This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 861111

DRONES4SAFETY

Drones4Safety

Research & Innovation Action (RIA)

Inspection Drones for Ensuring Safety in Transport Infrastructures

Use-case Document

D2.4

Due date of deliverable: 31.01.2021

Start date of project: June 1st, 2020

Type: Deliverable
WP number: WP2

Responsible institution: EUCENTRE
Editor and editor's address: Martina Mandirola (martina.mandirola@eucentre.it)
Chiara Casarotti (chiara.casarotti@eucentre.it)

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 861111

Version 3.5
Release Date: Dec 12, 2020

Project funded by the European Commission within the Horizon 2020 Programme		
Dissemination Level		
PU	Public	✓
CO	Confidential, only for members of the consortium (including the Commission Services)	

Change Log

Rev.	Date	Who	Site	Change
0.1	01/09/2020	Mandirola/ Casarotti	EUC	Created initial draft version
0.2.1	15/09/2020	Mandirola/ Casarotti/ Del Sole	EUC	Updates including rev. NEAT
0.3.0	08/10/2020	Mandirola/ Casarotti	EUC	UCA tables approach
0.3.1	20/10/2020	Mandirola/ Casarotti	EUC	Bridge UC description and minor changes
0.3.2	10/11/2020	Mandirola	EUC	Bridge UC integration and UCA tables removal
0.3.3	11/11/20	Casarotti	EUC	Reduced image size, minor revisions
0.3.4	16/11/20	Mandirola/ Casarotti/Taurino	EUC	Safety consideration integrations and Annex1
0.3.5	12/12/20	Mandirola	EUC	Minor changes and Integration including rev. from AU
0.3.6	28/01/2021	Cabasino / Venturucci / D'Orazio / Del Sole	NEAT	Review Railway Part
1.0	31/01/2021	Ebeid	SDU	First Issue

Executive Summary

The present deliverable is focused on the individuation and analysis of different sites in order to find specific use-cases for bridge and railway inspection suitable to test and validate the D4S platform. The actual experimentation and system validation, presented in WP7, will then be conducted on selected sites, according to the resulting best options.

The document is structured in 6 sections. After an introduction (Section 1) describing the purpose of the document and the partners involved, Section 2 presents a standard methodology applied in System Engineering to discover and represent the behaviour of the system by means of Use Case Action (UCA) modelling. The D4S functionalities as well as the UCAs expected to be validated during the in-situ exercises, are reported in Section 3. The description of the railway and bridge use cases (UCs) analysed and some preliminary general considerations about the safety assessment are reported in Section 4. Section 5 concludes the deliverable, summarising issues still open.

In Annex 1 (Section 6) general aspects, procedures and critical issues related to the use of UAS for the inspection of bridges are reported.

In Annex 2 (Section 7) some general aspects, procedures and critical issues related to the current use of drones for the inspection of railway are also reported.

Contents

List of Figures

List of Tables

Acronyms

Acronym	Description
AC	Alternating Current
AI	Artificial Intelligence
CAA	Civil Aviation Authority
D4S	Drones4Safety
DC	Direct Current
FOB	Foreign Object Debris
GSD	Ground Sample Distance
GNSS	Global Navigation Satellite System
PCW	Test and Validation Center Wildenrath
SfM	Structure for Motion
UAS	Unmanned Aircraft System
UC	Use Case
UCA	Use Case Action
UML	Unified Modeling Language
TBD	To Be Defined
V&V	Verification and Validation

References

Project Parent Documents

The Parent Documents establish the criteria and technical basis for the existence of this document. The D4S Parent Documents are listed in the following table.

Reference	Code	Title
[PD-1]	DoA	Drones4Safety Description of Action – digitally signed by EC on 209-09-12 16:47:45

Project Applicable Documents

Applicable Documents are those documents whose content are considered to form a part of this document. The specified parts of the Applicable Documents carry the same weight as if they were stated within the body of this document. The D4S Applicable Documents are listed in the following table.

Reference	Code	Title
[AD-1]	SRD	Drones4Safety – D2.3 System Requirements Document v1.0 – 2020-08-31
[AD-2]	RGBA	Drones4Safety – D2.2 Regulatory Gap/Barriers Analysis (initial) – v1.0 – 2020-09-14

External References

B. Anda, D. I. K. Sjøberg – Towards an inspection technique for use case models – Proceedings of the 14th international conference on Software engineering and knowledge engineering, 2002. pp. 127-134.

Circular ATM-09 (2019). Remotely piloted aircraft (RPA) criteria for the use of airspace. Available online: https://www.enac.gov.it/la-normativa/normativa-enac/circolari/serie-atm/circolare-atm-09

D-Flight. Portal dedicated to UAS Italian operators for the provision of registration services, geo-awareness, remote identification and publication of information on geographical areas. [online] https://www.d-flight.it/new_portal/en/

ENAC Guidelines (2020) Guidelines LG 2020/001-NAV Ed. 1 30th September 2020. Available online: https://www.enac.gov.it/la-normativa/normativa-enac/linee-guida/lg-2020001-nav

ENAC Regulation (2020). Regolamento mezzi aerei a pilotaggio remoto (RPAS Regulation). Available online: https://www.enac.gov.it/sites/default/files/allegati/2020-Lug/Regolamento_APR_Ed_3_Emend_1.pdf.

F. Armour and G. Miller – Advanced use case modeling: software systems – Addison-Wesley, 2001

Grady Booch, Ivar Jacobson, and James Rumbaugh – Unified Modeling Language Users Guide – Addison Wesley Longman, Inc, 1999 – ISBN 0-201-57169-2.

ISO/IEC 19501:2005 – Information technology – Open Distributed Processing — Unified Modeling Language (UML) – Version 1.4.2 – April 2005, confirmed in 2019 (Accessed: 2020/09/03)

ISO/IEC 19505-1:2012 – Information technology – Object Management Group Unified Modeling Language (OMG UML) – Part 1: Infrastructure" – April 2012, confirmed in 2017 (Accessed: 2020/09/03)

Unified Modeling Language (UML) 2.0, http://www.uml.org (Accessed: 2020/08/31)

1 Introduction

The main scope of the Drones4Safety (D4S) project is to develop a system of autonomous, self-charging, and collaborative drones that, inspecting a big portion of transportation infrastructures in a continuous operation, can increase the safety of the European civil transport network. This scope will be achieved through a series of objectives which may be summarised by means of the following keywords: Energy harvesting, AI inspection algorithms, Drone swarm, Failsafe inspection and Autonomous navigation.

The project outcomes, in forms of software services and hardware drone system, will offer to railway and bridge operators the chance to inspect their transportation infrastructure accurately, frequently, and autonomously.

Starting from the preliminary D4S system requirements defined in T2.3, the main purpose of this document is to provide a preliminary description and analysis of the different use-cases which may be used to validate the platform, with respect to the two different target environments: Bridges and Railways. As already anticipated, the actual experimentation and system validation, presented in WP7, will then be conducted on selected sites, according to the resulting best options from multiple point of views (safety, number of UCAs that can be tested, authorization processes, access to the area, etc.).

1.1 Drones4Safety involved partners and their role in the use-cases

In the Drone4Safety project, partners coming from different contexts (leading industrial, research and academic) cooperate and share their expertise in infrastructure inspection, energy harvesting, machine learning, communications, and drone technology. In particular, an overview of the expertise of the consortium partners is reported in Table 1.

	SDU	AU	FH	EUC	DL	NEAT	ARIC	DBL	ECTL
Drone design	X				X	X			
Infrastructure inspection				X	X	X	X		
Structural damages				X		X			
Structural modelling and assessment				X					
AI and fault detection	X				X				
Autonomous navigation	X	X			X		X		
Communication system design		X			X				
Swarm system		X							
Energy harvesting	X		X						
Path planning and mapping	X	X		X	X		X		
Access to test sites				X		X	X		
Drone Regulations	X			X	X	X		X	X

Table 1 – Expertise of consortium partners

As detailed in the following, the partners mainly involved in this task are EUC, NEAT, ARIC and DL who will still benefit from the collaboration of all the other partners.

For what concerns the railway inspection, NEAT will lead the use case with the collaboration of all partners. Primary roles will be conducted by both, NEAT, as a Drone Operator for Critical Operations and Railway expert in Italy, and ARIC, a research facility for rail systems in Germany. For the practical tests and drone flights, the Test and Validation Center Wildenrath (PCW) is available in Germany. ARIC will provide and organize all necessary access to this railway test bed, being operated by Siemens. The flights will be conducted by drone operators, duly trained and authorized for BVLOS flight, in charge of all the administrative and technical aspects of the flight (including meteorological evaluation). During the very first flights, in order to educate the AI algorithms, the drone operators will be assisted by a maintenance expert, in charge of the target's definition and real-time analysis, providing directions to the drone operators. Flights outside PCW will be conducted in non-restricted fly-zones with no hazard for the people.

Flights on real railway segment will be conducted in Italy by NEAT, also in collaboration with ARIC, in order to acquire material to nourish the AI algorithms and to prepare maps, and to perform preliminary tests and validation of the system components.

The bridge use-case validation will be managed by EUCENTRE in Italy with the collaboration of all partners. Different sites will be analysed, in order to find suitable locations to conduct the experimentations for the project.

2 Use Case Modelling Methodology

When dealing with a system, it is of paramount importance to describe the expected behaviour of the system form the point of view of the stakeholders and, in particular of the involved actor(s), i.e. the (end-)users of the system. In this section a standard methodology applied in System Engineering to discover and represent the behaviour of the system by means of Use Case Actions modelling is presented in a simplified form.

A UC describes a case study where a set of actions that the system should or can perform in collaboration with one or more external users of the system, i.e. the Actors. Each UC should provide some observable and valuable result to the Actors or other Stakeholders of the system. The proposed methodology foresees the use of the Unified Modelling Language (UML, 2020, Grady Booch, 1999, [RD-2]), a general-purpose, developmental, modeling language in the field of System Engineering (and, in particular, of Software Engineering), which provides a standard way to visualize the static and dynamic design of a system and includes UCAs among its Behavioural Diagrams. UML become an ISO standard under the Object Management Group (OMG) umbrella (ISO/IEC 19501:2005 and ISO/IEC 19505-1:2012).

The above-mentioned methodology foresees the following main activities:

1. Actors Discovery
2. Use Case Identification
3. Model Organisation
4. Use Case Prioritisation
5. Use Case Description
6. Model Verification and Validation (V&V)

which are detailed in the following subsections.

2.1 Actors Discovery

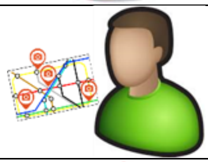
The first task of the proposed methodology is finding the actors involved in the use of the system, i.e. all the different roles that a user or external system plays when interacting with the system under design. This activity is fundamental because it represent a good starting point from which to identify UCs. Moreover, by defining the Actors, specific needs in terms of usage profiles of the systems and, thus, different configuration of the system itself may be discovered and properly taken into account.

Actors Discovery can be progressive task: at the very beginning, the goal is to identify the main actors of the system; by refining and deepening the analysis, more Actors can be identified, for example by defining specific roles that are a specialisation of the main ones. For example, a Maintenance Expert can be specialised in a Railway Maintenance Expert and in a Bridge Maintenance Expert. Going down into the refining, a Railway Maintenance Expert can be further specialised into a Railway Aerial Power Line Maintenance Expert and in a Railway Tracks Maintenance Expert.

The main sources for discovering the Actors, in any case, are organisational charts, work procedures, and interviews and brainstorming with end-users.

In D4S, the main Actors listed in the following table have been identified.

Table 2 – D4S Main Actors

Actor	Icon	Label	Description
Maintenance Manager		MM	An expert in the organisation of the maintenance of railways or bridges, able to address the mission planning, whose contribution is necessary during system setup, configuration and “education”.
Maintenance Expert		ME	An expert in the operational maintenance of railways or bridges, able to address the best way to inspect a given target, whose contribution is necessary during system setup, configuration and “education”.
Mission Planning Operator		MPO	A specialist able to define and validate a mission
Drone Pilot		DP	A specialist able to control a drone in Visual Line of Sight (VLOS) operations.
Drone Pilot Assistant		DPA	A specialist able to assist a drone pilot in the preparation of the equipment and in for the Extended Visual Line-of-Sight (EVLOS) operations.
Mission Execution Supervisor		MES	A specialist supervising the flight mission in Beyond Visual Line of Sight (BVLOS) operations and able to take the remote control of the drone, if necessary (a sort of Super-Pilot).
Maintenance Analyst		MA	A specialist (expert in railway or bridges structural performance) able to analyse the potential defects revealed by the drone and to validate the outcomes of the automatic AI elaboration
Computer Vision Algorithms Expert		CVE	A specialist able to configure and educate computer vision algorithms.
Drone		D	An automatic supervised drone used for inspection. The drone is programmed to take automatic decisions and can thereby trigger some use cases.

2.2 Use Case Identification

Use cases are first identified using basically one of the following approaches, explained in the following subsections:

1. Scenario-driven
2. Actor vs Responsibility
3. Unstructured aggregation
4. Mission decomposition

In any case, once identified, the UC is connected to the Actor(s) in a Use Case Diagrams, a graphical representation which show the interaction between the actors and the UCs and the relations between the various UCs in the model, as shown in the following picture.

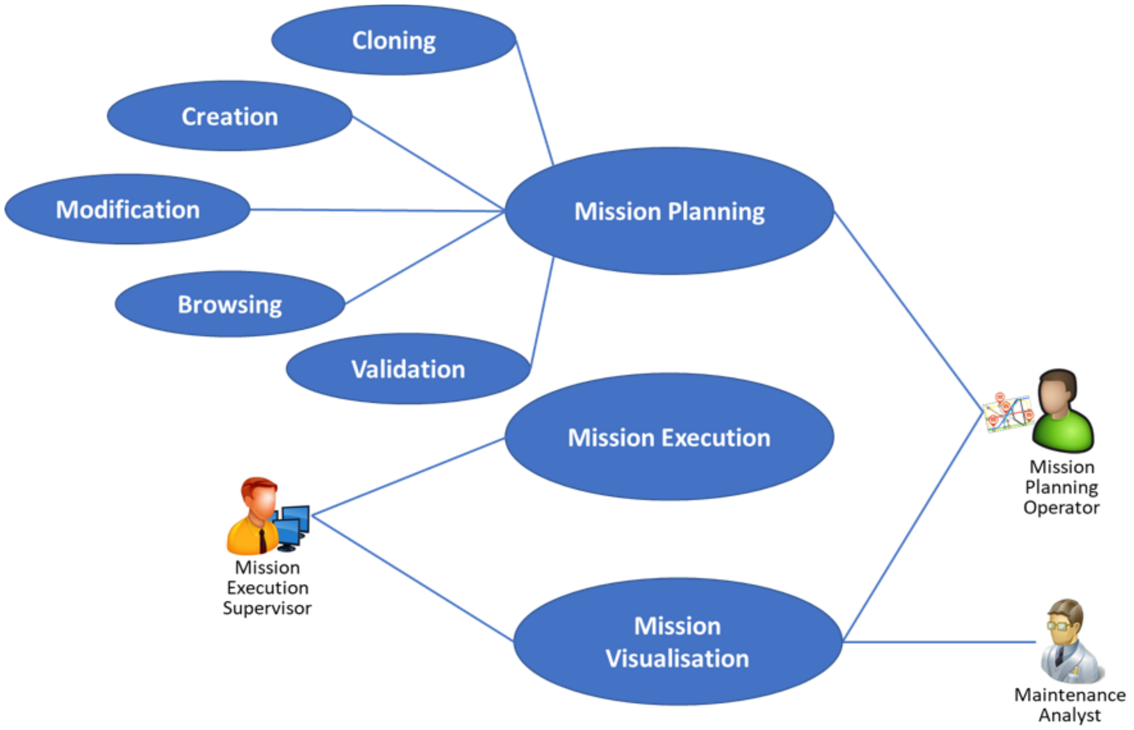


Figure 1 – Example of Use Case Diagram

In the "Scenario-driven" approach, the designer identifies the list of main Actors and, for each of them, try to answer for questions such as:

- What services does the Actor need from the system?
- What services does the Actor provide?
- What information does the Actor need from the system?
- What measurable value is needed by the Actor?
- What business event might this Actor initiate (based on her role)?
- What are the activities that are recurring and triggered by time?

Each identified UC shall encapsulate a meaningful value for the Actors. It is worth mentioning that UCs (especially at the higher levels) are about goals (i.e. an end condition) and not about user tasks i.e. an intermediate process performed to achieve the goal).

In the "Actor vs Responsibility" approach, the designer starts again from the list of Actors and, for each of them, discover their roles and the responsibilities they have for accomplishing tasks, together with the collaborations the actors have with other actors in accomplishing the tasks. The use cases are thus discovered by identifying the productive task results.

In the "Unstructured aggregation" approach, the designer analyses all the existing documentation about the envisaged system (e.g., organisational charts, procedures, work instructions, guidelines, manuals, regulations, etc.) looking for any active verb requirement that can be considered as a candidate UC. One benefit of this approach is that it helps incorporate non-functional requirements into specific UCs.

In the “Mission Decomposition” approach, the designer starts by pointing out the mission goal, i.e. the system main functionality. This goal is decomposed by asking what need to be done to reach it in terms of products, services, etc. The decomposition continues until a leaf can be considered as the output specification for a UC.

2.3 Model Organisation

Optionally, UCs may be described in terms of;

- Use Case Packages: A hierarchical contextualized representation between the UCs, where UCs are grouped by Actor, by subject (domain) or by level, in order to enhance their readability.
- Use Case Views: Views that help understand the model from different points of view (for example, the ones of the different stakeholders, or identified per subsystem or per partner in the development phase).

2.4 Use Case Prioritisation

As pointed out at the beginning of Section 2, UCs describe the actions that the system should or can perform in collaboration with one or more external users, thus they drive the development of the system. In case the development process is iterative instead of the waterfall / V-cycle, handling all the use cases in a single pass could be both counter-productive (by generating an overwhelming of the development teams) and wasteful (because the requirements may change during the development, when the project's team has better understanding of the system). Therefore, it could be useful to prioritize the UCAs, allowing the division of the modelling effort between the different iterations. For what concerns the risks, three classes of risks, presented here below in order of importance, are relevant in this approach:

1) Business risks: these risks should be mitigated in the initial phase of the project, by answering questions like: Are we building the right product? Is it feasible? What's its cost? Etc. The list of critical (concept level) use cases should be formalized from the use cases identified at this level.
2) Architectural/Technical risks: these risks shall be addressed by finding all UCs that are significant for the architecture of the system, and also considering, analysing and addressing all the issues within the UCs that are technically challenging.
3) Logistical risks: this class of risks encompasses all the ones not belonging to the previous classes and, in principle, they should not impact to much the progress of the deliverables needed in each iteration.

2.5 Use Case Action Description

Typically, UCAs are described by detailing the following information:

Table 3 – Use Case Action Description fields

Field	Mandatory / Optional	Description
ID	M	UCA unique identifier (UCA_<NNN>, where <NNN> is a progressive number.
Status	O	The current state of definition of the UCA, chosen among: draft, validated, approved, etc.)
Priority	O	The development priority (see Section 2.4) of the use case (<#>, where # is a number starting from 1, and one is the higher priority).
Name	M	Short (mnemonic) unique description of the UCA.
Parent UCA	O	The UCA from which the UCA is hierarchically linked.
Involved Actor(s)	M	The Actors which took part to the UCA.

