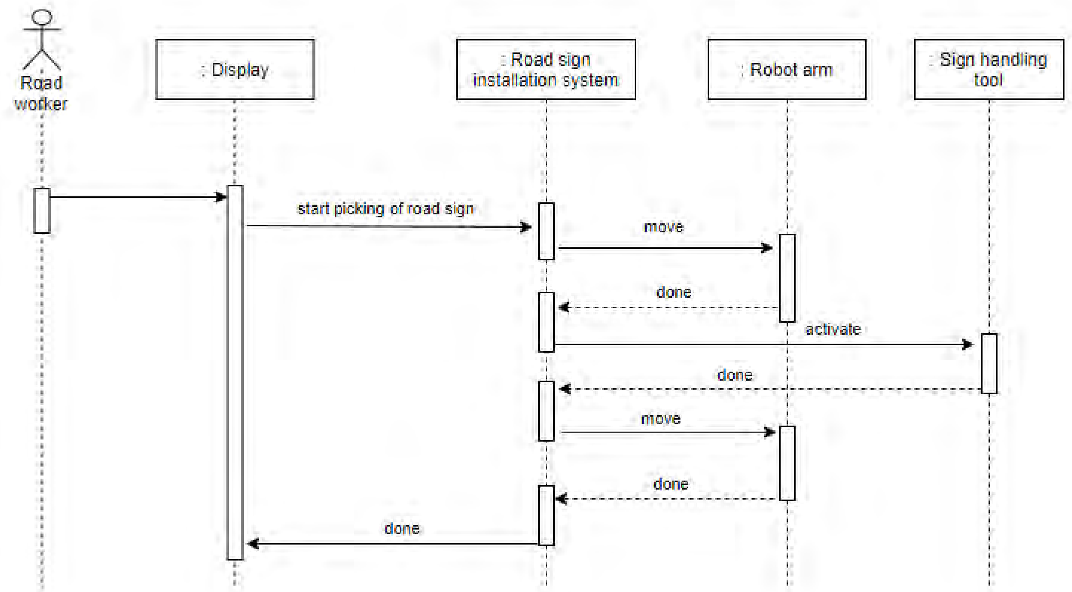
Sequence Diagram: Provide temporary road signs removing service



Sequence Diagram: Pick the road sign



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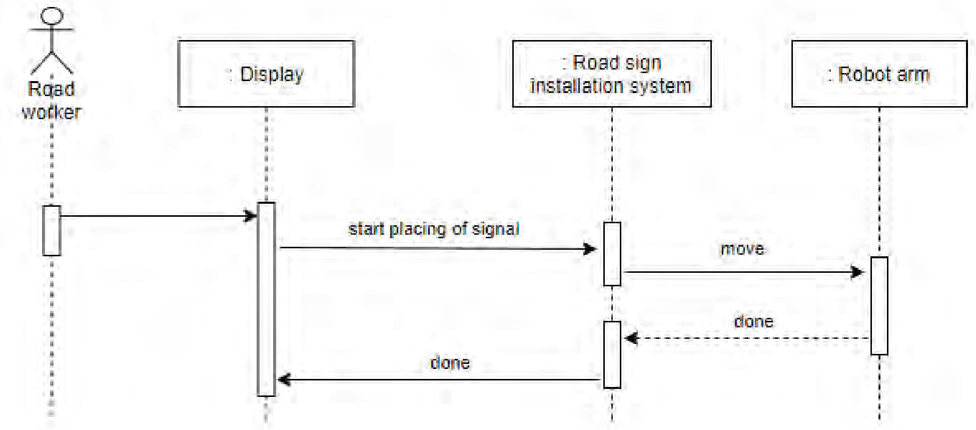
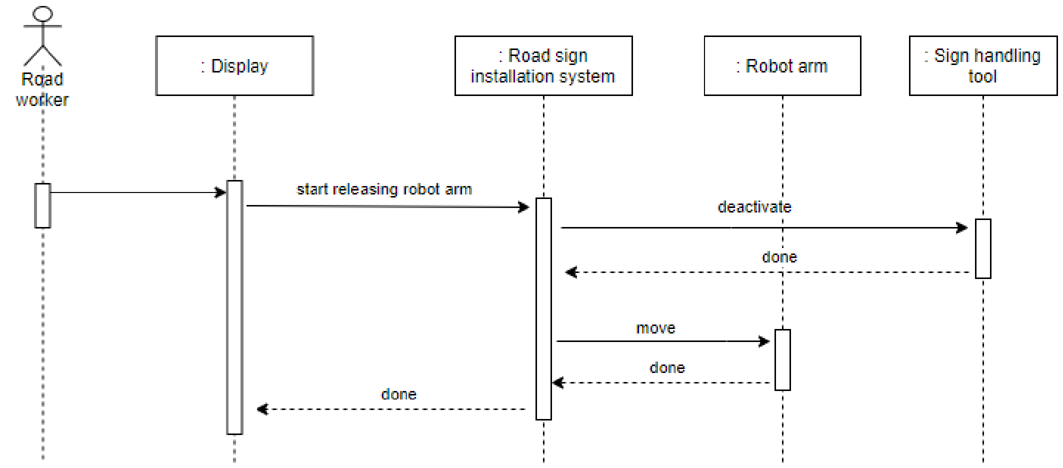
Sequence Diagram: Place the road sign



Sequence Diagram: Release robot arm



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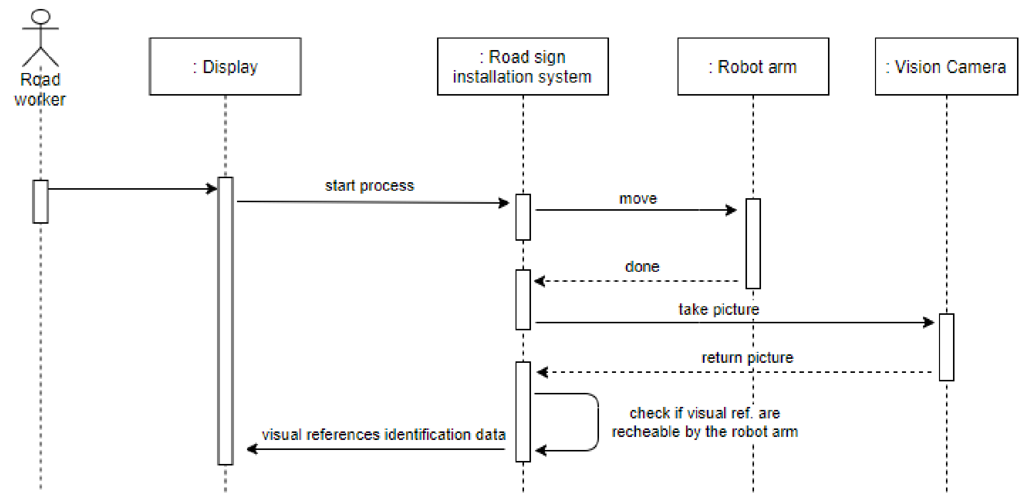
Sequence Diagram: Identify visual references



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3 Technical details of the Use Case - Actors

Actor Name	Actor Type	Actor Subcategories	Actor description	Further information specific to this Use Case	Equipment Manufacturer	Requirement(s) of the actor	Reference Standards/Legislation
Road administrator	Role	Road contractor	Notifies the road workers to performance	The administration manages the road and schedules the maintenance work to be carried out.			
Road Worker	Role	Road contractor	Performs road maintenance works	The road worker uses the robotic system to place and remove the temporary signs on the road during maintenance works			
Vehicle	System	Road machinery	The vehicle that carries the signs and the robotic system				
Robotic arm	System	Robotic element	An anthropomorphic industrial robotic arm	Picks and places signals. Operated by the road worker		- Shall be able to move loads of around 40 kilos. - Shall provide a sensitive mode for the operator to move it by hand (e.g., gravity compensation function).	ISO 10218, ISO12100, ISO 13849.

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Actor Name	Actor Type	Actor Subcategories	Actor description	Further information specific to this Use Case	Equipment Manufacturer	Requirement(s) of the actor	Reference Standards/Legislation
Vision camera	System	Robotic element	RGB-D camera for the perception of visual references (signs, humans)	The camera is mounted on the robot arm to take images that will serve to the system to identify the visual references (signs and/or humans).		- Lighting shall be integrated to ensure good visibility at night	
Sign handling tool	System	Road machinery	A tool that allows to hold road signs	The sign handling tool is mounted on the robotic arm flange		- Shall allow to grab and release the road signs (eg. Electromagnetic)	ISO 20218
Display	System	Road machinery	A device to interact with the robot	The display is used by the road worker to start/stop operations.			

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4 Step by Step Analysis of the Use Case

4.1 List of scenarios

S.No	Scenario Name	Scenario Description	Primary Actor	Triggering Event	Pre-Condition	Post-Condition
PS1	Provide the temporary road signs installation service	The road worker upload into the vehicle all the signs to be placed along the right-side of the road. The road worker drives the vehicle pushing the modular robotic platform to the first place where a road sign needs to be placed. The worker positions the vehicle in such a way that the robotic platform is close enough to perform the operation. After that, the road worker starts the road signs picking process (cf. pick the road sign). Then, the robot places the road sign in the right position. Finally, the road worker starts the release process to move the robot to the start position (cf. release the robot arm). Then, the road worker drives the vehicle to the next position where a road sign needs to be installed. This process is repeated for all the road signs that need to be installed on the right side of the road.	Road administration	Road administration notifies the start of maintenance works	The road signs to be installed have been notified and identified	All road signs are placed in the right position
PS2	Pick the road sign	The road worker uses the display to manually start the picking of the road sign to be placed. The robotic arm executes a specific program to pick the road sign that is placed next to it, on the platform. The road sign handling tool is used to pick the sign.	Robot arm	Road worker starts the picking process	The road sign to be picked is on the platform	The road sign is picked.

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S.No	Scenario Name	Scenario Description	Primary Actor	Triggering Event	Pre-Condition	Post-Condition
PS3	Place the road sign	The road worker uses the display to manually start the placing of the road sign.	Robot arm	Road worker starts the placing process	The road sign is picked	The road sign is placed on the road
PS4	Release the robot arm	The road worker uses the display to start the release process. The robot tool releases the road sign, and the robot arm moves to an initial pose.	Robot arm	Road worker starts the release process	The road sign is placed in the right position	The robot is in the initial pose
PS5	Provide the temporary road signs removing service	After carrying out the interventions on the road, the temporary signs must be removed. This task will also be performed with the help of the robotic arm. The road worker drives the vehicle to a position in which the robotic platform is close enough to perform the operation. Then, the road worker starts the identification of visual references process (cf. identify visual references). When the road sign is identified, the road worker starts the road signs picking process (cf. pick the road sign). After that, the robot places the road sign in the vehicle. Finally, the road worker starts the release process to move the robot to the start position (cf. release the robot arm). This process is repeated for all the road signs to be removed.	Road worker	Interventions works are finished.	Intervention works are finished, and road signs are placed on the road	All road signs are removed from the road.

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S.No	Scenario Name	Scenario Description	Primary Actor	Triggering Event	Pre-Condition	Post-Condition
PS6	Identify visual references	The road worker uses the display to manually start the visual references identification process. A vision camera provides the data to the road signs picking system for identifying the visual references. After this identification, the system checks that the robot is near enough to reach the destination. Finally, the information is sent to the display to be shown to the road worker.	Vision camera	Road worker starts the visual references identification process	The visual references are inside the working envelope of the robot	The road worker has received the data of the identification of the visual references

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4.2 Steps - Primary Scenario

Scenario Name: PS1 Provide the road temporary signs installation service (success)									
St No.	**Event**	**Description of Process/Activity**	**Information Producer**	**Information Receiver**	**Information Exchanged**	**Service**	**Requirements**	**Communication Media**	**Communication Means**
1	The road administration notifies the road worker	The road administration notifies the road worker that maintenance works are going to be executed on the road.	Road administration	Road worker	I-01	REPORT			
2	The road worker drives to the installation point	The road worker drives the vehicle to the point where the first road sign is needed to be placed.	Road worker	Vehicle					
3	The road worker starts the picking of the road sign	(cf. PS2)							
4	The road worker starts the placing of the road sign	(cf. PS3)							
5	The road worker starts the releasing of robot arm	(cf. PS4)							

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Scenario Name: PS1 Provide the road temporary signs installation service (success)									
St No.	Event	Description of Process/Activity	Information Producer	Information Receiver	Information Exchanged	Service	Requirements	Communication Media	Communication Means
6	All road signs are placed	Previous steps are repeated until all signs are installed.				REPEAT (2-5)			

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Scenario Name: PS2 Pick the road sign (success)									
St No.	**Event**	**Description of Process/Activity**	**Information Producer**	**Information Receiver**	**Information Exchanged**	**Service**	**Requirements**	**Communication Media**	**Communication Means**
1	The road worker manually starts the picking process	The road worker pushes a button in the display that starts the road sign picking process.	Display	Road sign installation system	I-02	REPORT			
2	Road sign installation system is notified	After receiving a signal from display, the road sign installation system requests the robot arm to move to a specific position.	Road sign installation system	Robot arm	I-03	GET			
3	Robot arm is addressed	The robot arm moves to the specified position.	Robot arm	Robot arm	I-03	EXECUTE			
4	Robot motion is finished	The robot arm sends a notification to the road sign installation system.	Robot arm	Road sign installation system	I-04	GET			
5	Road sign installation system has the signal	After receiving a notification from the robot arm, the road sign installation system requests the sign handling tool to activate.	Road sign installation system	Sign handling tool	I-08	REPORT			
6	The sign handling tool is addressed	The sign handling tool activates (electromagnetic system).	Sign handling tool	Sign handling tool	I-08	EXECUTE			

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Scenario Name: PS2 Pick the road sign (success)									
St No.	**Event**	**Description of Process/Activity**	**Information Producer**	**Information Receiver**	**Information Exchanged**	**Service**	**Requirements**	**Communication Media**	**Communication Means**
7	The tool is on	The sign handling tool sends a signal to the road sign installation system.	Sing handling tool	Road sign installation system	I-09	GET			
8	Road sign installation system has the signal	The road sign installation system sends a signal to the robot arm to start moving to a specific position.	Road sign installation system	Robot arm	I-03	GET			
9	Robot arm is addressed	The robot arm executes the motion.	Robot arm	Robot arm	I-03	EXECUTE			
10	Robot motion is finished	The robot arm sends a signal to the road sign installation system.	Robot arm	Road sign installation system	I-04	GET			
11	Road sign installation system has the signal	The road sign installation system sends a signal to the display, to notify the result of the process.	Road sign installation system	Display	I-10	GET			
12	Display receives the signal	The display shows the notification to the road worker.	Display	Display	I-10	EXECUTE			

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Scenario Name: PS3 Place the road sign (success)									
St No.	Event	Description of Process/Activity	Information Producer	Information Receiver	Information Exchanged	Service	Requirements	Communication Media	Communication Means
1	The road worker manually starts the placing process	The road worker pushes a button in the display that starts the road sign placing process.	Display	Road sign installation system	I-02	REPORT			
2	Road sign installation system is notified	After receiving a signal from display, the road sign installation system requests the robot arm to move to a position next to the signal on the vehicles.	Road sign installation system	Robot arm	I-03				
3	Robot arm is addressed	The robot arm moves to the specified position and the sign is placed.	Robot arm	Robot arm	I-03	EXECUTE			
4	Robot motion is finished	The robot arm sends a notification to the road sign installation system.	Robot arm	Road sign installation system	I-04	GET			
5	Road sign installation system has the signal	After receiving a notification from the robot arm, the road sign installation system sends a signal to the display	Road sign installation system	Display	I-10	GET			
6	Display receives the signal	The display shows the notification that the process has successfully finished to the road worker	Display	Display	I-10	EXECUTE			

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Scenario Name: PS4 Release the robot arm (success)									
St No.	**Event**	**Description of Process/Activity**	**Information Producer**	**Information Receiver**	**Information Exchanged**	**Service**	**Requirements**	**Communication Media**	**Communication Means**
1	The road worker manually starts the robot arm release process	The road worker pushes a button in the display that starts the robot arm release process.	Display	Road sign installation system	I-02	REPORT			
2	Road sign installation system is notified	After receiving a signal from display, the road sign installation system requests the sign handling tool to deactivate	Road sign installation system	Sign handling tool	I-08	REPORT			
3	The sign handling tool is addressed	The sign handling tool is deactivated (electromagnetic system)	Sign handling tool	Sign handling tool	I-08	EXECUTE			
4	The tool is deactivated	The sign handling tool sends a signal to the road sign installation system	Sign handling tool	Road sign installation system	I-09	GET			
5	Road sign installation system has the signal	After receiving a signal from the tool, the road sign installation system requests the robot arm to move to a specific position.	Road sign installation system	Robot arm	I-10	GET			
6	Robot arm is addressed	The robot arm executes the fixed motion	Robot arm	Robot arm	I-03	EXECUTE			

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Scenario Name: PS4 Release the robot arm (success)									
St No.	Event	Description of Process/Activity	Information Producer	Information Receiver	Information Exchanged	Service	Requirements	Communication Media	Communication Means
7	Robot motion is finished	The robot arm sends a signal to the road sign installation system	Robot arm	Road sign installation system	I-04	GET			
8	Road sign installation system has the signal	The road sign installation system sends a signal to the display	Road sign installation system	Display	I-10	GET			
9	Display receives the signal	The display shows the notification to the road worker	Display	Display	I-10	EXECUTE			

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Scenario Name: PS5 Provide the road temporary signs removing service (success)									
St No.	**Event**	**Description of Process/Activity**	**Information Producer**	**Information Receiver**	**Information Exchanged**	**Service**	**Requirements**	**Communication Media**	**Communication Means**
1	The road worker drives to the point where the signal is placed	The road worker drives the vehicle to the point where the first road sign needs to be removed.	Road worker	Vehicle					
2	The road worker starts the identification of visual references process.	(cf. PS6)							
3	The road worker starts the picking of the road sign	(cf. PS2)							
4	The road worker starts the placing of the road sign	(cf. PS3)							
5	The road worker starts the releasing of robot arm	(cf. PS4)							
6	All road signs are placed	Previous steps are repeated until all signs are installed.				REPEAT (2-5)			

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Scenario Name: PS6 Identify visual references (success)									
St No.	Event	Description of Process/Activity	Information Producer	Information Receiver	Information Exchanged	Service	Requirements	Communication Media	Communication Means
1	The road worker starts the service	The road worker uses the display to push the start process button. The display sends a signal to the road sign installation system.	Display	Road sign installation system	I-02	REPORT			
2	Road sign installation system is notified	After receiving a signal from display, the road sign installation system requests the robot arm to move to a specific position.	Road sign installation system	Robot arm	I-03	GET			
3	Robot arm is addressed	The robot arm moves to the specified position.	Robot arm	Robot arm	I-03	EXECUTE			
4	Robot arm finishes its motion	The robot arm sends a notification to the road sign installation system.	Robot arm	Road sign installation system	I-04	GET			
5	Road sign installation system is notified	After receiving a notification from the robot arm, the road sign installation system requests an image from the vision camera.	Road sign installation system	Vision camera	I-05	GET			

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Scenario Name: PS6 Identify visual references (success)									
St No.	Event	Description of Process/Activity	Information Producer	Information Receiver	Information Exchanged	Service	Requirements	Communication Media	Communication Means
6	Vision Camera is addressed	The vision camera takes a picture. The data is sent to the road sign installation system.	Vision camera	Road sign installation system	I-06	CREATE			
7	Road sign installation system receives picture data	The road sign installation system receives the picture data from the vision camera. Based on this, computer vision methods are applied to identify the visual references in the picture.	Road sign installation system	Road sign installation system	I-07	CREATE			
8	Visual references are identified	The road sign installation system checks whether the visual references are inside the working envelope of the robot arm.	Road sign installation system	Road sign installation system	I-07	EXECUTE			
9	Visual references are inside the working envelope of the robot	The road sign installation system sends the visual references identification data that will be shown to the road worker in the display	Road sign installation system	Display	I-07	GET			
10	Display receives visual	The display shows to the road worker the	Display	Display	I-07	EXECUTE			

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Scenario Name: PS6 Identify visual references (success)									
St No.	Event	Description of Process/Activity	Information Producer	Information Receiver	Information Exchanged	Service	Requirements	Communication Media	Communication Means
	references identification data	information of the visual references							

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4.3 Steps – Alternative, Error Management, and/or Maintenance/Backup Scenario

Scenario Name: AS1 temporary construction signs are not picked up									
St No.	Event	Description of Process/Activity	Information Producer	Information Receiver	Information Exchanged	Service	Requirements	Communication Media	Communication Means
01	Road worker uploads signs	Road worker uploads into the trailer all the signs to be placed along the road.							
02	Drives to the first position	Road worker drives the truck to the location of the first sign to be placed.					Workplace must be free of obstacles		
03	Activates robotic arm	Road worker activates robotic arm					Truck is positioned and ready to start placing signals		
04	Failure	Robotic arm fails at picking up the signal							

Scenario Name: AS2 temporary construction signs are not properly placed									
St No.	Event	Description of Process/Activity	Information Producer	Information Receiver	Information Exchanged	Service	Requirements	Communication Media	Communication Means
01	Road worker uploads signs	Road worker uploads into the trailer all the signs to be placed along the road.							

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02	Drives to the first position	Road worker drives the truck to the location of the first sign to be placed.					Workplace must be free of obstacles		
03	Activates robotic arm	Road worker activates robotic arm					Truck is positioned and ready to start placing signals		
04	Picks up signal	Robotic arm picks up the signal from the trailer							
05	Failure	Robotic arm fails at placing the signal properly.					Place must be free of obstacle		

Scenario Name: AS3 Temporary signs to be removed are not detected									
St No.	**Event**	**Description of Process/Activity**	**Information Producer**	**Information Receiver**	**Information Exchanged**	**Service**	**Requirements**	**Communication Media**	**Communication Means**
01	Drives to the first position	Road worker drives the truck to the position of the first sign to be removed.					Signals are placed on the road		
02	Failure	Perception module of the robotic arm fails at identifies the signal to be removed. Signals cannot be removed.							

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5 Information Exchanged

Inf. ID	Name of information exchanged	Description of information exchanged	Information Subcategories	Requirements
I-01	Kilometre points data	The road administration provides a set of kilometre points codes where maintenance works are going to be executed.	Network state	
I-02	Signal from the display	The display sends a signal to the road sign installation system to notify that the process must start	Information exchanged between IS or sent to device	
I-03	Robot movement goal	The message contains the pose of the robot end-effector.	Information exchanged between IS or sent to device	
I-04	Result of movement operation	Message to signal that robot movement finished. It contains the result of the movement process.	Information exchanged between IS or sent to device	
I-05	Signal from the road sign installation system for picture	The road sign installation system sends a signal to vision camera to get a picture.	Information exchanged between IS or sent to device	
I-06	Picture data	The picture data contains RGB and depth values	Information exchanged between IS or sent to device	
I-07	Visual references information	The message contains the information about the detected visual references.	Information exchanged between IS or sent to device	
I-08	Signal to the sign handling tool	The road sign installation system sends a signal to the sign handling tool. The signal is binary, i.e., only the values 0 and 1 exist (0 = activate, 1 = deactivate)	Information exchanged between IS or sent to device	
I-09	Signal from the sign handling tool	The sign handling tool sends a signal to the road sign installation system.	Information exchanged between IS or sent to device	

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Inf. ID	Name of information exchanged	Description of information exchanged	Information Subcategories	Requirements
I-10	Signal to the display	The road sign installation system sends a message containing the result of the operation	Information exchanged between IS or sent to device	

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OMI((RON

Intelligent Road Asset Management Platform

Sealing of Surface Pavement Cracks

Definition of Requirements

Publish Date: 2021.09.15

Use Case Number: UC3.2

Use Case Title: Sealing of Surface Pavement Cracks

Use Case Responsible Partner: PAVASAL

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1 Description of the Use Case

1.1 Use Case Identification

ID	Domain(s)	Name of Use Case	Level of Use Case
UC3.2	UC3: Large and extraordinary maintenance actions	Implementing a robotic system for the sealing of surface pavement cracks	Detailed Use Case

1.2 Scope and Objectives

Scope and Objectives of the Use Case	
Scope	Road maintenance workers shall be supported in the process of sealing cracks in surface pavement layers. This process comprises operating pipes of a dedicated machinery by a worker to follow and seal the crack. The machine heats up bituminous mixes to high temperatures. The manipulation of the bituminous materials can be dangerous, as they are very adherent, so any single mistake can induce severe burns in the worker. Additionally, the use of a modular robotic arm should reduce the corresponding workforce needed, resulting in a reduction in maintenance costs.
Objective	• Daily work support: Aim of the use case is to assist operators improving their working conditions. • Operator safety: The robotic system reduces the exposure of workers to the manipulation of the bituminous materials and to the impact of material that can come out during the blow operation, thereby reducing the probability of an accident. • Saving costs: The robotic solution has as a direct result the reduction of the corresponding workforce needed. This will result in a reduction in maintenance costs. • Equivalent quality to worker: The sealing of the cracks done by the robotic system have the equivalent quality to those sealed by the road worker.
Related Business Case	*Automation and robotisation of maintenance operations*

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1.3 Narrative of the Use Case

Short description – max 3 sentences
A robotic modular arm shall support road workers in the maintenance process of sealing cracks in surface pavement layers. For this process, a perception system that combines Artificial Vision and Artificial Intelligence is needed, which allows the robotic arm to locate and characterise (in terms of geometry) the cracks and generate the robot trajectory to track the width and length of the crack. Additionally, a specific tool shall be designed to: (1) apply hot air flow on the crack, so as to remove any material inside and prepare the surface for the sealing material and (2) apply sealing material.
Complete description

Road maintenance workers need support in the crack sealing processes, particularly in the direct application of bituminous mixes at high temperatures. The sealing of cracks in surface pavement layers is performed using a dedicated machine that heats up the sealing material. A robotic arm shall assume the operation of the pipes of the machine and the application of the sealing material over the cracks, minimizing the exposure of workers to the manipulation of the material and, hence, preventing accidents, like severe burns on workers.

Crack sealing is still a manual process that is performed using a dedicated machine. The full crack sealing process includes the following operations:

- Determination of the density of the cracks and delimitation and marking of the cracks to be treated.
- Cleaning the crack and heating its edges with a thermo-pneumatic lance.
- Hot application of the sealant in a small thickness, but not less than 3 mm, and in a constant width not less than 5 cm. This application will be carried out by displacement of a mechanical device along the crack, to achieve the formation of a watertight and continuous film between its edges.
- Application, with the product still hot, of a fine aggregate for its coverage and protection, to ensure the adherence of the tires and re-establishing the coefficient of friction. The occasional excess of aggregate must be removed from the road by sweeping or vacuuming before opening the repaired section to vehicle traffic.

The application of the fine aggregate is outside the scope of action of the robot arm, since this process is not necessary in all cases, and is usually carried out later.

The robotic modular platform is composed of a robotic arm, a perception module and a specific tool that combines the application of hot air flow and sealing material. The robot arm is mounted on a

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trailer that can be easily hooked up to the back of a vehicle (e.g., a truck) that carries the sealing machine, as shown in Figure 1.

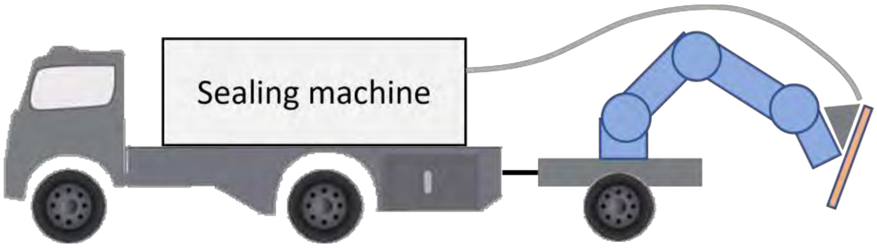

Figure 1 Robotic solution for crack sealing

The robot arm shall perform the blowing and sealing of cracks while the vehicle is stopped. Once the process is finished within the field of action of the arm, the vehicle shall slowly move a distance equivalent to the reach of the robot arm and repeat the process. The blowing and sealing tool shall be oriented towards the direction of travel of the vehicle, to ensure that material is not expelled into previously sealed areas.

A web-based VR platform is used to facilitate the teleoperation of the robotic arm, from a remote and safe environment (i.e., the vehicle cabin), to position the robot end-effector over the crack. Then, a perception system that combines Artificial Vision and Artificial Intelligence is needed, which allows the robotic arm to locate and characterise the cracks, using a vision camera mounted on the flange.

The sealing machine used for heating and melting the mastic is shown in Figure 2.

Figure 2 Sealing machine for heating and melting the mastic

A design concept of the specific tool that combines the heating, blowing and injection of mastic in a single solution is shown in Figure 3.