Field	Mandatory / Optional	Description
Primary Actor	M[1]	Actor who initiates an interaction with the system to achieve a goal (alternative to "Trigger").
Trigger	M[1]	Event that causes the UCA to be initiated (alternative to "Primary Actor").
Involved Stakeholder(s)	O	Someone or something interested in the behaviour of the system under discussion not actively involved in the steps described in the flow.
Setup	O	Description of the equipment necessary to run the UCA and their configuration. If the same setup is used in more than one UCA, it could be a reference to a description external to the table (such as another table with the catalogue of all the different available setups).
Description	M	Detailed textual description of the UCA.
Preconditions	O	List of all the conditions that SHALL be fulfilled before the use case runs.
Assumptions	O	List of the assumption made, usually the complimentary for preconditions as things that the system cannot guarantee.
Issues	O	Any open issues related to the UCA. N.B.: no issues should be present once the UCA is in its "final" state (e.g.: "Approved").
Basic Flow	M	List of the steps that describe the normal flow of actions/reactions. This list become a (System) Test Procedure that, once executed and marked with OK/KO, become the operational part of a Test Report.
Alternative Flow(s)	O	Paths (list of steps) which are a variation on the Basic Flow and describe the expected behaviour of the system under certain abnormal conditions occurred at runtime.
Postconditions	O	List of all the conditions that SHALL be fulfilled after the use case terminates.

2.6 Model Verification and Validation (V&V)

The term "Verification" refers to the set of tasks that ensures that the product / system / subsystem / component / module correctly implements a specific function and complies with a regulation, requirement, specification, or imposed condition. In short, Verification answers to the question: "Are we building the product right?"

The term "Validation", instead, refers to a different set of tasks that ensures that the product / system / subsystem / component / module that has been built meets the needs of the final user/customer and other identified stakeholders. In short, Validation answers to the question "Are we building the right product?"

For what concerns Model V&V, four different approaches are commonly followed, also mixing and matching them:

1) Inspections (both Verification & Validation): A specialist or a team looks at the UCs following pre-defined criteria to verify their adherence to standards and specifications. Appendix B holds a set of questions that can serve as a check list for use case model inspections (and reviews).
2) Reviews (both Verification & Validation): Several readers examine the different UC artifacts (text, diagrams) to check their consistence and completeness. Both internal (members of the design and development team) and external (stakeholders) reviewers can be involved in a two-stages review.
3) Walkthroughs (Validation): A form of review where a UC or a business scenario (i.e. several interacting UCs) is presented by the author to the Stakeholders (and possibly role-played) in-order to examine the flow of events.

[1] One among "Primary Actor" and "Trigger" is mandatory.

4) Prototyping (Validation): Based on the availability of fast prototypes of the system, especially for the User Interfaces (UIs), to demonstrate to stakeholders (esp. the customer) the behaviour of the system as depicted in the UC. This approach has the advantage of the visibility of the understanding captured by the UC, to be compared, of course, with an increase in the effort and, thus, the costs.

The following table recaps typical errors that can be found in UC modelling as pointed out in Anda and Sjøberg (2002).

Table 4 – Typical defects in UCs

Problem Type	Element					
	Actors	**UCs**	**Flow of events**	**Variations**	**Relation between UCs**	**Trigger, pre- and post-conditions**
Omissions	Human users or external entities that will interact with the system are not identified	Required functionality is not described in UCs. Actors have goals that do not have corresponding UCs.	Input or output for UCs is not described. Events that are necessary for understanding the UCs are missing.	Variations that may occur when attempting to achieve the goal of a UC are not specified.	Common functionality is not separated out in included UCs.	Trigger, pre- or post-conditions have been omitted.
Incorrect facts	Incorrect description of Actors or wrong connection between Actors and UCs.	Incorrect description of a UC.	Incorrect description of one or several events.	Incorrect description of a Variation	Not applicable	Incorrect assumptions or results have led to incorrect pre- or post-conditions
Inconsistencies	Description of Actor is inconsistent with its behaviour in UCs.	Description is inconsistent with reaching the goal of the UC.	Events that are inconsistent with reaching the goal of the UC they are part of.	Variations which are inconsistent with the goal of the UC.	Inconsistencies between diagram and descriptions, inconsistent terminology, inconsistencies between UCs, or different level of granularity.	Pre- or post-conditions are inconsistent with goal or flow of events.
Ambiguities	Too broadly defined Actors or ambiguous description of Actor.	Name of UC does not reflect the goal of the UC.	Ambiguous description of events, perhaps because of too little detail	Ambiguous description of what leads to a particular variation.	Not applicable.	Ambiguous description of trigger, pre- or post-conditions.
Extraneous information	Actors that do not derive value from/provide value to the system.	UCs with functionality outside the scope of the system or UCs that duplicate functionality.	Superfluous steps or too much detail in steps.	Variations that are outside the scope of the system.	Not applicable.	Superfluous trigger, pre- or post-conditions.

Problem Type	**Element**					
	Actors	**UCs**	**Flow of events**	**Variations**	**Relation between UCs**	**Trigger, pre- and post-conditions**
Consequences	Expected functionality is unavailable for some users or interface to other systems are missing.	Expected functionality is unavailable.	Too many or wrong constraints on the design or the goal is not reached for the Actor.	Wrong delimitation of functionality.	Misunderstandings between different stakeholders, inefficient design and code.	Difficult to test the system and bad navigability for users between different UCs

These problems may be discovered by answering to the questions reported in the following table.

Table 5 – Typical questions in UCs model V&V

Element	**Questions**
Actors	• Are there any actors that are not defined in the use case model, that is, will the system communicate with any other systems, hardware or human users that have not been described? • Are there any superfluous actors in the use case model, that is, human users or other systems that will not provide input to or receive output from the system? • Are all the Actors abstractions of specific roles? • Are all the Actors clearly described, and do you agree with the descriptions? • Is it clear which Actors are involved in which UCs, and can this be clearly seen from the UC diagram and textual descriptions? • Are all the Actors connected to the right UCs?
UCs	• Does the UC make sense? • For each iteration: Are all the UCs described at the same level of detail? • Is there any missing functionality? In other words, do the Actors have goals that must be fulfilled, but that have not been described in UCs? • Are there any superfluous UCs, i.e. UCs that are outside the boundary of the system, do not lead to the fulfilment of a goal for an Actor or duplicate functionality described in other UCs? • Do all the use cases lead to the fulfilment of exactly one goal for an Actor, and is it clear from the UC name what is the goal? • Are the descriptions of how the Actor interacts with the system in the UCs consistent with the description of the Actor? • Are the Actors external to the UC boundary? • Is it clear from the descriptions of the UCs how the goals are reached and do you agree with the descriptions? • When the UC can be derived by documentation about the envisaged system, is there bi-directional tractability between the UC and the originating documents? • Are the UCs testable? • Are all the UCs described according to the predefined template? • Do all the UC names follow the naming convention (most likely verb-noun)?

Element	Questions
Scenarios	• Is the start of each UC unambiguous? • Does an action by an Actor or a Trigger start each use case? • Is expected input and output correctly defined in each UC; is the output from the system defined for every input from the Actor, both for Normal Flow of events and Variations? • Does each event in the Normal Flow of events relate to the goal of its UC? • Is the Flow of events described with concrete terms and measurable concepts and is it described at a suitable level of detail without details that restrict the user interface or the design of the system? • Are there any Variants (Alternative Flows) to the Normal Flow of events that have not been identified in the UCs, that is, are there any missing Variations? (“happy days scenarios”, exceptions, variation, “soup-opera scenarios”). • Are the triggers, starting conditions, for each use case described at the correct level of detail? • Are the preconditions and guarantees correctly described for all use cases, that is, are they described with the correct level of detail, do the pre-conditions and guarantees match for each of the use cases and are they testable? • Does the behaviour of a use case conflict with the behaviour of other use cases? • Is the number of steps in the complex scenarios excessive (12 to 15 is getting borderline)?
UC Diagrams	• Does each use case have a representation in at least one diagram? • Do the use case diagram and the textual descriptions match? • Are all use case diagrams drawn using the same (preferably the UML's) diagramming notation? • Is each actor represented in the use case diagrams in which it is involved? • Should similar use case diagrams be combined (using extend and uses relations)? • Has the include-relation been used to factor out common behavior? • Are the diagrams readable (not too many relations, levels etc. in any single diagram)?
The use case organization and prioritization	• Are all the use cases organized in an appropriate manner (e.g. by functional area, by dependency, by actor etc)? • Are all the use cases within a package consistent with the theme of the package? • Is the priority mechanism documented? • Are the use cases prioritized correctly?

3 Drones4Safety functionalities to test during the use cases

During the UCs the following D4S objectives are expected to be validated:

Table 6 – D4S objectives expected to be validated in the UCs

D4S objectives	Railways UCs	Bridges UCs
Energy harvesting	X	X**
AI fault detection algorithms	X	X
3D reconstruction	X	X
Virtual model		X
Structural modelling and capacity assessment*		X
Swarming	X	X**
Mission control and autonomous navigation	X	X**

* based on the geometrical information from the 3D model (and from possible additional information provided by the infrastructure manager), and on the damage data generated by the AI.

** to be defined at a later stage of the project

Starting from the preliminary D4S system requirements, during the UCs a series of D4S technologies/functionalities will be validated. In particular, Table 7 reports a list of Use Case Actions (UCAs) that have been identified, grouped per "common actions" (applicable to all UCs), railways UCAs and bridge UCAs. All the UCAs are hierarchically organised in different levels.

Table 7 – UC actions expected to be validated in the UCs

	D4S_UC Action ID	Title (Level 1)	Title (Level 2)	Title (Level 3)
Bridge/Railways	UCA_001	Inspection Mission planning		
	UCA_002		Anomaly detected in Configuration / Plan	
	UCA_003	Autonomous navigation		
	UCA_004		Target minimum proximity check	
	UCA_005	Swarming		
	UCA_006		Fail safe swarm operation	
	UCA_007		Cooperative path planning	
	UCA_008		Mesh networking	
	UCA_009		Broken link of the Drones Swarm with Ground Segment	
	UCA_010	Energy harvesting		
	UCA_011		Flight to/from recharge point	
	UCA_012		Recharging (including docking, grasping and release)[2]	-
	UCA_013		Automatic detaching from cable and landing	

[2] This UCA can be validated only at PWC Test Site (see Table 9 – S1).

Railways	UCA_014	3D Map Generation		
	UCA_015	Target objects images inventory		
	UCA_016	Railway Inspection (Nominal)		
	UCA_017		Defects in overhead power lines	
	UCA_018			RGB Camera
	UCA_019			Therm Camera
	UCA_020		Defects in tracks and railbed geometry	
	UCA_021		Obstacles on tracks/overhead power lines	
	UCA_022	Railway Inspection (Degraded)	-	-
Bridge	UCA_023	3D bridge reconstruction		
	UCA_024		Manual/automatic Flight planning (*)	
	UCA_025		Flight execution, images acquisition, processing & validation	
	UCA_026	Bridge Visual inspection		
	UCA_027		Manual Flight planning (*)	
	UCA_028		Flight execution, data acquisition, processing & validation	
	UCA_029	Bridge assessment		
	UCA_030		Virtual inspection model	
	UCA_031		Structural modelling and capacity assessment	

- ***** Activities outside the objectives of D4S system but useful as a driving starting point for training the autonomous navigation.

Table 8 recaps a preliminary description of the main characteristics which could interested some of the UC actions with respect to the following parameters:

- Number and type of drone used
- Location of the operation
- Duration of the operation(s)
- Type of inspection
- Volume of operations (distance from the infrastructure and from the pilot/operator, altitude, etc.)

Table 8 – Preliminary description of the main characteristics which could interested some of the UC actions

UC action ID & Title	# and Type of Drones	Site(s)	Duration	Type of Inspection	Volume of operations
UCA_014 3D Map Generation	2 Commercial	S1 S2 S3 S4	TBD (depending on line length)	Piloted, VLOS/EVLOS	Each Drone Pilot will follow his/her drone, and will be supported by a Drone Pilot Assistant in case of EVLOS flight The Drone will be kept below 25 m from ground level The distance from the railway infrastructure want fall below 5 m
UCA_023 with Manual/automatic Flight planning (for 3D Bridge reconstruction)	1 Commercial	TBD	TBD (depending on bridge dimension)	Piloted, VLOS	Flight altitude: according to the operative scenario and the dimension of the bridge Distance from the structure: no less than 5-10m (assuring proper buffer from external obstacles). This value depends also on the local environmental conditions (obstacles like vegetations)
UCA_015 Target objects images inventory	1 or 2 Commercial	S1 S2 S3 S4	TBD (depending on assets to be acquired on the line)	Piloted, VLOS/EVLOS	Each Drone Pilot will follow his/her drone, and will be supported by a Drone Pilot Assistant in case of EVLOS flight The Drone will be kept below 25 m from ground level The distance from the railway infrastructure want fall below 5 m
UCA_016 Inspection (Nominal)	2 or more D4S Swarm	S3		Autonomous. BVLOS	Autonomous flight in swarm The Drone will be kept below 25 m from ground level The distance from the railway infrastructure want fall below 5 m
UCA_022 Inspection (Degraded)	3 or more D4S Swarm 1 Drone not Operational	S3		Autonomous. BVLOS	

UC action ID & Title	# and Type of Drones	Site(s)	Duration	Type of Inspection	Volume of operations
UCA_027 with Manual Flight planning (for Bridge Visual inspection)	1 or 2 Commercial	TBD	TBD (depending on bridge dimension)	Piloted, VLOS/EVLOS	Each Drone Pilot will follow his/her drone, and will be supported by a Drone Pilot Assistant in case of EVLOS flight Flight altitude: according to the operative scenario and the dimension of the bridge) Distance from the structure: no less than 3-5m (assuring proper buffer from external obstacles). This value depends also on the local environmental conditions (obstacles like vegetation)

4 Use Cases Description

The information provided in this Section may undergo to revisions during the project execution once the first UCA are executed, in case further optimisations arise.

4.1 Test sites

As a preliminary phase, a number of possible test sites have been identified and analysed (Table 9). The actual experimentation and system validation will then be conducted on selected sites, according to the resulting best options. For each test site, it is also specified whether it could be used in railway UCs, bridges UCs, or both.

Table 9 – Test Sites

ID	Site	Description	UC
S1	Test- and Validation Center Wegberg-Wildenrath (PCW), Germany	The PCW facility is owned and operated by Siemens, is being used for test- and certification drives of any kind of rail vehicles - from high-speed-train EUROSTAR and ICE to regional trains to metro lines to trams. Without interfering public traffic, complex manoeuvres with multiple vehicles can be driven at high speed. The main track is a ring of 6 km length but any other kind of rail infrastructure is available, too, i.e. tracks in various gauges, various catenary systems for railroads and trams, floor power lines for metros, etc. Moreover, the PCW was being equipped with railGATE (Galileo Test Environment for Rail), eight stationary Galileo-GNSS stations (pseudolites) to allow for development and testing of Galileo based applications for research purposes in the rail area providing real-life conditions, and with REDUS, an EU-funded GNSS measurement- and calibration set-up on a subset of the rail tracks inside of railGATE. By the way, PWC is located next to the D4S Partner ARIC's premises.	☑ Railway ☐ Bridges

ID	Site	Description	UC
S2	Valle Aurelia - Vigna Clara	Area: City of Rome (Lazio, Italy) Length: 7.5 km Status: Closed on 1990 Last Infrastructure Manager: Ferrovie dello Stato Power: 3 kV DC Gauge: Italian standard Current status: Built to transport fans during the 1990 Football World Cup, it has been closed to traffic in the same year. After 30 year of abandonment, in the last few years the line has been revamped and re-electrified facing a reopening, which could happen at the end of year 2020 or, more probable, later, due to the opposition of the citizens living in the nearby. The line is in between two the “Vigna Clara” Station (to be re-opened after a deep restoration) and “Valle Aurelia” Station, which is already operational in the line Roma-Viterbo. Despite the line is near LIT19 and “Urbe Airport” ATZ, an analysis of the Flight Map showed that flights can be conducted by a Drone Operator duly authorised by the Italian NAA for Critical Operations over a segment of the line whose length more than 1 km between “Pineto” and “Galleria San Giovanni” by simply sending an information to the “Questura di Roma) (Rome Police Headquarters)	☑ Railway ☐ Bridges
S3	Marina di S. Vito - Crocetta - Archi - Castel di Sangro	Area: Abruzzo, Italy Length: 103km Last Infrastructure Manager: Ferrovia Adriatico Sangritana Power: 3 kV DC Gauge: Italian standard Current status: Closed to traffic during the period 2003-2006, the line still functional, but in a very poor maintenance state, with the exception of some legs which are under renewal.	☑ Railway ☑ Bridges
S4	High Speed Line (TBD)	Area: Northern Italy Length: 25km Last Infrastructure Manager: Rete Ferroviaria Italiana Power: 25 kV AC Gauge: Italian standard Current status: New line under construction.	☑ Railway ☐ Bridges
S5	Castagnole delle Lanze (Asti)	Area: Piedmont, Italy Coordinates: 44°46'12.5"N 8°08'14.4"E Urban area Current status: from 2012, this railway is used only for the occasional circulation of tourist trains	☐ Railway ☑ Bridges
S6	Campagna (Salerno)	Area: Campania, Italy Coordinates: 40°36'23.0"N 15°07'51.4"E Extra-urban area Current status: abandoned segment of the E45 route (A3 motorway “Salerno-Reggio Calabria”)	☐ Railway ☑ Bridges

ID	Site	Description	UC
S7	Roccaprebalza (Parma)	Area: Emilia Romagna, Italy Coordinates: 44°30'48.6"N 9°57'42.6"E;44°30'35.9"N 9°57'27.5"E Extra-urban area Current status: active motorway (E31 route – A15 Cisa)	☐ Railway ☑ Bridges
S8	Ponte dell’Olio (Piacenza)	Area: Emilia Romagna, Italy Coordinates: 44°52'27.3"N 9°38'45.8"E Urban area Current status: abandoned railway route	☐ Railway ☑ Bridges
S9	Chivasso	Area: Piedmont, Italy Coordinates: 45°10'26.3"N 7°55'58.3"E Extra-urban area Current status: abandoned railway route	☐ Railway ☑ Bridges
S10	Mezzano Scotti (Piacenza)	Area: Emilia Romagna, Italy Coordinates: 44°48'30.8"N 9°26'09.0"E Urban area Current status: active road	☐ Railway ☑ Bridges
S11	Villalvernia (Alessandria)	Area: Piedmont, Italy Coordinates: 44°48'31.9"N 8°50'55.0"E Urban area Current status: Active road	☐ Railway ☑ Bridges
S12	Ronco Scrivia (Genoa)	Area: Liguria, Italy Coordinates: 44°35'41.2"N 8°56'49.3"E Urban area Current status: Active motorway (A7)	☐ Railway ☑ Bridges
S13	Valmozzola (Parma)	Area: Emilia Romagna, Italy Coordinates: 44°34'57.8"N 9°56'30.2"E Urban area Current status: Active road	☐ Railway ☑ Bridges

4.2 Bridge and Railway common Use Cases

4.2.1 Inspection Mission Planning

These UCs (the main one and its Alternative Flow) are related to the creation of a new swarm-based, automatic, supervised inspection mission “template” over a given target, i.e. a mission that can be scheduled and rescheduled over the time. The mission is composed by a high-level swarm-as-a-whole flight plan and a detailed flight and acquisition plan for each drone in the swarm.