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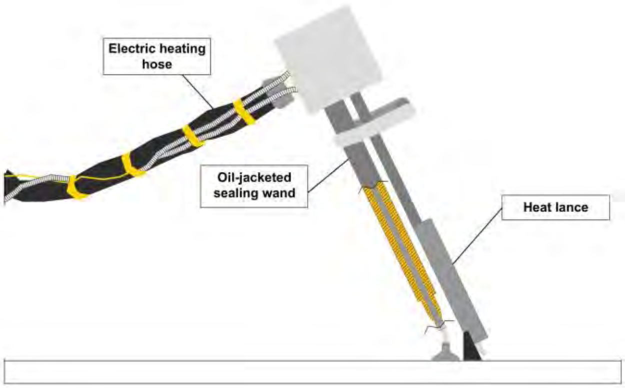

Figure 3 Design concept of specific tool for heating, blowing and injecting mastic

1.4 KPIs

ID	Name	Description	Target	Reference to mentioned Use Case objectives
KPI3	Volume of people in dangerous zones in road maintenance areas	The use of the robotic platform will allow that only the driver and the supervisor are present during the maintenance tasks	Reduction of the number of people in dangerous zones in maintenance areas by 75%	Operator safety
KPI9	Maintenance and inspection activity costs	The use of a modular robotic platform shall reduce the workforce needed for the crack sealing process	The enhancement in inspection and intervention tasks in OMICRON will reduce costs by 13%	Saving costs

1.5 Use Case Conditions

Actor	Triggering Event	Pre-conditions	Assumption
Describe which Actor(s) trigger(s)	Describe what event(s) trigger(s)	Describe what condition(s) should have been met	Describe the assumptions about conditions or system

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this Use Case	this Use Case	before this Use Case happens	configurations.
Road administration	The road administration contacts the road workers to notify that they need to provide a crack sealing service	Cracks on the road have been identified and located (at kilometre point level).	• The vehicle has enough fuel • The system works properly, including: ○ Robot arm ○ Camera ○ VR headset

1.6 Classification Information

Relation to Other Use Cases in the same project or area
UC2.1 Robotic Modular Platform UC2.1.1 Installation of safety barriers UC2.1.2 Installation of cones UC2.1.3 Road assets cleaning UC3.1 Signalling during construction works UC3.3 Removal of lane markings with laser
Level of Depth - the degree of specialization of the Use Case
Detailed Use Case
Further Keywords for Classification
Modular robotic arm, sealing of surface pavement cracks, automatic detection of cracks, automatic application of sealing material
Maturity of Use Case
Realized in R&D

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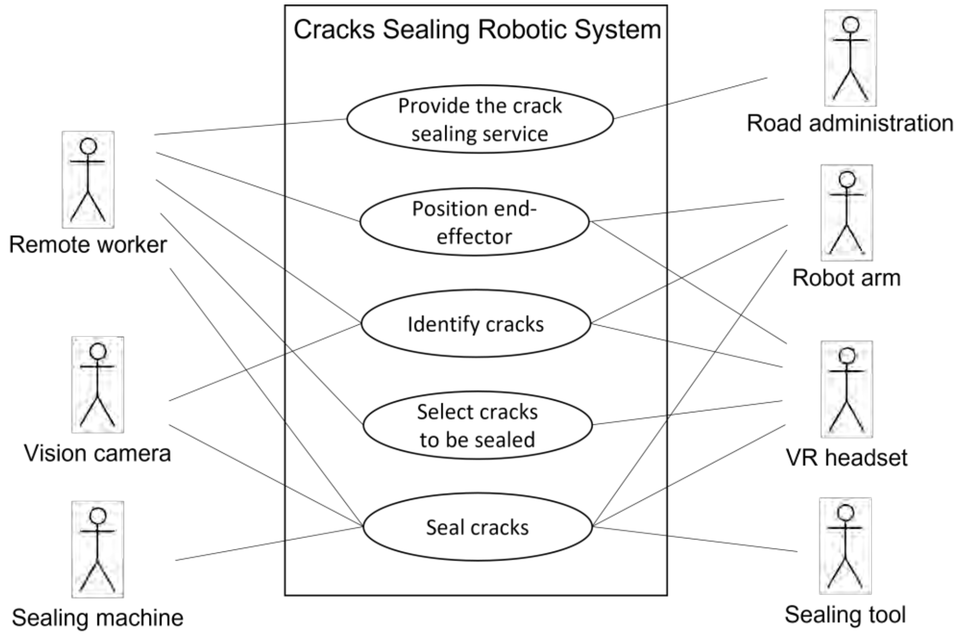
2 Diagrams of the Use Case

Context Diagram



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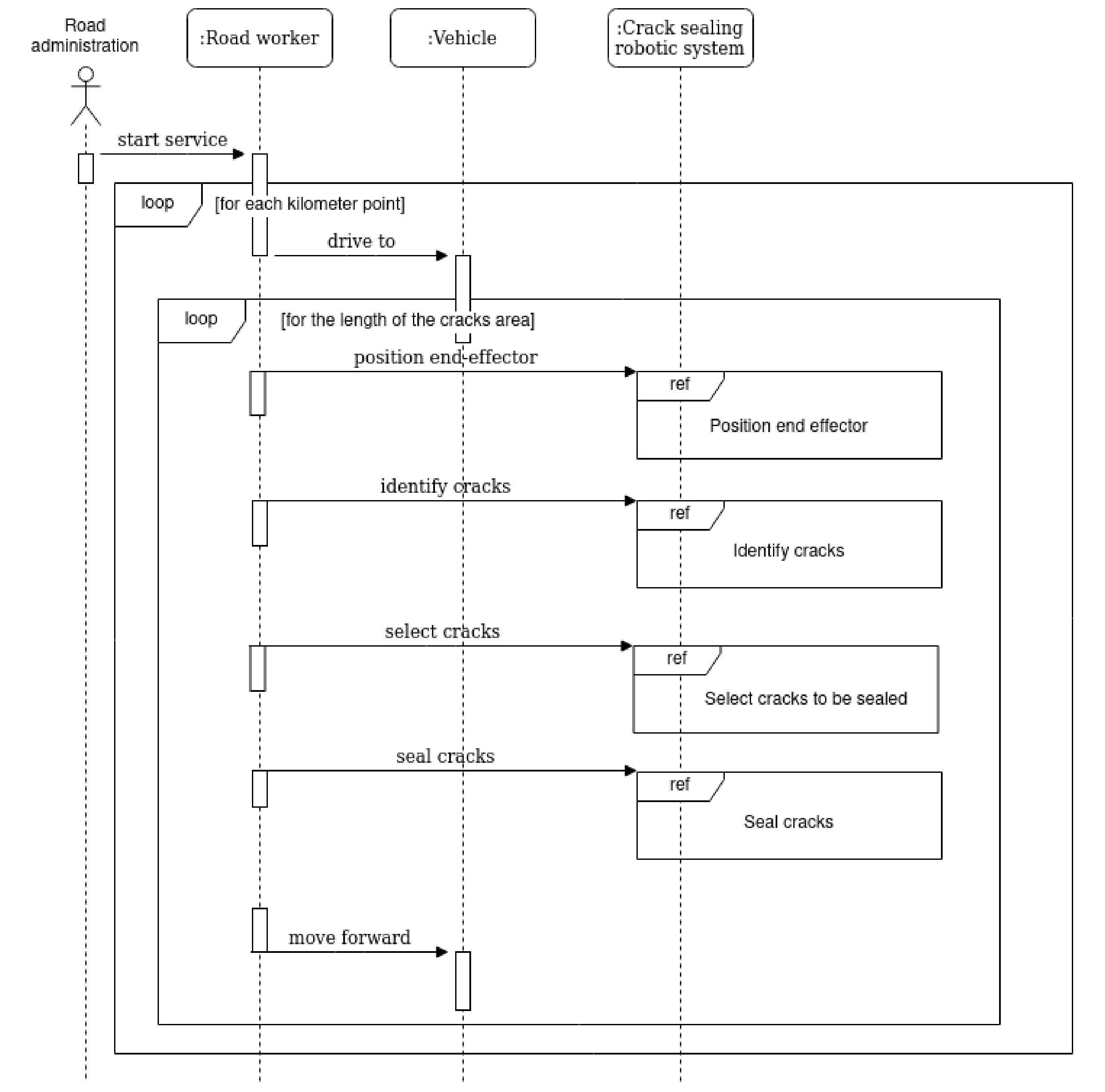
Sequence Diagram: Provide the crack sealing service



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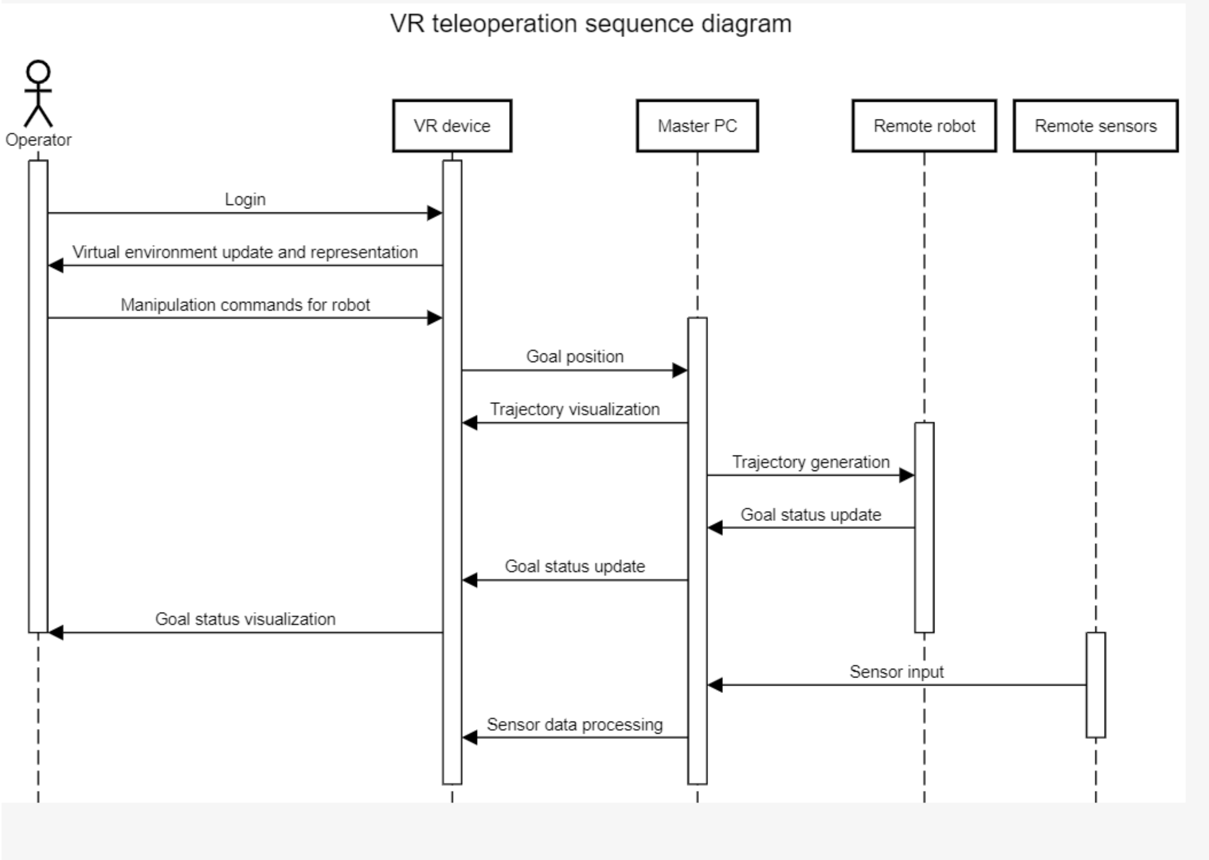
Sequence Diagram: Position end-effector



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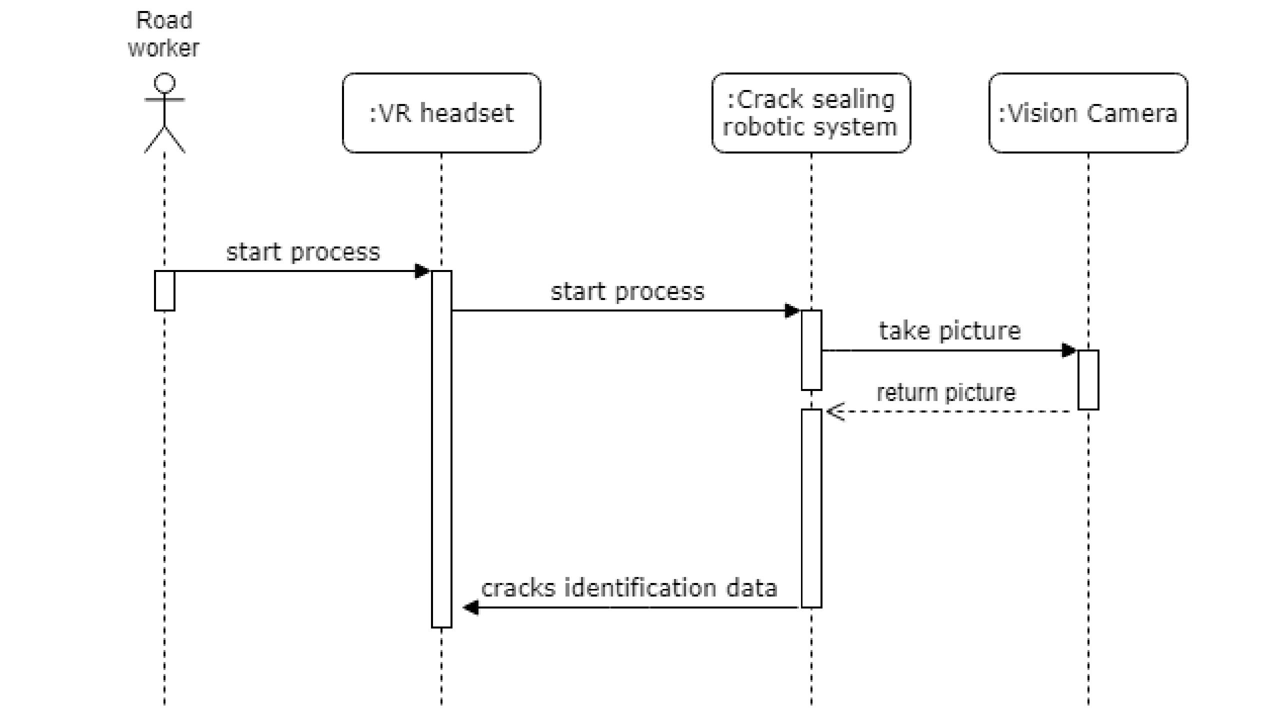
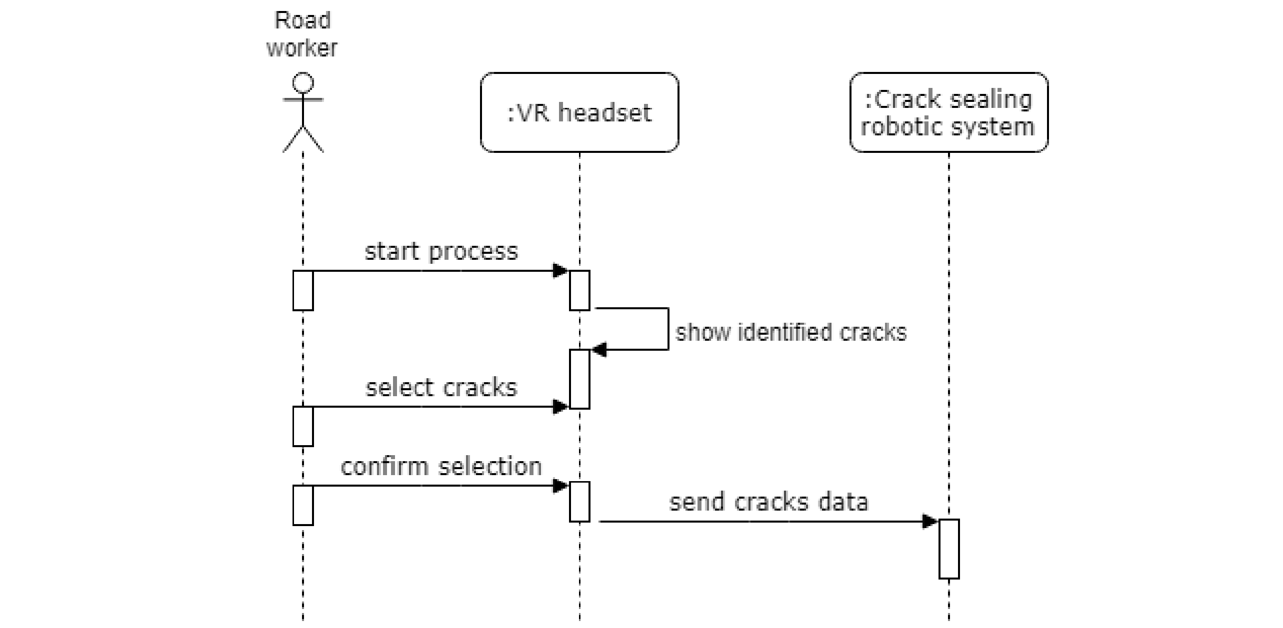
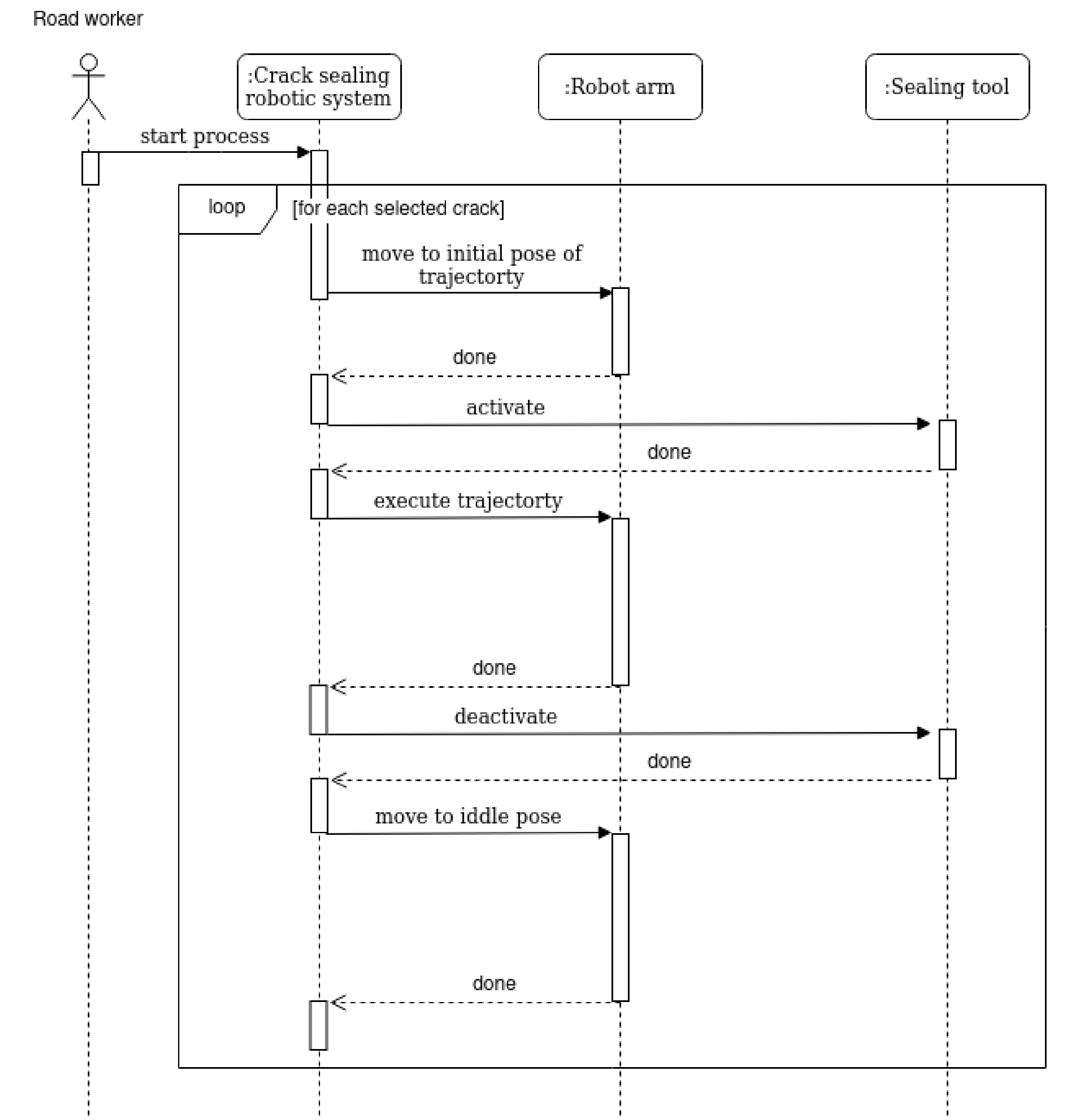
Sequence Diagram: Identify cracks



Sequence Diagram: Select cracks to be sealed



Sequence Diagram: Seal cracks



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3 Technical details of the Use Case - Actors

Actor Name	Actor Type	Actor Subcategories	Actor description	Further information specific to this Use Case	Equipment Manufacturer	Requirement(s) of the actor	Reference Standards/Legislation
Road administration	Role	Road contractor	The administration that notifies the road workers to perform a crack sealing service	The administration manages roads inspection data and, based on that, decides when a crack sealing service need to be started.		Shall have knowledge of the roads and service resources	
Remote worker	Role	Road contractor	The operator that performs the task of sealing the cracks, from the vehicle cabin, using the VR platform	The operator directly uses the crack sealing robotic system to start/stop the system and to select the cracks to be sealed. Operator uses real -time feedback to be aware of the environment and uses modelled kinematics in VE in order to manipulate robotic resources remotely		Shall have knowledge of VR operations Shall have possession of VR device Shall have a virtual environment constructed	
VR Headset	System	Interactive communication device	The VR headset used by the Remote Operator	The operator uses the headset to facilitate the remote operation of the robotic arm to position it over the track	e.g Oculus, Vive		UL 8400, IEEE P2048
Vehicle	System	Road machinery	The vehicle that carries the sealing machinery and the robotic system	The vehicle houses a generator set, a compressor, the sealing machine, the sealing material, and the robotic system.		Shall contain enough space to house a generator set, a compressor, the sealing machine, and the sealing material.	

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Actor Name	Actor Type	Actor Subcategories	Actor description	Further information specific to this Use Case	Equipment Manufacturer	Requirement(s) of the actor	Reference Standards/Legislation
						Shall be able to support the weight of a generator set, a compressor, the sealing machine and the sealing material. Shall be able to move at a very slow speed.	
Sealing machine	System	Road machinery	The asphalt crack sealing machine	The sealing machine heats up the bituminous mixes to high temperatures.			
Vision camera	System	Robotic element	RGB-D camera for road perception	The camera is mounted on the robot arm to take images of the road that will serve as input to the system to identify cracks	e.g., Intel Realsense 435D	Shall be able to operate under low light conditions (night operations) Shall provide a Field of View to cover the crack detection area.	
Robot arm	System	Robotic element	An anthropomorphic industrial robotic arm	The robot arm will operate the specific tool and apply the bitumen over the crack.	e.g., Kuka, ABB Universal Robots	At least 6 degrees of freedom. The reach of the robot arm shall cover the width of one lane. The robotic end-effector shall accommodate small positioning errors to ensure a proper contact between the sealing tool and the pavement surface.	ISO 10218, ISO12100, ISO 13849.

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Actor Name	Actor Type	Actor Subcategories	Actor description	Further information specific to this Use Case	Equipment Manufacturer	Requirement(s) of the actor	Reference Standards/Legislation
Sealing tool	System	Road machinery	A tool that combines the application of hot air flow and sealing material	The sealing tool is mounted on the robotic arm flange and is operated by the robotic arm		Shall allow to activate/deactivate blowing and injection of mastic separately.	ISO 20218

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4 Step by Step Analysis of the Use Case

4.1 List of scenarios

S.No	Scenario Name	Scenario Description	Primary Actor	Triggering Event	Pre-Condition	Post-Condition
PS1	Provide the crack sealing service	The road administration notifies the road workers that a crack sealing service need to be started. The road administration provides a set of the kilometre points where there are cracks that need to be sealed. Then, the road workers drive to the first kilometre point in the list. When they arrive, they stop at the beginning of the cracks. After that, the road worker positions the end-effector of the robotic arm (cf. Position end-effector use case). Once positioned, the road worker starts the crack identification (cf. Identify cracks use case). When the cracks are identified, the road worker selects manually the cracks to be sealed (cf. Select cracks to be sealed use case). Then, the road worker starts the crack sealing process (cf. Seal cracks use case). Once, finished the sealing, the road worker moves forward a small distance using the vehicle to repeat the process again until the crack area is covered. This process is repeated for all the kilometre points where cracks need to be sealed.	Road administration	Road administration notifies the start of the service	Cracks on the road have been identified and located (at kilometre point level).	All the cracks are sealed.
PS2	Position end-effector	The remote operator uses a web-based VR platform to position the robotic arm end-effector over the crack. The web-based VR platform allows remote operator to teleoperate the robotic arm in real time. The remote operator receives a	VR Headset	Road operator starts the positioning manoeuvre	The crack area is inside the working envelope of the robot.	The robot end-effector is positioned over the crack and the crack is in the field of view of the vision camera.

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S.No	Scenario Name	Scenario Description	Primary Actor	Triggering Event	Pre-Condition	Post-Condition
		video stream from the vision camera, facilitating the remote operation.				
PS3	Identify cracks	The road worker uses the display of the VR headset to manually start the crack identification process. Therefore, a vision camera provides data for the crack sealing robotic system for identifying and characterising the cracks. After this identification and characterisation, the information is sent to the VR headset to be shown to the road worker.	Vision camera	Road worker starts the crack identification process	The robotic arm end-effector is positioned over the crack. The vision camera and the VR headset are connected with the crack sealing robotic system.	The road worker has received the data of the crack identification and characterisation.
PS4	Select cracks to be sealed	The VR headset shows visually the identified cracks. The road worker uses the VR headset to manually select the cracks that will be sealed by the cracks sealing robotics system. Then the worker confirms the selection, and the cracks sealing robotics system receives the data.	VR headset	Road worker starts the selection process	Crack identification and characterisation information is in the VR display due to the previous execution of the crack identification process.	The crack sealing system has received the selected cracks data.
PS5	Seal cracks	The road worker uses the VR headset to manually start the cracks sealing process. Therefore, the crack identification and characterisation data are used by the cracks sealing robotics system to calculate the trajectory that the robot arm needs to execute. Then, the robot arm is positioned at the beginning of the trajectory. After this point, the crack sealing robotics system activates the tool to start applying hot air flow and sealing material. The robot arm will then execute the trajectory with a given constant speed. When the trajectory finishes, the crack sealing robotics	Robot arm	Road worker starts the crack sealing process	The crack sealing system has the selected cracks information.	The cracks are sealed.

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S.No	Scenario Name	Scenario Description	Primary Actor	Triggering Event	Pre-Condition	Post-Condition
		system deactivates the tool. This process is repeated for each crack that must be sealed.				
AS1	The road administration provides a set of incorrect kilometre points	The road worker reaches the kilometre point according to the information supplied by the road administration, but there are no cracks in the place.	Road worker	The worker drives to the kilometre point.	The kilometre point was wrongly communicated.	The road workers get the right position.
AS2	The crack area is not inside the working envelope of the robot.	The robot arm is not closed enough to the area of the crack to perform the crack detection and sealing operations	Robot arm	The worker drives to the crack area	The vehicle and trail are not placed close enough to the crack area	The robot arm can reach the crack area
AS3	The vision system fails identifying cracks	The cracks sealing robotic system does not recognize the cracks	Crack sealing robotic system	The Deep Learning system does not recognise the asset	The picture quality is bad (illumination, blur, perspective)	The crack is identified and characterised by the robotic system
AS4	The trajectory calculated by the robot is incorrect	The cracks sealing robotic system fails calculating a correct trajectory for the crack	Crack sealing robotic system	The robot system fails calculating a correct trajectory		The trajectory is manually defined by the remote worker
AS5	The sealant mastic does not come out	The sealant mastic has solidified on the tool tip and does not come out.	Remote worker	The remote worker realises that it does not come out	The sealant mastic has solidified due to a loss of temperature	The sealant mastic comes out and process is restarted
AS6	The crack is not completely filled	Some part of the crack is not completely filled by the mastic.	Remote worker	The remote worker realises that some part of the crack is not completely filled	The crack was quite deep in some part or trajectory was executed too fast.	The crack is completely filled

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4.2 Steps - Primary Scenario

Scenario Name: PS1.Provide the crack sealing service									
St No.	**Event**	**Description of Process/Activity**	**Information Producer**	**Information Receiver**	**Information Exchanged**	**Service**	**Requirements**	**Communication Media**	**Communication Means**
PS1.1	The road administration notifies the road worker	The road administration calls the road workers to notify that they need to provide a crack sealing service	Road administration	Road worker	I-01	REPORT		Phone call	Voice
PS1.2	The road worker drives to kilometre point	The road worker drives the vehicle to the kilometre point where cracks need to be sealed	Road worker	Vehicle					
PS1.3	The road worker positions the end-effector	(cf. PS2)							
PS1.4	The road worker starts the crack identification	(cf. PS3)							
PS1.5	The road worker selects the cracks	(cf. PS4)							

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Scenario Name: PS1.Provide the crack sealing service									
St No.	**Event**	**Description of Process/Activity**	**Information Producer**	**Information Receiver**	**Information Exchanged**	**Service**	**Requirements**	**Communication Media**	**Communication Means**
PS1.6	The road worker starts the crack sealing process	(cf. PS5)							
PS1.7	The road worker moves forward the vehicle	The road worker drives the vehicle to move forward a little bit to continue the sealing of cracks	Road worker	Vehicle					
PS1.8	cracks are sealed	Previous steps are repeated until all cracks in the area are sealed				REPEAT (3-7)			
PS1.9	All kilometre points are covered	Previous steps are repeated until all provided Kilometre points are covered				REPEAT (2-8)			

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Scenario Name: PS2.Position end-effector									
St No.	**Event**	**Description of Process/Activity**	**Information Producer**	**Information Receiver**	**Information Exchanged**	**Service**	**Requirements**	**Communication Media**	**Communication Means**
PS2.1	Feedback for the event is provided to the remote operator	Real-time data feedback is presented to the Operator	Remote sensors and communications	Virtual Device	I-02	GET	Data Management,	Web-based	protocol, e.g. TCP/IP
PS2.2	Successful	Manipulation commands sent from the operator to the PC that solves the kinematics	Virtual Device	Master PC	I-10	CHANGE	Configuration, Constrains or other issues	Web-based	protocol, e.g. TCP/IP
PS2.3	Successful	Movement goal sent to robotic resources	Master PC	Remote robotic resources	I-10	CHANGE	Configuration, Constrains or other issues	Web-based	protocol, e.g. TCP/IP
PS2.4	Successful	Robotic resource completes movement and sends result back to VR headset	Remote robotic resources	Remote Resources	I-04	GET	Configuration, Constrains or other issues	Web-based	protocol, e.g. TCP/IP

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Scenario Name: PS3.Identify cracks									
St No.	**Event**	**Description of Process/Activity**	**Information Producer**	**Information Receiver**	**Information Exchanged**	**Service**	**Requirements**	**Communication Media**	**Communication Means**
PS3.1	The road worker starts the process	The road worker uses the VR Headset to push the start process button. The display sends a signal to the crack sealing robotic system.	VR Headset	Crack sealing robotic system	I-05	REPORT		Ethernet	GUI
PS3.2	Crack sealing robotic system is notified	After receiving a signal from VR Headset, the crack sealing robotic system requests an image from the vision camera.	Crack sealing robotic system	Vision camera	I-06	GET		Ethernet	protocol
PS3.3	Vision Camera is addressed	The vision camera takes a picture. The data is sent to the crack sealing robotic system.	Vision camera	Crack sealing robotic system	I-07	GET		Ethernet	Protocol
PS3.4	Crack sealing robotic system receives picture data	The crack sealing robotic system receives the picture data from the vision camera. Based on this, a traditional computer vision and Deep Learning methods are applied to identify and characterise cracks in the picture.	Crack sealing robotic system	Crack sealing robotic system	I-07	CREATE			
PS3.5	Cracks have been identified and characterised	The crack sealing robotic system sends the cracks identification and characterisation data that will be shown to the road worker in the display.	Crack sealing robotic system	VR Headset	I-08	CHANGE		Wifi	Protocol

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Scenario Name: PS3.Identify cracks									
St No.	**Event**	**Description of Process/Activity**	**Information Producer**	**Information Receiver**	**Information Exchanged**	**Service**	**Requirements**	**Communication Media**	**Communication Means**
PS3.6	Display receives cracks identification and characterisation data	The VR Headset shows to the road worker the information of the cracks	VR Headset	VR Headset	I-08	REPORT			

Scenario Name: PS4.Select cracks to be sealed									
St No.	**Event**	**Description of Process/Activity**	**Information Producer**	**Information Receiver**	**Information Exchanged**	**Service**	**Requirements**	**Communication Media**	**Communication Means**
PS4.1	The road worker manually starts the selection process.	The road worker pushes a button on the VR Headset display that starts the crack selection process. After that the VR headset shows the identified cracks	VR Headset	VR Headset		CREATE			GUI
PS4.2	The road worker finishes selecting all the cracks to be filled	The road worker selects from the VR headset the cracks that want to be sealed by the crack sealing robotic system. After that, the road worker pushes the proceed button and the information is sent to the crack sealing robotic system	VR Headset	Crack sealing robotic system	I-09	CREATE		Ethernet	GUI

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Scenario Name: PS4.Select cracks to be sealed									
St No.	**Event**	**Description of Process/Activity**	**Information Producer**	**Information Receiver**	**Information Exchanged**	**Service**	**Requirements**	**Communication Media**	**Communication Means**
PS4.3	Crack sealing robotic system receives the data	The crack sealing robotic system seals the specified cracks using the robotic arm with the sealing tool (this process is described in another use case).	Crack sealing robotic system	Crack sealing robotic system	I-09	EXECUTE			

Scenario Name: PS5.Seal cracks									
St No.	**Event**	**Description of Process/Activity**	**Information Producer**	**Information Receiver**	**Information Exchanged**	**Service**	**Requirements**	**Communication Media**	**Communication Means**
PS5.1	Crack sealing robotic system is notified	After receiving a signal with selected cracks data from the VR headset, the crack sealing robotic system calculates the trajectory for the robot to follow a crack.	Crack sealing robotic system	Crack sealing robotic system	I-10	CREATE			
PS5.2	Trajectory is calculated	The crack sealing robotic system sends a signal to the robotic arm to move to the initial pose of the calculated trajectory.	Crack sealing robotic system	Robot Arm	I-03	CHANGE		Ethernet	Protocol
PS5.3	Robot arm is notified	The robot arm positions the sealing tool in the initial pose of the calculated trajectory.	Robot Arm	Robot Arm	I-03	EXECUTE			

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Scenario Name: PS5.Seal cracks									
St No.	Event	Description of Process/Activity	Information Producer	Information Receiver	Information Exchanged	Service	Requirements	Communication Media	Communication Means
PS5.4	Robot motion is finished	The robot arm sends a signal to the crack sealing robotic system.	Robot Arm	Crack sealing robotic system	I-04	GET		Ethernet	Protocol
PS5.5	Crack sealing robotic system has the signal	The crack sealing robotic system sends a signal to the sealing tool to activate.	Crack sealing robotic system	Sealing tool	I-11	CHANGE		Ethernet	Protocol
PS5.6	Sealing tool is addressed	The sealing tool switches on	Sealing tool	Sealing tool	I-11	EXECUTE			
PS5.7	Sealing tool is on	The sealing tool sends a signal to the crack sealing robotic system.	Sealing tool	Crack sealing robotic system	I-12	GET		Ethernet	Protocol
PS5.8	Crack sealing robotic system has the signal	The crack sealing robotic system sends a signal to the robot arm to execute the trajectory motion.	Crack sealing robotic system	Robot arm	I-10	CHANGE		Ethernet	Protocol
PS5.9	Robot arm is addressed	The robot arm executes the trajectory motion	Robot arm	Robot arm	I-10	EXECUTE			
PS5.10	Robot motion is finished	The robot arm sends a signal to the crack sealing robotic system.	Robot Arm	Crack sealing robotic system	I-04	GET		Ethernet	Protocol

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Scenario Name: PS5.Seal cracks									
St No.	**Event**	**Description of Process/Activity**	**Information Producer**	**Information Receiver**	**Information Exchanged**	**Service**	**Requirements**	**Communication Media**	**Communication Means**
PS5.11	Crack sealing robotic system has the signal	The crack sealing robotic system sends a signal to the sealing tool to deactivate.	Crack sealing robotic system	Sealing tool	I-11	CHANGE		Ethernet	Protocol
PS5.12	Sealing tool is addressed	The sealing tool switches off	Sealing tool	Sealing tool	I-11	EXECUTE			
PS5.13	Sealing tool is off	The sealing tool sends a signal to the crack sealing robotic system.	Sealing tool	Crack sealing robotic system	I-12	GET		Ethernet	Protocol
PS5.14	Crack sealing robotic system has the signal	The crack sealing robotic system sends a signal to the robot arm to move to the idle position	Crack sealing robotic system	Robot arm	I-03	CHANGE		Ethernet	Protocol
PS5.15	Robot arm is addressed	The robot arm moves to the idle position	Robot arm	Robot arm	I-03	EXECUTE			
PS5.16	Robot motion is finished	The robot arm sends a signal to the crack sealing robotic system.	Robot Arm	Crack sealing robotic system	I-04	GET		Ethernet	Protocol
PS5.17	All cracks are sealed	Previous steps are repeated until all cracks are sealed				REPEAT (2-16)			