Table 10 – Inspection Mission Planning UC

Field	Description
ID	UCA_001 / UCA_002
Status	Draft
Priority	1
Title	Flight Planning
Parent UC	None
Involved Actor(s)	1) Mission Planning Operator (MPO)
Primary Actor	Mission Planning Operator
Trigger	

Involved Stakeholder(s)	• Infrastructure Managers
Setup	Ground Segment Mission Command & Control
Description	The inspection mission of the autonomous drones' swarm is designed, verified and scheduled.
Preconditions	1) The 3D Map of the target railway (see UCA_014) with the corresponding target objects images inventory (see UCA_015) and/or the 3D bridge reconstruction (see UCA_023) are available on the Ground Segment. 2) The Ground Segment database is updated with the latest information concerning flight restrictions over the target asset, such as No Fly Zones, NOTAMs, etc.
Assumptions	1) The UC foresees the use of swarming capabilities 2) The UC foresees the capability for the swarm to perform BVLOS flight(s)
Basic Flow	1) The MPO accesses the Mission Command & Control front-end and authenticates himself/herself. 2) The MPO selects the target asset to be inspected from the assets database from the Mission Planning module. 3) The MPO creates a new mission for the swarm in the Mission Planning module. 4) The MPO defines the master flight plan for the drone swarm in BVLOS operations (i.e. the path followed by the swarm as a whole in executing the inspection mission), encompassing also admitted recharge points and safe landing points: The Mission Planning module warns the MPO about "static" flight restrictions over the mission flight path (such as No-Fly Zone invaded by the flight path). 5) The MPO selects the Objects Of Interest (OOIs) within the target from the inventory (such as specific classes of elements of the railway power line or parts/portions of the bridges): the Mission Planning module suggest the detailed flight plan of the drone swarm formation flight, i.e. the detailed plan of each drone of the swarm, together with the necessary sensor(s) and the details/instructions of the acquisitions to be performed, such as number of drones to be involved, number of acquisitions for the same target, relative position of the drone to the target (with a distance not smaller than the minimum one foreseen by the System Requirements), requested azimuth and orientation of the sensor(s) with respect to the target, etc., coming from the inventory. 6) The MPO performs the Specific Operations Risk Assessment (SORA) for the mission (e.g., using specific third-parties' wizards) 7) The MPO saves the mission as a "template", i.e., the mission can be re-executed over the time. 8) The MPO schedules one or more instances of the inspection mission on given dates and times in the Mission Planning module: the module checks restriction to flight known at each scheduled date and time, reporting the MPO with a feasibility check.
Alternative Flow(s)	5-bis) [UCA_002 "Anomaly detectetd in Configuration Plan"] The Mission Planning module does not contain the information necessary to create the Detailed Flight Plan (such as the presence of enough Point Of Recharge or the details/instructions of the acquisitions to be performed for a given classes of OOIs): the module warns the MPO to abort the creation of the mission or, if possible, to modify the mission (e.g. by reducing the endurance or by discarding the OOI class from the mission), and then the flow is continued from Step 6).

	8-bis) The Mission Planning module warn the MPO about the existence of dynamic restrictions to flight (e.g., NOTAM) that conflict with one or more instances of the inspection mission: the MPO reschedule the conflicting inspection mission instance(s).
Postconditions	The inspection mission template and the scheduled missions are present in the Mission C&C database.

4.2.2 Autonomous Navigation

This UC is related to the verification of the capabilities of automatic, supervised flight of a single drone with respect to a predefined inspection mission instance (and thus the corresponding master and detailed flight plans), by following the defined path, localising the target OOIs, and maintaining the communication with the Ground Segment.

It shall be intended as a test flight aiming at verifying and validating the setup of both the Ground Segment and the Drone.

Table 11 – Autonomous Navigation UC

Field	Description
ID	UCA_003
Status	Draft
Priority	2
Title	Autonomous Navigation
Parent UC	None
Involved Actor(s)	1) Mission Execution Supervisor (MES) 2) Drone Pilot (DP) ready to take the control of the Drone in case a problem arises
Primary Actor	Mission Execution Supervisor (MES)
Trigger	A test inspection mission instance scheduling is arrived at its due time
Involved Stakeholder(s)	• Infrastructure Managers
Setup	• Ground Segment Mission Command & Control in operation • Drone fully equipped and operational, and ready for take-off at the mission starting point (take-off area). • An inspection mission instance for a single drone is scheduled
Description	The drone is able to execute the inspection mission following the corresponding master and detailed flight plans in an automatic, supervised way.
Preconditions	1) The inspection mission instance (and thus the corresponding master and detailed flight plans) is correctly scheduled (see UCA_001). 2) The Ground Segment database is updated with the latest information concerning flight restrictions over the target asset, such as No Fly Zones, NOTAMs, etc. 3) The Drone is regularly connected via radio to the Ground Segment.
Assumptions	1) The UC does not foresee the use of swarming capabilities 2) The UC foresees the capability for the drone to perform a BVLOS flight
Basic Flow	1) The MES accesses the Mission Execution module of the Ground Segment Command & Control Front-End and authenticates himself/herself on it. 2) The MES takes control of the scheduled inspection mission instance and starts it. 3) The MES performs all the preliminary checks for the given inspection mission instance, namely:

	a. Controls that the drone are duly authorised to perform the mission (e.g., that the insurances are valid, that the necessary authorisation are valid, etc.). b. Verifies again the feasibility of the mission with respect to the latest "dynamic" restrictions present onto the database (such as NOTAMs). c. Controls the meteo conditions along the mission path with respect to the drones operating conditions. d. Verifies the correct functioning of the D4S System, in particular checks that the Drone is fully functional, its batteries are fully charged, the Drone-To-Ground Segment radio link is active. 4) The MES starts the inspection mission and supervises the Drone during the flight by: a. Checking the telemetry and diagnostic data, acknowledging / managing every warning/error/alarm raised by the Drone; b. Following the position of the Drone onto the map, controlling that it is coherent with the one foreseen by the master flight plan; c. Checking that every target OOI foreseen in the detailed flight plan is correctly detected; d. Verifying the advancements of the mission execution; until the mission is fully accomplished and the Drone lands in the mission ending point (landing area). 5) The MES ends the inspection mission.
Alternative Flow(s)	4-bis) The DP takes remote control of the Drone in case of problems with in the automatic flight.
Postconditions	1) The Drone is landed in the mission ending point (landing area). 2) The inspection mission results (telemetry, warnings/errors/alarms, acquired data and metadata) are available on the Mission Command & Control Front-End.

4.2.2.1 Target minimum proximity check

This sub-UC is related to the verification of the capability of a drone to avoid flying nearer to a target or to an obstacles more than the minimum distance foreseen by the System Requirements. It shall be intended as a test flight aiming at verifying and validating the System Requirement both against wrong configurations and dynamic obstacles.

Table 12 – Target minimum proximity check UC

Field	**Description**
ID	UCA_004
Status	Draft
Priority	2
Title	Target minimum proximity check
Parent UC	UCA_003
Involved Actor(s)	1) Mission Execution Supervisor (MES) 2) Drone Pilot (DP) ready to take the control of the Drone in case a problem arises 3) Drone Pilot Assistant (DPA)
Primary Actor	Mission Execution Supervisor (MES)
Trigger	A test inspection mission instance scheduling is arrived at its due time
Involved Stakeholder(s)	• Infrastructure Managers

<table>
<tr><td>Setup</td><td>• Ground Segment Mission Command & Control in operation
• Drone fully equipped and operational, and ready for take-off at the mission starting point (take-off area).
• A simple “malformed” inspection mission instance for a single drone is scheduled (see UCA_001), where the distance from which the drone shall acquire one or more target OOIs is shorter than the minimum allowed distance.
• The DP is positioned near one target OOI for which the distance from which the drone shall acquire it is bigger than the minimum one.</td></tr>
<tr><td>Description</td><td>The Drone is able to execute the inspection mission following the corresponding master and detailed flight plans in an automatic, supervised way, but it avoids flying near to the targets more than the minimum allowed distance, and raises an alarm.</td></tr>
<tr><td>Preconditions</td><td>1) The “malformed” inspection mission instance (and thus the corresponding master and detailed flight plans) is correctly scheduled.
2) The Ground Segment database is updated with the latest information concerning flight restrictions over the target asset, such as No Fly Zones, NOTAMs, etc.
3) The Drone is regularly connected via radio to the Ground Segment.</td></tr>
<tr><td>Assumptions</td><td>1) The UC does not foresee the use of swarming capabilities
2) The UC does not require the capability for the drone to perform a BVLOS flight. VLOS or EVLOS are also suitable.</td></tr>
<tr><td>Basic Flow</td><td>1) The MES accesses the Mission Execution module of the Ground Segment Command & Control Front-End and authenticates himself/herself on it.
2) The MES takes control of the scheduled inspection mission instance and starts it.
3) The MES performs all the preliminary checks for the given inspection mission instance, namely:
a. Controls that the Drone are duly authorised to perform the mission (e.g., that the insurances are valid, that the necessary authorisation are valid, etc.).
b. Verifies again the feasibility of the mission with respect to the latest “dynamic” restrictions present onto the database (such as NOTAMs).
c. Controls the meteo conditions along the mission path with respect to the drones operating conditions.
d. Verifies the correct functioning of the D4S System, in particular checks that the Drone is fully functional, its batteries are fully charged, the Drone-To-Ground Segment radio link is active.
4) The MES starts the inspection mission and supervises the Drone during the flight by:
a. Checking the telemetry and diagnostic data, acknowledging / managing every warning/error/alarm raised by the Drone;
b. Following the position of the Drone onto the map, controlling that it is coherent with the one foreseen by the master flight plan;
c. Checking that every target OOI foreseen in the detailed flight plan is correctly detected and, for the OOIs for which a distance to the detailed flight plan has been wrongly configured with respect to the minimum distance, that the alarm is raised and the Drone avoids flying nearer to a target more than the minimum distance.
d. Checking that the Drone reacts properly when it is acquiring the target OOI where the DPA is positioned and the DPA interpose an</td></tr>
</table>

	obstacle between the Drone and the target OOI, i.e., that the Drone moves enough far from the obstacle and an alarm is raised. e. Verifying the advancements of the mission execution; until the mission is fully accomplished and the drone lands in the mission ending point (landing area). 5) The DPA shall always follow the Drone in its flight and visually evaluate its distance from the target OOIs and its reaction against the appearing obstacle. 6) The MES ends the inspection mission.
Alternative Flow(s)	4-bis) The DP takes remote control of the drone in case of problems with in the automatic flight.
Postconditions	1) The Drone is landed in the mission ending point (landing area). 2) The inspection mission results (telemetry, warnings/errors/alarms, acquired data and metadata) are available on the Mission Command & Control Front-End.

4.2.3 Swarming

This UC and its Level 2 sub-UCs are related to the test of the Swarming capabilities of the Drones4Safety System.

Table 13 – Swarming UC

Field	Description
ID	UCA_005
Status	Draft
Priority	1
Title	Swarming
Parent UC	None
Involved Actor(s)	1) Mission Execution Supervisor (MES) 2) A Drone Pilot (DP) for each Drone of the swarm ready to take the control of the Drone in case a problem arises
Primary Actor	Mission Execution Supervisor (MES)
Trigger	An inspection mission instance scheduling is arrived at its due time
Involved Stakeholder(s)	• Infrastructure Managers
Setup	• Ground Segment Mission Command & Control in operation • Drones fully operational and ready for take-off at the mission starting point • An inspection mission instance is scheduled
Description	The drones are able to flight in swarm.
Preconditions	1) The Drones' Swarm inspection mission instance is correctly scheduled 2) The Ground Segment database is updated with the latest information concerning flight restrictions over the target asset, such as No Fly Zones, NOTAMs, etc. 3) The Drones are regularly connected via radio with the Ground Segment.
Assumptions	1) The UC foresees the use of swarming capabilities 2) The UC foresees the capability for the swarm to perform BVLOS flight(s)
Basic Flow	1) The MES accesses the Mission Execution module of the Ground Segment Command & Control Front-End and authenticates himself/herself on it. 2) The MES takes control of the scheduled inspection mission instance and starts it.

	3) The MES performs all the preliminary checks for the given inspection mission instance, namely: a. Controls that the drone are duly authorised to perform the mission (e.g., that the insurances are valid, that the necessary authorisation are valid, etc.). b. Verifies again the feasibility of the mission with respect to the latest "dynamic" restrictions present onto the database (such as NOTAMs). c. Controls the meteo conditions along the mission path with respect to the drones operating conditions. d. Verifies the correct functioning of the D4S System, in particular checks that each Drone is fully functional, its batteries are fully charged, the Drone-to-Drone and Drone-To-Ground Segment radio link are active. 4) The MES starts the inspection mission and supervises the swarm during the flight by: a. Checking the telemetry and diagnostic data, acknowledging / managing every warning/error/alarm raised by the drones; b. Following the position of the drones onto the map, controlling that every target OOI is properly inspected by the swarm; c. Verifying the advancements of the mission execution; d. Checking the correct behaviour of each part of the system, in particular with respect to the specific behaviour foreseen by the Level 2 UCs (see Alternative Flow(s) below); until the mission is fully accomplished and the drones land in the mission ending point. 5) The MES ends the inspection mission.
Alternative Flow(s)	4.d-bis) [UCA_006 "Fail safe swarm operation"]: All the drones in the swarm follow the master flight plan and its own detailed flight and acquisition plan by maintain the relative distance and position (flight formation) foreseen by the plan and avoiding collisions among them and with targets and obstacles: no alarm related to the violation of the safe condition is raised. 4.d.ter) [UCA_007 "Cooperative path planning"]: All the drones in the swarm correctly follow the (swarm) master flight plan and its own detailed flight and acquisition plan: no alarm related to the deviation from a plan is raised.
Postconditions	The inspection mission results (telemetry, warnings/errors/alarms, acquired data and metadata) are available on the Mission Command & Control Front-End.

4.2.3.1 Mesh Networking

This UC is Level 2 sub-UC of UCA_005 "Swarming" and it deals with the test of the Drone-To-Drone communication within the Swarm.

Table 14 – Mesh Networking UC

Field	**Description**
ID	UCA_008
Status	Draft
Priority	2
Title	Mesh Networking
Parent UC	UCA_005

Involved Actor(s)	1) Mission Execution Supervisor (MES) 2) A Drone Pilot (DP) for each Drone of the swarm
Primary Actor	Mission Execution Supervisor (MES)
Trigger	An inspection mission instance scheduling is arrived at its due time
Involved Stakeholder(s)	• Infrastructure Managers
Setup	• Ground Segment Mission Command & Control in operation • Drones fully operational and ready for take-off at the mission starting point • An inspection mission instance is scheduled
Description	The drones in the swarm are able to properly communicate one with the others.
Preconditions	1) The Drones' Swarm inspection mission instance is correctly scheduled 2) The Ground Segment database is updated with the latest information concerning flight restrictions over the target asset, such as No Fly Zones, NOTAMs, etc. 3) The Drones are regularly connected via radio with the Ground Segment.
Assumptions	1) The UC foresees the use of swarming capabilities 2) The UC does not necessarily foresee the capability for the swarm to perform BVLOS flight(s): VLOS or EVLOS flights are also suitable.
Basic Flow	1) The MES accesses the Mission Execution module of the Ground Segment Command & Control Front-End and authenticates himself/herself on it. 2) The MES takes control of the scheduled inspection mission instance and starts it. 3) The MES performs all the preliminary checks for the given inspection mission instance, namely: a. Controls that the drone are duly authorised to perform the mission (e.g., that the insurances are valid, that the necessary authorisation are valid, etc.). b. Verifies again the feasibility of the mission with respect to the latest "dynamic" restrictions present onto the database (such as NOTAMs). c. Controls the meteo conditions along the mission path with respect to the drones operating conditions. d. Verifies the correct functioning of the D4S System, in particular checks that each Drone is fully functional, its batteries are fully charged, the Drone-to-Drone and Drone-To-Ground Segment radio link are active. 4) The MES starts the inspection mission and supervises the swarm during the flight by: a. Checking the telemetry and diagnostic data, acknowledging / managing every warning/error/alarm raised by the drones; b. Following the position of the drones onto the map, controlling that every target OOI is properly inspected by the swarm; c. Verifying the advancements of the mission execution; d. Checking the correct behaviour of each part of the system, in particular that all the Drones in the swarm are able to activate and maintain for the whole mission duration a Drone-To-Drone communication, and to exchange messages / data one with all the other; until the mission is fully accomplished and all the Drones land in the mission ending point. 5) The MES ends the inspection mission.

Alternative Flow(s)	4.d-bis) A given Drone in the swarm is forced to lose its communication capabilities with the other ones in the swarm. This Drone follows the predefined procedure, i.e., tries to reconnect until a timeout is reached, and then goes into the safe state (landing in a predefined safe area). The other Drones also follows the predefined procedure in case of loss of communication with another element of the swarm, raising an alarm and checking whether the mission shall be aborted or can be continued in degraded mode.
Postconditions	The inspection mission results (telemetry, warnings/errors/alarms, acquired data and metadata) are available on the Mission Command & Control Front-End.

4.2.3.2 Broken link of the Drones Swarm with Ground Segment

This UC is Level 2 sub-UC of UCA_005 "Swarming" and it deals with the test of the correct behaviour of the Swarm in case the link of the Drones Swarm with Ground Segment is broken.

Table 15 – Broken link of the Drones Swarm with Ground Segment UC

Field	Description
ID	UCA_009
Status	Draft
Priority	2
Title	Broken link of the Drones Swarm with Ground Segment
Parent UC	UCA_005
Involved Actor(s)	1) Mission Execution Supervisor (MES) 2) A Drone Pilot (DP) for each Drone of the swarm 3) A Drone Pilot Assistant (DPA)
Primary Actor	Mission Execution Supervisor (MES)
Trigger	An inspection mission instance scheduling is arrived at its due time
Involved Stakeholder(s)	• Infrastructure Managers
Setup	• Ground Segment Mission Command & Control in operation • Drones fully operational and ready for take-off at the mission starting point • An inspection mission instance is scheduled
Description	The drones' swarm is able to manage the loss of connection with the Ground Segment.
Preconditions	4) The Drones' Swarm inspection mission instance is correctly scheduled 5) The Ground Segment database is updated with the latest information concerning flight restrictions over the target asset, such as No Fly Zones, NOTAMs, etc. 6) The Drones are regularly connected via radio with the Ground Segment.
Assumptions	1) The UC foresees the use of swarming capabilities 2) The UC does not foresee necessarily the capability for the swarm to perform BVLOS flight(s): VLOS/EVLOS flight are also suitable.
Basic Flow	1) The MES accesses the Mission Execution module of the Ground Segment Command & Control Front-End and authenticates himself/herself on it. 2) The MES takes control of the scheduled inspection mission instance and starts it. 3) The MES performs all the preliminary checks for the given inspection mission instance, namely: a. Controls that the drone are duly authorised to perform the mission (e.g., that the insurances are valid, that the necessary authorisation are valid, etc.).

	b. Verifies again the feasibility of the mission with respect to the latest “dynamic” restrictions present onto the database (such as NOTAMs). c. Controls the meteo conditions along the mission path with respect to the drones operating conditions. d. Verifies the correct functioning of the D4S System, in particular checks that each Drone is fully functional, its batteries are fully charged, the Drone-to-Drone and Drone-To-Ground Segment radio link are active. 4) The MES starts the inspection mission and supervises the swarm during the flight by: a. Checking the telemetry and diagnostic data, acknowledging / managing every warning/error/alarm raised by the drones. b. Following the position of the drones onto the map, controlling that every target OOI is properly inspected by the swarm. c. Verifying the advancements of the mission execution. d. Checking the correct behaviour of each part of the system until the link with Ground Segment is broken. until the mission is terminated and the drones land in the safe landing area. 5) Once the link is broken: a. The Dromes’ Swarm follows the predefined procedure, i.e. tries to restore the link until a timeout is reached, and then all the Drones land in the nearest safe landing area, still trying to reactivate the link with the Ground Segment. b. The Mission Execution module warns the MES about the failure. c. The MES aborts the inspection mission. d. The DPA goes to check that the all the Drones of the swarm landed in the safe landing area.
Alternative Flow(s)	5.a-bis) After the emergency landing, the Swarm resumes the link with the Ground Segment: the mission is restarted from the point in which it has been stopped.
Postconditions	The inspection mission results (telemetry, warnings/errors/alarms, acquired data and metadata) are available on the Mission Command & Control Front-End.

4.2.4 Energy Harvesting

This UC and it related sub-UCs deal with the test of the harvesting capabilities of the Drones4Safety System.

The UCA_001 UC is the concatenation of the specific actions foreseen by its Level 2 sub-UCs.

4.2.4.1 Flight to/from recharge point

This sub-UC deals with the test of the capability of the drone:

- to detect the need of recharging the batteries;
- to request the flight plan from the current position to the nearest suitable recharging place;
- to flight to and back from the recharging place.

Table 16 – Energy Harvesting / Flight to/from recharge point UC

Field	**Description**
ID	UCA_011
Status	Draft
Priority	2
Title	Flight to/from recharge point

Parent UC	UCA_010
Involved Actor(s)	1) Mission Execution Supervisor (MES) 2) A Drone Pilot (DP) for each Drone of the swarm ready to take the control of the Drone in case a problem arises. 3) A Drone Pilot Assistant (DPA) for each Drone
Primary Actor	Mission Execution Supervisor (MES)
Trigger	An inspection mission instance scheduling is arrived at its due time
Involved Stakeholder(s)	• Infrastructure Managers
Setup	• Ground Segment Mission Command & Control in operation • Drones fully operational and ready for take-off at the mission starting point • A simple “recharge flight plan” mission instance is scheduled
Description	The drones’ swarm (or a single drone) detects the need for recharge, ask a flight plan to the nearest suitable recharging place, flight to that position and then flight back to the position where the recharge flight plan has been initiated.
Preconditions	1) The Drones’ Swarm “recharge flight plan” mission instance is correctly scheduled 2) The Ground Segment database is updated with the latest information concerning flight restrictions over the target asset, such as No Fly Zones, NOTAMs, etc. 3) The Drones are regularly connected via radio with the Ground Segment.
Assumptions	1) The UC does not necessarily foresee the use of swarming capabilities: it can be executed also with only one Drone 2) The UC does not necessarily foresee the capability for the Drone/Drones’ Swarm to perform BVLOS flight(s): VLOS/EVLOS flights are also suitable.
Basic Flow	1) The MES accesses the Mission Execution module of the Ground Segment Command & Control Front-End and authenticates himself/herself on it. 2) The MES takes control of the scheduled inspection mission instance and starts it. 3) The MES performs all the preliminary checks for the given inspection mission instance, namely: a. Controls that the drones are duly authorised to perform the mission (e.g., that the insurances are valid, that the necessary authorisation are valid, etc.). b. Verifies again the feasibility of the mission with respect to the latest “dynamic” restrictions present onto the database (such as NOTAMs). c. Controls the meteo conditions along the mission path with respect to the drones operating conditions. d. Verifies the correct functioning of the D4S System, in particular checks that each Drone is fully functional, its batteries are fully charged, the Drone-to-Drone and Drone-To-Ground Segment radio link are active. 4) The MES starts the inspection mission and supervises the swarm during the flight by: a. Checking the telemetry and diagnostic data, acknowledging / managing every warning/error/alarm raised by the drones; b. Following the position of the drones onto the map, controlling that every target OOI is properly inspected by the swarm; c. Verifying the advancements of the mission execution; d. Checking the correct behaviour of each part of the system.

	5) Just after the take-off, a Drone detects (or it is forced to detect) the need to recharge its batteries, and it informs the other drones in the swarm and the Ground Segment. 6) The MES send a recharge flight plan to every drone to the nearest suitable recharge point. 7) Each Drone flies from its current position to the assigned recharge point. Once reached, in the full UC the Drone should recharge itself (see UCA_012), but in this UC the Drone is forced to immediately fly back to the position from which it started the recharge flight plan. The MES follows this flight. 8) Once the Drone reaches the position from which it started the recharge flight plan, the mission is terminated and the drones fly back to the mission starting point and land. 9) The MES ends the mission.
Alternative Flow(s)	6-bis) The MES decides whether to proceed the mission in degraded mode by recharging only the specific Drone or in nominal mode by recharging the whole swarm, and sends: a. a recharge flight plan to every drone that shall be recharged, and, b. a degraded flight plan to the Drones that shall continue the mission, if any.
Postconditions	• The inspection mission results (telemetry, warnings/errors/alarms, acquired data and metadata) are available on the Mission Command & Control Front-End. • All the Drones are landed in the mission starting point

4.2.4.2 Recharging

This sub-UC deals with the test of the recharging capability of the drone by harvesting energy from a power cable. The same UC (with a different setup for the drone) is suitable for both AC and DC harvesting.

Table 17 – Energy Harvesting / Recharging UC

Field	Description
ID	UCA012
Status	Draft
Priority	2
Title	Recharging
Parent UC	UCA_010/
Involved Actor(s)	1) Mission Execution Supervisor (MES) 2) A Drone Pilot (DP) for each Drone, ready to take the control of the Drone in case a problem arises. 3) A Drone Pilot Assistant (DPA) for each Pilot
Primary Actor	Mission Execution Supervisor (MES)
Trigger	An inspection mission instance scheduling is arrived at its due time
Involved Stakeholder(s)	• Infrastructure Managers
Setup	• Ground Segment Mission Command & Control in operation • Drones (one or more) fully operational and ready for take-off at the mission starting point • A simple "recharging" mission instance is scheduled • Drones equipped with the AC or the DC harvester, in according to the characteristics of the power line.
Description	The recharging drone(s) approaches the cable, perform the docking, grasp from it and then leave it.

Preconditions	1) The Drone "recharging" mission instance foresees that the Drones, after the take-off, directly flies to a recharge point. 2) The Ground Segment database is updated with the latest information concerning flight restrictions over the target asset, such as No Fly Zones, NOTAMs, etc. 3) The Drones are regularly connected via radio with the Ground Segment.
Assumptions	1) The UC foresees that all the Drones recharge at the same time, even if an Alternative Flow with part of the swarm recharging and part continuing the mission in Degraded Mode is possible. 2) The UC foresees the execution of a VLOS or EVLOS flight.
Basic Flow	1) The MES accesses the Mission Execution module of the Ground Segment Command & Control Front-End and authenticates himself/herself on it. 2) The MES takes control of the scheduled inspection mission instance and starts it. 3) The MES performs all the preliminary checks for the given inspection mission instance, namely: a. Controls that the drones are duly authorised to perform the mission (e.g., that the insurances are valid, that the necessary authorisation are valid, etc.). b. Verifies again the feasibility of the mission with respect to the latest "dynamic" restrictions present onto the database (such as NOTAMs). c. Controls the meteo conditions along the mission path with respect to the drones operating conditions. d. Verifies the correct functioning of the D4S System, in particular checks that each Drone is fully functional, its batteries are fully charged, the Drone-to-Drone and Drone-To-Ground Segment radio link are active. 4) The MES starts the inspection mission and supervises the Drones during the flight by: a. Checking the telemetry and diagnostic data, acknowledging / managing every warning/error/alarm raised by the drones; b. Following the position of the drones onto the map, controlling that every target OOI is properly inspected by the swarm; c. Verifying the advancements of the mission execution; d. Checking the correct behaviour of each part of the system. 5) After the take-off, each Drone is forced to approach a cable in a position defined inside the "recharging" mission flight plan. The operating mode is set to "Recharge", so that each Drone is allowed to approach the cable and the automatic countermeasures to avoid to get near to the cable more than the minimum allowed distance are disabled. 6) Each Drone docks to the power cable with its clamping mechanisms. 7) Each Drone starts harvesting energy from the cable trough the harvester, and the Batteries are recharged. 8) Each Drone, once the batteries are fully charged, stops harvesting, and inform the Mission Execution module. 9) The MES sends a "detach from cable" command to each drone. 10) Each Drone detaches itself from the power cable. 11) Each Drone flies away from the cable and, once far away from it more than the minimum allowed distance, change the operating mode to Nominal. 12) The DPA visually checks the behaviour of its Drone during all the steps from 5) to 11) and reports the MES and the DP in case any anomaly occurs.

	13) The mission is terminated and all the drones fly back to the mission starting point and land. 14) The MES ends the mission.
Alternative Flow(s)	If the UC is performed using a swarm (two or more drones): 5-bis) After the take-off, MES decides which Drone shall Recharge and which could continue the mission in degraded mode, and sends: a. a recharge flight plan to every drone that shall be recharged, and, b. a degraded flight plan to the Drones that shall continue the mission, if any. 9-bis) In case that more than one Drone is recharging, the MES decides whether a Drone that has completed the recharge re-join the swarm immediately, and in that case, sends them a new flight-plan, or all the Drones shall terminate the recharge before let them re-join the swarm, and in that case the nominal flight plan is resumed.
Postconditions	• The inspection mission results (telemetry, warnings/errors/alarms, acquired data and metadata) are available on the Mission Command & Control Front-End. • The Drones are landed in the mission starting point

4.2.4.3 Automatic detaching from cable and landing

This sub-UC deals with the test of the capability of the drone to detect a dangerous situation during recharge and automatically detach from power cable and land.

Table 18 – Energy Harvesting / Automatic detaching from cable and landing UC

Field	**Description**
ID	UCA013
Status	Draft
Priority	2
Title	Automatic detaching from cable and landing
Parent UC	UCA_010
Involved Actor(s)	1) Mission Execution Supervisor (MES) 2) A Drone Pilot (DP) for the Drone, ready to take the control of the Drone in case a problem arises. 3) A Drone Pilot Assistant (DPA)
Primary Actor	Mission Execution Supervisor (MES)
Trigger	A dangerous situation is detected by the Drone
Involved Stakeholder(s)	• Infrastructure Managers
Setup	• Ground Segment Mission Command & Control in operation • Drone fully operational and grasping from a cable • Drones equipped with the AC or the DC harvester, in according to the characteristics of the power line.
Description	The recharging drones detects the dangerous situation and automatically detaches itself from the cable and lands in the nearest safe landing area or fall on the ground.
Preconditions	1) The Ground Segment database is updated with the latest information concerning flight restrictions over the target asset, such as No Fly Zones, NOTAMs, etc. 2) The Drone is regularly connected via radio with the Ground Segment. 3) The Drone is already attached to a cable.
Assumptions	1) The UC foresees the execution of a VLOS or EVLOS flight.

	2) All the steps from 1) to 6) of UCA_012 has been already performed, so that the Drone is hanging from the cable. Energy harvesting is not necessary.
Basic Flow	1) The MES forces the drone to detect a potentially dangerous situation (such as a train approaching the drone, or the wind speed going aver the maximum tolerable level), or the DPA simulates them on the field so that the Drone detect it. 2) The Drone reacts by detaching itself from the cable and landing in the nearest safe landing area. If no area is defined, it simply drops on the ground. 3) The Drone sends an alarm to the Ground Segment. 4) The DPA visually checks the behaviour of its Drone during all the steps above and reports the MES and the DP in case any anomaly occurs. 5) The Drone mission is aborted. 6) The MES ends the mission.
Alternative Flow(s)	
Postconditions	• The inspection mission results (telemetry, warnings/errors/alarms, acquired data and metadata) are available on the Mission Command & Control Front-End. • The Drone is landed in the mission starting point

4.3 Railway Use Cases and UC Actions

For what concerns railway inspections, 3 main typologies of nominal missions have been identified:

1) Damages to the electric traction overhead contact lines
2) Tracks and roadbed deformation
3) Obstacles on tracks

plus two ancillary ones related to activities necessary to setup the D4S System:

4) Target infrastructure 3D-mapping
5) Target objects inventory creation

To cover them, different UCs have been defined. Moreover, some specific UCs focussed on the test of specific functionality of the D4S system once used for railway inspection. All these UCs can be executed in principles in every Test Site suitable for Railway defined in Table 9, with the sole exception of the full Rail Inspections (Nominal or Degraded) which are thought to be executed in the controlled environment of the Test and Validation Center Wildenrath. The exact place of the operation (including the nature of the surrounding airspace, the operation duration, the number and type of drones used for the operation and the volume of operations (distance from the infrastructure and from the pilot/operator, altitude, VLOS, EVLOS, BVLOS, etc.) will be defined in the updated issues of D2.2 "Regulatory Gap/Barriers Analysis".

4.3.1 3D-map generation

This UC deals with the generation of the 3D Map of the target railway asset, encompassing the overhead power line, the tracks and track-bed, and the surrounding. The generated 3D Map, once annotated with information about the target OOIs and the ancillary information (such as mission starting and ending points, allowed recharge point and safe landing areas), will be used by the drones as a reference during the inspection missions for the navigation and for the acquisition.

Table 19 – 3D Map generation UC action table

Field	Description
ID	UCA_014
Status	Draft

Priority	1
Title	3D Map Generation
Parent UC	None
Involved Actor(s)	1) Maintenance Manager (MM) 2) Mission Planning Operator (MPO) 3) Drone Pilot (DP) 4) Drone Pilot Assistant (DPA) 5) Computer Vision Algorithms Expert (CVE) 6) Maintenance Expert (ME)
Primary Actor	Maintenance Manager
Trigger	
Involved Stakeholder(s)	• Infrastructure Managers • Safety Authorities (UAV and railway)
Setup	Standard commercial drone equipped with sensors able to generate 3D Point Cloud files (such.a LIDAR or a stereocamera).
Description	
Preconditions	1) The MPO SHALL have verified the feasibility of the flight with respect to the restrictions 2) The DP SHALL have verified the feasibility of the flight with respect to: o NOTAMs o Permits to fly (if any), insurances, etc. o Meteorological conditions
Assumptions	1) The UC will not make use of swarming capabilities 2) The UC will not deal with BVLOS flight(s), but could deal with EVLOS flight(s); in that case the presence of the DPA is foreseen.
Basic Flow	1) The MM defines a target railway line to inspect, by defining the components of the infrastructure to be acquired (e.g. electrical power line, tracks, etc.) in the Mission Planning subsystem. 2) The MPO defines the flight plan for a single drone in VLOS operations in the Mission Planning subsystem and requires specific authorisation / sends specific communications to the involved authorities. 3) The DP verifies the flight plan, verifies that the proper authorisations have been granted / the proper communications have been sent, checks for temporary restrictions/denies in force on the target at the date/time of the flight, and take in charge the flight in the Mission Planning subsystem. 4) Just before the flight is executed, the DP verifies both the existence of NOTAMs and the feasibility with respect to the meteo conditions, and register the result in the Mission Execution subsystem. 5) The DPA prepares the Drone. 6) The DP executes the flight with the assistance of DPA. 7) The DP, with the support of the DPA, uploads the acquired point cloud file in the Mission Planning subsystem. 8) The CVE and the ME browse the data acquired within the flight in the Mission Visualisation subsystem, and use them to generate a 3D Maps of the target infrastructure and annotate the position of the target OOIs.
Alternative Flow(s)	4-bis) If NOTAMs or meteo adverse conditions are found, the flight is delayed and this occurrence is duly noted, then the flow is restarted at step 4) again.
Postconditions	The 3D Map is available in the Mission Command & Control database.

4.3.2 Target objects images inventory

This UC deals with the generation of the inventory of the target OOIs, encompassing the elements of the overhead power line, the tracks and track-bed, and the surrounding.

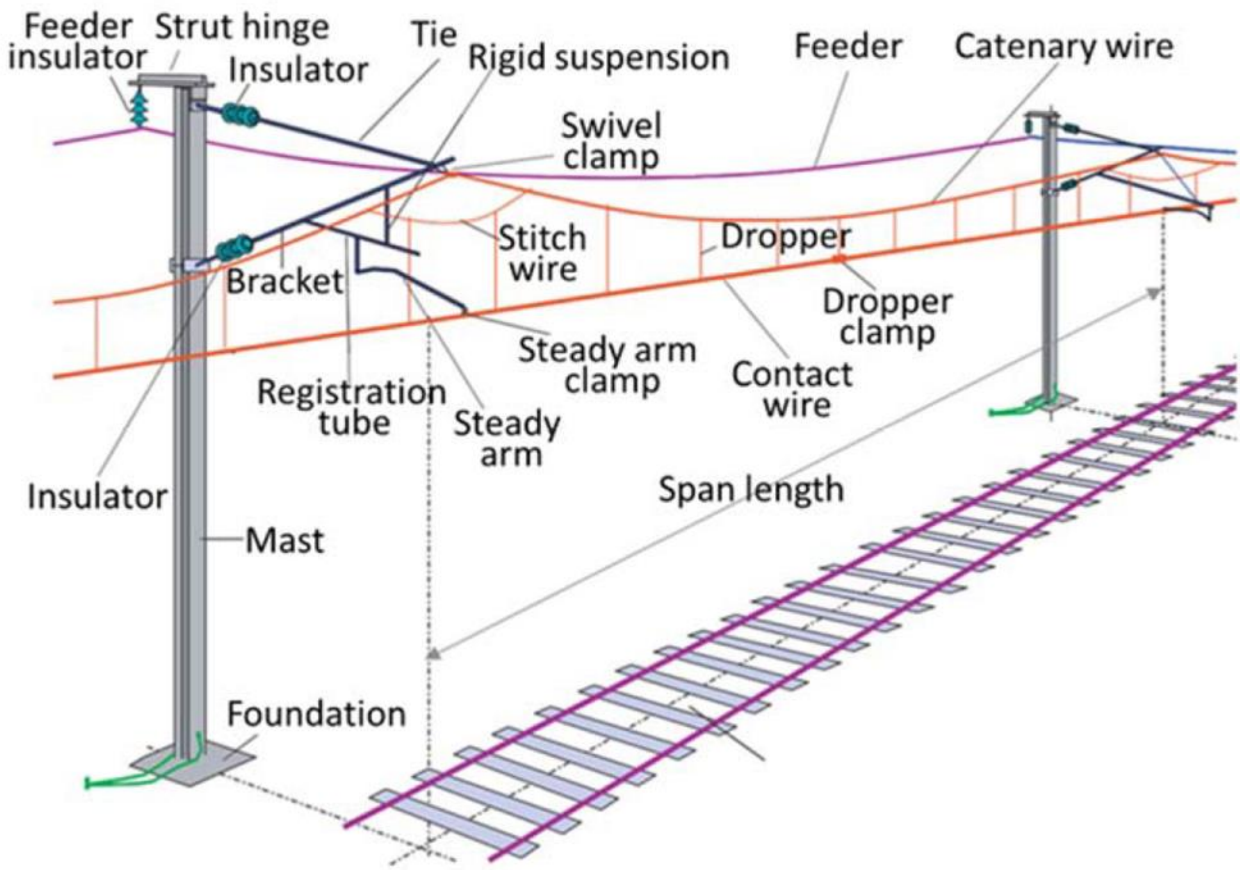


Figure 2 – Overhead Power Line constructive elements

With reference to Figure 2, the main elements that can be inspected in the overhead power line are:

1) Status of the upper parts of the structure/catenary pole/suspension (looking for corrosion)
2) Feeder wrench
3) Loosen/untightened bracket/stay arm
4) Catenary wire (looking for broken strands)
5) Catenary steady arm clamp
6) Droppers and dropper clamp on the contact line
7) Insulators (looking for damaged or bypass)
8) Damaged disconnectors (if present)
9) Broken weld in the contact line
10) Reheated cables
11) Damages in the contact line (e.g., flattening on the bottom part)

For what concerns the insulators, the following information should be annotated:

1) Manufacturer
2) Material
3) Form
4) Number of rings
5) Length
6) Thickness

7) Nominal position / angle (with respect to the pole or to the bracket)

Figure 3 – Example of image taken in Vigna Clara Station showing the pole and the other elements

The generated image inventory, once annotated with the ancillary information for their acquisition (such as number of images to acquire (and thus drones of the swarm to be involved), number of acquisitions for the same target, relative position (azimuth and orientation) of the sensor with respect to the target, etc., will constitute the reference mission starting and ending points, allowed recharge point and safe landing areas), will be used by the drones as a reference during the inspection missions for the navigation and for the acquisition.