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4.3 Steps – Alternative, Error Management, and/or Maintenance/Backup Scenario

Scenario Name: AS1. The road administration provides a set of incorrect kilometre points									
St No.	Event	Description of Process/Activity	Information Producer	Information Receiver	Information Exchanged	Service	Requirements	Communication Media	Communication Means
AS1.1	Kilometre point is incorrect.	The road workers notices that the kilometre point is incorrect. Therefore, they contact to road administration to get the right position.	Road administration	Road worker	I-01	CHANGE		Phone	Voice

Scenario Name: AS2. The crack area is not inside the working envelope of the robot.									
St No.	Event	Description of Process/Activity	Information Producer	Information Receiver	Information Exchanged	Service	Requirements	Communication Media	Communication Means
AS2.1	The crack area is not reachable by the robot	The robot arm is not able to perform the motion since it is outside its reach	Robot Arm	Robotic system		CREATE		Ethernet	Protocol
AS2.2	The remote worker indicates thru the VR headset that the sealing process must be stopped.	The road worker uses the VR headset to stop the process	Remote worker	VR headset		EXECUTE		Gesture	GUI
AS2.3	The VR headset sends to the robotic	The robotic system stops the task of sealing cracks and sends the order to stop the robotic	VR headset	Robotic system	I-05	EXECUTE		Wi-Fi	Protocol

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Scenario Name: AS2. The crack area is not inside the working envelope of the robot.									
St No.	**Event**	**Description of Process/Activity**	**Information Producer**	**Information Receiver**	**Information Exchanged**	**Service**	**Requirements**	**Communication Media**	**Communication Means**
	system the order to stop the process	arm. Perception system is not stopped.							
AS2.4	The robotic system sends the order to stop the task to the robot arm	The robot arm stops its movement	Robotic system	Robot arm	I-03	CANCEL		Ethernet	Protocol
AS2.5	Robot motion is stopped	The robot arm sends a signal to the robotic system.	Robot Arm	Crack sealing robotic system	I-04	GET		Ethernet	Protocol
AS2.6	Remote worker notifies the road worker to move the vehicle	The road worker drives the vehicle to position closer to the crack area	Road worker	Vehicle					
AS2.7	The remote worker requests to resume the task	The VR headset sends the confirmation to resume the task.	Road worker	VR headset		CHANGE		Gesture	GUI
AS2.8	The VR headset sends the order to resume the task	The display sends the message to resume the task. The road sealing robotic system is ready to carry out the next task.	Display	robotic system	I-05	CHANGE		Wi-Fi	Protocol

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Scenario Name: AS3. The vision system fails identifying cracks									
St No.	**Event**	**Description of Process/Activity**	**Information Producer**	**Information Receiver**	**Information Exchanged**	**Service**	**Requirements**	**Communication Media**	**Communication Means**
AS3.1	The vision system fails identifying cracks	The cracks sealing robotic system does not recognize the cracks	Robotic system	VR headset		CHANGE		Wi-Fi	GUI
AS3.2	The display shows the picture	The VR headset shows the picture in which the crack could not be automatically detected	VR headset	Remote worker		EXECUTE		Wi-Fi	GUI
AS3.3	The crack is manually identified by the remote worker	The remote worker selects in the picture the area in which the crack is	Remote worker	VR headset		EXECUTE		Gesture	GUI
AS3.4	The system restarts the process	The VR headset sends the confirmation of the crack and the order to start the system	VR headset	Robotic system		EXECUTE		Wi-Fi	Protocol

Scenario Name: AS4. The trajectory calculated by the robot is incorrect									
St No.	**Event**	**Description of Process/Activity**	**Information Producer**	**Information Receiver**	**Information Exchanged**	**Service**	**Requirements**	**Communication Media**	**Communication Means**
AS4.1	The trajectory calculated by the robot is incorrect	The robotic system fails calculating a correct trajectory for the crack	Robotic System	VR headset				Wi-Fi	GUI

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Scenario Name: AS4. The trajectory calculated by the robot is incorrect									
St No.	Event	Description of Process/Activity	Information Producer	Information Receiver	Information Exchanged	Service	Requirements	Communication Media	Communication Means
AS4.2	The display shows the picture	The VR headset shows the picture in which the crack could not be automatically detected	VR headset	Remote worker		EXECUTE		Wi-Fi	GUI
AS4.3	The trajectory is manually defined by the remote worker	The remote worker uses the picture of the area in which the crack is to define a trajectory as a set of points that the robot need to follow	Remote worker	VR headset		EXECUTE		Gesture	GUI
AS4.4	The system restarts the process	The VR headset sends the confirmation of the trajectory and the order to start the system	VR headset	Robotic system		EXECUTE		Wi-Fi	Protocol

Scenario Name: AS5. The sealant mastic does not come out									
St No.	Event	Description of Process/Activity	Information Producer	Information Receiver	Information Exchanged	Service	Requirements	Communication Media	Communication Means
AS5.1	The sealant mastic does not come out	The sealant mastic has solidified on the tool tip and the remote worker realizes that it does not come out.	VR headset	Remote worker				Wi-Fi	Real time streaming video
AS5.2	The remote worker indicates thru the VR headset that	The road worker uses the VR headset to stop the process	Remote worker	VR headset		EXECUTE		Gesture	GUI

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Scenario Name: AS5. The sealant mastic does not come out									
St No.	**Event**	**Description of Process/Activity**	**Information Producer**	**Information Receiver**	**Information Exchanged**	**Service**	**Requirements**	**Communication Media**	**Communication Means**
	the sealing process must be stopped.								
AS5.3	The VR headset sends to the robotic system the order to stop the process	The robotic system stops the task of sealing cracks and sends the order to stop the robotic arm. Perception system is not stopped.	VR headset	Robotic system	I-05	EXECUTE		Wi-Fi	Protocol
AS5.4	The robotic system sends the order to stop the task to the robot arm	The robot arm stops its movement	Robotic system	Robot arm	I-03	CANCEL		Ethernet	Protocol
AS5.5	Robot motion is stopped	The robot arm sends a signal to the robotic system.	Robot Arm	Crack sealing robotic system	I-04	GET		Ethernet	Protocol
AS5.6	The road worker removes mastic cap	The road worker accesses the robot tool to unblock the lance.	Road worker	Sealing tool		EXECUTE			

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Scenario Name: AS5. The sealant mastic does not come out									
St No.	**Event**	**Description of Process/Activity**	**Information Producer**	**Information Receiver**	**Information Exchanged**	**Service**	**Requirements**	**Communication Media**	**Communication Means**
AS5.4	The system restarts the process	The VR headset sends the confirmation of the trajectory and the order to start the system	VR headset	Robotic system		EXECUTE		Wi-Fi	Protocol

Scenario Name: AS6. The crack is not completely filled									
St No.	**Event**	**Description of Process/Activity**	**Information Producer**	**Information Receiver**	**Information Exchanged**	**Service**	**Requirements**	**Communication Media**	**Communication Means**
AS6.1	The crack is not completely filled	The remote worker realises that some part of the crack is not completely filled by the mastic.	VR headset	Remote worker		GET		Wi-Fi	Real time streaming video
AS6.2	The remote worker indicates through the VR headset that the sealing process must be stopped.	The road worker uses the VR headset to stop the process	Remote worker	VR headset		EXECUTE		Gesture	GUI
AS6.3	The VR headset sends to the robotic system the order to stop the process	The robotic system stops the task of sealing cracks and sends the order to stop the robotic arm. Perception system is not stopped.	VR headset	Robotic system	I-05	EXECUTE		Wi-Fi	Protocol

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Scenario Name: AS6. The crack is not completely filled									
St No.	**Event**	**Description of Process/Activity**	**Information Producer**	**Information Receiver**	**Information Exchanged**	**Service**	**Requirements**	**Communication Media**	**Communication Means**
AS6.4	The robotic system sends the order to stop the task to the robot arm	The robot arm stops its movement	Robotic system	Robot arm	I-03	CANCEL		Ethernet	Protocol
AS6.5	Robot motion is stopped	The robot arm sends a signal to the robotic system.	Robot Arm	Crack sealing robotic system	I-04	GET		Ethernet	Protocol
AS6.6	The remote worker indicates through the VR headset to execute the trajectory in reverse mode	The road worker uses the VR headset to notify the system to execute the trajectory in reverse mode	Remote worker	VR headset		EXECUTE		Gesture	GUI
AS6.7	The VR headset sends to the robotic system the order to execute trajectory	The robotic system sends the order to the robotic arm to execute trajectory.	VR headset	Robotic system	I-05	EXECUTE		Wi-Fi	Protocol
AS6.8	The robotic system sends the order to execute trajectory to the robot arm	The robot arm executes the trajectory	Robotic system	Robot arm	I-03	EXECUTE		Ethernet	Protocol
AS6.9	Robot motion is finished	The robot arm sends a signal to the robotic system.	Robot Arm	Crack sealing robotic system	I-04	GET		Ethernet	Protocol

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Scenario Name: AS6. The crack is not completely filled									
St No.	Event	Description of Process/Activity	Information Producer	Information Receiver	Information Exchanged	Service	Requirements	Communication Media	Communication Means
AS6.10	The crack is completely filled	The remote worker realises that the crack is completely filled by the mastic.	VR headset	Remote worker		GET		Wi-Fi	Real time streaming video

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5 Information Exchanged

Inf. ID	Name of information exchanged	Description of information exchanged	Information Subcategories	Requirements
I-01	Kilometer points data	The road administration provides a set of kilometer points codes where there are cracks to be filled	Network state	
I-02	Data stream (visual)		Information exchanged between IS or sent to device	
I-03	Robot movement goal	The message contains the pose of the robot end-effector.	Information exchanged between IS or sent to device	
I-04	Result of movement operation	Message to signal that robot movement finished. It contains the result of the movement process.	Information exchanged between IS or sent to device	
I-05	Signal from the VR Headset	The V R Headset sends a signal to the crack sealing robotic system to notify that the sealing process must start or stop. The signal is binary, i.e. only the values 0 and 1 exist (0 = start sealing, 1 = stop sealing).	Information exchanged between IS or sent to device	Correct communication establishment between VR headset and crack sealing robot
I-06	Signal from the Crack sealing robotic system for picture	The crack sealing robotic system sends a signal to vision camera to get a picture.	Information exchanged between IS or sent to device	
I-07	Picture data	The picture data contains RGB and depth values.	Information exchanged between IS or sent to device	
I-08	Cracks' information	Message containing the identification and characterisation data of all the cracks identified.	Information exchanged between IS or sent to device	

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Inf. ID	Name of information exchanged	Description of information exchanged	Information Subcategories	Requirements
I-09	Selected cracks' information	Message containing the identification and characterisation data of the cracks selected by the worker.	Information exchanged between IS or sent to device	
I-10	Robot movement trajectory	The message contains the trajectory for the robot to execute.	Information exchanged between IS or sent to device	
I-11	Signal from the crack sealing robotic system to the sealing tool	The signal specifies if the tool need to be activated or deactivated.	Information exchanged between IS or sent to device	
I-12	Signal from the sealing tool	Message to signal that sealing tool activation/deactivation process finished.	Information exchanged between IS or sent to device	

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OMI((RON

Intelligent Road Asset Management Platform

Removal of Lane Markings with Laser

Definition of Requirements

Publish Date: 2021.09.15

Use Case Number: UC3.3

Use Case Title: Removal of Lane Markings with Laser

Use Case Responsible Partner: PAVASAL

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1 Description of the Use Case

1.1 Use Case Identification

ID	Domain(s)	Name of Use Case	Level of Use Case
UC3.3	UC3: Large and extraordinary maintenance actions	Implementing a robotic system for the removal of lane markings with laser	Detailed Use Case

1.2 Scope and Objectives

Scope and Objectives of the Use Case	
Scope	A novel laser-based cleaning system shall be implemented for road marking removal. Currently available methods can create problems for motorists (scarring of the pavement, ghost stripes, etc.) OMICRON approach combines a vision system and the use of a modular robotic arm. All in all, it is expected that his solution should improve the quality of the cleaning process and reduce the corresponding workforce needed, resulting in a reduction in maintenance costs. Although the case is described considering all the necessary elements for an eventual industrial implementation, it will be provided as a proof of concept at laboratory scale in the framework of the project.
Objective	• Operator safety: The robotic system reduces the exposure of workers to laser radiation and to the impact of gaseous materials that are generated during the interaction, thereby reducing the probability of an accident. • Saving costs: The robotic solution has as a direct result the reduction of the corresponding workforce needed. This will result in a reduction in maintenance costs. • Equivalent or superior quality to worker: The laser removal by the robotic system has equivalent or superior quality than that provided by the road worker using current technologies.
Related Business Case	*Automation and robotisation of maintenance operations*

1.3 Narrative of the Use Case

Short description – max 3 sentences
A laser-based cleaning system is proposed as an alternative method to current road marking removal technologies. The approach relies on a robotic modular arm to mount the optical head, together with a perception system that combines Artificial Vision and Artificial Intelligence, which

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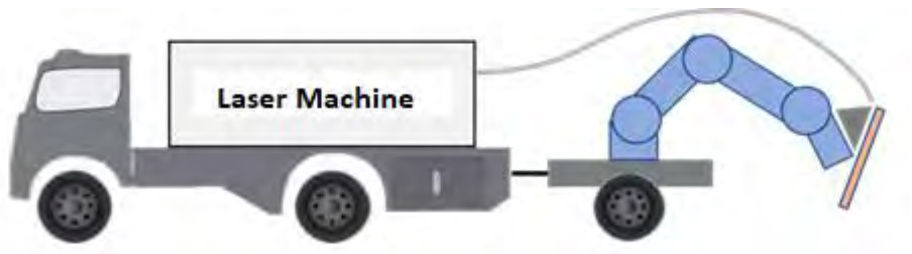
can detect the shape and size of the markings to be removed, as well as to generate the required trajectories and guide the robotised laser head.
Complete description
Temporary road markings are routinely used as a tool to redirect traffic, in the context of pavement reconstruction and improvement works. Once these works are completed, temporary markings must be removed. Due to the nature of the different technologies available for this task, it is not uncommon to have suboptimal results, in terms of the surface state of the pavement (colour, texture, markings) or incomplete removal, which can cause confusion among motorists when navigating these lanes. The potential danger of this situation is exacerbated under conditions of reduced visibility, such as night-time or with bad weather conditions. The robotic modular platform is composed of a robotic arm, a perception module, the laser head, and a suction unit to capture the generated debris. The robot arm is mounted on a trailer that can be easily hooked up to the back of a vehicle (e.g., a truck) that carries the laser generator and ancillary elements, as shown in Figure 1. Alternatively, the laser generator and robot can be mounted on a continuous track vehicle.  *Figure 1 Robotic solution for laser cleaning* The robot arm shall perform the laser cleaning while the vehicle is stopped. Once the process is finished, within the field of action of the arm and available field of view of the optical system, the vehicle shall slowly move a distance equivalent to the reach of the robot arm and repeat the process. A web-based VR platform is used to facilitate the teleoperation of the robotic arm, from a remote and safe environment (i.e., the vehicle cabin), to position the robot end-effector over the marking to be removed. Then, a perception system that combines Artificial Vision and Artificial Intelligence is needed, which allows the robotic arm to locate and characterise the marking (length, width, colour), using a vision camera mounted on the flange.

1.4 KPIs

ID	Name	Description	Target	Reference to mentioned Use Case objectives
KPI3	Volume of people in dangerous zones in road	The use of the robotic platform will allow that only the driver and the	Reduction of the number of people in dangerous zones in maintenance areas by	Operator safety

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	maintenance areas	supervisor are present during the maintenance tasks	90%	
KPI9	Maintenance and inspection activity costs	The use of a modular robotic platform shall reduce the workforce needed for marking removal	The enhancement tasks in OMICRON will reduce costs by 26%	Saving costs

1.5 Use Case Conditions

Actor	Triggering Event	Pre-conditions	Assumption
Describe which Actor(s) trigger(s) this Use Case	Describe what event(s) trigger(s) this Use Case	Describe what condition(s) should have been met before this Use Case happens	Describe the assumptions about conditions or system configurations.
Road administration	The road administration contacts the road workers to notify that they need to provide a marking cleaning service	Temporary works completed. Markings to be erased have been identified and located (at kilometre point level).	• The vehicle has enough fuel • The system works properly, including: ○ Robot arm ○ Laser source and head ○ Camera ○ VR headset

1.6 Classification Information

Relation to Other Use Cases in the same project or area
UC2.1 Robotic Modular Platform UC2.1.1 Installation of safety barriers UC2.1.2 Installation of cones UC2.1.3 Road assets cleaning UC3.1 Signalling during construction works UC3.2 Sealing of surface pavement cracks
Level of Depth - the degree of specialization of the Use Case

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Detailed Use Case
Further Keywords for Classification
Modular robotic arm, removal of lane markings with laser, automatic detection of lane markings
Maturity of Use Case
Realized in R&D

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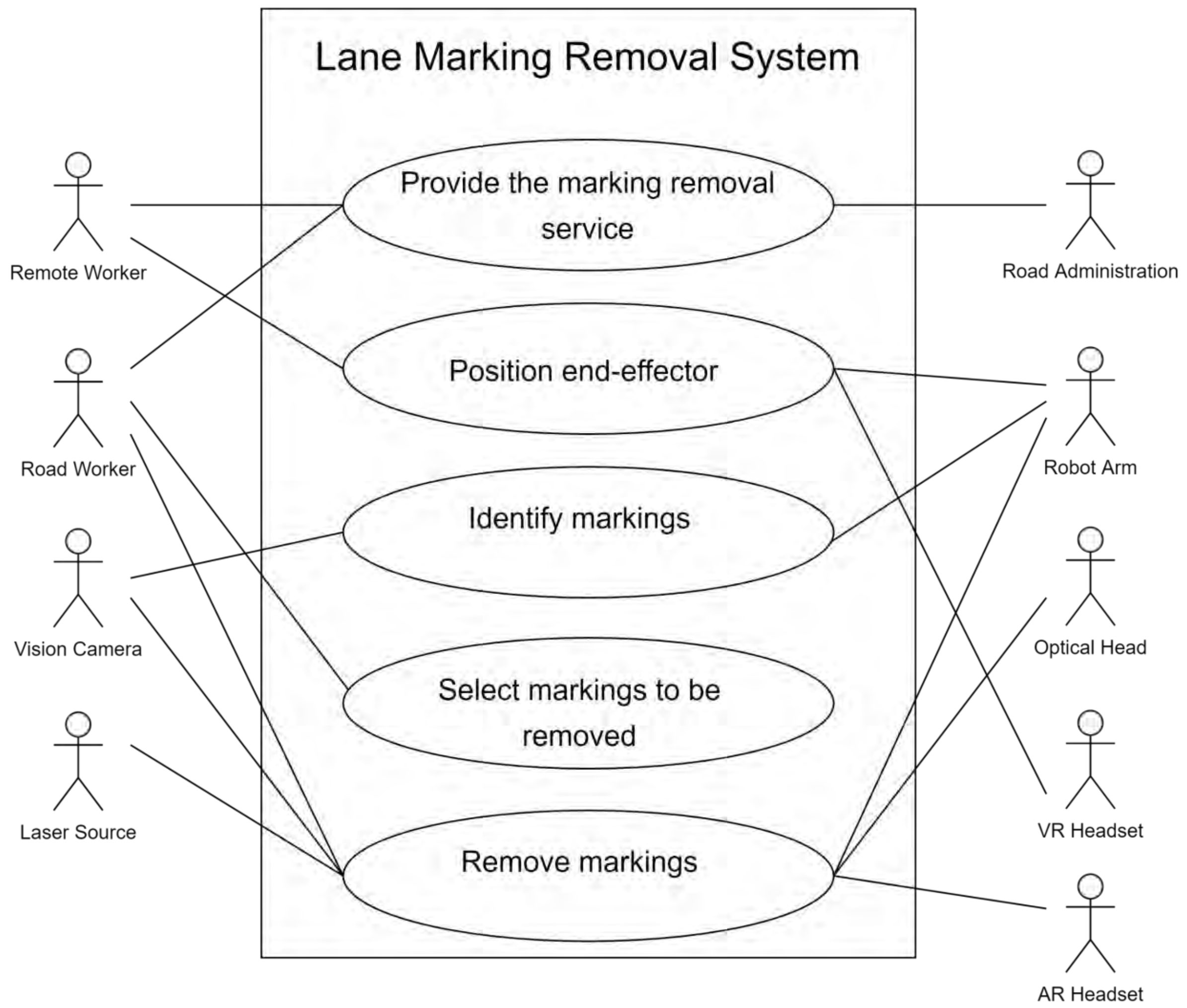
2 Diagrams of the Use Case

Context Diagram



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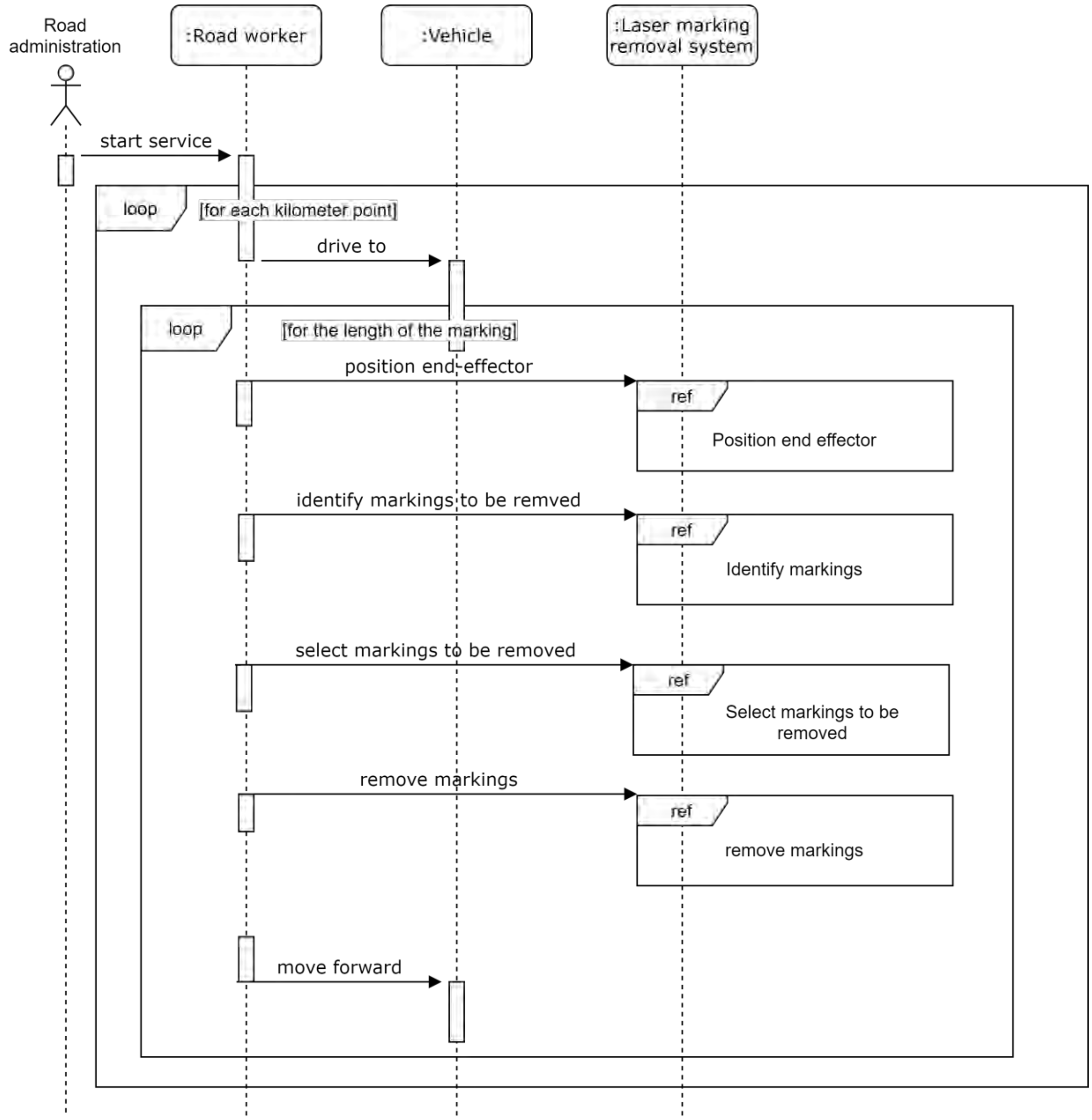
Sequence Diagram: Provide the marking cleaning service



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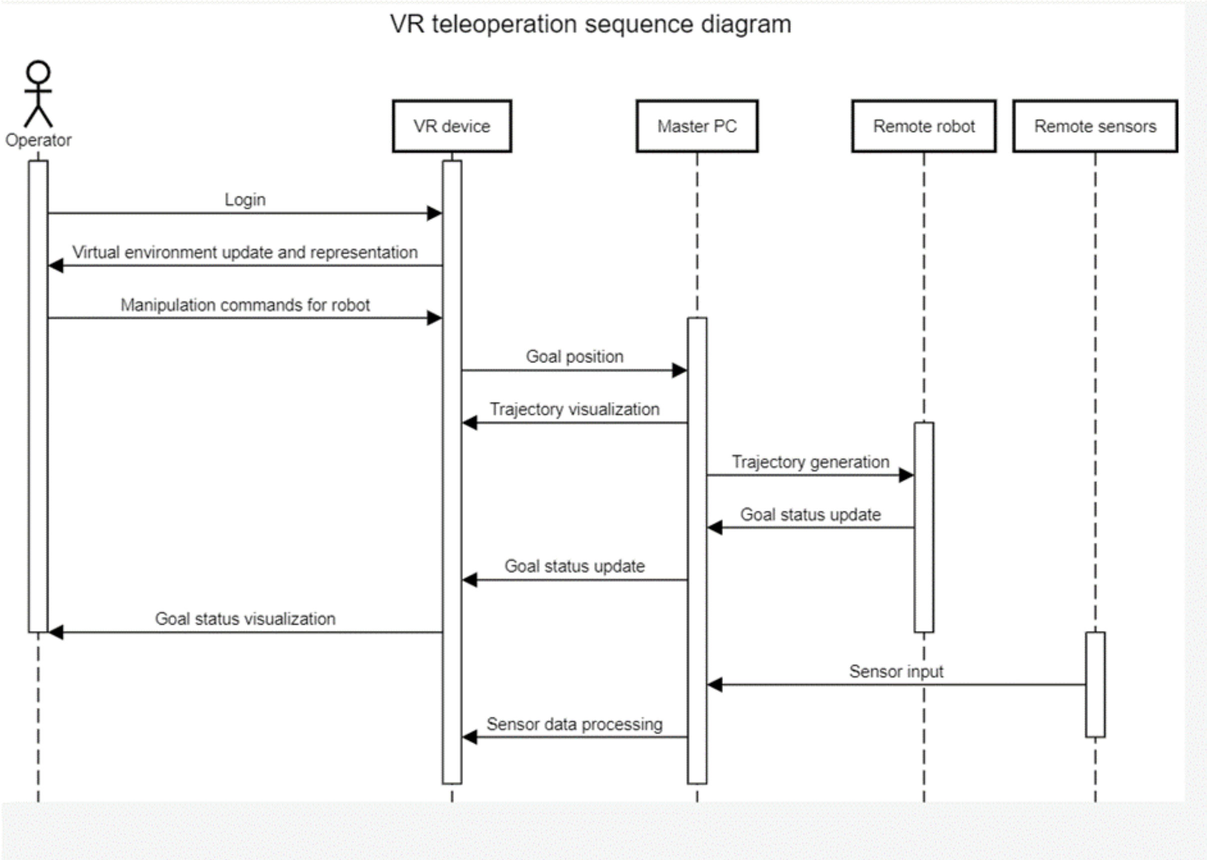
Sequence Diagram: Position end-effector



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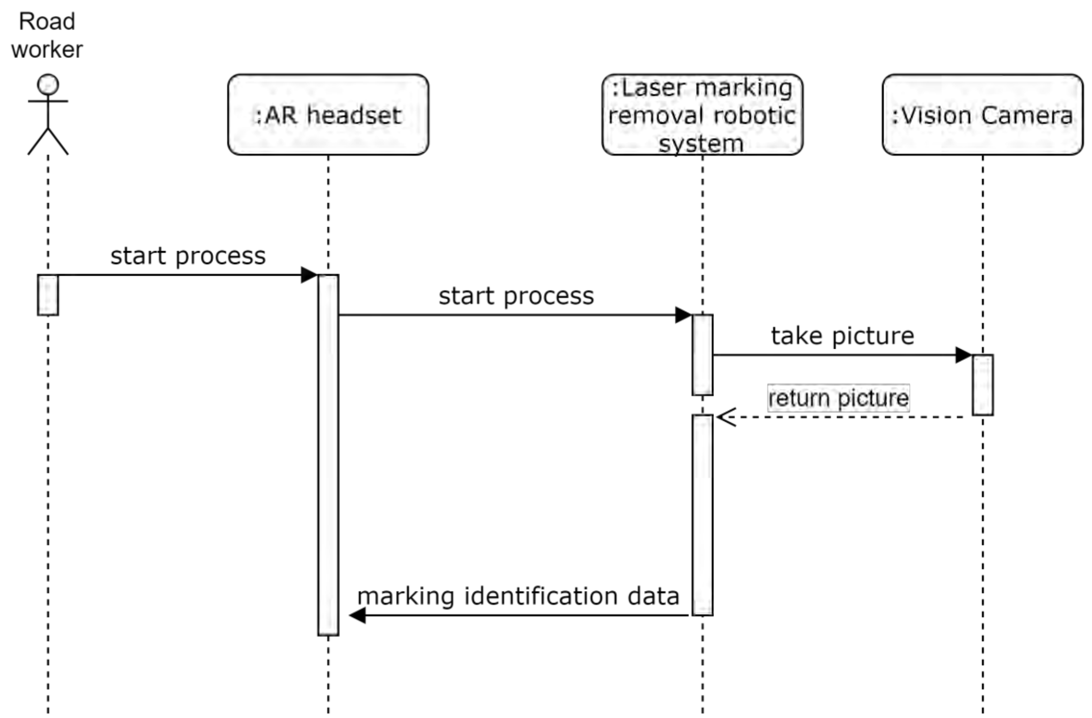
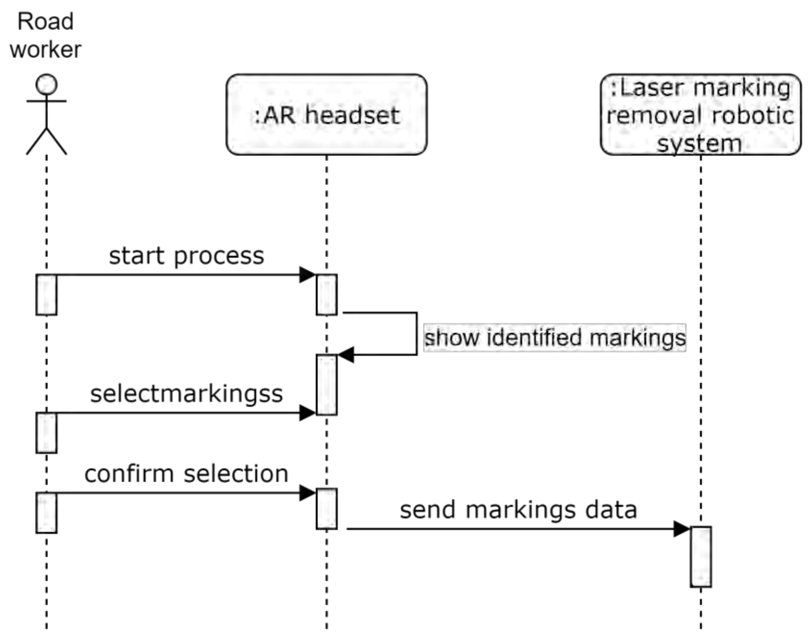
Sequence Diagram: Identify markings