Field	Description
ID	UCA_015
Status	Draft
Priority	1
Title	Target objects images inventory
Parent UC	None
Involved Actor(s)	1) Maintenance Expert (ME) 2) Mission Planning Operator (MPO) 3) Drone Pilot (DP) 4) Drone Pilot Assistant (DPA) 5) Computer Vision Algorithms Expert (CVE)
Primary Actor	Maintenance Manager
Trigger	

Involved Stakeholder(s)	• Infrastructure Managers • Safety Authorities (UAV and railway)
Setup	Standard commercial drone equipped with a ùn RGB or a Therm camera
Description	
Preconditions	1) The MM has defined the target railway line to inspect 2) A 3D Map of the target railway line is available 3) The MPO SHALL have verified the feasibility of the flight with respect to the restrictions 4) The DP SHALL have verified the feasibility of the flight with respect to: o NOTAMs o Permits to fly (if any), insurances, etc. o Meteorological conditions
Assumptions	1) The UC will not make use of swarming capabilities 2) The UC will not deal with BVLOS flight(s)
Basic Flow	1) The MM defines a target railway line to inspect, by defining the area of the infrastructure to be acquired in the Mission Planning subsystem. 2) The MPO defines the flight plan for a single drone in VLOS / EVLOS operations in the Mission Planning subsystem and requires specific authorisation / sends specific communications to the involved authorities. 3) The DP verifies the flight plan, verifies that the proper authorisations have been granted / the proper communications have been sent, checks for temporary restrictions/denies in force on the target at the date/time of the flight, and take in charge the flight in the Mission Planning subsystem. 4) Just before the flight is executed, the DP verifies both the existence of NOTAMs and the feasibility with respect to the meteo conditions, and register the result in the Mission Execution subsystem. 5) The DPA prepares the Drone and radio equipment if EVLOS has been planned. 6) The DP executes the flight with DPA assistance 7) The DP with DPA assistance uploads the acquired images and metadata in the Mission Planning subsystem. 8) The CVE browse all the data acquired within the flight in the Mission Visualisation subsystem and with ME produce the inventory. 9) For each OOI, the CVE and the ME generates an annotated dataset composed by positive results and negative results, e.g.: a. For the damages of overhead power line, images of the OOI with no damages and images showing the typical damages; b. For the defect in the tracks and railbed geometry, a measure of the expected gauge (with tolerances) among the tracks and the height of the railbed; c. For the presence of obstacles, how the target (railbed or overhead power line appear in standard condition).
Alternative Flow(s)	9-bis) The CVE and the ME can also make use of third-party annotated dataset, if available.
Postconditions	The inventory is populated and present in the Mission Command & Control Database.

4.3.3 Railway Inspection Nominal

This UC deals with the standard way of operating of the Drone Swarm in performing inspection missions over a railway target.

The standard flow is common to each of the three main typologies of nominal missions, namely the search of:

1) Damages to the electric traction overhead contact lines
2) Deformations of the tracks and roadbed
3) Presence of obstacles on tracks

The UC is then further specialised in sub-UCs according to specific type of mission.

Field	Description
ID	UCA_016
Status	Draft
Priority	2
Title	Railway Inspection (Nominal)
Parent UC	None
Involved Actor(s)	1) Mission Execution Supervisor (MES) 2) Maintenance Analyst (MA) 3) Drone Pilot (DP) for each Drone of the swarm, ready to take the control of the Drone in case a problem occurs.
Primary Actor	Mission Execution Supervisor (MES)
Trigger	An inspection mission instance scheduling is arrived at its due time
Involved Stakeholder(s)	• Infrastructure Managers
Setup	• Ground Segment Mission Command&Control in operation • Drone equipped with the sensors necessary to accomplish the specific type of nominal mission and the corresponding AI algos and datasets (see Level 2 UCs) • Drones fully operational and ready for take-off at the mission starting point • An inspection mission instance is already scheduled (see UCA_001)
Description	The drones' swarm is able to perform a scheduled inspection mission.
Preconditions	1) The Drones' Swarm inspection mission instance is correctly scheduled 2) The Ground Segment database is updated with the latest information concerning flight restrictions over the target asset, such as No Fly Zones, NOTAMs, etc. 3) The Drones are regularly connected via radio with the Ground Segment.
Assumptions	1) The UC foresees the use of swarming capabilities 2) The UC foresees the capability for the swarm to perform BVLOS flight(s)
Basic Flow	1) The MES accesses the Mission Execution module of the Ground Segment Command&Control Front-End and authenticates himself/herself on it. 2) The MES takes control of the scheduled inspection mission instance and starts it. 3) The MES performs all the preliminary checks for the given inspection mission instance, namely: a. Controls that the drone are duly authorised to perform the mission (e.g., that the insurances are valid, that the necessary authorisation are valid, etc.). b. Verifies again the feasibility of the mission with respect to the latest "dynamic" restrictions present onto the database (such as NOTAMs).

	c. Controls the meteo conditions along the mission path with respect to the drones operating conditions. d. Verifies the correct functioning of the D4S System, in particular checks that each Drone is fully functional, its batteries are fully charged, the Drone-to-Drone and Drone-To-Ground Segment radio link are active. 4) The MES starts the inspection mission and supervises the swarm during the flight: a. Checking the telemetry and diagnostic data, acknowledging / managing every warning/error/alarm raised by the drones; b. Follows the position of the drones onto the map, controlling that every target OOI is properly inspected by the swarm; c. Verifies the advancements of the mission execution with respect to the specific type of mission; d. Controls the Energy Harvesting activities (see UCA_010). e. Check together with the MA every potential defect discovered by the swarm for the given type of mission with respect to the target image inventory; until the mission is fully accomplished and the drones land in the mission ending point. 5) The MES ends the inspection mission.
Alternative Flow(s)	4.e-bis) [UCA_017 “Defects in overhead power lines”]: The use case can be specialised with respect to the detection of defects in the overhead power lines, and can be further specialised searching defects revealed in the visible range ([UCA_018], with an RGB Camera) or in the infrared range ([UCA_019], with a Therm Camera). This is reflected in the inspection mission plan, in the swarm setup, and in the specific experience of the MA. 4.e-ter) [UCA_020 “Defects in tracks and railbed geometry”]: The use case can be specialised with respect to the detection of defects in the tracks and/or railbed geometry. This is reflected in the inspection mission plan, in the swarm setup, and in the specific experience of the MA. 4.e-quater) [UCA_021 “Obstacles on tracks/overhead power lines”]: The use case can be specialised with respect to the detection of obstacles along the tracks/railbed and/or on the overhead power lines This is reflected in the inspection mission plan, in the swarm setup, and in the specific experience of the MA.
Postconditions	The inspection mission results (telemetry, warnings/errors/alarms, acquired data and metadata) are available on the Mission Command & Control Front-End.

4.3.4 Railway Inspection (Degraded)

This UC deals with a degraded way of operating of the Drone Swarm in performing inspection missions over a railway target when one or more Drones of the swarm are no longer available.

In this UC, we do not differentiate the among the three main typologies of mission described in UCA_016 and its sub-UCs, but we concentrate on the behaviour of the swarm.

Field	Description
ID	UCA_022
Status	Draft

Priority	2
Title	Railway Inspection (Degraded)
Parent UC	None
Involved Actor(s)	1) Mission Execution Supervisor (MES) 2) Maintenance Analyst (MA) 3) Drone Pilot (DP) for each Drone of the swarm, ready to take the control of the Drone in case a problem occurs.
Primary Actor	Mission Execution Supervisor (MES)
Trigger	An inspection mission instance scheduling is arrived at its due time
Involved Stakeholder(s)	• Infrastructure Managers
Setup	• Ground Segment Mission Command & Control in operation • Drone equipped with the sensors necessary to accomplish the specific type of nominal mission (see Level 2 UCs) • Drones fully operational and ready for take-off at the mission starting point • An inspection mission instance is already scheduled (see UCA_001)
Description	One or more drones of the swarm become no longer able to participate to a scheduled inspection mission.
Preconditions	1) The Drones' Swarm inspection mission instance is correctly scheduled 2) The Ground Segment database is updated with the latest information concerning flight restrictions over the target asset, such as No Fly Zones, NOTAMs, etc. 3) The Drones are regularly connected via radio with the Ground Segment.
Assumptions	1) The UC foresees the use of swarming capabilities 2) The UC foresees the capability for the swarm to perform BVLOS flight(s) 3) All the steps of UCA_020 from 1) to 4) have been already executed.
Basic Flow	5) One or more Drones of the Swarm become no longer available to contribute to the mission execution (e.g., because they detect some malfunctioning or need to recharge themselves) and inform the Mission Execution module of the Mission Command & Control. 6) The MES decides that the mission can be continued in degraded mode and sends a new mission inspection plan to the drones still available, while the ones no longer available follow a specific plan (i.e., the safe landing procedure or the recharging flight plan). 7) The degraded mission continues until it is fully accomplished and the all the drones are landed in the mission ending point. 8) The MES ends the inspection mission.
Alternative Flow(s)	7-bis) In case the drones excluded by the mission become available again (e.g., because they completed the recharge) they inform the Mission Execution module of the Mission Command & Control and the MES could redefine the inspection mission (in a new degraded mode or in the nominal mode).
Postconditions	The inspection mission results (telemetry, warnings/errors/alarms, acquired data and metadata) are available on the Mission Command & Control Front-End.

4.4 Bridge Use Cases and UC Actions

As anticipated in 4.1, different sites, located in Italy, have been analysed, in order to find possible suitable locations to conduct the experimentations for the project. Actual experimentation in WP7 will be conducted in some of the selected sites, according to the best option from multiple point of views (safety, number of UCAs that can be tested, authorization processes, access to the area, presence of obstacles etc.). A proper description of the operations (including the related safety assessment, stakeholders involved, etc..) will be reported in more detail in D7.3, for the UCs actually selected for the in-situ exercises.

Unused (reinforced concrete) bridges/viaducts overpassed no trafficked roads (e.g., river or valley) in easy-to-access areas without strong regulatory restrictions (according to the national regulations) have been the first solutions researched (but not the only ones). The identification and location of the possible use-cases analysed, briefly described in the following sections, are summarised in Table 20 and reported in Figure 4.

Table 20 – Location of the possible bridge use-cases analysed

UC ID	Location	Coordinates	Operative conditions
01	Site S5	44°46'12.5"N 8°08'14.4"E	Abandoned railway route, used only for the occasional circulation of tourist trains
02	Site S6	40°36'23.0"N 15°07'51.4"E	Abandoned segment of the road
03	Site S7	44°30'48.6"N 9°57'42.6"E 44°30'35.9"N 9°57'27.5"E	Active motorway
04	Site S3	41°55'40.6"N 14°19'24.4"E	Railway route in a very poor maintenance state (to be checked if abandoned)
05	Site S8	44°52'27.3"N 9°38'45.8"E	Abandoned railway route
06	Site S9	45°10'26.3"N 7°55'58.3"E	Abandoned railway route
07	Site S10	44°48'30.8"N 9°26'09.0"E	Active road
08	Site S11	44°48'31.9"N 8°50'55.0"E	Active road
09	Site S12	44°35'41.2"N 8°56'49.3"E	Active motorway
10	Site S13	44°34'57.8"N 9°56'30.2"E	Active road

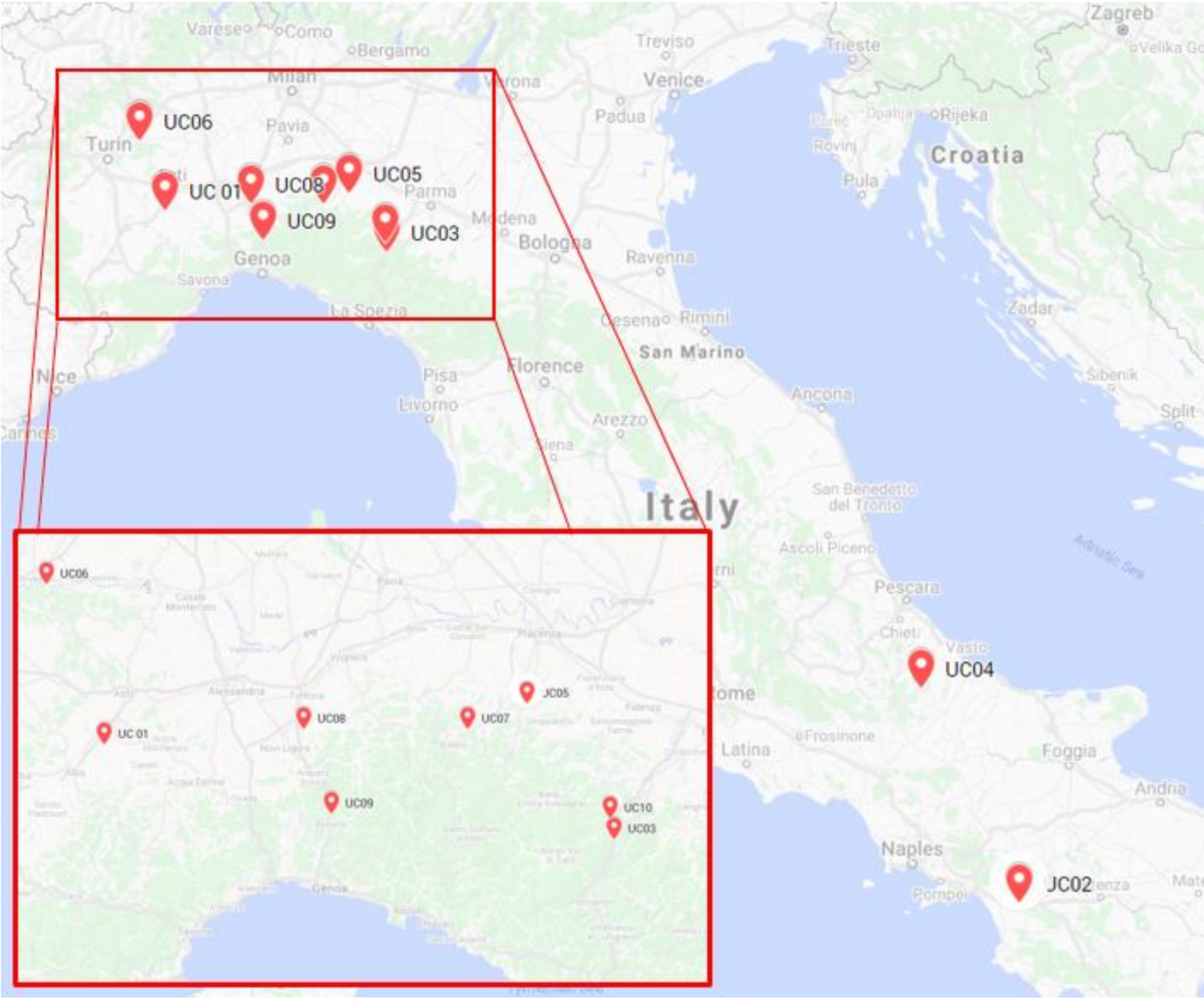


Figure 4 – Location of the possible bridge use-cases analysed (Google Maps).

4.4.1 UC 01 - Viaduct on the railway route near Castagnole delle Lanze (North Italy)

The present use-case consists in a series of activities supposed to be conducted on a portion of a long viaduct on an abandoned railway route near Castagnole delle Lanze in the province of Asti, in Piedmont. From 2012, this railway is used only for the occasional circulation of tourist trains (https://www.ferrovieabbandonate.it/linea_dismessa.php?id=272).

The viaduct, a reinforced concrete girder railway structure with wall piers, consists of 144 bays with a total length of about 3.7 km and a maximum high of about 20m.

An image of a portion of the viaduct (extracted from Google Maps) is reported in Figure 6.

Figure 5 – Viaduct near Castagnole delle Lanze - plan view of the operative context extracted from Google Maps .

Figure 6 – A picture of a portion of the viaduct near Castagnole delle Lanze.

4.4.1.1 Use Case Actions to be validated

The following table summarises the list of UC actions supposed to be validated during the present UC. As shown, this UC is supposed to take place in two different in-situ missions.

Table 21 – List of the UCAs supposed to be validated during the UC01.

Actions	Mission 1	Mission 2*
3D Bridge reconstruction (UCA_023)	UCA_024/025	UCA_002/025
Bridge Visual Inspection (UCA_026)	UCA_027/028	UCA_002/028
Bridge Assessment (UCA_029)	UCA_030/031	UCA_030/031
Swarming (UCA_004)		UCA_004
Energy harvesting (UCA_010)		UCA_010
*To be defined at a later stage of the project taking into consideration also the regulatory framework		

4.4.1.2 Preliminary Safety and Regulatory considerations

According to the national regulation (ENAC, 2020; Circular ATM-09, 2019 - available also through the D-Flight Portal, see Section 4.3.1 of [AD-2]), in the location of the viaduct the maximum flight height allowed is 45m (with the possibility to increase up to the higher infrastructure present), as shown in Figure 5 together with a plan view of the surrounding context of a portion of the viaduct. As it is possible to observe most of the viaduct is inserted in a sparsely populated (mostly industrial) easy-to-access area.

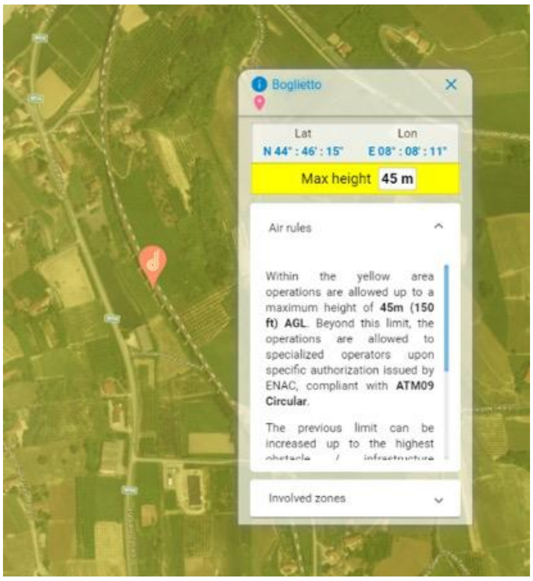


Figure 7: Viaduct near Castagnole delle Lanze - plan view of the operative context extracted from D-Flight Portal

As regarding foreseen VLOS operations conducted in Mission 1, (UCA_027/028, UCA_024/025), the preliminary safety and regulatory assessment leads to the conclusion that they may be classified as falling under the Open category (see Section 4.2.1 of [AD-2] for the requirements to be included in the Open category operations). This means that an authorization from the Competent Authorities (in this case ENAC, the Italian CAA) is not needed and the operation can be carried out considering only the requirements about registration and pilot competence (see Section 4.3.1 of [AD-2]). The above-mentioned preliminary assessment needs to be refined and finalized once the operational details are finally defined (including the model of drone to be used, the competence of the chosen pilot, etc.) and on-site surveys and checks will be done, as part of Work Package 7 that is devoted to use cases validation and demonstration.

For Mission 2, and in particular for UCA 002, UCA_004 and UCA_010, as introduced in Section 4.2.3 of [AD-2], a clear regulatory framework has not yet been established. This means that a specific risk assessment and a potentially related experimental plan will need to be prepared and agreed with the Competent Authorities. The Italian partners in the consortium (EUCENTRE, NEAT, Deep Blue) have previous experiences with the filing and approval of experimental plans with the Italian CAA, and will accordingly contribute to the authorisation process for these operations. If needed, the scope of the demonstrations foreseen in WP7 will be refined to accommodate the regulatory constraints that may emerge during the process.

4.4.2 UC 02 - Viaduct Tenza (South Italy)

The present use-case consists in a series of activities supposed to be conducted on a reinforced concrete arch viaduct (with a total length of about 200m) on the E45 route (A3 motorway "Salerno-Reggio Calabria"), laying along an abandoned segment of the road.

Some images of the viaduct are reported in Figure 8.

Figure 8: Some pictures of the viaduct Tenza

4.4.2.1 Use Case Actions to be validated

The following table summarises the list of UC actions supposed to be validated during the present UC.

Table 22 – List of the UCAs supposed to be validated during the UC02.

Actions	Mission 1*
3D Bridge reconstruction (UCA_023)	UCA_002/025
Bridge Visual Inspection (UCA_026)	UCA_002/028
Bridge Assessment (UCA_029)	UCA_030
Swarming (UCA_004)	UCA_004
Energy harvesting (UCA_010)	UCA_010
*To be defined at a later stage of the project taking into consideration also the regulatory framework	

4.4.2.2 Preliminary Safety and Regulatory considerations

According to the national regulation (ENAC, 2020; Circular ATM-09, 2019 - available also through the D-Flight Portal), in the location of the viaduct the maximum flight height allowed is 120m, as shown in Figure 9 together with a plan view of the surrounding context of the bridge (extracted from Google Maps).

Figure 9: Viaduct Tenza - plan view of the operative context extracted from Google Maps (top) and D-Flight Portal (bottom)

As it is possible to observe the viaduct is inserted in a non-urban area close to a natural park (if this UC will be selected for the WP7 in-situ exercises, according to the activities that will be actually carried out, a proper authorisation from the park could be needed).

The same considerations about categorization of operations and related authorisation process as for Use Case 01 (Mission 2) remain valid for this use case and for Use Case Actions foreseen in its Mission 1.

4.4.3 UC 03 – Bridges near Roccaprebalza (North Italy)

The present use-case consists in a series of activities supposed to be conducted on a series of bridges laying along the E31 route (A15 – Cisa motorway), near Roccaprebalza (municipality of Berceto – in province of Parma, Emilia Romagna).

In Table 23 the details about the location of each bridge, are reported. All these structures are reinforced concrete girder bridges.

Bridge name	Coordinates	Approximate length
Bridge “Rio Dei cani”	44°30'48.6"N 9°57'42.6"E	180 m
Bridge “Rio Pizzarotta”	44°30'35.9"N 9°57'27.5"E	180 m

Table 23 – List of the viaducts near Roccaprebalza analysed

Some images of the bridges are reported in Figure 10. As it is possible to notice, for each location a series of two, structurally independent viaducts laying in parallel, are present.

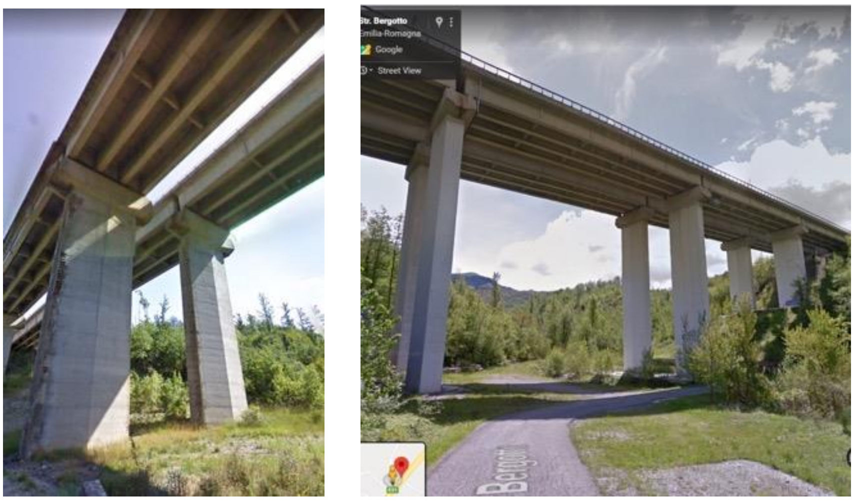


Figure 10 – Some pictures of the bridges on the E31 route (A15 – Cisa motorway), near Roccaprebalza: bridge “Rio Dei Cani” (left) and bridge “Rio Pizzarotta” (right).

4.4.3.1 Use Case Actions to be validated

The following table summarises the list of UC actions supposed to be validated during the present UC.

Table 24 – List of the UCAs supposed to be validated during the UC03.

Actions	Mission 1
3D Bridge reconstruction* (UCA_023)	UCA_024/025
Bridge Visual Inspection (UCA_026)	UCA_027/028
Bridge Assessment (UCA_029)	UCA_031
*If possible, only a side of the bridge will be reconstruct in order to provide the metric information for the structural capacity assessment	

4.4.3.2 Preliminary Safety and Regulatory considerations

According to the national regulation (ENAC, 2020; Circular ATM-09, 2019 - available also through the D-Flight Portal), in the location of the bridges the maximum flight height allowed is 120m, as shown in Figure 11 together with a plan view of the surrounding context of the bridges (extracted from Google Maps).

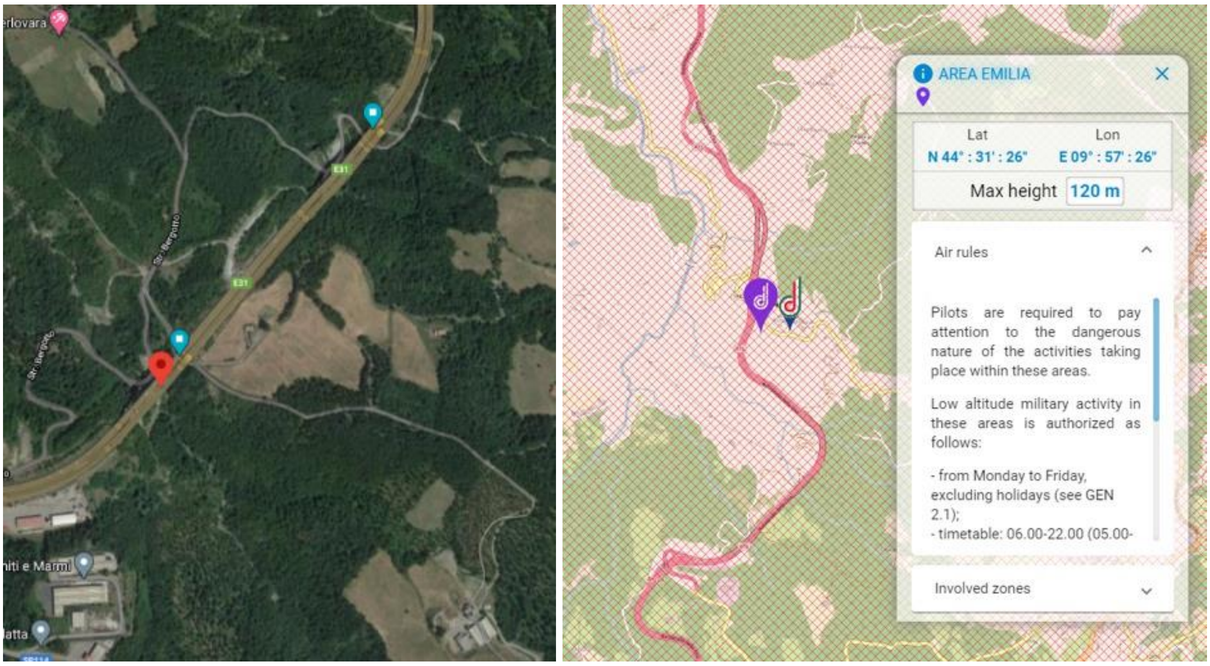


Figure 11: Bridges on the E31 route (A15 – Cisa motorway), near Roccaprebalza - plan view of the operative context extracted from Google Maps (left) and D-Flight Portal (right).

As it is possible to observe the bridges are inserted in a non-urban area. The main critical aspect related to these possible use-cases is the fact that all these bridges are part of an active motorway. If this UC will be selected for the WP7 in-situ exercises, according to the activities that will be actually carried out, proper buffer and safety procedures will be carefully planned according to the Italian regulations. In particular, the operations will not fall in the Open Category and may instead fall under one of the standard scenarios defined by the Italian CAA (see Section 4.3.3 of [AD-2]), namely standard scenario IT-STS-02: Non-Urban[3]. This standard scenario has been introduced by the Guidelines LG 2020/001-NAV Ed. 1 of the 30th September 2020 (ENAC Guidelines, 2020) and introduces a number of technical and operational presciptions and limitations for ”VLOS over a controlled ground area in a non-urban populated environment”

If Work Package 7 will select Use Case 03 for in-situ exercises, the compliance to all the conditions foreseen by IT-STS-02 must be checked in the planning phase and the adherence to the reference standard scenario must be declared to the Italian Civil Aviation Authority (ENAC) before carrying out the operations (see Section 4.3.3 of [AD-2]).

[3] https://www.enac.gov.it/sites/default/files/allegati/2020-Ott/IT-STS-02_NON-URBAN-Rev.%201.pdf

4.4.4 UC 04 – Bridge near Borrello (South Italy)

The present use-case consists in a series of activities supposed to be conducted on a reinforced concrete arch bridge (with a total length of about 130m) on a railway line near Borrello in the province of Chieti, in Abruzzo. The line, still functional, is in a very poor maintenance state with the exception of some legs which are under renewal (https://www.ferrovieabbandonate.it/linea_dismessa.php?id=227). Some images of the bridge are reported in Figure 12.

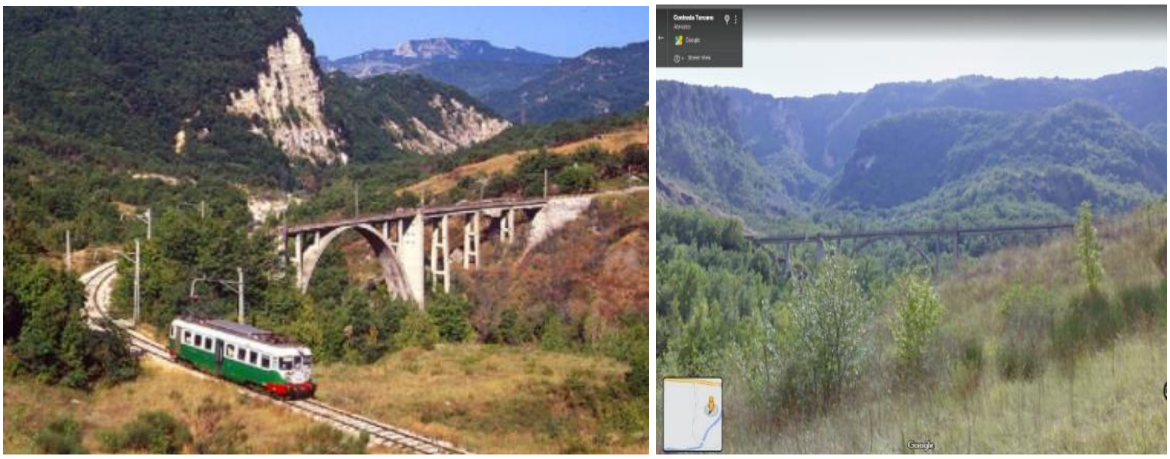


Figure 12 – Some pictures of the bridge near Borrello.

4.4.4.1 Use Case Actions to be validated

The following table summarises the list of UC actions supposed to be validated during the present UC.

Table 25 – List of the UCAs supposed to be validated during the UC04.

Actions	Mission 1*
3D Bridge reconstruction (UCA_023)	UCA_002/025
Bridge Visual Inspection (UCA_026)	UCA_002/028
Bridge Assessment (UCA_029)	UCA_030
Swarming (UCA_004)	UCA_004
Energy harvesting (UCA_010)	UCA_010
*To be defined at a later stage of the project taking into consideration also the regulatory framework	

4.4.4.2 Preliminary Safety and Regulatory considerations

According to the national regulation (ENAC, 2020; Circular ATM-09, 2019 - available also through the D-Flight Portal), in the location of the bridge the maximum flight height allowed is 120m, as shown in Figure 13 together with a plan view of the surrounding context of a portion of the bridge (extracted from Google Maps).

Figure 13 – Bridge near Borrello - plan view of the operative context extracted from Google Maps (left) and D-Flight Portal (right).

The structure is inserted in a non-urban area close to a natural park. If this UC will be selected for the WP7 in-situ exercises, according to the activities that will be actually carried out, a proper authorisation from the park could be needed. The accessibility of the site and the effective service condition of the line need to be checked as well.

For the Use Case Actions UCA02, UCA_004 and UCA_010, the considerations already made in section 4.4.1.2 are applicable.

4.4.5 UC 05 – Bridge near Ponte Dell'Olio (North Italy)

The present use-case consists in a series of activities supposed to be conducted on a reinforced concrete arch bridge (with a total length of about 160m) on an abandoned railway route near Ponte Dell'Olio in the province of Piacenza, in Emilia-Romagna (https://www.ferrovieabbandonate.it/linea_dismessa.php?id=131).

Some images of the bridge are reported in Figure 14.

Figure 14 – Some pictures of the bridge near Ponte Dell'Olio.

4.4.5.1 Use Case Actions to be validated

The following table summarises the list of UC actions supposed to be validated during the present UC.

Table 26 – List of the UCAs supposed to be validated during the UC05.

Actions	Mission 1
3D Bridge reconstruction (UCA_023)	UCA_024/025
Bridge Visual Inspection (UCA_026)	UCA_027/028
Bridge Assessment (UCA_029)	UCA_030/031

4.4.5.2 Preliminary Safety and Regulatory considerations

According to the national regulation (ENAC, 2020; Circular ATM-09, 2019 - available also through the D-Flight Portal), in the location of the bridge the maximum flight height allowed is 25m (with the possibility to increase up to the higher infrastructure present), as shown in Figure 15 together with a plan view of the surrounding context of a portion of the bridge (extracted from Google Maps).

Figure 15 – Bridge near Ponte Dell'Olio - plan view of the operative context extracted from Google Maps (left) and D-Flight Portal (right).

As it is possible to observe the bridge is inserted in an urban area inside the boundary of a natural park. If this UC will be selected for the WP7 in-situ exercises, according to the activities that will be actually carried out, a proper authorisation from the park could be needed. Being the location within an urban area, the operation falls under the standard scenario IT-STS-01: Urban[4]. This standard scenario has been introduced by the Guidelines LG 2020/001-NAV Ed. 1 of the 30th September 2020 (ENAC Guidelines, 2020) and introduces a number of technical and operational presciptions and limitations for "VLOS over a controlled ground area in an urban populated environment".

If Work Package 7 will select Use Case 05 for in-situ exercises, the compliance to all the conditions foreseen by IT-STS-01 must be checked in the planning phase and the adherence to the reference standard scenario must be declared to the Italian Civil Aviation Authority (ENAC) before carrying out the operations (see Section 4.3.3 of [AD-2]).

4.4.6 UC 06 – Bridge near Chivasso (North Italy)

The present use-case consists in a series of activities supposed to be conducted on a mixed reinforced concrete-masonry arch bridge (with a total length of about 380m) on an abandoned railway route, near Chivasso in the metropolitan city of Turin, in Piedmont (https://www.ferrovieabbandonate.it/linea_dismessa.php?id=253).

An image of the bridge is reported in Figure 16.

[4] https://www.enac.gov.it/sites/default/files/allegati/2020-Ott/IT-STS-01_URBAN%20Rev.%201.pdf

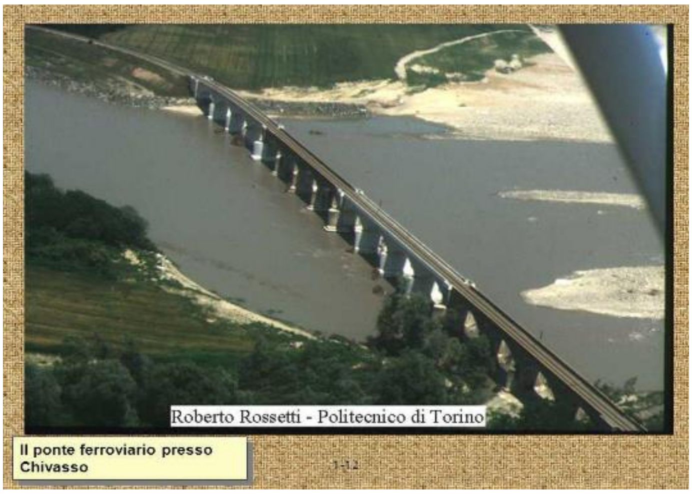


Figure 16 – A picture of the bridge near Chivasso.

4.4.6.1 Use Case Actions to be validated

The following table summarises the list of UC actions supposed to be validated during the present UC. As shown, this UC is supposed to take place in two different in-situ missions.

Table 27 – List of the UCAs supposed to be validated during the UC06.

Actions	Mission 1	Mission 2*
3D Bridge reconstruction (UCA_023)	UCA_024/025	UCA_002/025
Bridge Visual Inspection (UCA_026)	UCA_027/028	UCA_002/028
Bridge Assessment (UCA_029)	UCA_030/031	UCA_030/031
Swarming (UCA_004)		UCA_004
Energy harvesting (UCA_010)		UCA_010
*To be defined at a later stage of the project taking into consideration also the regulatory framework		

4.4.6.2 Preliminary Safety and Regulatory considerations

According to the national regulation (ENAC, 2020; Circular ATM-09, 2019 - available also through the D-Flight Portal), in the location of the bridge the maximum flight height allowed is 120m, as shown in Figure 17 together with a plan view of the surrounding context of a portion of the bridge (extracted from Google Maps).

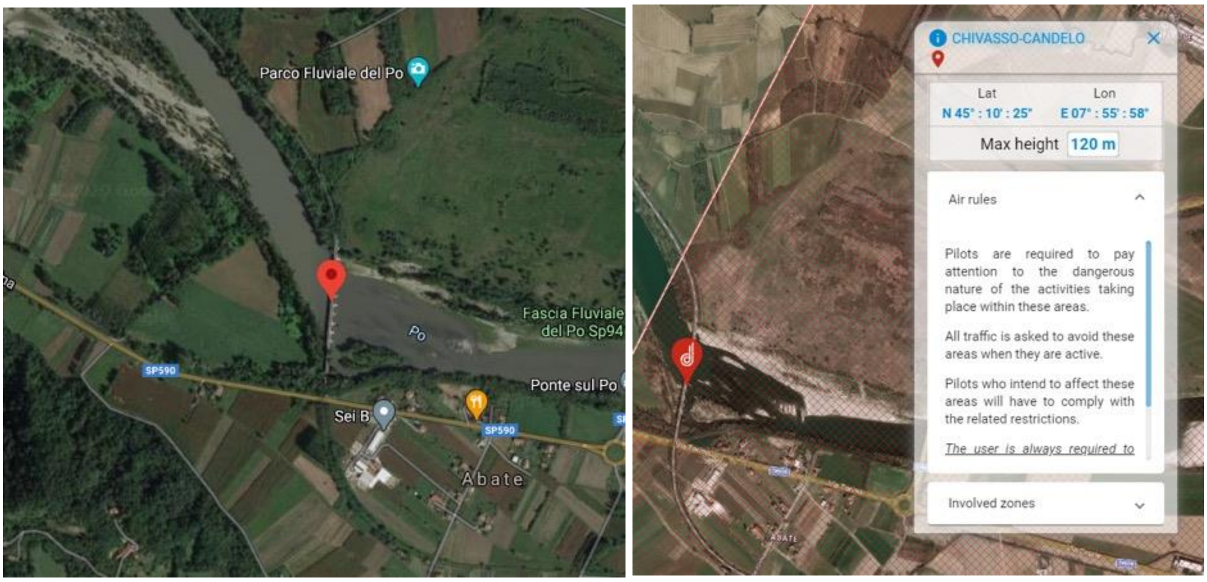


Figure 17 – Bridge near Chivasso - plan view of the operative context extracted from Google Maps (left) and D-Flight Portal (right).

As it is possible to observe the bridge is inserted in a sparsely populated area, then the same conditions described in section 4.4.1.2 would apply. For the Use Case Actions UCA 002, UCA_004 and UCA_010, the considerations already made in section 4.4.1.2 are also applicable.

4.4.7 UC 07 – Bridge near Mezzano Scotti (North Italy)

The present use-case consists in a series of activities supposed to be conducted on a reinforced concrete girder bridge (with a total length of about 380m and a maximum high of about 10m) laying along the SS45 route near Mezzano Scotti (in province of Piacenza, Emilia Romagna).

Some images of the bridge are reported in Figure 18.

Figure 18 – Some pictures of the bridge near Mezzano Scotti.

4.4.7.1 Use Case Actions to be validated

The following table summarises the list of UC actions supposed to be validated during the present UC.

Table 28 – List of the UCAs supposed to be validated during the UC07.

Actions	Mission 1*
3D Bridge reconstruction** (UCA_023)	UCA_024/025
Bridge Visual Inspection*** (UCA_026)	UCA_027/028
Bridge Assessment (UCA_029)	UCA_031
*Additional activities could be considered at a later stage of the project taking into consideration the possibility to interrupt the traffic as well as the regulatory framework. **Only a side of the bridge could be reconstructed in order to provide the metric information for the structural capacity assessment *** The data obtained through VLOS manually piloted missions could be used to train the planning of the trajectories for the autonomous/swarm navigations and for the training of the AI algorithms.	

4.4.7.2 Preliminary Safety and Regulation considerations

According to the national regulation (ENAC, 2020; Circular ATM-09, 2019 - available also through the D-Flight Portal), in the location of the bridge the maximum flight height allowed is 120m, as shown in Figure 19 together with a plan view of the surrounding context of the bridges (extracted from Google Maps).

Figure 19 – Bridge near Mezzano Scotti: plan view of the operative context extracted from Google Maps (left) and D-Flight Portal (right).