Sequence Diagram: Select markings to be removed



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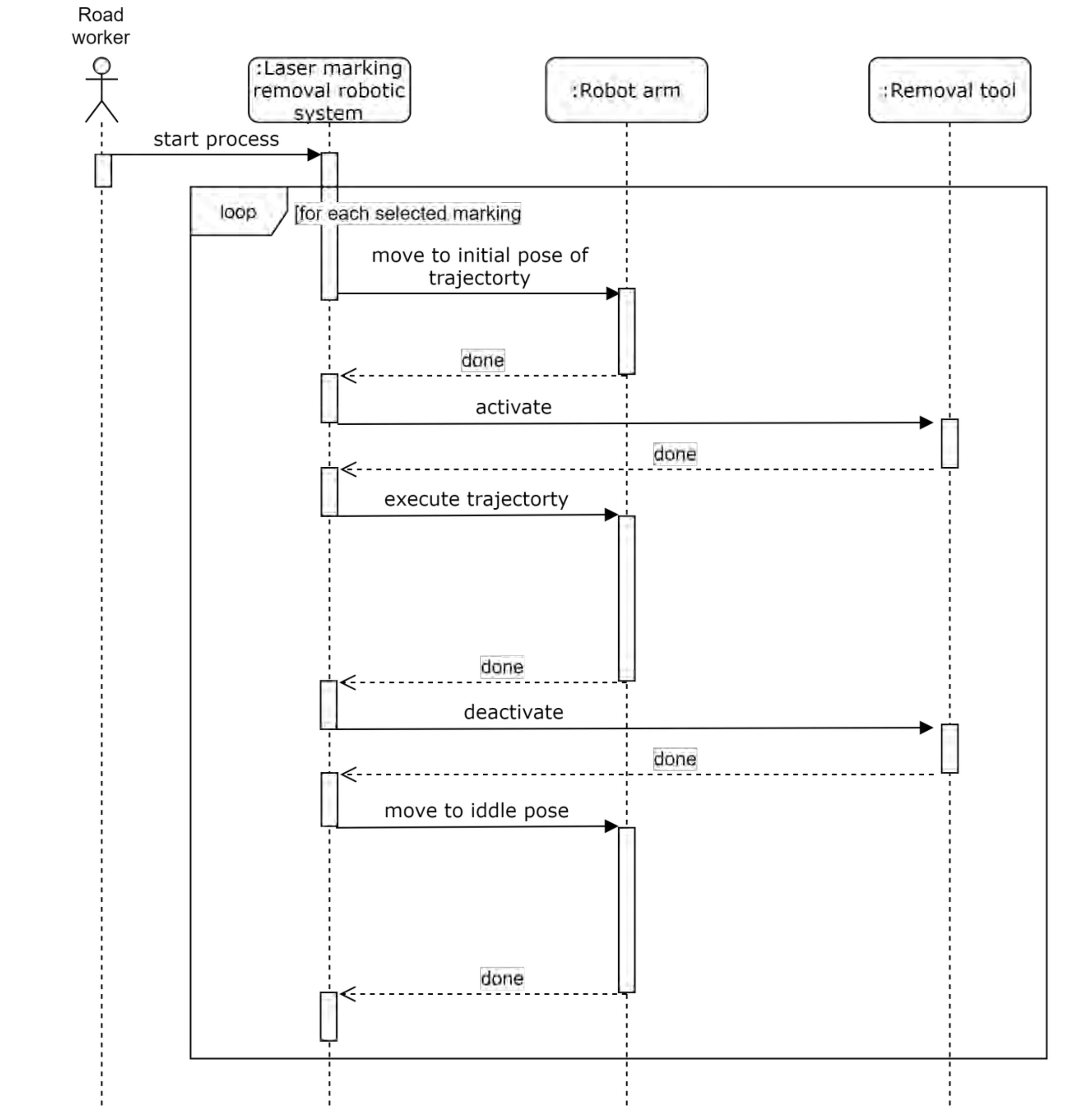
Sequence Diagram: Seal markings



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3 Technical details of the Use Case - Actors

Actor Name	Actor Type	Actor Subcategories	Actor description	Further information specific to this Use Case	Equipment Manufacturer	Requirement(s) of the actor	Reference Standards/Legislation
Road administration	Role	Road contractor	The administration that notifies the road workers to perform a marking removal service	Improvement works with temporary markings completed or The administration manages roads inspection data and based on that, decides when a marking removal service needs to be started.		Shall have knowledge of the roads and service resources	
Remote worker	Role	Road contractor	The operator that performs the marking removal task, , from the vehicle cabin, using the VR platform	The operator directly uses the robotic laser system to start/stop the system and to select the markings to be removed. Operator uses real - time feedback to be aware of the environment and uses modelled kinematics in VE in order to manipulate robotic resources remotely		Shall have knowledge of VR operations Shall have possession of VR device Shall have a virtual environment constructed	
VR Headset	System	Interactive communication device	The VR headset used by the Remote Operator	The operator uses the headset to facilitate the remote operation of the robotic arm to position it over the track	e.g Oculus, Vive		UL 8400, IEEE P2048
Vehicle	System	Road machinery	The vehicle that carries the laser machinery and	The vehicle houses a laser generator, a chiller, the optical system and the robotic system.		Shall contain enough space to house a laser generator set, a cooling system and the optical head	

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Actor Name	Actor Type	Actor Subcategories	Actor description	Further information specific to this Use Case	Equipment Manufacturer	Requirement(s) of the actor	Reference Standards/Legislation
			the robotic system			Shall be able to support the weight of all the aforementioned elements Shall be able to move at a very slow speed.	
Laser machine	System	Road machinery	The marking laser cleaning machine	The laser removal systems evaporates the undesired markings			
Vision camera	System	Robotic element	RGB-D camera for road perception	The camera is mounted on the robot arm to take images of the road that will serve as input to the system to identify lane markings to be removed		Shall be able to operate under low light conditions (night operations) Shall provide a Field of View to cover the marking to be removed	
Robot arm	System	Robotic element	An anthropomorphic industrial robotic arm	The robot arm will operate the specific tool and direct the laser head over the marking to be removed.		At least 6 degrees of freedom. The reach of the robot arm shall cover the width of the marking The robotic end-effector shall accommodate small positioning errors to ensure the right working distance between the laser head and the road	ISO 10218, ISO12100, ISO 13849.

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4 Step by Step Analysis of the Use Case

4.1 List of scenarios

S.No	Scenario Name	Scenario Description	Primary Actor	Triggering Event	Pre-Condition	Post-Condition
PS1	Provide the marking removal service	The road administration notifies the road workers that a marking removal service need to be started. The road administration provides a set of the kilometre points where there are markings that need to be removed. Then, the road workers drive to the first kilometre point in the list. When they arrive, they stop at the position of the first marking to be removed. After that, the road worker positions the end-effector of the robotic arm (cf. Position end-effector use case). Once positioned, the road worker starts the marking identification (cf. Identify markings use case). When the markings are identified, the road worker selects manually the markings to be removed (cf. Select markings to be removed use case). Then, the road worker starts the marking removal process (cf. Remove markings use case). Once the removal is completed, the road worker moves forward a small distance using the vehicle to repeat the process again until the markings are removed. This process is repeated for all the kilometre points where markings need to be removed.	Road administration	Road administration notifies the start of the service	Improvement or maintenance works completed Ghost markings the road have been identified and located (at kilometre point level).	All the markings are removed

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S.No	Scenario Name	Scenario Description	Primary Actor	Triggering Event	Pre-Condition	Post-Condition
PS2	Position end-effector	The remote operator uses a web-based VR platform to position the robotic arm end-effector over the marking. The web-based VR platform allows remote operator to teleoperate the robotic arm in real time. The remote operator receives a video stream from the vision camera, facilitating the remote operation.	VR Headset	Road operator starts the positioning manoeuvre	The marking is inside the working envelope of the robot.	The robot end-effector is positioned over the marking and the marking is in the field of view of the vision camera.
PS3	Identify markings	The road worker uses the display of the VR headset to manually start the marking identification process. Therefore, a vision camera provides data for the marking removal robotic system for identifying and characterising the markings. After this identification and characterisation, the information is sent to the VR headset to be shown to the road worker.	Vision camera	Road worker starts the marking identification process	The robotic arm end-effector is positioned over the marking. The vision camera and the VR headset are connected with the marking removal robotic system.	The road worker has received the data of the marking identification and characterisation.
PS4	Select markings to be removed	The VR headset shows visually the identified markings. The road worker uses the VR headset to manually select the markings that will be removed by the markings removal robotic system. Then, the worker confirms the selection, and the markings removal robotics system receives the data.	VR headset	Road worker starts the selection process	Marking identification and characterisation information is in the AR display due to the previous execution of the marking identification process.	The marking removal system has received the selected markings data.
PS5	Remove markings	The road worker uses the VR headset to manually start the marking removal process. Therefore, the marking identification and characterisation data are used by the markings removal robotics system to calculate the trajectory that the robot arm needs to	Robot arm	Road worker starts the marking removal process	The marking removal system has the selected markings information.	The markings are removed.

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S.No	Scenario Name	Scenario Description	Primary Actor	Triggering Event	Pre-Condition	Post-Condition
		execute. Then, the robot arm is positioned at the beginning of the trajectory. After this point, the marking removal robotics system activates the tool to start applying hot air flow and removal material. The robot arm will then execute the trajectory with a given constant speed. When the trajectory finishes, the marking removal robotics system deactivates the tool. This process is repeated for each marking that must be removed.				
AS1	The road administration provides a set of incorrect kilometre points	The road worker reaches the kilometre point according to the information supplied by the road administration, but the place is not the right place to remove lane markings.	Road worker	The worker drives to the kilometre point	The kilometre point was wrongly communicated.	The road workers get the right position.
AS2	Marking is not identified	The marking removal robotics system does not recognize the marking.	Laser marking removal robotic system	The vision system does not identify the marking	The quality picture is bad, (illumination, blur, perspective). The marking is dirty. Others.	The marking is known and located by the robotic system.

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4.2 Steps - Primary Scenario

Scenario Name: PS1.Provide the marking removal service									
St No.	**Event**	**Description of Process/Activity**	**Information Producer**	**Information Receiver**	**Information Exchanged**	**Service**	**Requirements**	**Communication Media**	**Communication Means**
PS1.1	The road administration notifies the road worker	The road administration calls the road workers to notify that they need to provide a marking removal service	Road administration	Road worker	I-01	REPORT		Phone call	Voice
PS1.2	The road worker drives to kilometre point	The road worker drives the vehicle to the kilometre point where markings need to be removed	Road worker	Vehicle					
PS1.3	The road worker positions the end-effector	(cf. PS2)							
PS1.4	The road worker starts the marking identification	(cf. PS3)							
PS1.5	The road worker selects the markings	(cf. PS4)							
PS1.6	The road worker starts the marking removal process	(cf. PS5)							

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Scenario Name: PS1.Provide the marking removal service									
St No.	Event	Description of Process/Activity	Information Producer	Information Receiver	Information Exchanged	Service	Requirements	Communication Media	Communication Means
PS1.7	The road worker moves forward the vehicle	The road worker drives the vehicle to move forward a little bit to continue the removal of markings	Road worker	Vehicle					
PS1.8	markings are removed	Previous steps are repeated until all markings in the area are removed				REPEAT (3-7)			
PS1.9	All kilometre points are covered	Previous steps are repeated until all provided Kilometre points are covered				REPEAT (2-8)			

Scenario Name: PS2.Position end-effector									
St No.	Event	Description of Process/Activity	Information Producer	Information Receiver	Information Exchanged	Service	Requirements	Communication Media	Communication Means
PS2.1	Feedback for the event is provided to the remote operator	Real-time data feedback is presented to the Operator	Remote sensors and communications	Virtual Device	I-02	GET	Data Management,	Web-based	protocol, e.g. TCP/IP

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Scenario Name: PS2.Position end-effector									
St No.	**Event**	**Description of Process/Activity**	**Information Producer**	**Information Receiver**	**Information Exchanged**	**Service**	**Requirements**	**Communication Media**	**Communication Means**
PS2.2	Successful	Manipulation commands sent from the operator to the PC that solves the kinematics	Virtual Device	Master PC	I-10	CHANGE	Configuration, Constrains or other issues	Web-based	protocol, e.g. TCP/IP
PS2.3	Successful	Movement goal sent to robotic resources	Master PC	Remote robotic resources	I-10	CHANGE	Configuration, Constrains or other issues	Web-based	protocol, e.g. TCP/IP
PS2.4	Successful	Robotic resource completes movement and sends result back to VR headset	Remote robotic resources	Remote Resources	I-04	GET	Configuration, Constrains or other issues	Web-based	protocol, e.g. TCP/IP

Scenario Name: PS3.Identify markings									
St No.	**Event**	**Description of Process/Activity**	**Information Producer**	**Information Receiver**	**Information Exchanged**	**Service**	**Requirements**	**Communication Media**	**Communication Means**
PS3.1	The road worker starts the process	The road worker uses the VR Headset to push the start process button. The display sends a signal to the robotic system.	VR Headset	Robotic system	I-05	REPORT		Ethernet	GUI

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Scenario Name: PS3.Identify markings									
St No.	Event	Description of Process/Activity	Information Producer	Information Receiver	Information Exchanged	Service	Requirements	Communication Media	Communication Means
PS3.2	Robotic system is notified	After receiving a signal from VR Headset, the robotic system requests an image from the vision camera.	Robotic system	Vision camera	I-06	GET		Ethernet	protocol
PS3.3	Vision Camera is addressed	The vision camera takes a picture. The data is sent to the robotic system.	Vision camera	Robotic system	I-07	GET		Ethernet	Protocol
PS3.4	Robotic system receives picture data	The robotic system receives the picture data from the vision camera. Based on this, a traditional computer vision and Deep Learning methods are applied to identify and characterise the markings in the picture.	Robotic system	Robotic system	I-07	CREATE			
PS3.5	Markings have been identified and characterised	The robotic system sends the markings identification and characterisation data that will be shown to the road worker in the display.	Robotic system	VR Headset	I-08	CHANGE		Wifi	Protocol
PS3.6	Display receives markings identification and characterisation data	The VR Headset shows to the road worker the information of the markings	VR Headset	VR Headset	I-08	REPORT			

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Scenario Name: PS4. Select markings to be removed									
St No.	Event	Description of Process/Activity	Information Producer	Information Receiver	Information Exchanged	Service	Requirements	Communication Media	Communication Means
PS4.1	The road worker manually starts the selection process.	The road worker pushes a button on the VR Headset display that starts the marking selection process. After that the VR headset shows the identified markings	VR Headset	VR Headset		CREATE			GUI
PS4.2	The road worker finishes selecting all the markings to be removed	The road worker selects from the VR headset the markings that want to be removed by the robotic system. After that, the road worker pushes the proceed button and the information is sent to the robotic system	VR Headset	Robotic system	I-09	CREATE		Ethernet	GUI
PS4.3	Robotic system receives the data	The robotic system removes the specified markings using the robotic arm with the laser head (this process is described in another use case).	Robotic system	Robotic system	I-09	EXECUTE			

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Scenario Name: PS5. Remove markings									
St No.	Event	Description of Process/Activity	Information Producer	Information Receiver	Information Exchanged	Service	Requirements	Communication Media	Communication Means
PS5.1	Robotic system is notified	After receiving a signal with selected markings data from the VR headset, the robotic system calculates the trajectory for the robot to follow a marking.	Robotic system	Robotic system	I-10	CREATE			
PS5.2	Trajectory is calculated	The robotic system sends a signal to the robotic arm to move to the initial pose of the calculated trajectory.	Robotic system	Robot Arm	I-03	CHANGE		Ethernet	Protocol
PS5.3	Robot arm is notified	The robot arm positions the laser head in the initial pose of the calculated trajectory.	Robot Arm	Robot Arm	I-03	EXECUTE			
PS5.4	Robot motion is finished	The robot arm sends a signal to the robotic system.	Robot Arm	Robotic system	I-04	GET		Ethernet	Protocol
PS5.5	Robotic system has the signal	The robotic system sends a signal to the laser system to activate.	Robotic system	Laser system	I-11	CHANGE		Ethernet	Protocol
PS5.6	Laser system is addressed	The laser system switches on	Laser system	Laser system	I-11	EXECUTE			
PS5.7	Laser system is on	The laser system sends a signal to the robotic system.	Laser system	Robotic system	I-12	GET		Ethernet	Protocol

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Scenario Name: PS5. Remove markings									
St No.	**Event**	**Description of Process/Activity**	**Information Producer**	**Information Receiver**	**Information Exchanged**	**Service**	**Requirements**	**Communication Media**	**Communication Means**
PS5.8	Robotic system has the signal	The robotic system sends a signal to the robot arm to execute the trajectory motion.	Robotic system	Robot arm	I-10	CHANGE		Ethernet	Protocol
PS5.9	Robot arm is addressed	The robot arm executes the trajectory motion	Robot arm	Robot arm	I-10	EXECUTE			
PS5.10	Robot motion is finished	The robot arm sends a signal to the robotic system.	Robot Arm	Robotic system	I-04	GET		Ethernet	Protocol
PS5.11	Robotic system has the signal	The robotic system sends a signal to the laser system to deactivate.	Robotic system	Laser system	I-11	CHANGE		Ethernet	Protocol
PS5.12	Laser system is addressed	The laser system switches off	Laser system	Laser system	I-11	EXECUTE			
PS5.13	Laser system is off	The laser system sends a signal to the robotic system.	Laser system	Robotic system	I-12	GET		Ethernet	Protocol
PS5.14	Robotic system has the signal	The robotic system sends a signal to the robot arm to move to the idle position	Robotic system	Robot arm	I-03	CHANGE		Ethernet	Protocol
PS5.15	Robot arm is addressed	The robot arm moves to the idle position	Robot arm	Robot arm	I-03	EXECUTE			

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Scenario Name: PS5. Remove markings									
St No.	Event	Description of Process/Activity	Information Producer	Information Receiver	Information Exchanged	Service	Requirements	Communication Media	Communication Means
PS5.16	Robot motion is finished	The robot arm sends a signal to the robotic system.	Robot Arm	Robotic system	I-04	GET		Ethernet	Protocol
PS5.17	All markings are removed	Previous steps are repeated until all markings are removed				REPEAT (2-16)			

4.3 Steps – Alternative, Error Management, and/or Maintenance/Backup Scenario

Scenario Name: The road administration provides a set of incorrect kilometre points									
St No.	Event	Description of Process/Activity	Information Producer	Information Receiver	Information Exchanged	Service	Requirements	Communication Media	Communication Means
AS1.1	Kilometre point is incorrect.	The road workers notices that the kilometre point is incorrect. Therefore, they contact to road administration to get the right position.	Road administration	Road worker	I-01	CHANGE		Phone	Voice

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Scenario Name: Marking is not identified									
St No.	Event	Description of Process/Activity	Information Producer	Information Receiver	Information Exchanged	Service	Requirements	Communication Media	Communication Means
AS2.1	The robotic system does not recognise the marking	The robotic system stops the process and sends the picture to the display.	Laser marking removal robotic system	Display	I-07	CHANGE		Ethernet	GUI
AS2.2	The display shows the picture	The display shows the picture to the worker. The system waits until the road worker marks the area where the marking is.	Display	Road worker		CHANGE		Screen	GUI
AS2.3	The mark is marked by the road worker	The road worker marks the area where the marking is located on the picture	Road worker	Display		CREATE		Tactile	GUI
AS2.4	The system restarts the process	The display sends the area of the marking and the order to restart the process.	Display	Laser marking removal robotic system	I-13	EXECUTE		Ethernet	Protocol

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5 Information Exchanged

Inf. ID	Name of information exchanged	Description of information exchanged	Information Subcategories	Requirements
I-01	Kilometre points data	The road administration provides a set of kilometre points codes where there are markings to be removed	Network state	
I-02	Data stream (visual)		Information exchanged between IS or sent to device	
I-03	Robot movement goal	The message contains the pose of the robot end-effector.	Information exchanged between IS or sent to device	
I-04	Result of movement operation	Message to signal that robot movement finished. It contains the result of the movement process.	Information exchanged between IS or sent to device	
I-05	Signal from the VR Headset	The VR Headset sends a signal to the marking removal robotic system to notify that the removal process must start or stop. The signal is binary, i.e. only the values 0 and 1 exist (0 = start removal, 1 = stop removal).	Information exchanged between IS or sent to device	Correct communication establishment between VR headset and marking removal robot
I-06	Signal from the Marking removal robotic system for picture	The marking removal robotic system sends a signal to vision camera to get a picture.	Information exchanged between IS or sent to device	
I-07	Picture data	The picture data contains RGB and depth values.	Information exchanged between IS or sent to device	

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I-08	Markings' information	Message containing the identification and characterisation data of all the markings identified.	Information exchanged between IS or sent to device	
I-09	Selected markings' information	Message containing the identification and characterisation data of the markings selected by the worker.	Information exchanged between IS or sent to device	
I-10	Robot movement trajectory	The message contains the trajectory for the robot to execute.	Information exchanged between IS or sent to device	
I-11	Signal from the marking removal robotic system to the removal tool	The signal specifies if the tool need to be activated or deactivated.	Information exchanged between IS or sent to device	
I-12	Signal from the removal tool	Message to signal that removal tool activation/deactivation process finished.	Information exchanged between IS or sent to device	
I-13	Message			

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OMI((RON

Intelligent Road Asset Management Platform

Smart rehabilitation of surface pavement layer

Definition of Requirements

Publish Date: 14/09/2021

Use Case Number: UC3.4

Use Case Title: Smart rehabilitation of surface pavement layer

Use Case Responsible Partner: EIFFAGE

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1 Description of the Use Case

1.1 Use Case Identification

ID	Domain(s)	Name of Use Case	Level of Use Case
UC3.4	UC3: Large and extraordinary maintenance actions.	Smart rehabilitation of surface pavement layer	Detailed

1.2 Scope and Objectives

Scope and Objectives of the Use Case	
Scope	Adaptation and automation of machinery dedicated to the replacement of asphalt pavement layers. Integration of smart automation solutions to support the replacement of surface pavement layers.
Objective	SO5.2. Smart solutions to support the replacement of surface pavement layers, using automation technologies and fostering the use of AUTLs (Asphalt for Ultra-Thin Layers). The automation of paving interventions in OMICRON will lead to reductions in overall project costs and time and will enhance pavement lifetime via a better execution. EO2. Promoting the use of AUTLs in pavement rehabilitation via enabling technologies which will reduce costs and the amount of material needed, ensuring the required final mechanical properties. EO3. Fostering the use of recycled materials in pavement rehabilitation to address national and local demands for increased recycling and environmentally friendly asphalt mixtures. The project will incorporate in the demonstrators AUTLs with high percentages of Recycled Asphalt Pavement (RAP).
Related Business Case	*BC4. Automation and robotization of maintenance operations.* UC3. UC3.4. Rehabilitation of surface pavement layers.

1.3 Narrative of Use Case

Short description
Adaptation of existing machinery to automate extraordinary maintenance tasks. This will include the replacement of pavement surface layers fostering the use of AUTLs (Asphalt for Ultra-Thin Layers) using recycled materials in its composition.

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Complete description

Pavement overlays represent a common technique used for pavement rehabilitation and maintenance. These works involve the following steps:

(1) Preparing an existing pavement surface for overlay, which can involve activities such as replacing localised areas, applying a levelling course, milling, etc.

(2) Tack coat (emulsion) application between old pavement surface and new asphalt mix surface layer.

(3) Asphalt mix laying, considering the desired width, grade, cross slope, and thickness to produce a uniform surface with a desired macrotexture.

(4) Adequate compaction of the mix to increase fatigue life, decrease permanent deformation (rutting), reduce aging, decrease moisture damage, increase strength and stability, and decrease low-temperature cracking.

Furthermore, AUTLs are thinner asphalt mixtures of aggregates and plain or polymer modified bitumen, which may contain fibre additives. The use of Asphalt for Ultra-Thin Layers (AUTL) constitutes a greener and more agile methodology in pavement rehabilitation.

The automation of the surface pavement layer rehabilitation process, providing decision-support information along the whole process will improve it and will enhance human operator decisions. The information will be collected by means of sensors and other sensing gadgets. The timestamped added value information will include, among other: i) temperature, ii) density over time, iii) dose, iv) amount of material (depth and level), v) speed of deployment, vi) macrotexture, and v) distance between the extension and the compacting vehicle.

The automation of the process will result in higher performance and immediate opening to traffic. Moreover, maintenance techniques can be used to reduce the overall cost of pavement by increasing its useful life. The characteristics of the AUTL (skid resistance, noise level) guarantee greater safety and comfort for road users. The reduced thickness of the set-up achieved will save resources: energy, aggregates, and bitumen.

The automation of paving interventions will lead to reductions in overall project costs and time and will enhance pavement lifetime via a better execution. The replacement of surface pavement layers is considered a crucial task that will be tackled in WP4 from two different perspectives in OMICRON:
a) The application of the emulsion tack coat and the bituminous mix to the pavement surface.
b) The application of the compaction of the pavement layer, given proper and uniform compaction of the pavement layer is essential in achieving the desired final compacted density.

Technical Demonstrator 3 (TD3): The demonstration of pavement rehabilitation and maintenance technologies will be performed at the A-92 in Spain, as part of the Mediterranean corridor (TRL7).

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1.4 KPIs

Key performance indicators description for the Use Case:

ID	Name	Description	Target	Reference to mentioned Use Case objectives
KPI 2	Emergency, ordinary, and extraordinary maintenance intervention times	Surface pavement layer rehabilitation with AUTL means higher paving speed compared to other surface layers. Thus, in these processes, pavement works can save up to 20% of time. On the other hand, under ideal weather conditions, traffic may be allowed on the treated surface after only 2 hours.	20%	SO 5; EO2,3
KPI 6	Traffic disruptions due to maintenance interventions	Ultra-Thin Overlay helps to extend pavement life by providing a top “seal” that reduces water infiltration and oxidation. Thus, it is expected less traffic disruption due to maintenance intervention on pavement as sealing cracks or pit repairs.	30%	SO 3,4,5
KPI 9	Maintenance and inspection activity costs	Ultra-thin overlays (less than 2.0 cm) offer an economical resurfacing, preservation and renewal paving solution for roads requiring safety and smoothness improvements. Thin asphalt overlays not only provide a new pavement surface for a fraction of the cost of rebuilding a roadway, but they are the only preventive maintenance technique that adds structural value while helping to extend a pavement’s service life.	25%	SO 2,3,5

1.5 Use Case Conditions

1.- General

Actor	Triggering Event	Pre-conditions	Assumption
Describe which Actor(s) trigger(s) this Use Case	**Describe what event(s) trigger(s) this Use Case**	**Describe what condition(s) should have been met before this Use Case happens**	**Describe the assumptions about conditions or system configurations.**
Road owner or concessionaire company	Road owner or concessionaire company request	Technical specifications	Provide a job mix formula prior to the start of work. Provide traffic control.

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	old road surface restoration		Mill roadways, remove and dispose of material, if specified. Provide and apply tack coat. Supply, deliver, spread, and compact material. Provide material weight slips. Provide all necessary supervision, labour, and equipment. Clean up any debris from the performance of the work.

1.1.- Tack coat (emulsion) application.

Actor	Triggering Event	Pre-conditions	Assumption
Describe which Actor(s) trigger(s) this Use Case	**Describe what event(s) trigger(s) this Use Case**	**Describe what condition(s) should have been met before this Use Case happens**	**Describe the assumptions about conditions or system configurations.**
Emulsion Distributor	Old road surface preparation requirements (specifications about type and rate of emulsion to be applied)	1. Tank 2. Heating System 3. Asphalt Pump and Circulating System 4. Spray Bar 5. Flushing and Clean-out System 6. Power 7. Application Control and Metering 8. Chassis	The distributor is designed to apply a controlled and metered amount of bituminous material. The unit of measurement is in grams per square meter. Distributors are used to apply applications from 100 g/m2 up to 1,500 g/m2. The metering system has advanced with technology.
Driver (operator)	Old road surface preparation requirements (specifications about type and rate of emulsion to be applied)	1. Fill the tank. 2. Heat material in tank. 3. Circulate material in tank. 4. Circulate material in spray bar. 5. Spray a metered amount of material. 6. Handspray. 7. Suck-back material from spray bar. 8. Wash out. 9. Transfer / unload.	Four important features need to be considered 1) Desired Application Rate - g/m2 2) Forward Ground Speed - m per minute 3) Asphalt Pump Output – m3 per minute 4) Width of Spray - m

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1.2.- Asphalt laying (asphalt mix application)

Actor	Triggering Event	Pre-conditions	Assumption
Describe which Actor(s) trigger(s) this Use Case	**Describe what event(s) trigger(s) this Use Case**	**Describe what condition(s) should have been met before this Use Case happens**	**Describe the assumptions about conditions or system configurations.**
Asphalt paver	Old road surface overlaying requirements	Several factors, such as the paving speed, head of material, mix consistency, pre-compaction, and screed angle of attack influence the vertical position of the screed. If any one of these factors is varied during the paving operation, the variation causes a change in the mat depth, density, and/or texture.	1) Be a self-contained power propelled unit 2) Be equipped with an activated (vibratory) screed or strike-off assembly capable of being heated for the full length, including extensions 3) Be capable of spreading and finishing mix in lane widths indicated on the typical sections for the contract 4) Be equipped with automatic grade and slope controls if the width of the roadway or shoulder to be paved is 2.5 m or wider. The operator's control panel is required to have gauges that indicate compliance with the established grade and slope. 5) Have a grade leveller (commonly called a ski or mat reference) for attachment to the paver to activate the automatic grade control.
Driver and operators	Old road surface overlaying requirements	Controlling the vertical position of the free-floating screed, with respect to the grade surface over which the paver is moving, is the primary concern in producing high quality paving.	The three primary variable factors which influence the vertical position of the free-floating screed are: 1) Factor F-1 -- Angle of Attack 2) Factor F-2 -- Head of Material 3) Factor F-3 -- Paving Speed

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2.- Asphalt compaction (asphalt mix density-compaction)

Actor	Triggering Event	Pre-conditions	Assumption
Describe which Actor(s) trigger(s) this Use Case	**Describe what event(s) trigger(s) this Use Case**	**Describe what condition(s) should have been met before this Use Case happens**	**Describe the assumptions about conditions or system configurations.**
Asphalt rollers	Old road surface overlaying requirement	The QCP for the contract is required to specify the type of rollers to be used. Sufficient rollers are required to be operated to complete the compaction before the temperature of the mix has cooled to a point where the density cannot be obtained.	All rollers are required to have proper sprinkling systems to wet the drums or tires to prevent the mix from sticking. Scrapers are usually required on steel-wheel rollers. Rollers are required to be equipped with drip pans to prevent oil, grease, or fuel from dropping onto the roadway. Clutches are required to function smoothly. A roller that jerks when starting, stopping, or reversing causes a rough surface.
Driver (operator)	Old road surface overlaying requirement	Compaction may be controlled by the number of passes of a specified series of rollers or by density.	Density is determined by cores obtained from the mat after all rolling is complete. Specific responsibilities include: 1) Communicating with the paving crew, foreman and breakdown operator for the project requirements 2) Confirming maintenance and water system checks on a daily basis 3) Being aware of the material temperature and avoiding the tender zone 4) Determining if the rolling mode is vibratory or static depending on the requirements to achieve density and smoothness 5) Optimizing the water system controls to avoid pick-up and eliminate excessive water usage

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			6) Establishing the proper rolling pattern determined by the paving width, rolling drum width, unsupported edges, and drum overlap 7) Coordinating the final rolling process with QC personnel 8) Monitoring the rolling temperature and working within the optimum temperature zones 9) Making the required rolling coverage to achieve density requirements and to remove drum edge marks 10) Maintaining consistency throughout the entire working shift

1.6 Classification Information

Relation to Other Use Cases in the same project or area
Use Case 1.2. Inspection vehicle and automatic computation of road parameters include different inspections and related digital technologies, specifically AI camera inspection system for road pathologies detection indicators and, concretely, friction measurement is linked to the surface pavement macrotexture, data to be collected for construction site in this use case. Anyway, in general, OMICRON use cases related to advanced Digital Inspection Technologies, using autonomous and remote piloted drones and terrestrial inspection vehicles, the Digital Twin representation of the infrastructure using both information coming from technologies developed in OMICRON and other already existing monitoring and inspection technologies to develop a Decision Support Tool processing the information available from the Digital Twin to perform a nowcasting and forecasting of the infrastructure and generate optimal maintenance intervention planning solution for pavement may be associated to this use case.
Level of Depth - the degree of specialization of the Use Case
Detailed Use Case
Further Keywords for Classification
Pavement rehabilitation and maintenance, smart automation solutions for machinery, asphalt paving.

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Maturity of Use Case
TRL 7 – System prototype demonstration in operational environment. This corresponds to full validation on a representative pilot case. The “tool” has to be successfully validated in a pilot case, representative of the intended project application.