The main critical issue related to this possible use-case is the fact that this bridge is part of an active road. If this UC will be selected for the WP7 in-situ exercises, according to the activities that will be actually carried out, proper buffer and safety procedures will be carefully planned according to the national regulations (especially if the traffic interruption will not be possible). In particular the considerations about the standard scenarios IT-STS-01 are still applicable here (see section 4.4.5.2).

The bridge is located close to an urban area inside the boundary of a natural park (a proper authorisation could be needed for the in-situ exercises).

4.4.8 UC 08 – Bridge near Villalvernia (North Italy)

The present use-case consists in a series of activities supposed to be conducted on a reinforced concrete girder bridge (with a total length of about 240m and a maximum high of about 10m) laying along the SP151 route near Villalvernia (in province of Alessandria, Piedmont).

Some images of the bridge are reported in Figure 20.

Figure 20 – Some pictures of the bridge near Villalvernia.

4.4.8.1 Use Case Actions to be validated

The following table summarises the list of UC actions supposed to be validated during the present UC.

Table 29 – List of the UCAs supposed to be validated during the UC08.

Actions	**Mission 1***
3D Bridge reconstruction (UCA_023)	UCA_024/025
Bridge Visual Inspection** (UCA_026)	UCA_027/028
Bridge Assessment (UCA_029)	UCA_031
*Additional activities could be considered at a larger stage of the project taking into consideration the possibility to interrupt the traffic as well as the regulatory framework. ** The data obtained through VLOS manually piloted missions could be used to train the planning of the trajectories for the autonomous/swarm navigations and for the training of the AI algorithms.	

4.4.8.2 *Preliminary Safety and Regulatory considerations*

According to the national regulation (ENAC, 2020; Circular ATM-09, 2019 - available also through the D-Flight Portal), in the location of the bridge the maximum flight height allowed is 120m, as shown in Figure 21 together with a plan view of the surrounding context of the bridges (extracted from Google Maps).

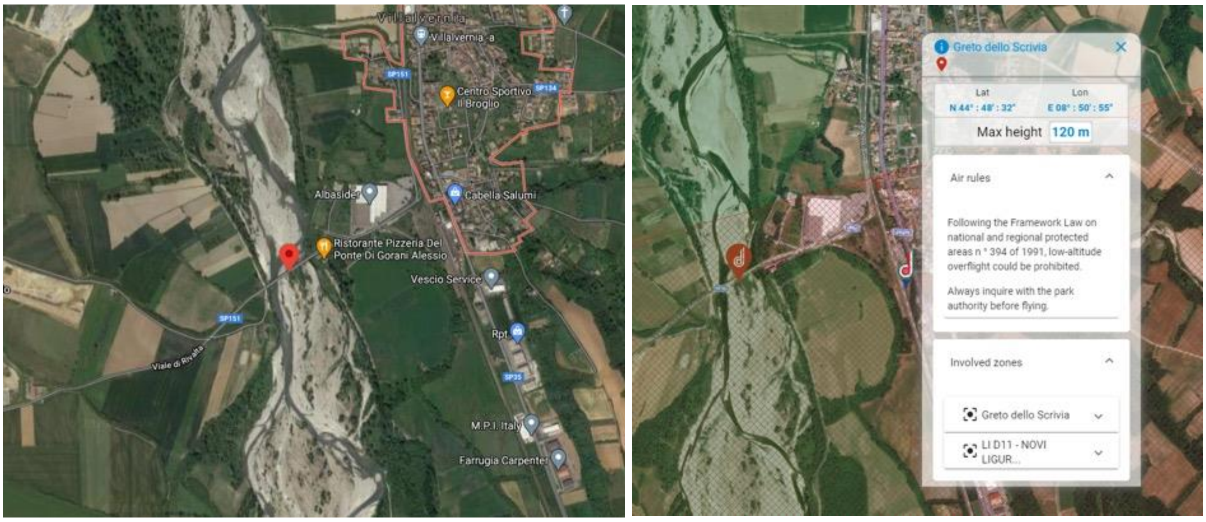


Figure 21 – Bridge near Villalvernia: plan view of the operative context extracted from Google Maps (left) and D-Flight Portal (right).

The main critical issue related to this possible use-case is the fact that this bridge is part of an active road. If this UC will be selected for the WP7 in-situ exercises, according to the activities that will be actually carried out, proper buffer and safety procedures will be carefully planned according to the national regulations (especially if the traffic interruption will not be possible). As it is possible to observe the bridge is located near an urban area inside the boundary of a natural park (a proper authorisation could be needed for the in-situ exercises). The same considerations as for UC07 are here applicable.

4.4.9 UC 09 – Bridge near Ronco Scrivia (North Italy)

The present use-case consists in a series of activities supposed to be conducted on a reinforced concrete girder bridge (with a total length of about 110m and a maximum high of about 10m) laying along the A7 motorway near Ronco Scrivia (in province of Genoa, Liguria).

Some images of the bridge are reported in Figure 22.

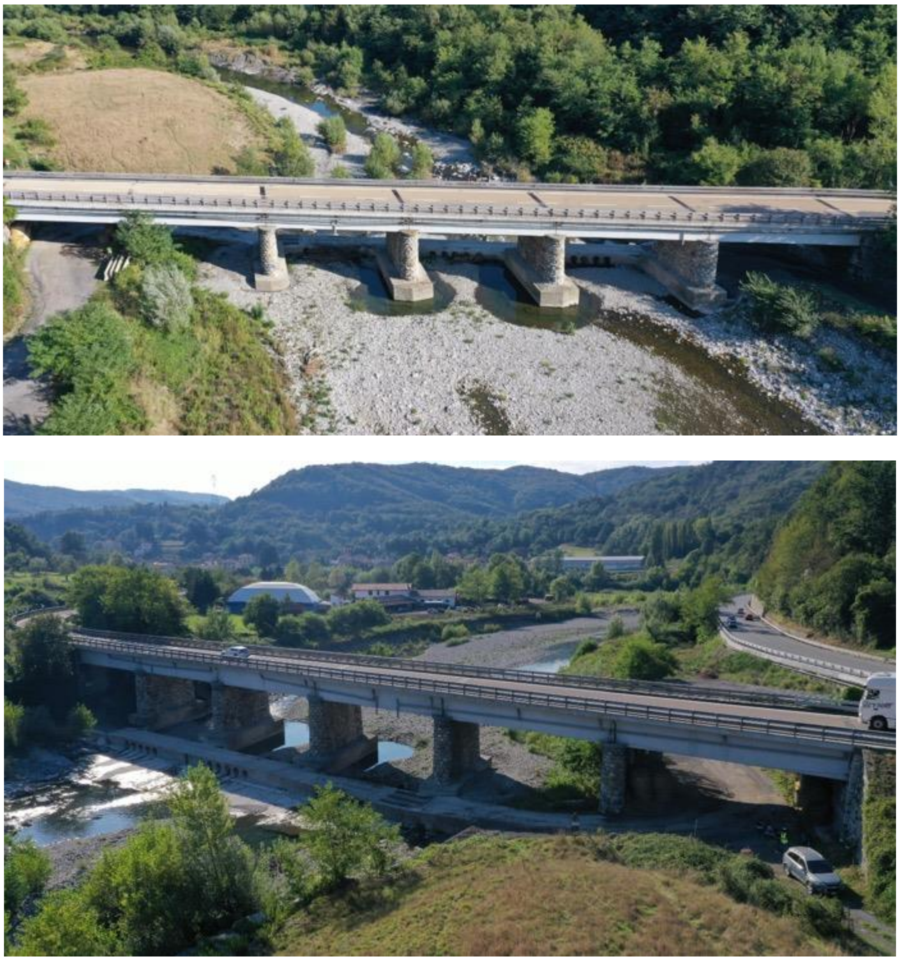


Figure 22 – Some pictures of the bridge near Ronco Scrivia.

4.4.9.1 Use Case Actions to be validated

The following table summarises the list of UC actions supposed to be validated during the present UC.

Table 30 – List of the UCAs supposed to be validated during the UC09.

Actions	**Mission 1**
3D Bridge reconstruction* (UCA_023)	UCA_024/025
Bridge Visual Inspection** (UCA_026)	UCA_027/028
Bridge Assessment (UCA_029)	UCA_031
*Only a side of the viaduct could be reconstructed in order to provide the metric information for the structural capacity assessment ** The data obtained through VLOS manually piloted missions could be used to train the planning of the trajectories for the autonomous navigations/swarm navigations and for the training of the AI algorithms.	

4.4.9.2 Preliminary Safety and Regulatory considerations

According to the national regulation (ENAC, 2020; Circular ATM-09, 2019 - available also through the D-Flight Portal), in the location of the bridge the maximum flight height allowed is 120m, as shown in Figure 23 together with a plan view of the surrounding context of the bridges (extracted from Google Maps).

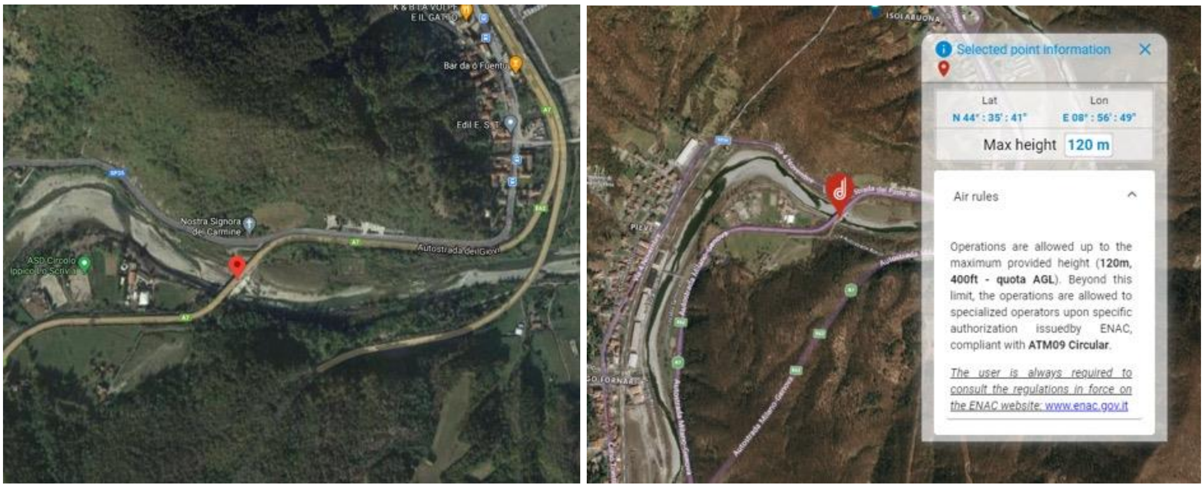


Figure 23 – Bridge near Ronco Scrivia: plan view of the operative context extracted from Google Maps (left) and D-Flight Portal (right).

The main critical issue related to this possible use-case is the fact that this bridge is part of an active motorway. If this UC will be selected for the WP7 in-situ exercises, according to the activities that will be actually carried out, proper buffer and safety procedures will be carefully planned according to the national regulations. As it is possible to observe the bridge is located near an urban area. The same considerations made for UC07 are applicable for UC09.

4.4.10 UC 10 – Bridge near Valmozzola (North Italy)

The present use-case consists in a series of activities supposed to be conducted on a reinforced concrete girder bridge (with a total length of about 130m and a maximum high of about 10m) laying along the SP308R route near Valmozzola (in the municipality of Berceto, in province of Parma, Emilia Romagna).

Some images of the bridge are reported in Figure 24.

Figure 24 – Some pictures of the bridge near Valmozzola.

4.4.10.1 Use Case Actions to be validated

The following table summarises the list of UC actions supposed to be validated during the present UC.

Table 31 – List of the UCAs supposed to be validated during the UC10.

Actions	**Mission 1***
3D Bridge reconstruction** (UCA_023)	UCA_024/025
Bridge Visual Inspection*** (UCA_026)	UCA_027/028
Bridge Assessment (UCA_029)	UCA_031
*Additional activities could be considered at a larger stage of the project taking into consideration the possibility to interrupt the traffic as well as the regulatory framework. **Only a portion of the bridge could be reconstructed in order to provide the metric information for the structural capacity assessment *** The data obtained through VLOS manually piloted missions could be used to train the planning of the trajectories for the autonomous navigations/swarm navigations and for the training of the AI algorithms.	

4.4.10.2 Preliminary Safety and Regulatory considerations

According to the national regulation (ENAC, 2020; Circular ATM-09, 2019 - available also through the D-Flight Portal), in the location of the bridge the maximum flight height allowed is 120m, as shown in Figure 25 together with a plan view of the surrounding context of the bridges (extracted from Google Maps).

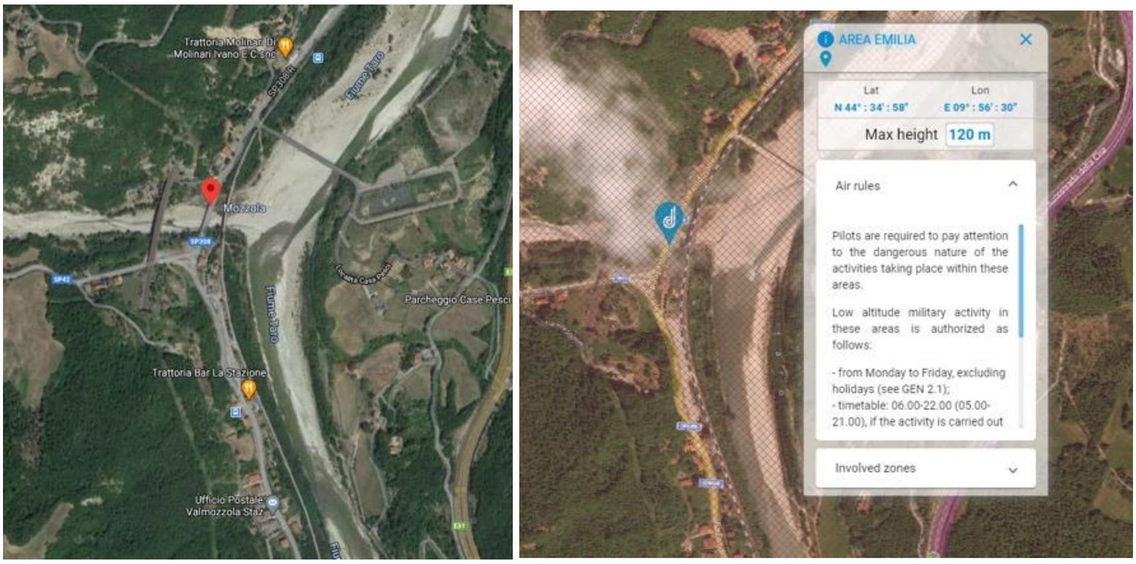


Figure 25 – Bridge near Valmozzola: plan view of the operative context extracted from Google Maps (left) and D-Flight Portal (right).

The main critical issue related to this possible use-case is the fact that this bridge is part of an active road. If this UC will be selected for the WP7 in-situ exercises, according to the activities that will be actually carried out, proper buffer and safety procedures will be carefully planned according to the national regulations (especially if the traffic interruption will not be possible). As it is possible to observe the bridge is located near an urban area. The same considerations made for UC07 are applicable for UC10.

5 Conclusions

During the work-package WP7 the validation and implementation of some the use case defined in the present deliverable will be carried out. In particular:

- the suitable UCs will be chosen according to the best option from multiple point of views (safety, number of UCAs that can be tested, authorization processes, access to the area, etc.).
- all the preliminary safety and regulatory assessments reported in the present document need to be refined and finalized (in WP7) once the operational details will be finally defined (including the model of drone to be used, the competence of the chosen pilot, the exact tasks of the mission, etc.) and on-site surveys and checks will be done, for the UCs actually selected.
- all the activities necessary to obtain an authorization (if needed) to perform the flight trials will be carried out.

6 ANNEX 1: UAV-based Bridge inspection protocols

6.1 Introduction

The structural integrity, safety and serviceability of bridges and viaducts are fundamental targets to be achieved and guaranteed due to the crucial role of such infrastructure components in the (highway and railways) transportation system. Recent collapse of several bridges (such as the I-35 truss bridge in Minneapolis in 2007, Ponte Morandi cable stayed bridge in Genoa, Italy, in 2018, Florida International University Pedestrian Bridge in 2018 and Nanfang'ao steel single-arch bridge in Taiwan in 2019) have highlighted how the design service life of many ordinarily used bridges is approaching its limit, probably due to ageing combined with a lack of appropriate maintenance and monitoring. On the other hand, the assessment of the extent and severity of damage and service performance of core infrastructure nodes is very important also during an emergency response scenario (e.g., after a seismic event) where the time factor is a key determinant for the management of both search and rescue and recovery and reconstruction phases.

The relevance of both routine condition assessments and rapid post-event damage inspections, as well as the need for proper bridge maintenance programs, are established by several national guidelines and inspection manuals (BSIPM, 2020; BIFM, 2020; WisDOT, 2020; AASHTO, 2018 and 2019; Dorafshan and Maguire, 2018; ODOT, 2017; NYSDOT, 2017; Ryan et al., 2012; Fenwick et al., 2004; NZTA, 2001; INDOT, 2000). In Italy, the Ministry of Infrastructure and Transport (MIT) has recently approved guidelines for the classification and management of risk, the assessment of safety and the monitoring of existing bridges and viaducts (LLGG, 2020). The inspection procedures and methodologies described in the document, which will be subject to an experimental application phase, are based on a multi-level approach (with different degree of detail, complexity and prioritisation) aiming at the definition of "attention classes".

The traditional practices for bridge inspection and monitoring, mostly based on visual investigations, are technically and logistically complex, time and resources consuming, costly and even unsafe for the inspectors. Special aerial platform, scaffolding, large under bridge vehicle or skilled trained staff (climbers) are required to closely inspect critical structural components difficult to reach (especially portions of the deck substructure or upper parts of piers, in long-span and high bridges).

The use of Unmanned Aircraft System (UAS) equipped with different camera and sensor technologies may represent an efficient and cost-effective support, or in some cases an alternative, to the conventional visual inspection methods. In the field of infrastructure inspections, the deployment of UAS, with respect to the conventional (manned) aircraft or to the traditional investigation methods, presents several advantages: the ability to fly at low altitudes, the possibility to closely inspect critical inaccessible zones and to acquire high-resolution photograms from different viewpoints, low operating and acquisition cost, reduced risk for operator, speed of survey and elaboration.

In the last years, the introduction of UAS technology as an additional remote non-destructive method within the infrastructural inspection manuals (both for damage assessment and condition monitoring) is increasingly attracting the interest of state and local transportation authorities and stakeholders (LLGG, 2020; Wells and Lovelace, 2018; Gillins *et al.* 2018).

The various range of advanced sensors (e.g., LiDAR, thermal/multispectral and optical camera) which can be carried as payloads, enable UASs to play an important role as non-contact (and non-destructive) remote tools for bridge condition assessment. As an example, through aerial thermal images is possible to highlight subsurface defects (delamination) in bridge deck. Moreover, 3D virtual models (digital twin), obtained from the post-processing of the aerial acquired data (images or video frames), are additional useful tools enabling realistic digital inspection and providing basic input information for the vulnerability assessment of bridge by means of simplified numerical analyses (Bellotti *et al.*, 2019 and Morandi *et al.*, 2019).

Despite all the undoubted benefits listed above, UAS technology has some limitations related, for example, to the dependence on weather conditions, the limited battery autonomy and a relatively reduced load capacity. Depending on the specific location of the target infrastructure, the environmental context may involve additional challenging issues in the employment of UAS: insufficient GNSS signal, turbulent wind gusts, presence of obstacles (vegetation) limiting the close approaching and view of the structure, electromagnetic interference and variable light conditions. Moreover, according to the authors' opinion, the data obtained from UAS-based inspection, although very suitable for different purposes, need to be considered as complementary and not an alternative to the ones deriving from direct inspection methods (where possible) or structural health monitoring (SHM) and modelling techniques, in order to perform a complete diagnostic and assessment of the inspected structure.