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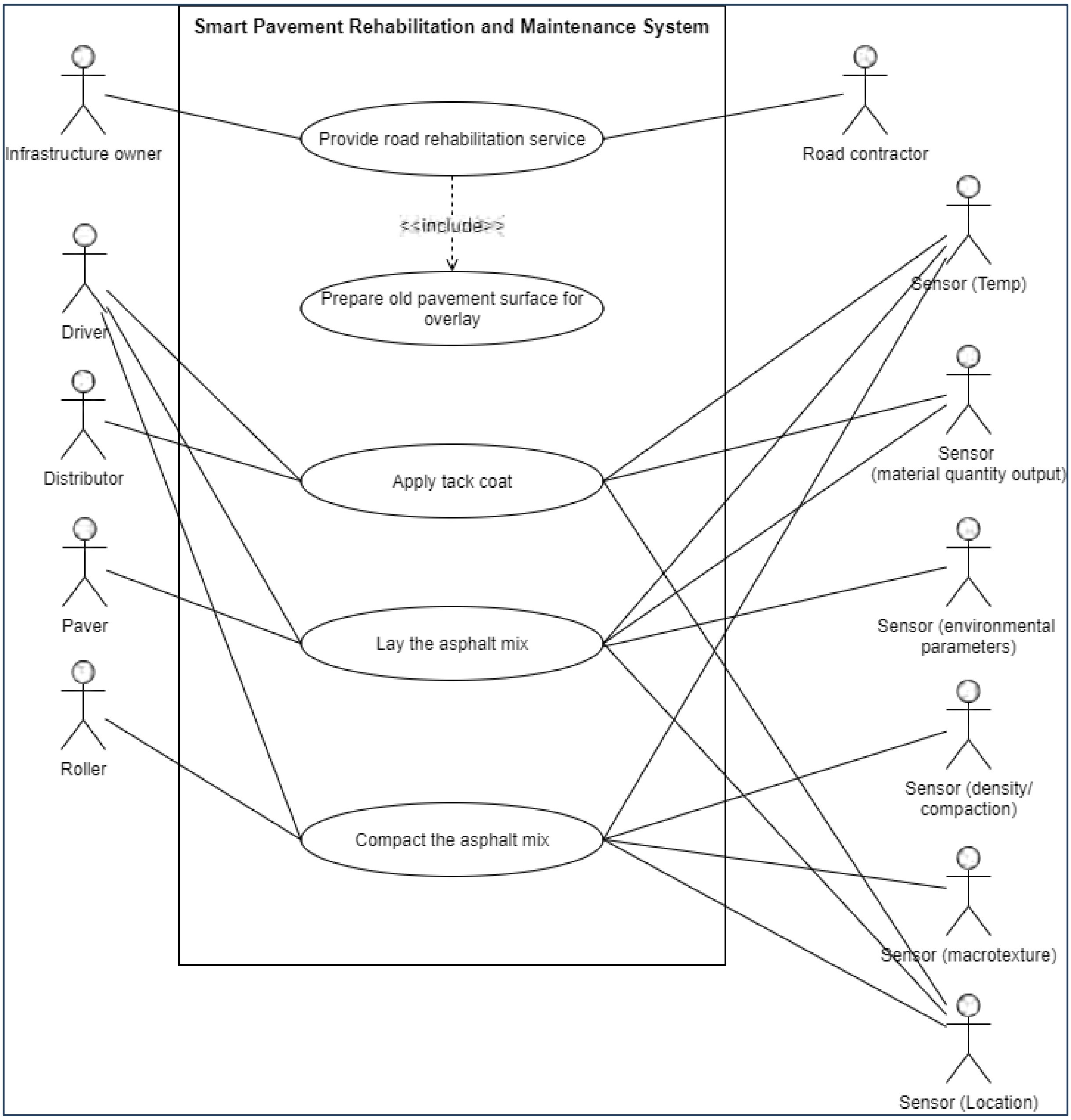
2 Diagrams of the Use Case

Context Diagram



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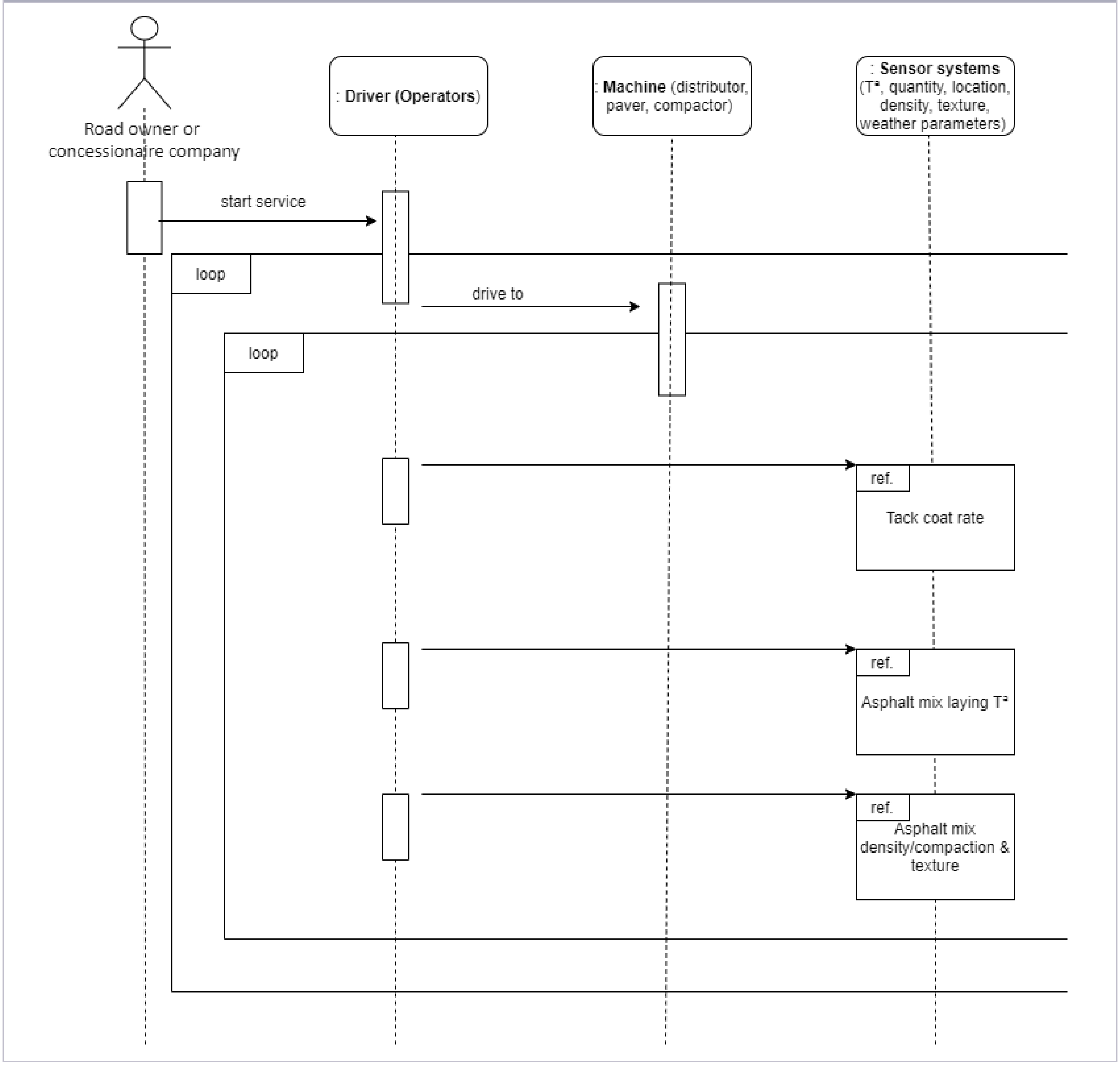
Sequence Diagram: Provide road rehabilitation service



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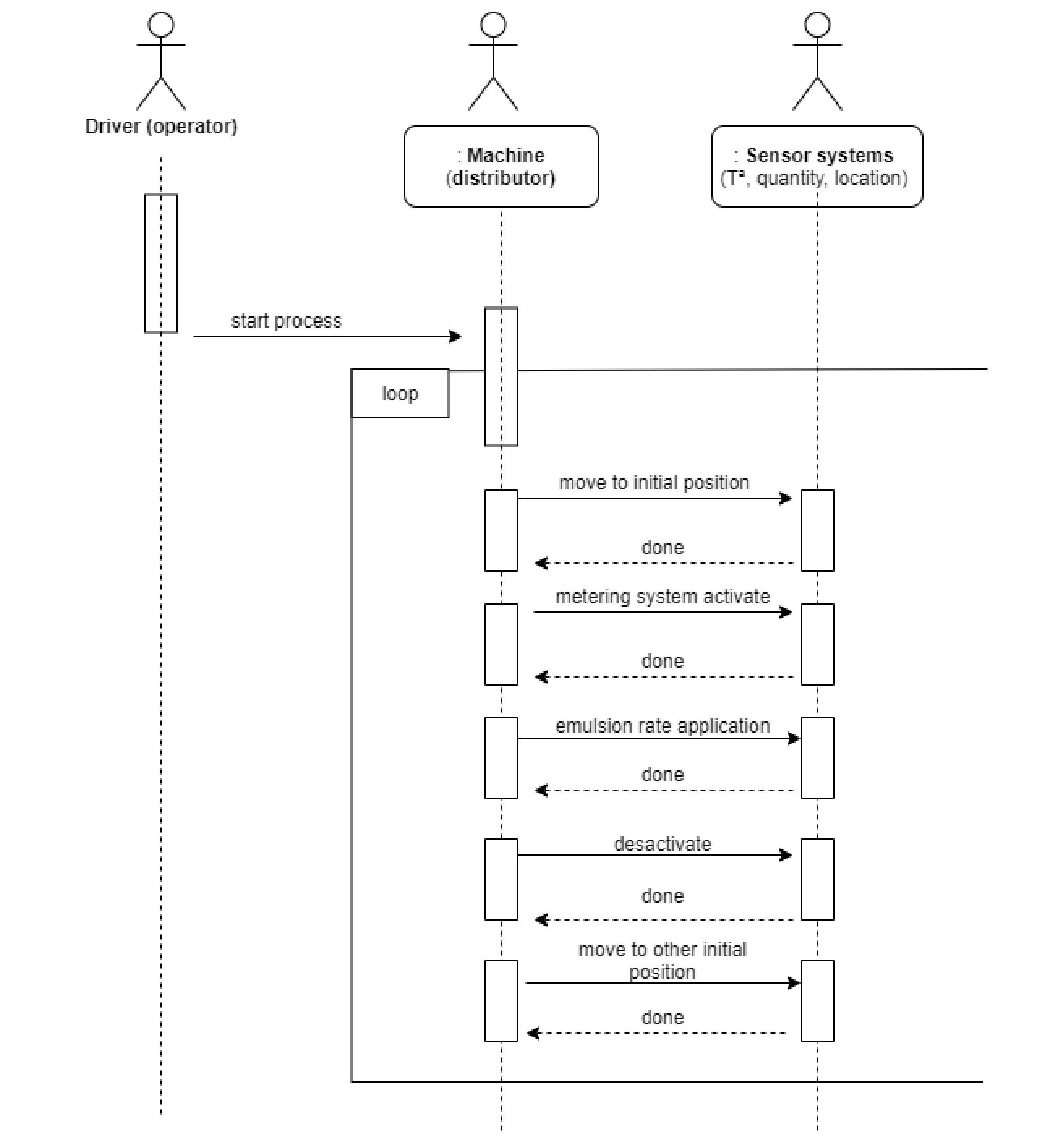
Sequence Diagram: tack coat (emulsion) application



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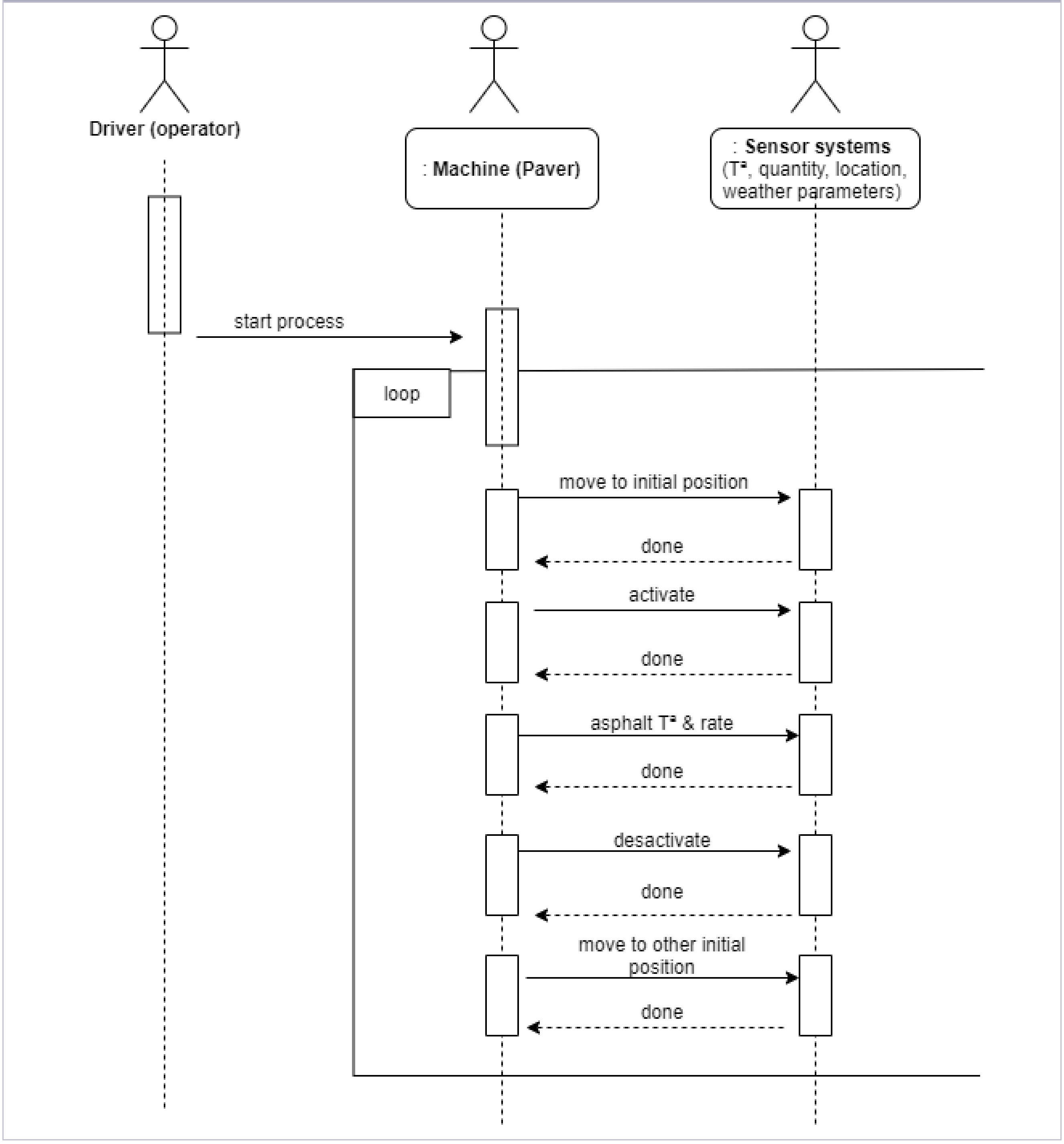
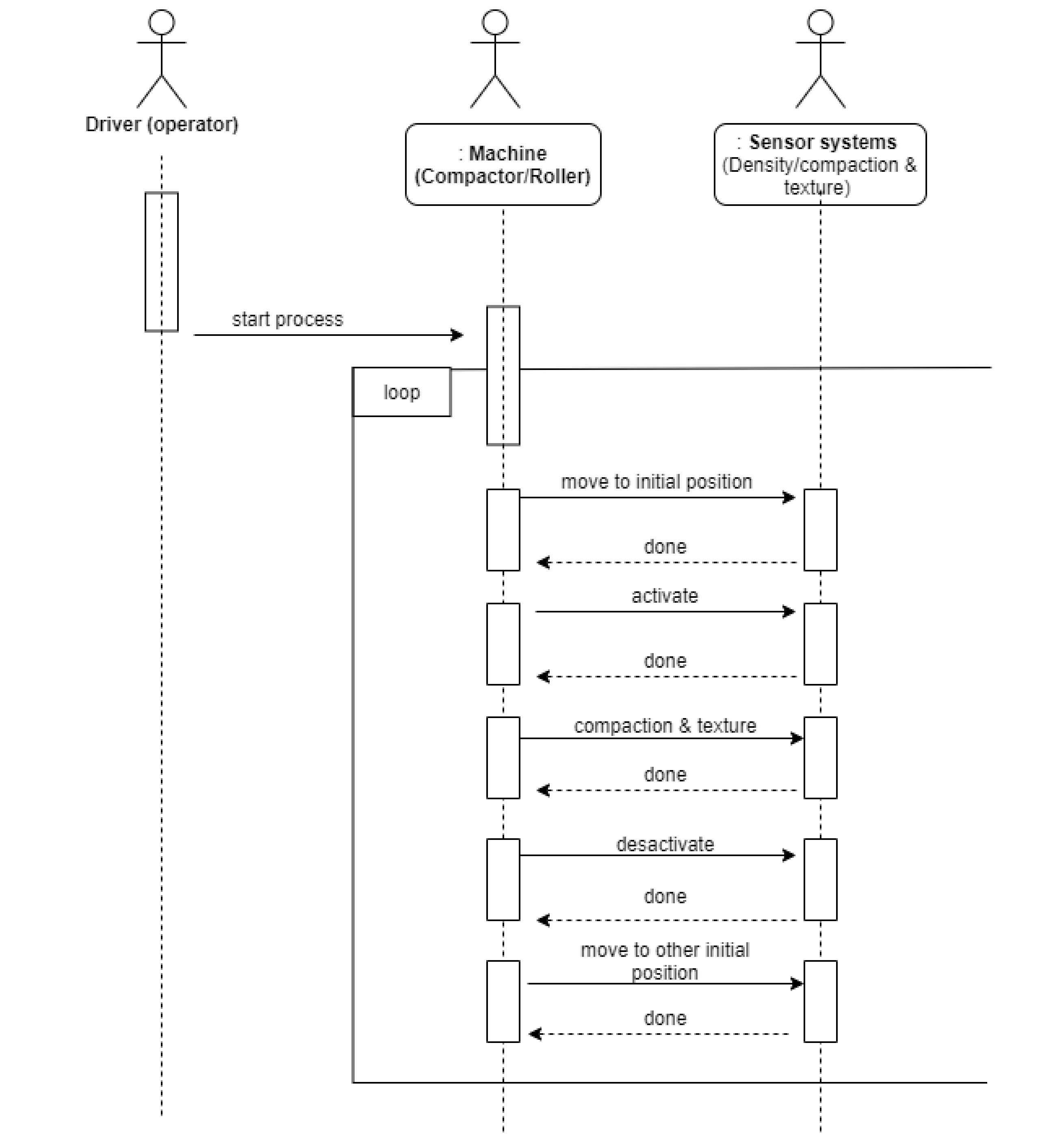
Sequence Diagram: asphalt mix laying



This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 955269

Sequence Diagram: asphalt mix compaction



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3 Technical details of the Use Case - Actors

Actor Name	Actor Type	Actor Subcategories	Actor description	Further information specific to this Use Case	Equipment Manufacturer	Requirement(s) of the actor	Reference Standards/Legislation
Road owner or concessionaire company	Role	Infrastructure owner or road concessionaire	Owner and, depending on the specific case, manager of the infrastructure	Provide technical specifications			National or international technical specifications
Driver (operator)	Role	User	A physical user that is involved at any task of the use case (tack coat, asphalt laying and compaction)	The operator directly uses the machinery to start/stop the system and receive data to select available options.			Truck license, training certificates, etc.
Distributor	System	Road machinery	A distributor is used to apply the liquid asphalt material used for tack coats.	The distributor consists of an insulated tank mounted on a truck or trailer. A power-driven pump forces the asphalt through a system of spray bars and nozzles onto the construction surface.	Fayat Group (Secmair)	The distributor is designed to apply a controlled and metered amount of bituminous material.	European and national legislation related to machinery.
Paver	System	Road machinery	Asphalt mixtures are spread and finished with the use of paver finishers.	The paver consists essentially of a tractor and a screed.	Fayat Group, Wirtgen Group & Volvo	- Generally, a paver required: - 1) Be a self-contained power propelled unit - 2) Be equipped with an activated (vibratory) screed or strike-off assembly capable of being heated for	European and national legislation related to machinery.

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						the full length, including extensions - 3) Be capable of spreading and finishing mix in lane widths indicated on the typical sections for the contract - 4) Be equipped with automatic grade and slope controls if the width of the roadway or shoulder to be paved is 2.5 m or wider. The operator's control panel is required to have gauges that indicate compliance with the established grade and slope. - 5) Have a grade leveller (commonly called a ski or mat reference) for attachment to the paver to activate the automatic grade control.	
Roller	System	Road machinery	Six types of rollers are used for compacting HMA: two-axle tandem, three-wheeled, pneumatic tire, vibratory, oscillatory, and trench rollers.	All of the rollers have steel wheels, except for the pneumatic-tire roller which has rubber wheels. All rollers are required to have proper sprinkling systems to wet the drums or tires to prevent the mix from sticking.	Fayat Group, Wirtgen Group	Scrapers are usually required on steel-wheel rollers. Rollers are required to be equipped with drip pans to prevent oil, grease, or fuel from dropping onto the roadway. Clutches are required to function smoothly. A roller that jerks when starting, stopping, or reversing causes a rough surface.	European and national legislation related to machinery.

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Distributor Sensors	System	Network element	Location, temperature, ground speed, pump output, width of spray			The distributor is required to be equipped with: 1) Accurate volume measuring gauges or a calibrated tank 2) A thermometer for measuring temperatures 3) A power unit for the pump 4) Full circulating spray bars to prevent material cooling in the spray bars. The spray bars are required to be adjustable vertically.	
Paver Sensors	System	Network element	Location, temperature, ground speed, width, and thickness			Several factors, such as the paving speed, head of material, mix consistency, pre-compaction, and screed angle of attack influence the vertical position of the screed. If any one of these factors is varied during the paving operation, the variation causes a change in the mat depth, density, and/or texture.	
Roller Sensors	System	Network element	Location, temperature, ground speed, density & texture			Compaction and texture may be controlled by the number of passes of a specified series of rollers.	

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4 Step by Step Analysis of the Use Case

4.1 List of scenarios

S. No	Scenario Name	Scenario Description	Primary Actor	Triggering Event	Pre-Condition	Post-Condition
PS1	Road owner or concessionaire company request old road surface restoration	The road administration notifies (contract) the contractor company that old road surface restoration service needs to be started. Road owner or concessionaire company provides a set of technical specifications (engineering project).	Road owner or concessionaire company	Road owner or concessionaire company notify (contract) old road surface restoration	Technical specifications	Old road surface restoration is executed according to technical specifications.
PS2	Tack coat Tack Coat (Emulsion application)	Distributor driver (operator) uses the display of the sensor system (GPS, Tª, emulsion rate) to manually start the process. Therefore, a sensor system provides data about the emulsion rate which was applied on the surface. The information is sent to display to be shown to the operator.	Distributor sensor system	Road operator starts emulsion application	Distributor is in the working area, emulsion Tª is correct & metering system is working correctly	Emulsion rate is applicated according to specified rate
PS3	Asphalt laying	Paver driver (operator) uses the display of the sensor system (GPS, Tª, asphalt rate) to manually start the process. Therefore, a sensor system provides data about the asphalt Tª, weather conditions and asphalt quantity which was applied on the surface. The information is sent to display to be shown to the operator.	Paver sensor system	Road operator starts laying asphalt process	Paver is in the working area, asphalt Tª is according to specifications, weather conditions are in line with specifications	Asphalt is laying at correct Tª & asphalt quantity (rate) is applied according to specifications
PS4	Asphalt mix compaction	Roller/compactor driver (operator) uses the display of the sensor system (GPS, Tª, density & texture) to manually start the process. Therefore,	Roller / Compactor sensor system	Road operator starts compaction process	Roller / Compactor is in the working area, asphalt Tª is according to	Asphalt density / compaction and texture are in line

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		a sensor system provides data about the asphalt Tª, density & texture. The information is sent to display to be shown to the operator.			specifications to be compacted	with specifications

4.2 Steps - Primary Scenario

Scenario Name: PS1. Road owner or concessionaire company request old road surface restoration									
St No.	**Event**	**Description of Process/Activity**	**Information Producer**	**Information Receiver**	**Information Exchanged**	**Service**	**Requirements**	**Communication Media**	**Communication Means**
1	Road owner or concessionaire company notify to contractor company	Road owner or concessionaire company notify (by phone call, email, or other way) to contractor company that they need old road surface restoration	Road owner or concessionaire company	Operators or road workers	ID-01	Report		by call, email, or other way	voice, email, paper
2	Operators or road worker drives to restoration area (km point)	The operators (road workers) drive the machines to the kilometer point where restoration service needs to be executed	Operators (road workers)	Machines					
3	Operator positions distributor machine	(cf. PS2)							
4	Operator positions paver machine	(cf. PS3)							
5	Operator positions roller or compactor	(cf. PS4)							

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	machine								
6	Restoration surface is completed	The operators (road workers) drive the machines outside restoration area	Operators (road workers)	Machines					

Scenario Name: PS2. Tack coat Tack Coat (Emulsion application)

St No.	Event	Description of Process/Activity	Information Producer	Information Receiver	Information Exchanged	Service	Requirements	Communication Media	Communication Means
1	Road worker starts the process	the sensor system gives information to the worker	Sensor system	Dashboard	I-02-1	GET	Data	Road worker starts the process	the sensor system gives information to the worker

Scenario Name: PS3. Asphalt laying

St No.	Event	Description of Process/Activity	Information Producer	Information Receiver	Information Exchanged	Service	Requirements	Communication Media	Communication Means
1	Road worker starts the process	the sensor system gives information to the worker	Sensor system	Dashboard	I-02-2	GET	Data	Road worker starts the process	the sensor system gives information to the worker

Scenario Name: PS4. Asphalt mix compaction

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St No.	Event	Description of Process/Activity	Information Producer	Information Receiver	Information Exchanged	Service	Requirements	Communication Media	Communication Means
1	Road worker starts the process	the sensor system gives information to the worker	Sensor system	Dashboard	I-02-3	GET	Data	Road worker starts the process	the sensor system gives information to the worker

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5 Information Exchanged

Inf. ID	Name of information exchanged	Description of information exchanged	Information Subcategories	Requirements
ID-01	Location and specifications about pavement restoration works	The road administration provides instructions about works to be done	Network state	
I-02-1	Sensor system parameters	Distributor location, Emulsion temperature, and applied emulsion rate	Information exchanged between IS or sent to device	Sensor measurement according to standardized or specified requirements. Correct communication between sensor system and dashboard.
I-02-2	Sensor system parameters	Paver location, weather conditions, asphalt temperature and asphalt laid quantity	Information exchanged between IS or sent to device	Sensor measurement according to standardized or specified requirements Correct communication between sensor system and dashboard
I-02-3	Sensor system parameters	Roller location, asphalt temperature, density or compaction and texture (macrotexture)	Information exchanged between IS or sent to device	Sensor measurement according to standardized or specified requirements Correct communication between sensor system and dashboard

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OMICRON

Intelligent Road Asset Management Platform

Modular Construction for Bridges

Definition of Requirements

Publish Date:	30/07/2021
Use Case Number:	4
Use Case Title:	Modular Construction for Bridges
Use Case Responsible Partner:	Teixeira Duarte

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1 Description of the Use Case

1.1 Use Case Identification

ID	Domain(s)	Name of Use Case	Level of Use Case
UC4	UC4: Modularisation and use of premanufactured components in bridges	Modular construction for bridges	Detailed Use Case

1.2 Scope and Objectives

Scope and Objectives of the Use Case	
Scope	Design of a modular and hybrid solution for bridges, focusing mainly on highway overpasses, through optimization of the assets and methods used in bridge construction and an increased industrialization level by introducing optimized processes in the bridge components production pipeline.

Objective	• Solution will allow industrialization of deck construction, which leads to:
	  • reduction of construction/deconstruction material waste
	  • reduction of manpower at the construction site
	  • reduction of scaffolding
	  • reduction in construction time
	  • reduction in traffic interruption time
	• Solution will allow an increased use of recycled materials:
	  • increased usage of steel

Related Business Case	Smart design for modular construction (BC1).

1.3 Narrative of Use Case

Short description – max 3 sentences
The construction of concrete traditional bridges represents long construction times and traffic interruptions. Trying to minimise these disruptions and at the same time contributing to circular economy, a hybrid modularised solution is proposed. An enhanced modular solution for hybrid bridges will be developed, aiming to minimise construction site operations while fostering the use of industrial pre-manufactured components. The goal of the methodology will be to create modularised solutions to build bridges (focusing on highway overpasses) avoiding or minimising traffic interruptions. The methodology will provide enhanced

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information both in terms of the mechanical behaviour and in terms of manufacturing (and installation) advantages compared to traditional solutions.

Complete description

Traditionally, the construction of bridge structures over or under highways relies on methodologies that present a variety of risks and shortcomings leading to a heavy human presence in the vicinities of bridges and at the construction sites themselves, along with traffic disruptions that hinder the usage of the highway infrastructure partially or totally, even if for a limited time. Progressively, road concessionaries were forced to comply with new standards and regulations that demanded increased safety and sought the measures that also guaranteed the maintenance of a high level of service, with the associated economic benefits.

A short number of solutions have been proposed and used that not only allow the reduction of construction time and manpower usage, but also require the infrastructure to be interrupted for much shorter periods of time. The conventional concrete bridges were replaced by precast concrete bridges or composite steel-concrete solutions. The former suffered from being less structurally efficient, requiring increased deck heights whereas the latter revealed to be less than optimal due the use of the expensive steel while also having higher maintenance costs.

Some other solutions have emerged and have been tested, that seek to gather the best qualities of both worlds: erecting concrete structures in the side spans, further away from the road line and replacing the main central span with a pre-manufactured, put-in-place steel segment which, once connected to the side concrete parts, re-establishes the structural continuity of the bridge. This differentiated layout and material distribution along the length of the bridge also contributed to its structural efficiency, by indirectly balancing the side-to-central span ratio, which is usually very shifted towards the main span, in order to maximize clearance. This optimization process can be taken even further by using precast concrete side spans, eliminating operations such as reinforcement assembly and concrete pouring in the proximities of the main infrastructure altogether, thereby greatly reducing the human presence executing risky assembly and preparation tasks during the interventions.

By taking the knowledge acquired with the experimental use of these existing "hybrid" solutions, the OMICRON project intends to further enhance their performance and optimize their design and production process in order to achieve a flexible solution template that can be easily adapted to the many possible road profiles, hence requiring different span arrangements, and a robust connection layout on the steel parts, towards a quicker, easier and safer assembly procedure on site.

Through the use of improved production methods, brought upon by data acquired with on-site load and in-lab testing campaigns, goals such as the reduction in material waste and gains in production times are expected to be achieved.

Overall, these aspects shall have a positive impact on the number of accidents and road network disruptions while also contributing to an increase in the percentage of recycled and recyclable materials that go into the construction of the structure.

This enhanced solution, and the data gathered in its design, shall be used to assemble a BIM model that ultimately will showcase and demonstrate the practical results and achievements sought by the project.

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1.4 KPIs

Key performance indicators description for the Use Case:

ID	Name	Description	Target	Reference to mentioned Use Case objectives
7	Bridge construction traffic disturbances	The modular methodology for bridge construction will reduce intervention times and hence traffic disturbances	Reduction of traffic disturbance of 30%	Reduction in construction time Reduction in traffic interruption times Reduction of scaffolding
3	Volume of people in dangerous zones in road maintenance areas (connected to the number of road users and workers accidents)	The modular methodology for bridge construction will reduce the number of accidents	Reduction of road accidents of 5%	Reduction of manpower at the construction site Reduction of scaffolding Reduction in construction time
10	Contribution to circular economy	The use of steel allows an increased usage of recycled materials in the construction as well as an increase of material recycling at the deconstruction and also the use of industrialised and automatised solutions allows a reduction of construction material waste. The comparison will be based on the reduction of carbon footprint (carbon emissions).	Increase in circularity of 30%	Increased usage of steel Increased amount of recyclable materials at deconstruction

*** KPI Note:**

KPI 10 - Bridge maintenance costs after modular retrofitting - Proposal

Due to the high maintenance costs of the steel parts of the proposed hybrid solution, which need to be repainted every 15 years, it would not be possible to reduce maintenance costs when compared to a conventional concrete solution. Therefore we now propose replacing it with following:

KPI 10 - Contribution to circular economy - Revision

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This is based on the fact that this solution incorporates larger quantities of steel, thereby increasing the amount of material that can be recycled at the deconstruction and reused in new constructions. By replacing significant concrete parts of the structure with steel counterparts, high percentage gains can be expected.

KPI 3 - Volume of people in dangerous zones in road maintenance areas – Revision

Considering that a renewal/upgrade of an overpass can be seen as a maintenance action, the hybrid solution can adhere to this KPI instead of proposing a new, specific KPI for this objective.

1.5 Use Case Conditions

Actor	Triggering Event	Pre-conditions	Assumption
BRISA	Monitoring campaign	Access permits	Load test permit by October 2021
LNEC	Monitoring campaign and lab-tests	Appropriate equipment, technical specifications for load-testing and knowledge	Calibrated equipment and adequate methodology
Municipality	Monitoring campaign	Access permits	Traffic diversion by October 2021
TDU	Monitoring campaign	Access permits	Monitoring equipment installed
TDU	Prefabrication of model	Appropriate equipment and detailed design of the connecting part	Stock of raw material and quality control system in place
ARI	Detailed design of the bridge	Monitoring campaign results and knowledge	-
CEM	BIM model	Detailed design of the bridge	-

1.6 Classification Information

Relation to Other Use Cases in the same project or area
Intelligent Construction Platform
Level of Depth - the degree of specialization of the Use Case
Detailed Use Case
Further Keywords for Classification
Bridge, modular construction, hybrid structure

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Maturity of Use Case
- In business operation.

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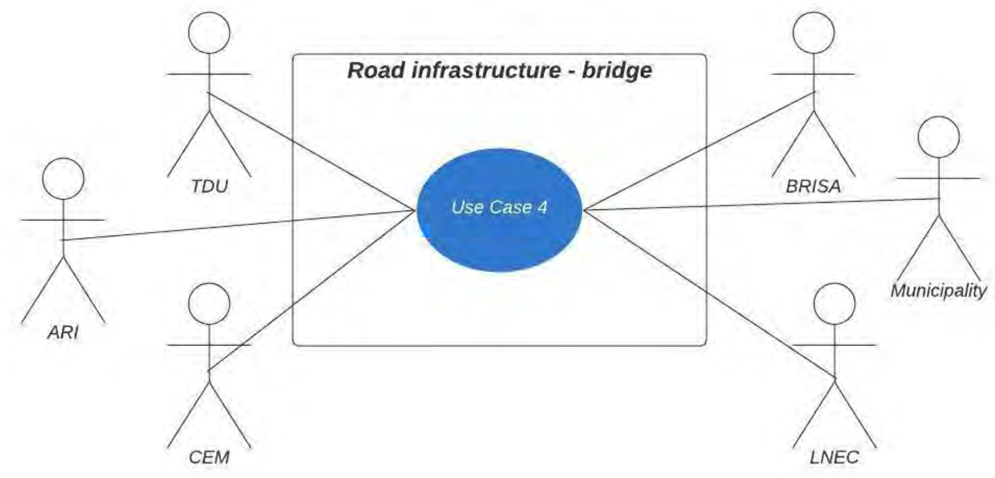
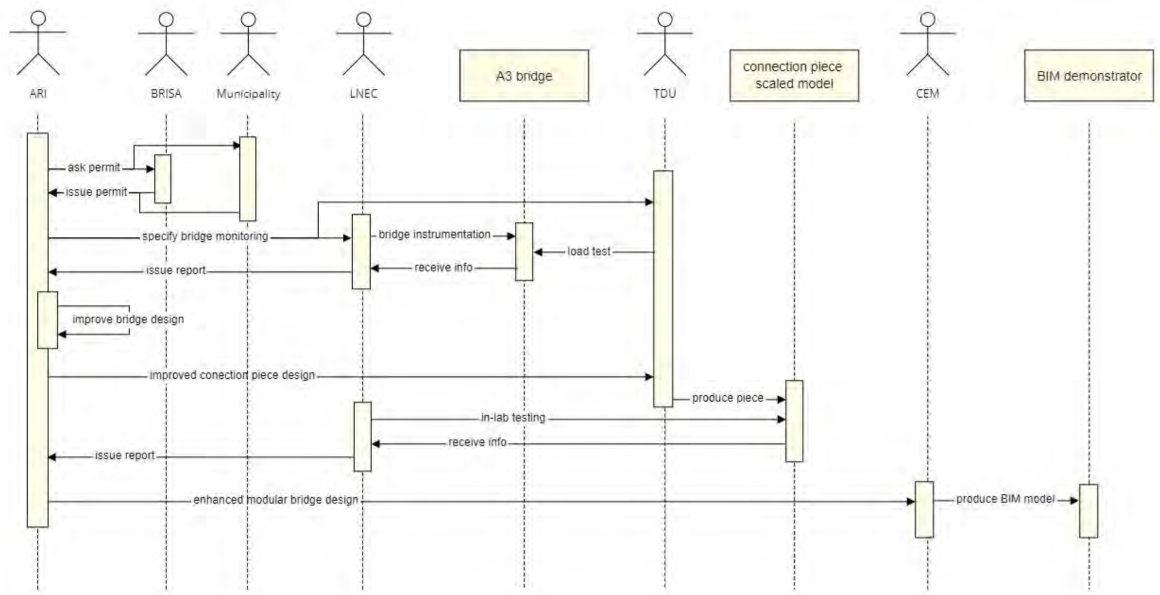
2 Diagrams of the Use Case

Context Diagram



Sequence Diagram

Use Case 4 Sequence Diagram



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3 Technical details of the Use Case – Actors

Actor Name	Actor Type	Actor Subcategories	Actor description	Further information specific to this Use Case	Equipment Manufacturer	Requirement(s) of the actor	Reference Standards/Legislation
Brisa	role	Road concessionaire	Largest Portuguese private road operator	Brisa is responsible for the A3 where the bridge to monitor is located	_	Provide the A3 access permits during load testing	
Municipality	role	Road concessionaire	Municipality that covers the area where the bridge to monitor is located	The municipality of the bridge to monitor will be responsible for organizing traffic diversion and police support	_	Provide police support to traffic diversion	
Teixeira Duarte	role	Road constructor	Large Portuguese construction company	Supply the loaded trucks for load testing Build modular bridges	_	Provide trucks with 250kN Technical knowledge on construction	EN206, EN1090, Structural Eurocodes
Teixeira Duarte	role	Industrial partner	Large Portuguese construction company	Develop modular construction for bridges	_	Industrial capacity to build the scaled model of the connecting part	International Standards and/or National Norms

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Armando Rito Engenharia	role	Civil engineering contractor	Civil engineering consultancy company specialized in bridges	Develop modular construction for bridges		Knowledge of modular bridge design	Structural Eurocodes
Cemosa	role	Civil engineering contractor	Company specialized in engineering services and quality control	Develop modular construction for bridges		Knowledge of BIM	
LNEC	role	University and research partner	Portuguese national engineering laboratory	Develop monitoring campaign and scaled model lab-testing		Availability of load testing equipment and lab-testing capacity	International Standards and National Norms or Specifications (LNEC)
LNEC	system	Laboratory	Equipment necessary to perform the monitoring campaign and scaled model lab-testing	Develop monitoring campaign and scaled model lab-testing		Appropriate calibration and methods	International Standards and National Norms or Specifications (LNEC)

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4 Step by Step Analysis of the Use Case

4.1 List of Scenarios

S.No	Scenario Name	Scenario Description	Primary Actor	Triggering Event	Pre-Condition	Post-Condition
PS1	No fault, results as expected	Best case scenario	ARI, TDU and CEM	Delivery of BIM model demonstrator	- Authorizations emitted - Load tests successful - Lab tests successful - Design enhancement achieved	Success of Use Case
AS1	No Load Test	Load test execution authorization denied	BRISA and Municipality	Load tests unable to be performed due to lack of authorization from the responsible entities	Request authorizations to perform bridge monitoring from both BRISA and the Municipality	Design of the connection piece and the bridge itself should proceed based on numerical model results
AS2	Fabrication Failure	The fabrication of the connection pieces 1:2 scaled model fails	TDU	Equipment failure	Improved design of the connection piece	Repeat connection piece fabrication
AS3	Failure in Lab Tests	Lab tests unable to be performed or results not as expected	LNEC	Technical faults may prevent the Lab tests from being performed or results are not as expected	A connection piece design must have been established by TDU/ARI in order to be tested	Although not fulfilling expectations in design improvement, a non-optimised design of the connection piece shall be used

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4.2 Steps - Primary Scenario

Scenario Name: No Fault Scenario, Results as expected									
St No.	Event	Description of Process/Activity	Information Producer	Information Receiver	Information Exchanged	Service	Requirements	Communication Media	Communication Means
1		Definition of test specifications	ARI	LNEC TDU	Definitions of equipment and tests to be performed	Create	In line with applicable Eurocodes	Technical Specification document	
2		Install bridge instrumentation	LNEC			Execute	Test specification, coordination with Municipality and Brisa		
3		Load test	TDU			Execute	Test specification, coordination with Municipality and Brisa		
4		Load test monitoring	Monitoring System	LNEC	Bridge deflections and verticality and tridimensional accelerations, etc.	Get	Equipment in place	Equipment data	GSM
5		Monitoring report	LNEC	ARI	Monitoring report	Report	Successful test	Monitoring Report document	
6		Improved bridge design, including connection piece	ARI	TDU	Improved design of connection piece	Create		CAD drawings, specifications	
7		Production of scaled models	TDU	LNEC	Improved connection piece scaled models	Execute		Delivery of product	

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8		Definition of lab test specifications	LNEC	LNEC	Definitions of equipment and tests to be performed	Create	In line with applicable Eurocodes	Technical Specification document	
9		In lab testing of connection piece	LNEC			Execute			
10		In lab testing	Lab Test System	LNEC	Compression and tension strength, etc.	Get	Connection piece delivered	Equipment data	
11		Lab test report	LNEC	ARI	Lab test report	Report	Lab test successful	Lab Test Report document	
12		Design review of existing bridge	ARI	CEM	Design review of existing bridge incorporating the results from the previous tasks	Create		CAD drawings	
13		Production of BIM model	CEM		BIM model which will be the Use Case demonstrator	Execute	Enhanced modular bridge design	BIM model	

4.3 Steps – Alternative, Error Management, and/or Maintenance/Backup Scenario

Scenario Name: Not possible to perform Load Test – Bypass of tests									
St No.	**Event**	**Description of Process/Activity**	**Information Producer**	**Information Receiver**	**Information Exchanged**	**Service**	**Requirements**	**Communication Media**	**Communication Means**
6	No Load Tests	Improvement of connection piece design will proceed without results from Load tests and will be based on numerical model results	ARI	TDU	Improved design of connection piece	Create		CAD drawings, specifications	

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Scenario Name: Connecting piece fabrication failure – Refabricate the piece									
St No.	**Event**	**Description of Process/Activity**	**Information Producer**	**Information Receiver**	**Information Exchanged**	**Service**	**Requirements**	**Communication Media**	**Communication Means**
7	Fabrication Failure	Refabricate scaled models	TDU	LNEC	Improved connection piece scaled models	Execute		Delivery of product	

Scenario Name: Connecting piece lab tests failure – Bypass of some tests									
St No.	**Event**	**Description of Process/Activity**	**Information Producer**	**Information Receiver**	**Information Exchanged**	**Service**	**Requirements**	**Communication Media**	**Communication Means**
12	Failed Lab Tests	Lab tests not performed or results not according to expectations. Design review of existing bridge will be attained based on results from a numerical model instead	ARI	CEM	Design review of existing bridge incorporating the results from the previous tasks	Create		CAD drawings	

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5 Information Exchanged

Inf. ID	Name of information exchanged	Description of information exchanged	Information Subcategories	Requirements
1	Definition of test specifications	Definitions of equipment and tests to be performed	Internal document	In line with applicable Eurocodes
4	Load test monitoring	Bridge deflections and verticality and tridimensional accelerations, etc.	Internal document	Equipment in place
5	Monitoring report	Monitoring report	Internal document	Successful test
6	Improved bridge design, including connection piece	Improved design of connection piece	Internal document	
7	Production of scaled models	Improved connection piece scaled models	Internal document	
8	Definition of lab test specifications	Definitions of equipment and tests to be performed	Internal document	In line with applicable Eurocodes
10	In lab testing	Compression and tension strength, etc.	Internal document	Connection piece delivered
11	Lab test report	Lab test report	Internal document	Lab test successful
12	Design review of existing bridge	Design review of existing bridge incorporating the results from the previous tasks	Internal document	
13	Production of BIM model	BIM model which will be the Use Case demonstrator	Internal document	Enhanced modular

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				bridge design

VR Platform

Definition of Requirements

Publish Date:	20.09.2021
Use Case Number:	UC5.1
Use Case Title:	VR Platform
Use Case Responsible Partner:	LMS

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1 Description of the Use Case

1.1 Use Case Identification

ID	Domain(s)	Name of Use Case	Level of Use Case
UC5.1	UC5: Road personnel support	Robot Teleoperation Using Virtual Reality	Detailed Use Case

1.2 Scope and Objectives

Scope and Objectives of the Use Case	
Scope	The scope of the use case is the validation of a Virtual Reality platform that will enable the teleoperation of robotic resources engaged in road maintenance activities, as well as the training of new road workers.
Objective	• Utilization of a web-based VR platform for the teleoperation of the robotic resources ○ Construction of Virtual Environment using data from various resources (google images, cameras) ○ Validate the capability to directly control the position of the robotic resources and the movement of robotic arms, allowed by reception of localization data of the resources • Utilization of VR based training tool that allows the training of new road workers in relevant procedures
Related Business Case	*BC4, Automation and robotization of maintenance operations*

1.3 Narrative of Use Case

Short description – max 3 sentences
The operator will use a VR device to access a Virtual Environment. Using the VE, the operator will be able to manipulate the remote robotic resources that are situated on the road, from a safe place. Aside from this, new operators will be trained in the safe Virtual Environment on the operations they will later work on in the road.
Complete description

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In case of teleoperation: The Operator responsible for manipulating the robotic resources in the road environment, will access a Virtual Reality device (e.g Oculus) in his work environment of choice, which can be remote, far from the road environment where the robotic resources will be situated. They will "enter" the Virtual Environment which will be a Digital Twin of the real environment and will receive continuous, real-time feedback from it, thus enabling their complete awareness of the real environment from a remote location. The Virtual Device will establish communications with a Master PC, which in turn will act as an intermediary between the Virtual Device and the remote sensors and robot. The kinematics of the robots will have been modelled in the Master PC, and a web-based communication between the Master PC and the actual robot will have been established. Using this communication, and with the modelled kinematics, the Operator will be able to manipulate the remote real robotic resources by manipulating the virtual robotic resources, as the real ones will copy the virtual ones. With this teleoperation, the operator will be able to move the robotic resources to execute road maintenance or monitoring operations.

In case of training: Any new road worker or an experienced road worker working on new operations, will need training for their tasks on the road. Using a Virtual Environment with a VR device, which will be a Digital Twin of an actual road environment, the new worker will be able to train on the road operations from a safe environment, without supervision from experienced workers. Inside the Environment there will be instructions and models representing all the tools the worker will need for their operations. Every occurrence in the real environment that the worker will have to respond to in their work can be modelled in the Virtual Environment, thus a realistic experience will be provided in a digital environment identical to a real one.

1.4 KPIs

Key performance indicators description for the Use Case:

ID	Name	Description	Target	Reference to mentioned Use Case objectives
UC5.1	KPI 2	Emergency, ordinary and extraordinary maintenance intervention times	Reduction of the intervention times of the different robot-assisted maintenance tasks addressed in the project by 15%	Development of automated and robotised intervention procedures
UC5.1	KPI 3	Volume of people in dangerous zones in road maintenance areas	Reduction of the number of people in dangerous zones in maintenance areas by 50% via the use of AR, VR and robotic platforms	Robotic and teleoperation tools specification

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1.5 Use Case Conditions

Actor	Triggering Event	Pre-conditions	Assumption
Describe which Actor(s) trigger(s) this Use Case	Describe what event(s) trigger(s) this Use Case	Describe what condition(s) should have been met before this Use Case happens	Describe the assumptions about conditions or system configurations.
Operator New road worker	Teleoperation of robotic resources Training	In case of teleoperation: ○ Construction of Virtual Environment ○ Modelling of robot kinematics ○ Establishment of communication between VE and robotic resources In case of training: ○ Construction of Virtual Environment ○ Modelling of operations and tools	• Proper function of Virtual Device • Proper function of Master PC • Proper function of remote sensors • Proper function of robotic resource • Ability to establish communications

1.6 Classification Information

Relation to Other Use Cases in the same project or area
There is a relation to UC2.1: Robotic Modular Platform
Level of Depth - the degree of specialization of the Use Case
High Level Use Case
Further Keywords for Classification
Virtual Reality, teleoperation, Virtual Environment, training, robots, Digital Twin, VR headset, Human-robot-interaction
Maturity of Use Case
By the end of the project, UC5.1 will have been executed in demonstration level

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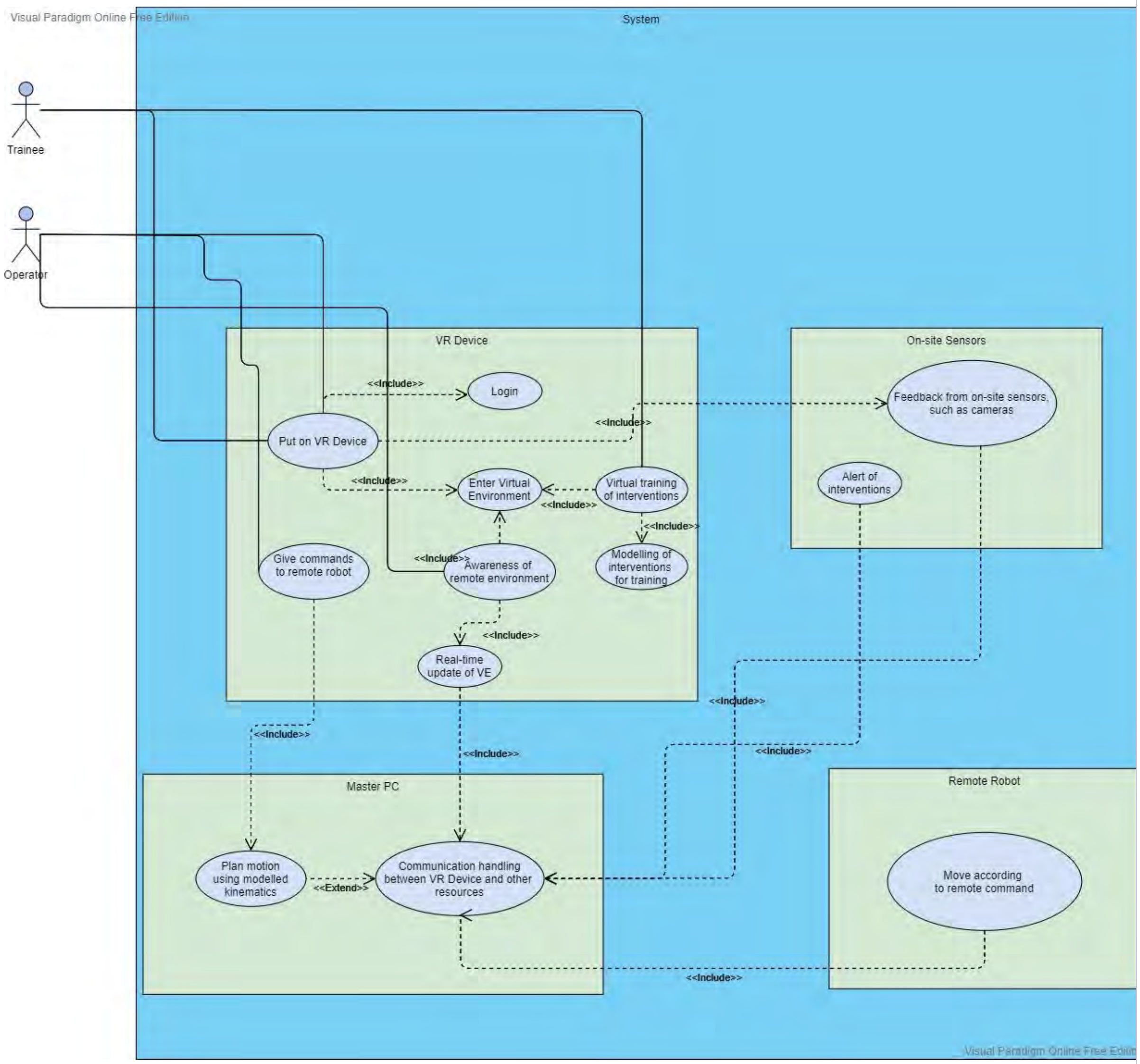
2 Diagrams of the Use Case

Context Diagram



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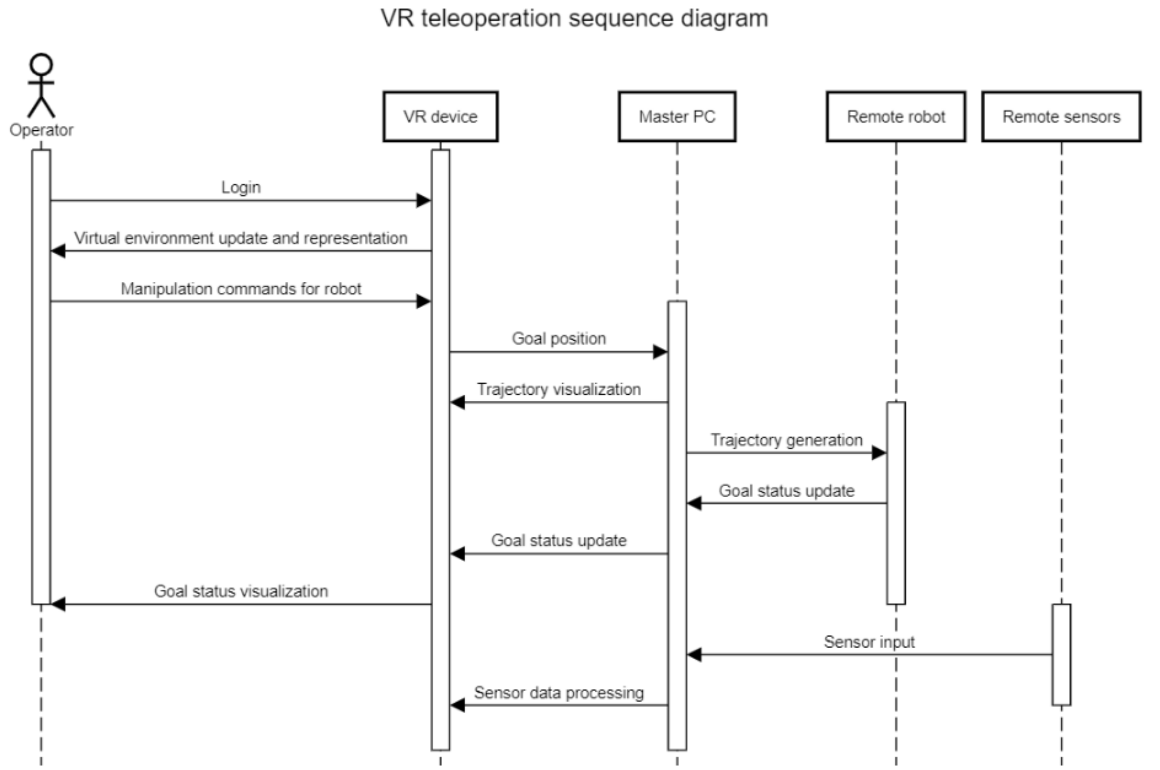
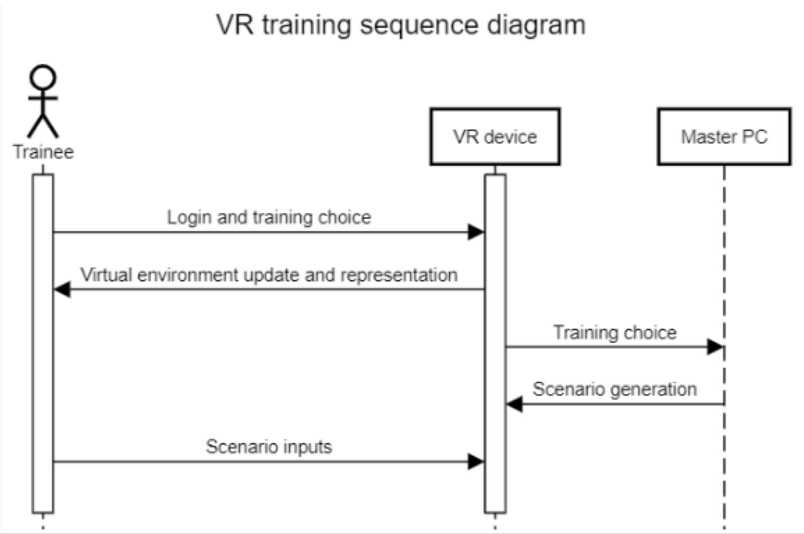
Sequence Diagram





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3 Technical details of the Use Case - Actors

Actor Name	Actor Type	Actor Subcategories	Actor description	Further information specific to this Use Case	Equipment Manufacturer	Requirement(s) of the actor	Reference Standards/Legislation
Operator (with VR headset)	role	User	Operator that uses VR headset for teleoperation of robotic resources	Operator uses real -time feedback to be aware of the environment and uses modelled kinematics in VE in order to manipulate robotic resources remotely	(for the headset) e.g Oculus, Vive	Knowledge of VR operations, possession of VR device, construction of VE, awareness of remote environment	(for the headset) UL 8400, IEEE P2048
Robotic resource	System	Robotic element	Remote robotic resource on road operations	The robotic resource will be operated remotely and will operate in road interventions		Communication protocols with VR device	ISO 10218-1 ISO 10218-2 ISO/TS 15066 ISO 12100 ISO 13849-1 ISO 13849-2 ISO 60204-1

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New road worker (with VR headset)	role	User	New road worker in training	New worker will use VR training tool to train on the operations they will conduct on the road	(for the headset) e.g Oculus, Vive	Basic knowledge of VR device	(for the headset) UL 8400, IEEE P2048

3.1 Other requirements

Provide any further requirements (technical or of other kind) which were not provided in section 3 or 5.

Master PC	System	Implementation system	Master PC to handle communications	The master PC will handle communications for the VR headset, solve kinematic and produce virtual environments for training. A different PC may also be used for developments before deploying to the headset.	Suggested requirements: Intel i7 4+ core CPU (or AMD equivalent) 16GB RAM nVidia 1060 or better graphics (or AMD equivalent)	

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4 Step by Step Analysis of the Use Case

4.1 List of scenarios

S.No	Scenario Name	Scenario Description	Primary Actor	Triggering Event	Pre-Condition	Post-Condition
PS1	Successful teleoperation	Operator uses VR platform to manipulate remote robotic resources successfully	Operator	Initialization of communication with remote resources	Communication protocols should be established, kinematics must have been modelled in VE	Success: Operator will have moved the robotic resource in the desired way
AS1	Unsuccessful teleoperation	Operator uses VR platform to manipulate remote robotic resources unsuccessfully due to communication error	Operator	Initialization of communication with remote resources	Insufficient communication protocols have been established, kinematics must have been modelled in VE	Failure: Operator could not communicate with robotic resource
AS2	Unsuccessful teleoperation	Operator uses VR platform to manipulate remote robotic resources unsuccessfully due to wrong kinematics	Operator	Initialization of communication with remote resources	Communication protocols should be established, kinematics have been wrongly modelled in VE	Failure: Robotic resources did not comply with the exact commands of the operator
AS3	Unsuccessful teleoperation or training	Operator or road worker uses VR platform to manipulate remote robotic resources or train unsuccessfully due to malfunction of the VR device	Operator or trainee	Login in VR Device		Failure: Teleoperation or training did not start because of device failure

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AS4	Unsuccessful teleoperation	Operator uses VR platform to manipulate remote robotic resources unsuccessfully due to malfunction in the robot	Operator	Manipulation commands sent to the robot	Robot has suffered damage to the arm or the controller	Failure: Erroneous movement or no movement at all
AS5	Unsuccessful teleoperation	Operator uses VR platform to manipulate remote robotic resources unsuccessfully due to malfunction in remote sensors	Operator	Operator waiting on data feedback	Sensors are malfunctioning	Failure: No feedback to operator
AS6	Unsuccessful teleoperation	Operator uses VR platform to manipulate remote robotic resources unsuccessfully due to malfunction in the Master PC	Operator	Manipulation commands sent to the master PC	Master PC is malfunctioning	Failure: No movement
PS2	VR training	New road worker uses VR tools to train for road operations	New road worker	Choice of training operation from new road worker	Modelling of all operation tools and processes	Success: New road worker trained successfully on desired operation

4.2 Steps - Primary Scenario

Scenario Name:									
St No.	**Event**	**Description of Process/Activity**	**Information Producer**	**Information Receiver**	**Information Exchanged**	**Service**	**Requirements**	**Communication Media**	**Communication Means**

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PS1 .1	Start	Operator wears VR Device				Execute	Configuration		GUI
PS1 .2	Successful	Operator initializes communication of VR Device with Master PC	Virtual Device	Master PC	Communication packets	Create	Configuration, Data management	Web-based	protocol, e.g. TCP/IP
PS1.3	Successful	Master PC initiates communication with remote robotic device	Master PC	Remote robotic resources	Communication packets	Create	Configuration, Data management	Web-based	protocol, e.g. TCP/IP
PS1 .4	Successful	Remote resource replies and communication is established	Remote robotic resources	Master PC	Communication packets	Create	Configuration, Data management	Web-based	protocol, e.g. TCP/IP
PS1 .5	Successful	Rea-time data feedback is given to the Master PC	Remote robotic resources	Master PC	Data stream	Get	Data Management,	Web-based	protocol, e.g. TCP/IP
	Successful	Rea-time data feedback is presented to the Operator	Master PC	Virtual Device	Data stream (Visual)	Get	Data Management,	Web-based	protocol, e.g. TCP/IP
PS1 .6	Successful	Manipulation commands sent from the operator to the Master PC	Virtual Device	Master PC	Movement goals	Change	Configuration, Constrains or other issues	Web-based	protocol, e.g. TCP/IP
PS1 .7	Successful	Kinematics are solved in Master PC	Master PC						
PS1 .8	Successful	Movement goal sent robotic resources	Master PC	Remote robotic resources	Movement goals	Change	Configuration, Constrains or other issues	Web-based	protocol, e.g. TCP/IP

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PS1.9	Successful	Robotic resource completes movement and sends result to Master PC	Remote robotic resources	Master PC	Result of operation	Get	Configuration, Constrains or other issues	Web-based	protocol, e.g. TCP/IP
PS1.10	End	Status of operation presented to Operator	Master PC	Virtual Device	Result of operation	Get	Configuration, Constrains or other issues	Web-based	protocol, e.g. TCP/IP
PS2.1	Start	Trainee wears VR device				Execute	Configuration		
PS2.2	Successful	Choice of training is sent to Master PC	Virtual Device	Master PC	Communication packets	Create	Configuration, Data management	Web-based	protocol, e.g. TCP/IP
PS2.3	Successful	Master PC feeds scenario to VR device	Master PC	Virtual Device	Training scenario	Create	Quality service	Web-based	protocol, e.g. TCP/IP
PS2.4	End	Trainee completes scenario	Virtual Device	Master PC	Communication packets	Create	Configuration, Data management	Web-based	protocol, e.g. TCP/IP

4.3 Steps – Alternative, Error Management, and/or Maintenance/Backup Scenario

Scenario Name:									
St No.	**Event**	**Description of Process/Activity**	**Information Producer**	**Information Receiver**	**Information Exchanged**	**Service**	**Requirements**	**Communication Media**	**Communication Means**
AS1.1	Start - unsuccessful	Operator attempts to communicate with remote robotic resources, but connection fails	Master PC	Remote robotic resources	Communication packets	Create	Configuration, Data management	Web-based	protocol, e.g. TCP/IP

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AS1.2	Corrective	Operator checks communication parameters, makes changes when necessary and reattempts; if needed in-site operator is informed to check communications on remote robotic resources	Virtual Device	Remote robotic resources	Communication packets	Create	Configuration, Data management	Web-based	protocol, e.g. TCP/IP
AS2.1	Unsuccessful	Operator attempts to correctly manipulate the robotic resources, but the kinematics are not correct and the motion is wrong	Master PC	Remote robotic resources	Movement goals	Change	Configuration, Constrains or other issues	Web-based	protocol, e.g. TCP/IP
AS2.2	Corrective	Operator stops the motion and re-models the kinematics	Virtual Device, Master PC	Virtual Device, Master PC	Configuration files	Change	Configuration, Constrains or other issues	Web-based	protocol, e.g. TCP/IP
AS4.1	Unsuccessful	Operator attempts to correctly manipulate the robotic resources, but the robotic resources are damaged	Virtual Device	Remote robotic resources	Movement goals	Change	Configuration, Constrains or other issues	Web-based	protocol, e.g. TCP/IP
AS4.2	Corrective	Robotic resources must be fixed							

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AS3.1	Unsuccessful	Operator attempts to login and utilize Virtual Device, but it is not working	Operator	Virtual Device	GUI commands	Execute	Management, quality service		GUI
AS3.2	Corrective	Virtual device is repaired either by the operator, or by the manufacturer							
AS5.1	Unsuccessful	Remote sensor feedback freezes	Remote resources	Master PC	Communication packets, data (video) stream	Repeat	Data management	Web-based	protocol, e.g. TCP/IP
AS5.2	Corrective	In-site operator is informed to check sensor communications							
AS6.1	Unsuccessful	Operator attempts to utilize Master PC, but it is not working	Virtual Device	Master PC	GUI commands	Execute	Management, quality service		GUI
AS6.2	Corrective	Master PC must be repaired either by operator or manufacturer							

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5 Information Exchanged

Inf. ID	Name of information exchanged	Description of information exchanged	Information Subcategories	Requirements
1	Login and commands from operator via Virtual Device	Utilization of Virtual Device by operator, using the graphical interface of the device,	Information exchanged between IS or sent to device	Correct function of Virtual Device
2	Sensor feedback from in-site sensors	Sensor (e.g. camera) feedback, from sensors on the road, to the VR device of the operator	Information exchanged between IS or sent to device	Correctly set communication protocols between Virtual Device, Master PC and remote sensors
3	Commands from Virtual Device to Master PC	Commands by the Operator for movement and for communication to other resources, which go through the Master PC as intermediary	Information exchanged between IS or sent to device	Correctly set communication protocols between Virtual Device, Master PC and remote robot
4	Signal from robotic resources of task status	The robotic resources will provide feedback to the operator about the status of the assigned task, e.g. motion completed.	Information exchanged between IS or sent to device	Correctly set communication protocols between Virtual Device, Master PC and remote robot
5	Communication queries	Communication queries from Virtual device and Master PC and Master PC and remote resources for initial establishment	Network topology	Correctly set communication protocols between Virtual Device, Master PC and remote robot

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AR Tools

Definition of Requirements

Publish Date:	15.09.2021
Use Case Number:	UC5.2
Use Case Title:	AR Tools
Use Case Responsible Partner:	LMS

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1 Description of the Use Case

1.1 Use Case Identification

A Use Case is a list of actions or event steps, defining the interactions between an Actor and a system, to achieve a goal.

ID	Domain(s)	Name of Use Case	Level of Use Case
UC5.2	UC5: Road personnel support.	AR tools	Detailed Use Case

1.2 Scope and Objectives

Scope and Objectives of the Use Case	
Scope	The scope of this use case is the validation of AR tools that support in-field workers with road information and maintenance guidance

Objective	• Successful utilization of AR tools that will support in-field road workers
	  ○ Achieve an improvement in the management of maintenance works
	  ○ Improve safety conditions during the interventions
	• Successful Connection of tools to (WP2) V2X module
	  ○ Provide workers with road information from V2X communications
	  ○ Provide workers with step by step instructions on maintenance operations
	  ○ Enhance workers' awareness of the surrounding environment

Related Business Case	*BC4, Automation and robotization of maintenance operations*

1.3 Narrative of Use Case

Short description – max 3 sentences
In this use case, the on-site operator will use AR devices with tools developed to support them on their road operations and maintenance.
Complete description
The on-site operator will make use of an AR device (e.g. AR glasses). The AR device will be loaded with s/w to support the operator. The AR device will connect to a master PC, which will handle

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communications with other resources. The operator will receive information from V2X communications from the road, giving them information about the situation of the road, and improving the safety conditions by informing them about the traffic. When there is a need for maintenance operations, the operator will perform road maintenance operations using the step-by-step digital instructions provided by the AR tools. The operator will also use the tools to manage the maintenance operations.

1.4 KPIs

Key performance indicators description for the Use Case:

ID	Name	Description	Target	Reference to mentioned Use Case objectives
UC5.2	KPI2	Emergency, ordinary and extraordinary maintenance intervention times	Reduction of the intervention times of the different robot-assisted maintenance tasks addressed in the project by 15%	Workers equipped with the AR device will take les time to complete their part in interventions due to the instructions.
UC5.2	KPI3	Volume of people in dangerous zones in road maintenance areas	Reduction of the number of people in dangerous zones in maintenance areas by 50% via the use of AR, VR and robotic platforms	The AR tool with its instructions will speed up the process and help workers be less time in dangerous positions, as well as providing road information which will aid them in avoiding dangerous situations.

1.5 Use Case Conditions

Actor	Triggering Event	Pre-conditions	Assumption
Describe which Actor(s) trigger(s) this Use Case	Describe what event(s) trigger(s) this Use Case	Describe what condition(s) should have been met before this Use Case happens	Describe the assumptions about conditions or system configurations.
Operator	Maintenance operations	• V2X communications established	• Proper function of AR Device • Proper function of

		• Digital instructions developed	Master PC • Proper function of V2X communications

1.6 Classification Information

Relation to Other Use Cases in the same project or area
There is a relation to UC2.1: Robotic Modular Platform
Level of Depth - the degree of specialization of the Use Case
High Level Use Case
Further Keywords for Classification
Augmented reality, maintenance operations, V2X communication, digital instructions
Maturity of Use Case
- By the end of the project, UC5.2 will have been executed in demonstration level

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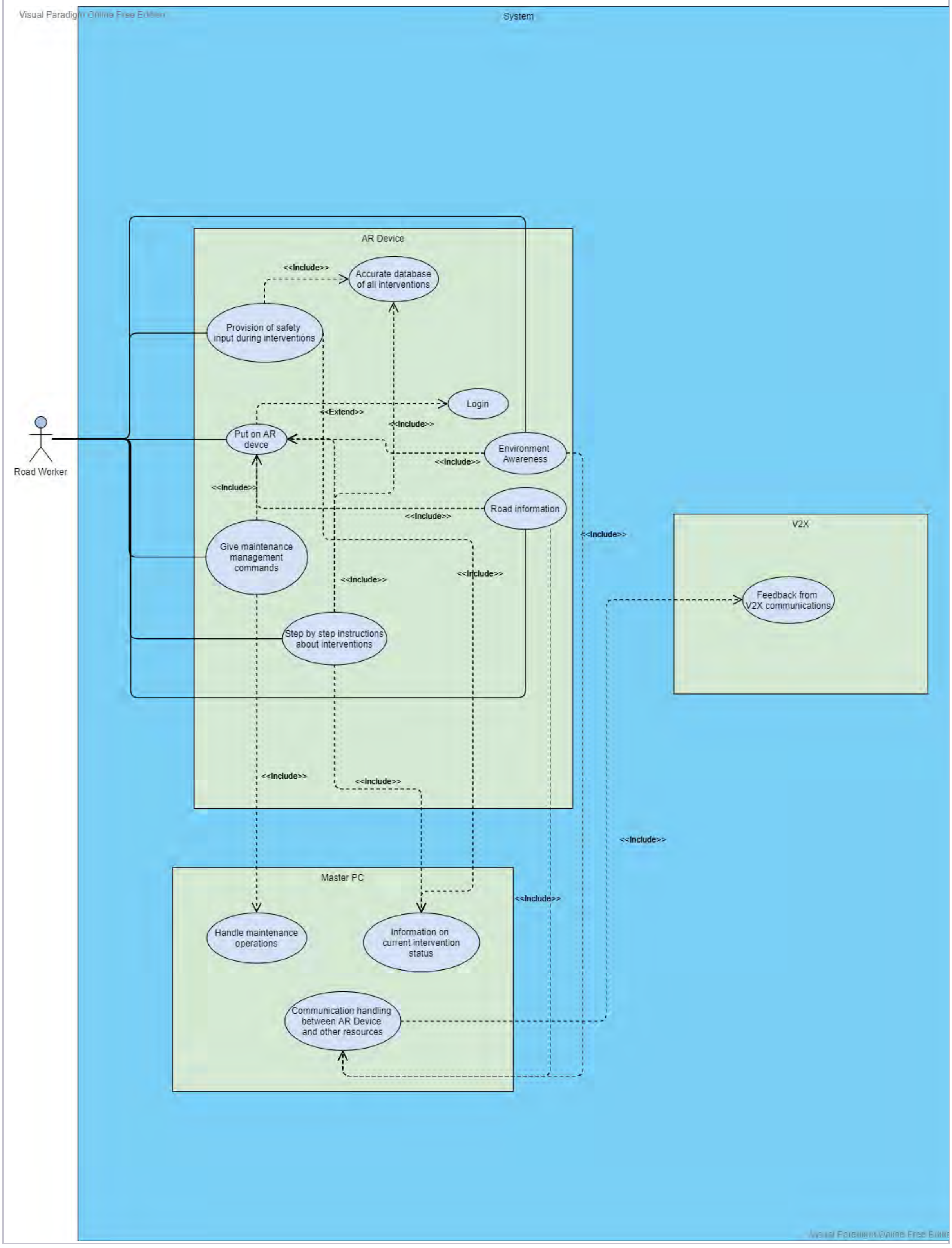
2 Diagrams of the Use Case

Context Diagram



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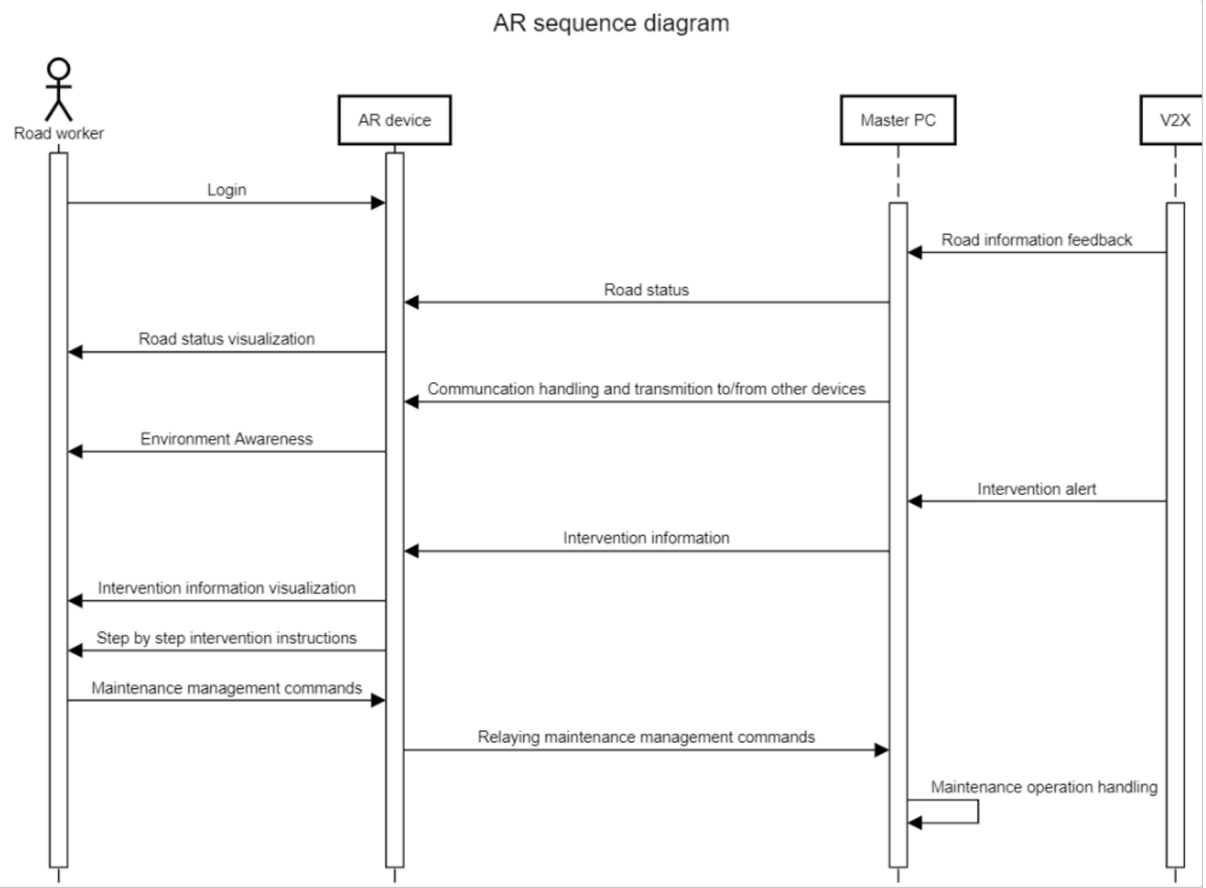
Sequence Diagram



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3 Technical details of the Use Case - Actors

Actor Name	Actor Type	Actor Subcategories	Actor description	Further information specific to this Use Case	Equipment Manufacturer	Requirement(s) of the actor	Reference Standards/Legislation
Operator	role	User	Operator in maintenance operations	Operator will use AR tools to receive road information and follow step-by-step instructions	(for the headset) e.g HoloLens 2	Usage of AR device	(for the headset) UL 8400, IEEE P2048
Every actor needs a unique actor name. E. g. Voltage sensor/ switch/ Scada/operator	System/ Role	Refer to Annex A		Describe specific role of an Actor within this Use Case.		Please provide a list of specific requirements	Please provide the reference to the applicable standards or legislation (if any)

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3.1 Other requirements

Master PC	System	Implementation system	Master PC to handle communications	The master PC will handle communications for the VR headset, solve kinematic and produce virtual environments for training. A different PC may also be used for developments before deploying to the headset.	Suggested requirements: Intel i7 4+ core CPU (or AMD equivalent) 16GB RAM nVidia 1060 or better graphics (or AMD equivalent)	

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4 Step by Step Analysis of the Use Case

4.1 List of scenarios

S.No	Scenario Name	Scenario Description	Primary Actor	Triggering Event	Pre-Condition	Post-Condition
PS1	Maintenance enhanced by AR	Operator uses step-by-step instructions, receives V2X communication data and is safely aware of the environment and can manage maintenance through headset	Maintenance operator	Maintenance is needed, operator is alerted by AR device	Proper communication configuration	Success: Maintenance operation completed
AS1	Maintenance failed because of AR device malfunction	Operator attempts to perform maintenance actions, but there are no instructions due to headset malfunction, or operator never receives maintenance alert, or management of maintenance is impossible, or operator does not have environment awareness	Maintenance operator	Maintenance is needed, or management is needed	AR headset malfunctioning	Failure: No maintenance or management, unsafe environment
AS2	Maintenance failed because of Master PC malfunction	Operator is not alerted for maintenance operations due to Master PC not communicating	Maintenance operator	Maintenance is needed, or management is needed	Master PC malfunctioning	Failure: No maintenance or management, unsafe environment
AS3	Environment awareness fails because of V2X communication error	Operator does not receive info from V2X communications and is not aware of their environment	Maintenance operator	Environment awareness is needed	V2X communications are failing	Failure: No environment awareness

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AS4	Communication between resources fails because of wrong communication configuration	Headset is not connected to Master PC, or Master Pc is not connected to V2X, or nothing is connected	Maintenance operator	Communication in the system	Communications failing	Failure: Operations do not work

4.2 Steps - Primary Scenario

Scenario Name:									
St No.	Event	Description of Process/Activity	Information Producer	Information Receiver	Information Exchanged	Service	Requirements	Communication Media	Communication Means
PS1.1	Start	Operator receives road awareness information	AR device	Operator	Data stream	Report	Security, Data	AR device	V2X
PS1.2	Successful	Operator is informed by the AR device that maintenance operation is required	AR device	Operator	alert message	Create	Data Management	AR device	GUI
PS1.3	Successful	Instructions are provided by AR app for maintenance operation	AR device	Operator	Digital instructions	Get	Quality service	AR device	GUI
PS1.4	Successful	Operator receives safety enhancement from AR Device for the intervention	AR device	Operator	Digital instructions	Get	Quality service	AR device	GUI
PS1.5	Successful	Operator completes maintenance actions and registers it in AR device	Operator	AR device	Digital GUI input	Execute	Quality service	AR device	GUI
PS1.6	Successful	AR device communicates result to Master PC	AR device	Master PC	Communication packets	Get	Data Management	Web-based	protocol, e.g. TCP/IP

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4.3 Steps – Alternative, Error Management, and/or Maintenance/Backup Scenario

Scenario Name:									
St No.	Event	Description of Process/Activity	Information Producer	Information Receiver	Information Exchanged	Service	Requirements	Communication Media	Communication Means
AS1.1	Unsuccessful	Operator attempts to perform maintenance actions, but there are no instructions due to headset malfunction, or operator never receives maintenance alert, or management of maintenance is impossible, or operator does not have environment awareness	AR device	Operator	Instructions, environment data	Get	Quality service	AR device	GUI
AS1.2	Corrective	Operator checks type of malfunction and decides how to fix the error (e.g. by himself or manufacturer)							
AS2.1	Unsuccessful	Operator is not alerted for maintenance operations due to Master PC malfunction	Master PC	AR device	Intervention alerts	Get	Data Management	Web-based	protocol, e.g. TCP/IP
AS2.2	Corrective	Operator checks type of malfunction and decides how to fix the error (e.g. by himself or manufacturer)							
AS3.1	Unsuccessful	Operator does not receive info from V2X communications and is not aware of their environment	V2X	Master PC	Environment data	Get	Data Management	Web-based	protocol, e.g. TCP/IP

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AS3.2	Corrective	Operator checks type of malfunction and decides how to fix the error							
AS4.1	Unsuccessful	Communication between resources fails because of wrong communication configuration	Any resource	Any resource	Any kind of data	Get	Data Management	Web-based	protocol, e.g. TCP/IP
AS4.2	Corrective	Operators reconfigure communications							

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5 Information Exchanged

This section provides detailed information about the information exchanged within the Use case (in the scenario steps).

Inf. ID	Name of information exchanged	Description of information exchanged	Information Subcategories	Requirements
1	V2X	traffic, weather conditions of the road	Forecast data	Proper set-up of V2X communication with AR tools
2	Data from Master PC to AR device	Maintenance alerts, environment data from V2X	Forecast data	Proper set up of communications between AR device and Master PC
3	Information from GUI to operator	Instructions, management interface	Information exchanged between IS or sent to device	Proper set u of AR headset

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OMI((RON

Intelligent Road Asset Management Platform

Road Digital Twin

Definition of Requirements

Publish Date: 17.10.2021

Use Case Number: UC6.1

Use Case Title: Road Digital Twin

Use Case Responsible Partner: UOC

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1 Description of the Use Case

1.1 Use Case Identification

ID	Domain(s)	Name of Use Case	Level of Use Case
UC 6.1	UC6: Road Digital Twin and decision support tool.	Road Digital Twin	Detailed Use Case

1.2 Scope and Objectives

Scope and Objectives of the Use Case	
Scope	The scope of this use case is the implementation of digital twin technology in road operation and maintenance management to support maintenance activities and decision making.

Objective	• Successful utilization of digital twin technology that will support the visualization of the road system
	  ○ Implementation of the digital twin technology, such as laser scanning, image processing, etc., to generate the 3D models of road
	• Successful integration of virtual model and physical models in road decision-making platform to support operation and maintenance
	  ○ Provide users with virtual models of the road system to support visualization
	  ○ Provide users with integration of virtual model and physical model
	  ○ Provide users with data integration of virtual models and real-time sensing data.

Related Business Case	*BC4, Automation and robotization of maintenance operations* *Digitalization and automation of the inspection process, please refer to Use Case and Business Case document.*

1.3 Narrative of Use Case

Short description – max 3 sentences

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In this use case, the on-site operator will use a road digital twin system to support the decision making on their road operations and maintenance.
Complete description
The on-site operator will make use of the road digital twin and decision support system. The road digital twin system will provide the function of road inspection and condition checking. Road digital twin system includes BIM-oriented digital twin, legacy system and digital inspection. The road digital twin models will be stored in a master PC, which will handle the visualization functions and automatic analysis to support the decision making for operations and maintenance. When there is a need for the maintenance inspection and operation, the operator will view the condition of each road section to check the status and decide whether it needs maintenance.

1.4 KPIs

ID	Name	Description	Target	Reference to mentioned Use Case objectives
1	KPI4	Volume of major intervention actions	Reduction of major intervention actions by 10% due to a better maintenance planning	DT and DST development process (WP5) and comparison to real world scenarios (WP1 and WP6)
2	KPI11	Road infrastructure maintenance costs	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	Development and integration of the asset management platform (WP5), comparison to real world scenarios (WP6) and assessment with business models (WP7)

1.5 Use Case Conditions

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Actor	Triggering Event	Pre-conditions	Assumption
Describe which Actor(s) trigger(s) this Use Case	Describe what event(s) trigger(s) this Use Case	Describe what condition(s) should have been met before this Use Case happens	Describe the assumptions about conditions or system configurations.
Operator	Maintenance operations	• Road digital twin model development • Digital twin platform instructions developed	• Proper functions of digital twin platform • Proper functions of Master PC • Proper functions of road inspection and maintenance

1.6 Classification Information

Relation to Other Use Cases in the same project or area
There is a relation to UC6.2: Road decision support tool
Level of Depth - the degree of specialization of the Use Case
Detailed Use Case
Further Keywords for Classification
Digital twin, Road maintenance and operations, sensors, decision making
Maturity of Use Case
By the end of the project, UC6.1 will have been executed in the demonstration level

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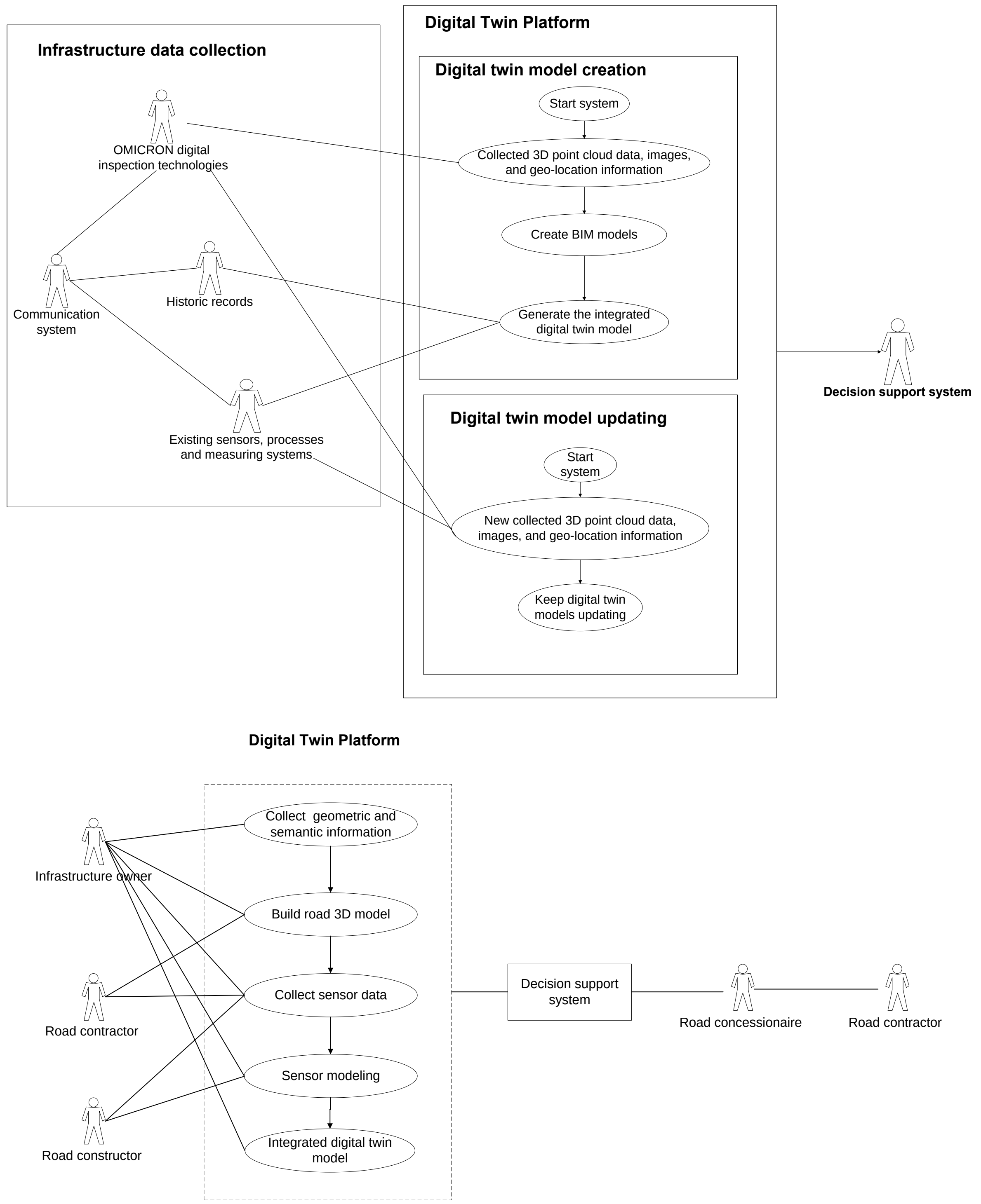
2 Diagrams of the Use Case

Context Diagram



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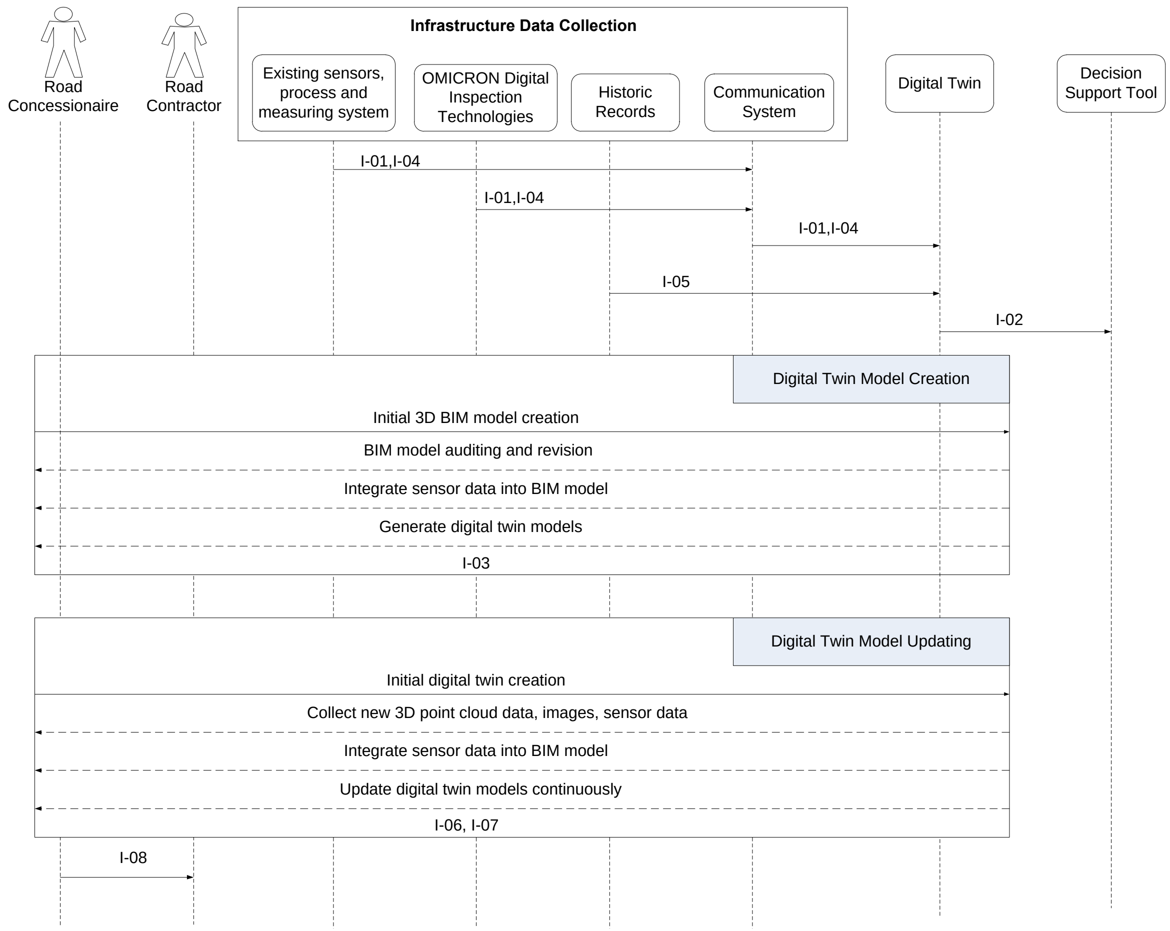
Sequence Diagram



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3 Technical details of the Use Case - Actors

Actor Name	Actor Type	Actor Subcategories	Actor description	Further information specific to this Use Case	Equipment Manufacturer	Requirement(s) of the actor	Reference Standards/Legislation
Operator	Role	User	Operator in maintenance operations	The operator will use the collected information to create digital twin models to generate the digital twin tool to do decision-making in O & M period	Master PC Mobile device AR device	Usage of master PC and mobile devices	
Road contractor	Role	Road contractor	The person working on the maintenance of the road.	This person receives the work orders defined by the road concessionaire with the help of the digital twin platform. This could be an internal maintenance department or an external maintenance provider.		To perform the maintenance of the road, the road contractor must receive adequate work orders from the road concessionaire.	
Road concessionaire	Role	Road concessionaire	Person in charge of operating the digital twin platform	The road concessionaire runs the digital twin platform and receives the information generated by it.		For the road concessionaire to execute the digital twin platform, the digital twin platform and all the technologies on which it relies on must be correctly implemented	

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Digital twin	System	IS IT	Different sources of data are integrated into the Digital Twin to generate a virtual model	The Digital Twin provides the functions of digital twin tool with the infrastructure information		The Digital Twin is one of the OMICRON project technologies, and for its functioning, it must receive information from several sources, including other OMICRON digital inspection technologies. This actor requires the correct implementation of the Digital Twin and the digital inspection technologies, the adequate installation of sensors and processes and access to historic data.	The search of the legislation and standard of the different technologies of OMICRON is part of the OMICRON project and is described in Task 1.2
Historic records	System	IS IT	General historic data about resources and use of the road which influence the decision making, this data can include economic information, records of vehicles flow, usage data, past inspections and maintenance records.	The information of the Historic records is necessary for the Digital twin and the Decision Support Tool functioning		The sources of information must be selected and the information gathered.	
Existing sensors, processes and measuring systems	System	Network elements	Devices that measure external conditions and infrastructure condition parameters like weather and temperature and that were already	This actor obtains part of the external condition data needed by the Digital Twin	These devices are prior to the project, this information must be provided by	The sensors and measuring devices must be correctly installed.	

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			functioning before OMICRON project.		the road owner or road operator		
OMICRON Digital Inspection Technologies	System	Network elements	Technologies developed during OMICRON project to perform inspections and obtain infrastructure and external conditions.	This actor obtains part of the external condition data needed by the Digital Twin	Developed during OMICRON project	Each of these technologies has their own prerequisites which are defined in their specific Use Case	The search of the legislation and standard of the different technologies of OMICRON is part of the OMICRON project
Communication system	System	Communication infrastructure	Performs the interchange of information between actors	Communication infrastructure that allows the communication between the Digital Twin and the sensors, processes and other technologies involved on the external measures		The existing sensors, processes and measuring systems and the OMICRON Digital inspection technologies must be correctly implemented and installed.	
Master PC	System	Implementation system	Master PC to visualize the road system in digital twin system	The master PC will handle the digital twin models of road and visualize the 3D models and real-time sensing data. The mobile device will assist the functions of road digital twin.	Suggested requirements: • Intel i7 4+ core CPU (or AMD equivalent) • 16GB RAM Nvidia 1060 or better graphics (or AMD equivalent)		

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4 Step by Step Analysis of the Use Case

4.1 List of scenarios

S.No	Scenario Name	Scenario Description	Primary Actor	Triggering Event	Pre-Condition	Post-Condition
PS1	Correct performance of the Digital Twin Tool: Data collection of Geometric information, semantic information, and sensor information, 3D point cloud data, and geo-location information.	There is a need of using the digital twin tool to visualize the 3D model of the road and connect the sensor data with the 3D model to support the decision making.	Once the necessary technology is ready to collect adequate information for the digital twin platform. It can start working.	There is a need for interaction and visualization of road systems for better decision making.	All the inspection technology, AR devices, sensor devices, GPS devices are working correctly.	The digital twin tool will perform a visualization and interaction platform to provide the road information, sensor information, condition information for decision making.
PS2	Correct performance of Digital Twin Tool: digital twin model creation (3D model creation and integration of 3D model and sensor data).	There is a need of using the digital twin tool to build the 3D model of the road to support the interaction of people and road for decision making.	Once the necessary data is collected and providing adequate information to the digital twin tool. It can start working.	There is a need for interaction and visualization of road systems for better decision making.	All the inspection technology, AR devices, sensor devices are working correctly.	The digital twin tool will perform a visualization and interaction platform to provide the road information, sensor information, condition information for decision making.
PS3	Correct performance of Digital Twin Tool: integration of 3D model and sensor data.	There is a need of using the digital twin tool to visualize the road and sensor to support better decision making	Once the 3D model is created and sensor data is collected. It can start working.	There is a need for interaction and visualization of road systems for better decision making.	All the road 3D models are created and sensor data are collected.	The digital twin tool will perform a visualization and interaction platform to provide the road information, sensor information for road condition assessment.

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PS4	Correct performance of Digital Twin Tool: digital twin model updating.	There is a need of using the continuously collected data to update the digital twin model.	Once there is new information required for decision making. It can start working.	There is a need for historic data and continuously updating information of road systems for better decision making.	All the digital twin models are created and sensor data are collected.	The digital twin tool will perform a visualization and interaction platform to provide the road information, sensor information for road condition assessment.
AS1	Failure receiving information	The information gathered is correct but a failure in the communications makes the delivered information incorrect or incomplete.	Communication system	Some failure on the communication systems		A protocol to detect this kind of failure and to react to it must be implemented.
AS2	Inadequate data	The digital twin tool and the communication are correctly implemented but the information provided to it is incorrect. This will result in inadequate output from the digital twin tool to the decision-making tool.	OMICRON Digital inspection technologies, Historic records, Existing sensors, processes and measuring systems.	Some failures on the data acquisition or the data processing before the digital twin tool (failures on terrestrial vehicles, sensors, drones…)		A protocol to detect this kind of failure and to react to it must be implemented.
AS3	Failure in digital twin tool: 3D model creation	There are failures in the implementation of the digital twin of 3D model creation will provide inadequate results	Digital twin tool	Some failure on the implementation of the digital twin tool		A protocol to detect this kind of failure and to react to it must be implemented.

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AS4	Failure in digital twin tool: integrated digital twin tool.	There are failures in the implementation of the digital twin tool for integration which will provide inadequate results	Digital twin tool	Some failure on the implementation of the digital twin tool		A protocol to detect this kind of failure and to react to it must be implemented.

4.2 Steps - Primary Scenario

Scenario Name: Digital Twin Model Creation									
St No.	**Event**	**Description of Process/Activity**	**Information Producer**	**Information Receiver**	**Information Exchanged**	**Service**	**Requirements**	**Communication Media**	**Communication Means**
1	Information reception	The information gathered by the inspection technologies is provided to the digital twin	Existing sensors, processes and measuring systems and OMICRON Digital Inspection technologies	Digital twin	Get	Get	Road concessionaire must initiate the process	Communication system	Communication means to be agreed with all partners involved in the Digital Twin.
2	3D model creation	3D model creation techniques are used to process the data provided by inspection technologies and sensors. The Digital Twin will integrate the 3D model with external	Existing sensors, processes and measuring systems and OMICRON Digital Inspection technologies	Digital twin	Get	Create	The Digital Twin must have correctly received the right information from the inspection technologies, sensors, communication system and the historic records	Digital Twin communication system	Communication means to be defined during the development of the Digital Twin.

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		conditions and the historic records data							
3	Digital twin model auditing and revision	Digital twin models are audit to make sure the accuracy of the 3D models.	Digital twin tool	Digital twin tool		Change	The digital twin must be correctly implemented	Digital Twin communication system	

Scenario Name: Digital Twin Model Updating

St No.	Event	Description of Process/Activity	Information Producer	Information Receiver	Information Exchanged	Service	Requirements	Communication Media	Communication Means
1	Information reception	The information gathered by the inspection technologies is provided to the digital twin	Existing sensors, processes and measuring systems and OMICRON Digital Inspection technologies	Digital twin	Get	Get	Road concessionaire must initiate the process	Communication system	Communication means to be agreed with all partners involved in the Digital Twin.
2	3D model updating	3D model creation techniques are used to process the data provided by inspection technologies and sensors.	3D model designer	Digital twin	Create	Create	The Digital Twin must have correctly received the right information from the inspection technologies, sensors, communication system and the historic records	Digital Twin communication system	Communication means to be defined during the development of the Digital Twin.
3	Digital twin model integration	The 3D models are integrated with external conditions and	Digital twin tool	Digital twin tool		Create	The digital twin must be correctly implemented	Digital Twin communication system	Communication means to be defined during the

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		the historic records data to generate the whole digital twin models.							development of the Digital Twin.

4.3 Steps – Alternative, Error Management, and/or Maintenance/Backup Scenario

Scenario Name: AS1 Failure receiving information									
St No.	**Event**	**Description of Process/Activity**	**Information Producer**	**Information Receiver**	**Information Exchanged**	**Service**	**Requirements**	**Communication Media**	**Communication Means**
1	Information reception failure	The external sensor data or the laser scanning data captured by LiDAR devices and camera sent to the digital twin is correct but a failure on the communication system makes the delivered information incorrect or incomplete.	Existing sensors, processes and measuring systems and OMICRON Digital inspection technologies	Digital Twin	I-01, I-04	Get		Communication means to be agreed with the rest of partners involved in the digital twin and decision support tool	Communication means to be agreed with the rest of partners involved in the digital twin and decision support tool

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Scenario Name: AS2 Inadequate data									
St No.	Event	Description of Process/Activity	Information Producer	Information Receiver	Information Exchanged	Service	Requirements	Communication Media	Communication Means
1	Failure on the information received	The digital twin (DT) and the communication systems are correctly implemented but the information provided to it is incorrect. This will result in inadequate output from the DT or even on computing problems.	Digital twin, historic records, existing sensors, processes and measuring systems and/or OMICRON Digital inspection technologies	Digital Twin	I-01,I-02, I-03, I-04, I-05	Create			

Scenario Name: AS3 Failure in Digital Twin: Digital twin model creation									
St No.	Event	Description of Process/Activity	Information Producer	Information Receiver	Information Exchanged	Service	Requirements	Communication Media	Communication Means
1	Information reception and gathering	The digital twin system gathers the information from the inspection technology, the historic records and the information generated previously.	Digital Twin, Historic records, Existing records, processes and measuring systems and OMICRON Digital inspection technologies	Digital twin	I-01, I-04, I-05	Get	All the information must be correctly defined and sent to the digital twin	Communication means to be agreed with the rest of partners involved in the digital twin.	Communication means to be agreed with the rest of partners involved in the digital twin.
2	Digital twin model creation	There is a failure in the digital twin model creation, and therefore	Infrastructure data collection	Digital twin	I-03	Create			

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		inadequate results are provided.							

Scenario Name: AS4 Failure in DT: digital twin model updating									
St No.	**Event**	**Description of Process/Activity**	**Information Producer**	**Information Receiver**	**Information Exchanged**	**Service**	**Requirements**	**Communication Media**	**Communication Means**
1	Information reception and gathering	The digital twin system gathers the information from the existing sensors, measuring system, inspection technology, the historic records and communication system	Digital Twin, Historic records, Existing records, processes and measuring systems and OMICRON Digital inspection technologies	Digital twin	I-01, I-03, I-04, I-05	Get	All the information must be correctly defined and sent to the DT	Communication means to be agreed with the rest of partners involved in the DT.	Communication means to be agreed with the rest of partners involved in the DT.
2	Digital twin model creation	digital twin model is created correctly.	Infrastructure data collection	Digital twin	I-03	Create			
3	Digital twin model updating failure	The digital twin system correctly updates the information in updating process.	Digital twin platform	Digital twin platform	I-06, I-07	Create			

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5 Information Exchanged

Inf. ID	Name of information exchanged	Description of information exchanged	Information Subcategories	Requirements
I-01	Infrastructure information	Road infrastructure information is measured by the sensors and the OMICRON inspection technologies.	Network state	
I-02	Infrastructure data models	Data models of the road infrastructure which mirrors the real road assets in all relevant aspects of the road asset geometry and enable its comprehensive analysis	Network state	
I-03	Infrastructure condition	The DST assets the infrastructure condition from the information provided by the Digital Twin	Network state	
I-04	External conditions	Information related to the road environment and surrounding conditions. This includes weather predictions and measurements of temperature and other relevant information captured by the sensors.	Condition parameter	
I-05	Historic records	General historic data about resources and use of the road which influence the decision making, this data can include economic information, records of vehicles flow, usage data, etc.	Historic data	
I-06	New Infrastructure information	Road infrastructure information is measured by the sensors and the OMICRON inspection technologies.	Network state	
I-07	New Infrastructure condition	The DST assets the infrastructure condition from the information provided by the Digital Twin	Network state	
I-08	Work orders	The actuations that the road contractor must perform during the maintenance works	Operator information	

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Road Decision Support Tool

Definition of Requirements

Publish Date: 15.09.2021

Use Case Number: UC6.2

Use Case Title: Road Decision Support Tool

Use Case Responsible Partner: CEMOSA

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1 Description of the Use Case

1.1 Use Case Identification

ID	Domain(s)	Name of Use Case	Level of Use Case
UC6.2	UC6: DT and Predictive maintenance	Road decision support tool	Detailed Use Case

1.2 Scope and Objectives

Scope and Objectives of the Use Case	
Scope	The scope of this Use Case is the development and implementation of OMICRON's Decision Support Tool (DST) for roads. The DST will use information previously gathered or obtained through different technologies to assess and predict the infrastructure condition and infrastructure degradation risk, so as to generate optimal road intervention planning. Therefore, this tool provides decision-making support reducing human effort and helping in the case of unexpected events and develops maintenance plans depending on road asset state, intervention level and term planning.
Objective	Through the implementation of the DST, the Use Case aims to: • Improve availability and reliability of the infrastructure. • Optimise maintenance times and use of resources. • Implement improved maintenance plans. Among others.
Related Business Case	BC3: Predictive maintenance based on infrastructure digitalisation.

1.3 Narrative of Use Case

Short description
The decision support system to be developed in OMICRON will combine methodologies and models for optimal planning of interventions and resources towards predictive maintenance. This system will analyse and predict infrastructure condition, assess infrastructure degradation risk and define optimal road intervention planning.
Complete description
The goal of this Use case is the implementation of the decision support tool. The decision support tool will process data from different sources, including (1) already existing systems, (2) digital inspection systems from OMICRON's WP2, and (3) intervention information from WP3 and WP4. These sources will integrate information such as historical records, real-time data recorded by sensors, digital twin simulations, etc. It will use different methodologies and models for the optimal planning of interventions and resources. The decision support tool will implement predictive maintenance and automated interventions. One of the main features of the decision support system is the infrastructure condition analysis. AI techniques, advanced models for asset status computation and decision-making and clustering methods for road sectioning according to condition state, safety risk and accessibility are used to process the data from the digital twin, assess infrastructure degradation risk and analyse and predict infrastructure condition. The other main feature is asset management plan optimisation, which develops the maintenance planning functionality to improve the availability and reliability of the infrastructure, maintaining the levels of service and the safety of the road infrastructure. It also enables higher level of automation in decision-making through advanced optimisation techniques. The maintenance plans will adapt to short, medium and long-term planning procedures, emergency, routine and extraordinary intervention levels and different road assets. The prioritization of interventions considers the previous results from the infrastructure condition analysis, as well as road section in terms of safety and impact on traffic and the optimisation of resources. The DST will use advanced optimisation techniques, maintenance plan simulation and comparison via what-if scenarios. The DST will be integrated with the rest of technologies (inspection technologies, robotic technologies, V2X communication platform, AR and VR tools and digital twin) and implemented in the intelligent platform.

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1.4 KPIs

Key performance indicators description for the Use Case are presented below.

ID	Name	Description	Target	Reference to mentioned Use Case objectives
KPI 4	Volume of major intervention actions	Reduction of the number of major intervention actions through the efficient implementation of the maintenance plans.	10%	Implementing improved maintenance plans
KPI 11	Road infrastructure maintenance cost	The DST chooses the optimum road infrastructure maintenance method, reducing costs.	12%	Reducing maintenance times and resources
KPI 12	Road Hazard Index	The decision support system will improve the infrastructures maintenance controlling and reducing risks and will give a fast response in case of the occurrence of emergency situations.	Contribution towards the overall project's 50% decrease	Improve availability and reliability of the infrastructure
KPI 13	Availability of the network. Impact of a reduced number of disruptions due to accidents and interventions	The optimisation of intervention actions from the DST will reduce the number and duration of disruptions, thereby increasing the availability of the infrastructure.	Contribution towards the overall project's 15% decrease	Improve availability and reliability of the infrastructure
KPI14	Availability of the network. Impact of reduced number of traffic disruptions due to maintenance	Reduction of the number of disruptions through the efficient implementation of the maintenance plans.	5%	Implementing improved maintenance plans

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1.5 Use Case Conditions

Actor	Triggering Event	Pre-conditions	Assumption
Road concessionaire	• The need to start developing maintenance plans • The need of support for the decision making	Before the decision support tool can start working, all the previous digital inspection technologies which provide information to the Digital twin must be complete and the DT must be correctly developed and tuned to provide adequate information to the platform.	UAV inspection technologies
			Vehicle inspection technologies
			Sensors, measuring and monitoring systems
			Digital twin

1.6 Classification Information

Relation to Other Use Cases in the same project or area
Use Case 6.2 implements the road decision support tool which takes information from: • UC1.1 UAVs: Management tool • UC1.2 Inspection Vehicle • UC6.1 Road digital twin
Level of Depth - the degree of specialization of the Use Case
Detailed Use Case
Further Keywords for Classification
Maintenance, decision support system, decision support tool
Maturity of Use Case
To be realized in demonstration project

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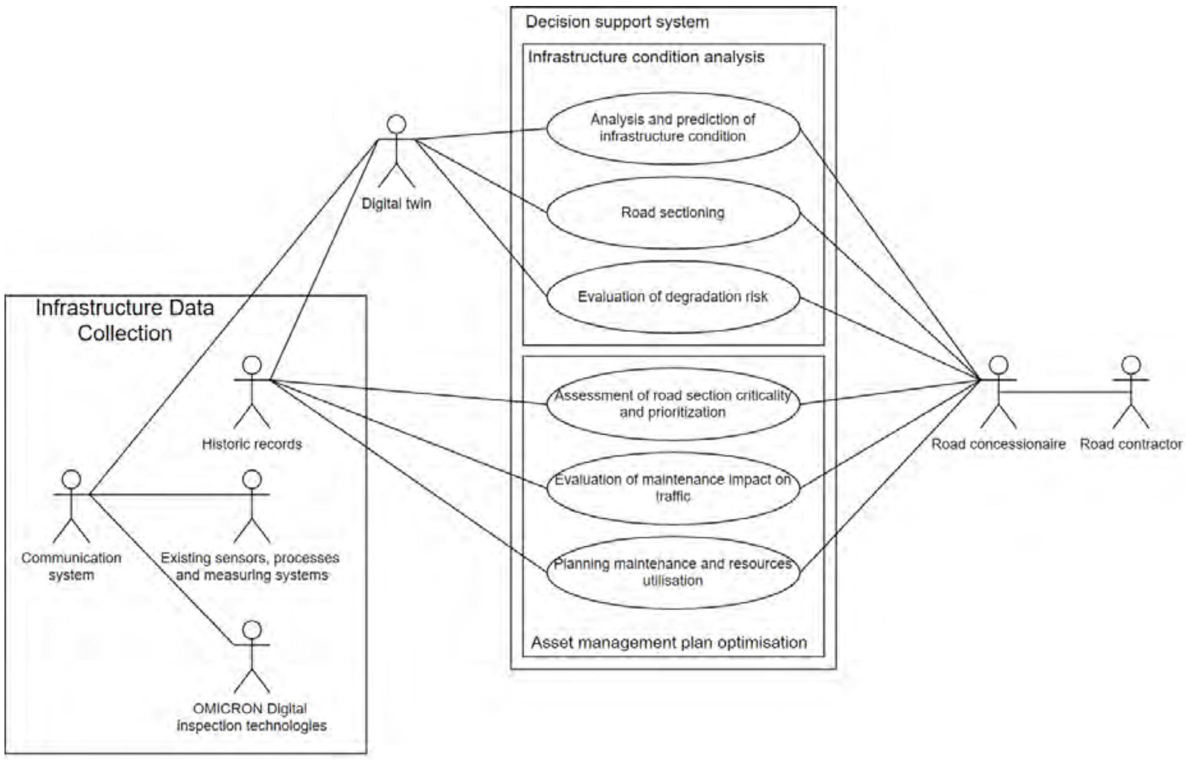
2 Diagrams of the Use Case

Context Diagram



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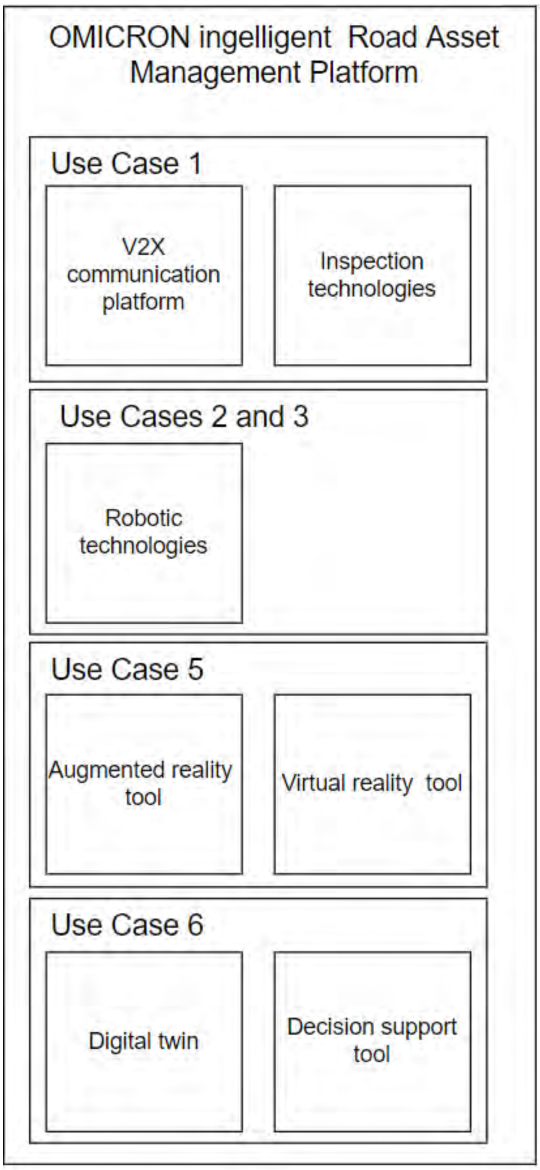
Project Context Diagram



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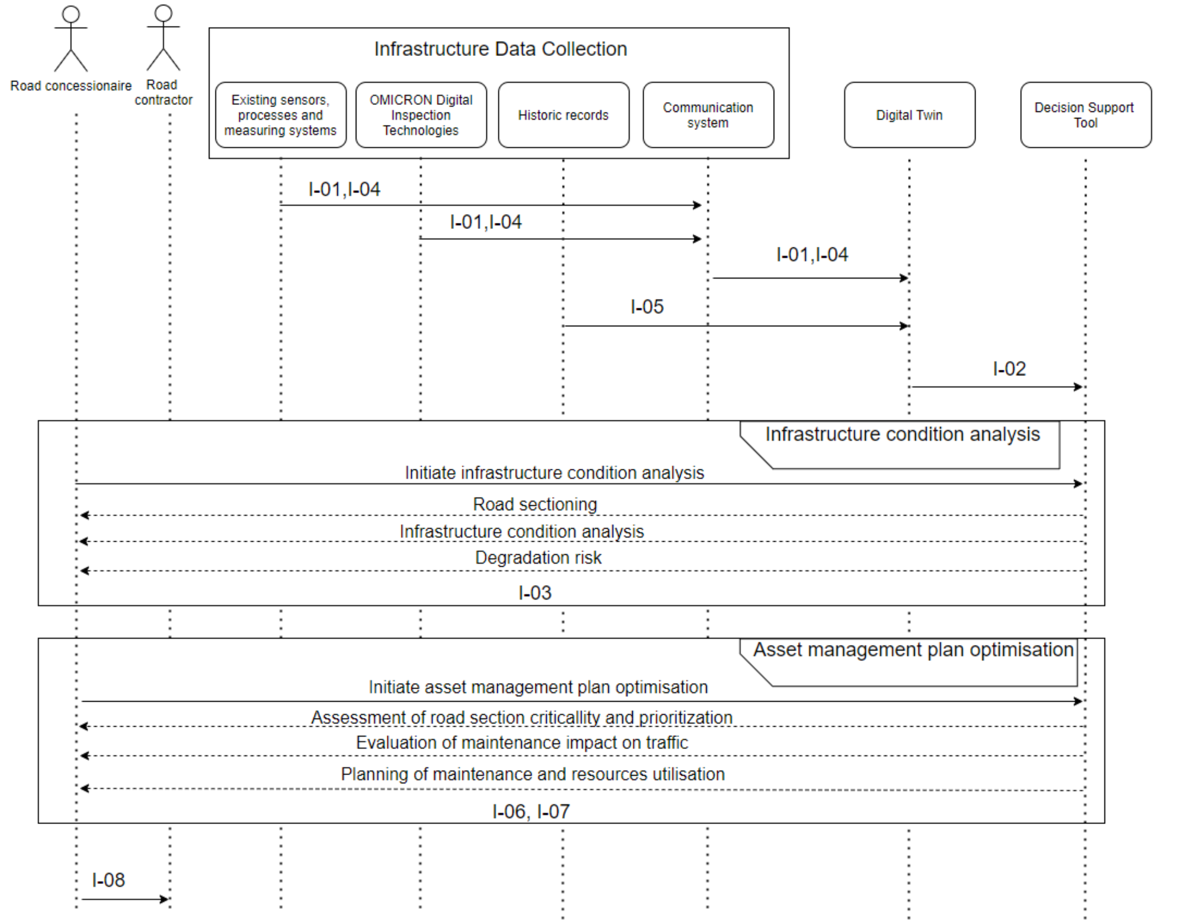
Sequence Diagram



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3 Technical details of the Use Case - Actors

Actor Name	Actor Type	Actor Subcategories	Actor description	Further information specific to this Use Case	Equipment Manufacturer	Requirement(s) of the actor	Reference Standards/Legislation
Decision Support Tool	System	IS IT	The Decision Support Tool performs the infrastructure condition analysis and the asset management plan optimisation	The Decision Support Tool provides to the road concessionaire/Manager an evaluation of road infrastructure condition and an optimized maintenance plan,		The Decision Support Tool is one of the OMICRON project technologies; it must receive information from the Digital Twin. This actor requires the correct implementation of the Digital Twin and the digital inspection technologies, the adequate installation of sensors and processes and the access to historic data. Moreover, it requires the correct implementation of the Decision Support Tool itself, in particular of the two modules “Infrastructure condition analysis” and “Asset management plan optimisation”	The search of the legislation and standard of the different technologies of OMICRON is part of the OMICRON project and is described in the Task 1.2
Digital twin	System	IS IT	Different sources of data are integrated into the Digital Twin to	The Digital Twin provides the Decision Support Tool with infrastructure information		The Digital Twin is one of the OMICRON project technologies, and for its functioning it must receive information from	The search of the legislation and standard of the different technologies of OMICRON is part

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			generate a virtual model			several sources, including other OMICRON digital inspection technologies. This actor requires the correct implementation of the Digital Twin and the digital inspection technologies, the adequate installation of sensors and processes and the access to historic data.	of the OMICRON project and is described in the Task 1.2
Historic records	System	IS IT	General historic data about resources and use of the road which influence the decision making, this data can include economic information, records of vehicles flow, usage data, past inspections and maintenance records.	The information of the Historic records is necessary for the Digital twin and the Decision Support Tool functioning		The sources of information must be selected and the information gathered.	
Existing sensors, processes and	System	Network elements	Devices that measure external	This actor obtains part of the external condition	These devices are prior to the project, this	The sensors and measuring devices must be correctly installed	

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measuring systems			conditions and infrastructure condition parameters like weather and temperature and that were already functioning before OMICRON project.	data needed by the Digital Twin	information must be provided by the road owner/operator		
OMICRON Digital Inspection Technologies	System	Network elements	Technologies developed during OMICRON project to perform inspections and obtain infrastructure and external conditions.	This actor obtains part of the external condition data needed by the Digital Twin	Developed during OMICRON project	Each of these technologies have their own prerequisites which are defined in their specific Use Case	The search of the legislation and standard of the different technologies of OMICRON is part of the OMICRON project
Road contractor	Role	Road contractor	Entity incharge of the maintenance of the road	This entity receives the work orders defined by the road concessionaire with the help of the DST. This could be an internal maintenance department or an external maintenance provider.		To perform the maintenance of the road, the road contractor must receive adequate work orders from the road concessionaire	

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Road concessionaire	Role	Road concessionaire	Entity in charge of operating the road and hence the Decision Support Tool	The road concessionaire runs the DST and receives the information generated by it		For the road concessionaire to execute the DST, the DST and all the technologies on which it relies on must be correctly implemented	
Communication system	System	Communication infrastructure	Performs the interchange of information between actors	Communication infrastructure that allows the communication between the Digital Twin and the sensors, processes and other technologies involved on the external measures		The existing sensors, processes and measuring systems and the OMICRON Digital inspection technologies must be correctly implemented and installed.	

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4 Step by Step Analysis of the Use Case

4.1 List of scenarios

S.No	Scenario Name	Scenario Description	Primary Actor	Triggering Event	Pre-Condition	Post-Condition
PS1	Correct performance of the Decision support tool: Infrastructure condition analysis	There is a need of using the decision support tool to perform infrastructure condition analysis. The DST receives the adequate information and works correctly, providing the desired results.	Once the digital twin is developed and providing adequate information to the decision support tool, it can start working.	There is a need for the infrastructure condition analysis	All the technologies on which the decision support tool depends on are working correctly.	The Decision Support Tool will perform a condition analysis of a road section or sections providing infrastructure condition, road sectioning and degradation risk.
PS2	Correct performance of the Decision support tool: Asset management plan optimization	There is a need of using the decision support tool to perform asset management plan optimization. The DST receives the adequate information and works correctly, providing the desired results.	Once the technologies that provide information to the DST are developed and provide adequate information to the DST, it can start working.	There is a need for the asset management plan optimization	All the technologies on which the decision support tool depends on are working correctly.	The Decision Support Tool will assess the road section criticality and prioritization and provide a maintenance plan in the short, medium or long term and on different intervention levels.
AS1	Failure receiving information.	The information gathered is correct but a failure on the communications makes the delivered information incorrect or incomplete.	Communication system	Some failure on the communication systems.		A protocol to detect this kind of failure and to react to it must be implemented.

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AS2	Inadequate data	The decision support tool and the communications are correctly implemented but the information provided to it is incorrect. This will result in inadequate output from the DST or even on computing problems.	Digital Twin, Historic records, Existing sensors, processes and measuring systems or OMICRON Digital inspection technologies	Some failure on the data acquisition or on the data processing before the DST (failures on terrestrial vehicles, sensors, drones…)		A protocol to detect this kind of failure and to react to it must be implemented
AS3	Failure in DST: Infrastructure condition analysis	There are failures in the implementation of the DST infrastructure condition analysis which will provide inadequate results	DST	Some failure on the implementation of the DST		A protocol to detect this kind of failure and to react to it must be implemented
AS4	Failure in DST: Asset management plan optimisation	There are failures in the implementation of the DST Asset management plan optimisation which will provide inadequate results	DST	Some failure on the implementation of the DST		A protocol to detect this kind of failure and to react to it must be implemented

4.2 Steps - Primary Scenario

Scenario Name: PS1 Correct performance of the decision support tool: infrastructure decision analysis									
St No.	Event	Description of Process/Activity	Information Producer	Information Receiver	Information Exchanged	Service	Requirements	Communication Media	Communication Means
1	Information reception	The information gathered by the sensors is provided to the digital twin	Existing sensors, processes and measuring systems and	Digital Twin	I-01, I-04	Get	Road concessionaire must initiate the process	Communication system	Communication means to be agreed with the rest of partners

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			OMICRON Digital Inspection technologies						involved in the DT and DST
2	Digital Twin operation	The Digital Twin will integrate the external conditions and the historic records data to generate the infrastructure information	Digital Twin	Decision Support System	I-02	Create	The Digital Twin must have correctly received the right information from the communication system and the historic records	Digital Twin communication system	Communication means to be defined during the development of the DT
3	Decision Support System process of data	AI techniques are used to process the data provided by the DT	Decision Support Tool	Decision Support Tool		Create	The DST must be correctly implemented		
4	Assess infrastructure degradation (and failure) risk	Advanced models for asset status computation and decision-making are used to assess the infrastructure degradation risk.	Decision support tool	Decision Support Tool		Create	The DST must be correctly implemented		
5	Analyse and predict infrastructure condition	Advanced models for asset status computation are used to analyse and predict infrastructure condition	Decision Support Tool	Decision Support Tool		Create	The DST must be correctly implemented		

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6	Road sectioning	AI techniques and clustering methods are used to perform the road sectioning according to condition state, safety risk and accessibility.	Decision Support Tool	Decision Support Tool		Create	The DST must be correctly implemented		
7	Sending of information	The information created by the DST is sent to the road concessionaire.	Decision support tool	Road concessionaire	I-03	Get	The infrastructure condition analysis ran correctly	Data query in the system	Data query in the system
8	Work orders reception	If desired the road concessionaire uses the information provided by the DST in relation to infrastructure condition to give the road contractor adequate work orders	Road concessionaire	Road contractor	I-08	Get	The road concessionaire must receive an adequate output from the DST	Decided by the road concessionaire	Decided by the road concessionaire

Scenario Name: PS2 Correct performance of the decision support tool: Asset management plan optimisation									
St No.	**Event**	**Description of Process/Activity**	**Information Producer**	**Information Receiver**	**Information Exchanged**	**Service**	**Requirements**	**Communication Media**	**Communication Means**
1	Information reception and gathering	The decision support system already has access to the information previously received by the Digital Twin and the information generated during the infrastructure condition	Decision Support Tool and Historic records	Decision Support Tool	I-01, I-02,I-03, I-04, I-05	Get	Road concessionaire must initiate the process	Data query in the system	Data query in the system

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		analysis and receives information from historic records.							
2	Assessment of road section criticality and prioritization of maintenance interventions	Stochastic models and comparison of what-if scenarios are used to assess road section criticality	Decision Support Tool	Decision Support Tool		Create	The DST must be correctly implemented		
3	Evaluation of maintenance impact on traffic	Simulation models of road traffic are used to evaluate the impact on road users.	Decision Support Tool	Decision Support Tool		Create	The DST must be correctly implemented		
4	Development of optimisation models for planning maintenance and resources utilisation	Advanced optimisation techniques are used to provide optimised asset management plans.	Decision Support Tool	Decision Support Tool		Create	The DST must be correctly implemented		
5	Sending of information	The information created by the DST is transmitted to the road concessionaire	Decision Support Tool	Road concessionaire	I-06, I-07	Get	The asset management plan optimisation ran correctly	Visualisation	HMI
6	Work orders reception	If desired, the road concessionaire can use the maintenance plans and prioritization of interventions provided by the DST to give the road constructor adequate work orders	Road concessionaire	Road contractor	I-08	Get	The road concessionaire must receive an adequate output from the DST	Decided by the road concessionaire	Decided by the road concessionaire

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4.3 Steps – Alternative, Error Management, and/or Maintenance/Backup Scenario

Scenario Name: AS1 Failure receiving information									
St No.	Event	Description of Process/Activity	Information Producer	Information Receiver	Information Exchanged	Service	Requirements	Communication Media	Communication Means
1	Information reception failure	The external conditions sent to the DT is correct but a failure on the communication system makes the delivered information incorrect or incomplete.	Existing sensors, processes and measuring systems and OMICRON Digital inspection technologies	Digital Twin	I-01, I-04	Get		Communication means to be agreed with the rest of partners involved in the DT and DST	Communication means to be agreed with the rest of partners involved in the DT and DST

Scenario Name: AS2 Inadequate data									
St No.	Event	Description of Process/Activity	Information Producer	Information Receiver	Information Exchanged	Service	Requirements	Communication Media	Communication Means
1	Failure on the information received	The Decision Support Tool and the communication systems are correctly implemented but the information provided to it is incorrect. This will result in inadequate output from the DST or even on computing problems.	Digital twin, historic records, existing sensors, processes and measuring systems and/or OMICRON Digital inspection technologies	Decision Support Tool	I-01,I-02, I-03, I-04, I-05	Create			

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Scenario Name: AS3 Failure in DST: infrastructure condition analysis									
St No.	Event	Description of Process/Activity	Information Producer	Information Receiver	Information Exchanged	Service	Requirements	Communication Media	Communication Means
1	Information reception and gathering	The decision support system gathers the information from the Digital Twin, the historic records and the information generated previously.	Digital Twin, Historic records, Existing records, processes and measuring systems and OMICRON Digital inspection technologies	Decision Support Tool	I-01, I-02, I-04, I-05	Get	All the information must be correctly defined and sent to the DST	Communication means to be agreed with the rest of partners involved in the DT and DST.	Communication means to be agreed with the rest of partners involved in the DT and DST.
2	DST infrastructure condition analysis failure	There is a failure in the DST processing, and therefore inadequate results are provided.	Decision Support Tool	Decision Support Tool	I-03	Create			

Scenario Name: AS4 Failure in DST: Asset management plan optimisation									
St No.	Event	Description of Process/Activity	Information Producer	Information Receiver	Information Exchanged	Service	Requirements	Communication Media	Communication Means
1	Information reception and gathering	The decision support system gathers the information from the Digital Twin, the historic records and the information generated previously.	Digital Twin, Historic records, Existing records, processes and measuring systems and OMICRON	Decision Support Tool	I-01, I-02, I-03, I-04, I-05	Get	All the information must be correctly defined and sent to the DST	Communication means to be agreed with the rest of partners involved in the DT and DST.	Communication means to be agreed with the rest of partners involved in the DT and DST.

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			Digital inspection technologies						
2	DST infrastructure condition analysis failure	The decision support system correctly evaluates the infrastructure condition	Decision Support Tool	Decision Support Tool	I-03	Create			
3	DST asset management plan optimisation failure	There is a failure in the DST processing, and therefore inadequate results are provided.	Decision Support Tool	Decision Support Tool	I-06, I-07	Create			

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5 Information Exchanged

This section provides detailed information about the information exchanged within the Use case (in the scenario steps).

Inf. ID	Name of information exchanged	Description of information exchanged	Information Subcategories	Requirements
I-01	Infrastructure information	Road infrastructure information measured by the sensors and the OMICRON inspection technologies.	Network state	
I-02	Infrastructure data models	Data models of the road infrastructure which mirrors the real road assets in all relevant aspects of the road asset geometry and enable its comprehensive analysis	Network state	
I-03	Infrastructure condition	The DST assets the infrastructure condition from the information provided by the Digital Twin	Network state	
I-04	External conditions	Information related to the road environment and surroundings conditions. This includes weather predictions and measurements of temperature and other relevant information captured by the sensors.	Condition parameter	
I-05	Historic records	General historic data about resources and use of the road which influence the decision making, this data can include economic information, records of vehicles flow, usage data, etc.	Historic data	
I-06	Prioritization of interventions	The asset management plan optimization task provides a prioritization of interventions to help in the decision making.	Optimised value	
I-07	Maintenance plans	The DST develops different maintenance plans depending on the time span (short, medium or long term maintenance plans) and the intervention levels (emergency, routine and extraordinary).	Operator information	
I-08	Work orders	The actuations that the road contractor must perform during the maintenance works	Operator information	

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