The present document focuses on two main aspects related to the use of UASs for the condition assessment and damage inspection of critical infrastructures: visual inspections and methodologies for the 3D-reconstruction.

6.2 Bridge inspection framework

The target of bridge inspections can be roughly divided into two categories:

1) post-event damage assessment, with the scope of evaluating the usability of a structure damaged by a shocking event (e.g., earthquake, flood, landslides, explosion), where damages are likely to be more evident and strongly dependent on the peculiar extreme loading;

2) ordinary maintenance checks, when defects possibly affecting the performance can be related to wear, construction defects, design mistakes or changes in the use of the structure over the years.

Bridges are thus assessed in the perspective of evaluating the structural performance both in service conditions and under ultimate limit states due to extreme loading. As an example, the recent Italian guidelines (LLGG, 2020) for bridge assessment consider different "attention classes", based on the evaluation of four risk categories: structural-foundation, seismic, landslides and hydraulic. The method of classification starts from visual appraisal, which may imply different levels of knowledge possibly requiring test on materials, up to the full structural modelling, also utilising available historical technical documentation (e.g., as-built drawings, past inspection reports).

A crucial aspect of the ordinary maintenance checks is the frequency of the inspections. Table 1 reports the minimum frequency of the ordinary inspections according to the recent Italian guidelines (LLGG, 2020).

Bridge Typology	**Attention classes**				
	Low	**Medium-Low**	**Medium**	**Medium - High**	**High**
Type 1 Bridge*	Bi-annual	18 months	Annual	Depending on the monitoring or 6 months	Depending on the monitoring or 6 months
Type 2 Bridge**	Annual	9 months	6 months	Depending on the monitoring or 3 months	Depending on the monitoring or 3 months

*Bridge already included in a surveillance system (the state of conservation and expected evolution of defects are therefore sufficiently known)
**New Bridge (or already in operation from several years) for which no periodic inspections have been carried out.

Table 32 – ANNEX1: Minimum frequencies of the ordinary inspections according to the Italian Standard (LLGG, 2020).

For what concerns the extraordinary inspections, intervals no longer than 5 years are recommend for bridges with “low” and “medium-low” attention classes and 2 years for all the other classes.

Table 33 reports the different types of inspections and their respective intervals in other European countries. The Italian guidelines seem to be more conservative than most of the other European standards in terms of minimum frequency, even though the definition of inspection types is not uniform, and therefore, it is difficult to make a direct comparison among different countries. The inspection methods indicated with one or two asterisks in Table 33 are not so detailed; such types of inspection are not considered by the Italian guidelines.

Inspection interval	**UK** (CS 450, 2020)	**France** (ITSEOA, 2010)	**Germany** (Hsien-Ke et al. 2017)	**Denmark** (DRD, 1994)	**Finland** (Finnra, 2004)	**Sweden** (Gruber, 1996)	**Norway** (NPRA, 1998)
< 3 months	Safety*			Daily*		Regular*	
3 months			Superficial*				
1 year		Annual*		Routine**	Annual*	Superficial**	General
2 years	General						
3 years		IQOA***	Minor			General	
5 years					General		Major
6 years	Principal	Detailed	Major	Principal		Major	
8 years					General		
* Very fast and superficial visual inspection **Aimed to verify that minimal maintenance requirements are met ***Image de la Qualité des Ouvrages d’Art							

Table 33- ANNEX 1: Summary of bridge inspection types and their corresponding frequencies for some European countries.

Depending on the bridge typology, information (e.g., geometry, damage identification and quantification, material mechanical properties) should be gathered on the following structural components: deck, beams, arch, pier, pier cap, isolators, foundation, bearings, abutment, joints, connections and cables. The condition evaluation of non-structural bridge elements (e.g., parapets, curbs, walls, pavement, sub-services), as well as the assessment of potential risk related to the external environment (e.g., embankments, riverbed), are additional crucial aspects to be considered, influencing both the service operativity and the repairability-cost evaluation.

Most of this information can be obtained from visual, non-destructive and no-contact, inspection methods. Safety, cost-sustainability, data completeness, repeatability and measurability are some of the most important features for infrastructural inspections conducted on a large scale basis. According to the authors’ opinion, UAS-based bridge visual assessment carried out by skilled and qualified operators (although with some limitations) suitably fulfils many of these requirements.

6.3 Inspection protocols and damage assessment methodology

The assessment of bridges is a complex operation, which can be carried out at different levels of complexity, and consequently of confidence. The role of the UAS is that of an high level "qualifying technology", but it is anyway a tile within a more articulated engineering framework (Figure 26). The present endeavour is focused on the use of drones and the data processing for the inspection part.

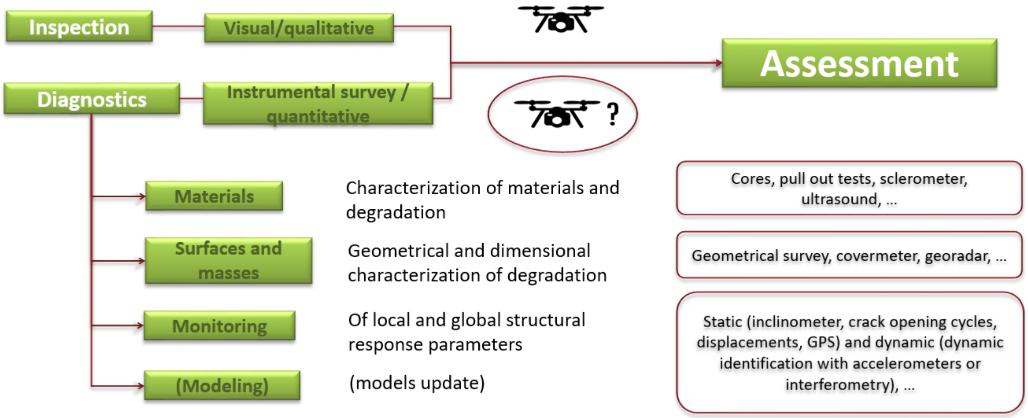


Figure 26 – ANNEX1: Bridge damage assessment framework.

In addition, it has to be observed that within the scope of bridge assessment, the needed accuracy of the structure reconstruction is much lower than for other purposes (e.g. restoration of cultural heritage, etc.).

The UAS-based visual survey of bridges can be carried out with different approaches according to the scope of the inspection and the required level of detail. After disastrous events (e.g., an earthquake) a quick visual preliminary assessment of the safety and serviceability conditions of the infrastructure network is crucial in order to rapidly highlight the most critical cases and support the technical emergency management. The employment of UAS during this fast structural condition screening may reduce both time consuming and first responders' risks, compared to traditional methods.

Especially in this scenario where the time factor is determinant, a proper order of priority for inspections should be considered according to the strategic role of the structure in the transportation system (i.e., bridges along the primary routes) and its vulnerability (if known from existing studies). The level of accuracy during the preliminary visual inspection should be aimed at identifying problems compromising the public safety (e.g. incipient total or partial collapse) and at categorising the structure as: open with/without restrictions (e.g., loads, velocity, partial lane closure), temporarily closed with repair/retrofit needs or requiring additional detailed structural checks and analyses (to be conducted later).

This multi-level approach, starting from a first rapid visual screening up to a refined assessment (if needed) passing from in-depth inspections and proper prioritisation of the interventions, is at the base of the bridge inspection methodologies (also for monitoring and maintenance purposes) reported in the national guidelines of several countries (e.g., LLGG, 2020).

Thanks to the high-resolution sensors carried by modern UASs, both video and aerial imagery data are powerful and suitable tools able to properly support infrastructure inspections in several operative contexts. In particular, in the following sections, some possible flight trajectories are qualitatively described according to the purpose of the flight mission: mapping for 3D-reconstrucion and visual inspection.

The number and the detailed characteristics of the flight paths (e.g, distance from the target, the amount of the data acquired) are strongly influenced by the dimension and typology of the bridge, its visible damage condition, as well as the surrounding environment (terrain morphology or obstacles like vegetation). The duration of the operations is others aspect strongly influenced by the dimension and typology of the bridge.

6.3.1 Mapping for 3D-reconstruction

The aerial images captured during an inspection could result in a large amount of data difficult to consult. 3D virtual models, obtained from the post-processing of these images and video frames, are very useful tools enabling realistic digital inspection and providing basic input information for the performance assessment of bridge through simplified numerical analyses.

The accuracy and quality of the 3D model are highly influenced by the capability to fully cover the target structure: the flight paths need to be carefully planned in order to ensure that each part of the infrastructure is visible at least in two images from multiple viewpoints (create an ideal virtual image cage all around the structure). In particular:

- Super-structure mapping paths (Figure 27 in red): straight-line trajectories parallel to the longitudinal direction of the bridge (both with nadiral and inclined configurations of the camera). The number of flights depends on the dimensions and typology of the bridge (minimum 3 missions: one nadiral and two lateral with inclined camera). If the traffic cannot be interrupted, these flights should be conducted guaranteeing a proper buffer from the structure according to the current regulation. Moreover the flight heights, as well as, the camera inclinations need to be set in order to cover with proper image overlaps all the super-structure.
- Sub-structure mapping paths (Figure 27 in blue): straight-line flights facing the lateral elevation profile of the bridge at different heights and with different tilt and yaw camera angles (including upward orientation for underdeck mapping). If safe, each vertical single pier should be interested by additional spiral (or Point of Interest) flights along its height in order to ensure a complete covering of all its surfaces. The number of flights depends on the dimensions and typology of the bridge, as well as the surrounding environment (e.g., obstacles like vegetation)
- Overlap between adjacent images: 70-80%.
- Accuracy: A Ground Sample Distance (GSD) not higher than 1-1.5 cm/pixel is considered suitable for the task of these missions. The distance from the structure and the flight height depend on the camera sensors typology (e.g., with Mavic 2 Pro a GSD of about 1cm/pixel correspond to a distance of about 40 m). If safe, additional flight at lower distances (around 10-15m), are recommended.

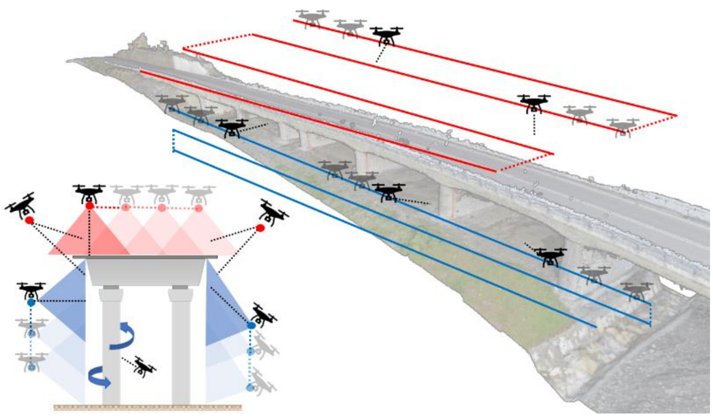


Figure 27 – ANNEX1: Schematic qualitative examples of flight routes with different camera inclinations.

The presence of similar repeatable elements (in colour and shape) within the infrastructure may cause difficulties by the SfM aligning algorithm in properly recognising the object and determining the spatial orientation and location of each image. To address this issue, a possible flight methodology could be first to capture some overall photos of the bridge from a farther distance and then to approach the structure slowly, capturing the images of the desired details. In performing this methodology it is important to plan the flights in order to limit the differences between the GSD of the images as much as possible (in order to facilitate the elaboration and to ensure an almost homogenous accuracy of the results). A general idea could be to limit the ratio between the GSD of two successive approaching flights to about 2 (Figure 28).

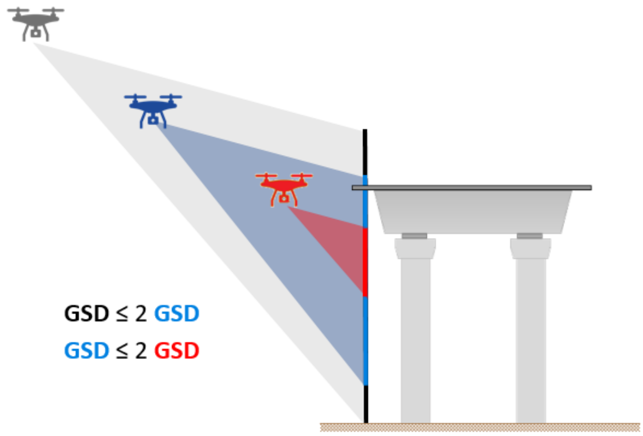


Figure 28 – ANNEX1: Schematic representation of a possible methodology of approaching the target structure, in order to facilitate the 3d-reconstruction.

6.3.2 Visual inspection

All the flight trajectories qualitatively described in the previous section may also be performed for visual inspection purposes. In addition to the aspects described above, depending on the structural typology of the bridge and the surrounding environment (terrain morphology and vegetations), additional flight paths, as the ones schematically reported in the figures below, could be considered.

In particular:

- Straight-line trajectories parallel to the transversal direction of the bridge (with different inclinations of the camera) in order to inspect the surface of deck intrados, pier walls, abutments, bearings (Figure 29a and Figure 29b)
- Straight-line trajectories parallel to the spanning direction of the deck beams (if present - i.e., no solid r.c. deck). If safe, each vertical single pier should be inspected by additional spiral (or Point Of Interest) flights along their height in order to ensure a complete covering of all its surfaces (Figure 29d).
- No identical flight paths due to the local environment: terrain morphology and vegetation (Figure 29c).
- Combination of vertical and horizontal straight lines following the lateral profile of the piers (Figure 29e).

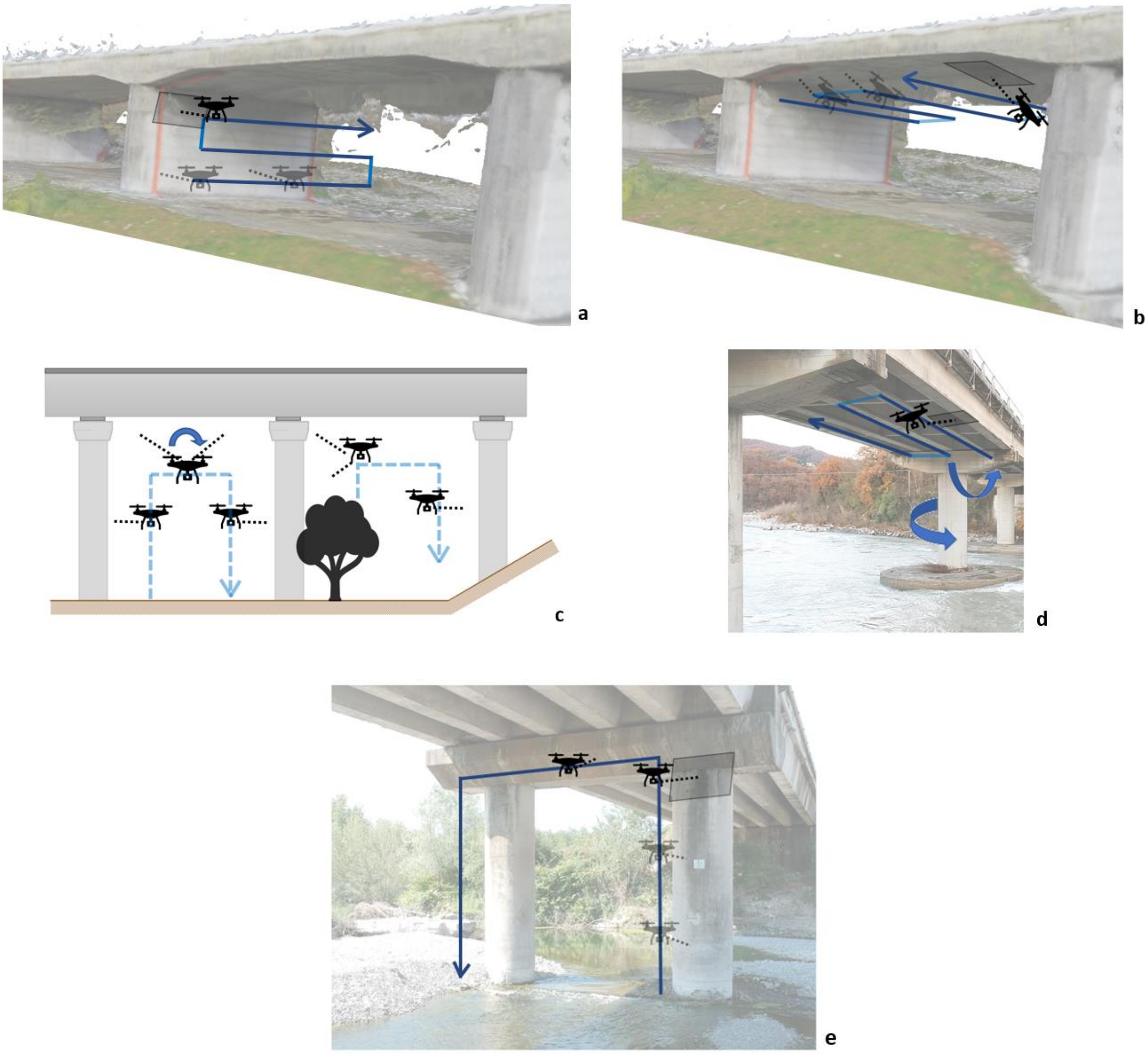


Figure 29 – ANNEX1: Schematic qualitative examples of possible flight paths for bridge inspection

- Figure 30: Combination of vertical and horizontal straight lines following the lateral profile of each bridge bay (i.e., two subsequent piers and the relative span), with different yaw and tilt camera angles, in order to properly capture critical points (like pier cap, bearing and bottom part of the deck r.c. curb/slab, if present).
- The flight paths schematically reported in Figure 30 could be an alternative (also for 3d-reconstruction purporses) to the continuous straight lines along all the longitudinal direction of the bridge reported in blue in Figure 27 (for example in case of obstacles, like vegetation).

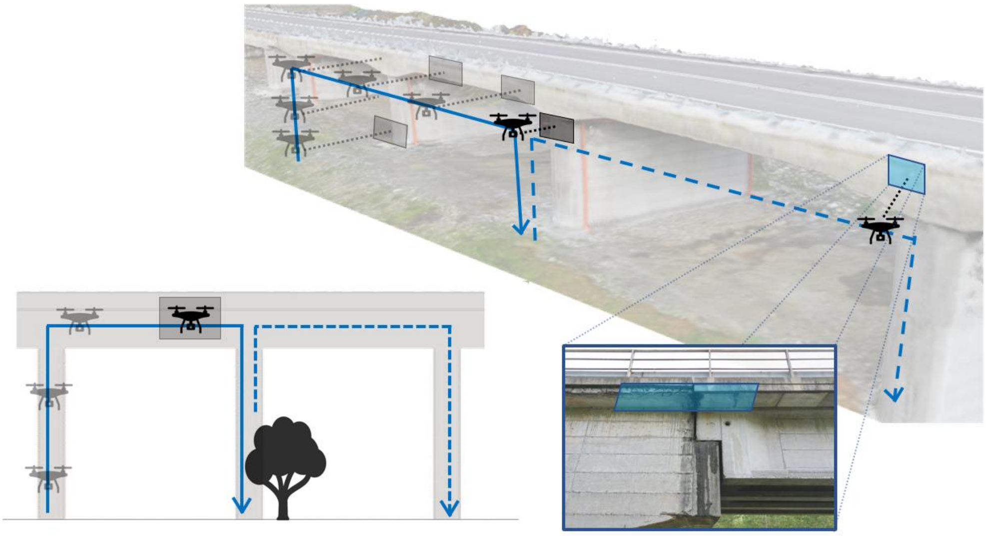


Figure 30 – ANNEX1:Schematic qualitative examples of possible flight paths for bridge inspection

The flight paths schematically reported in this section cloud be repeated for each bridge bay. The distance from the structure, during the inspection flights, should be set according to the desired/required level of details (e.g., for the visible detection of defects /cracks), the regulation limit and the flight safety (typically no closer than 3-5m). In addition, some data captured from a farther distance could be useful to provide an overall picture of the bridge and/or to clearly identify the portion investigated

The inspection of critical points (like pier cap, bearing and bottom part of the deck r.c. curb/slab, if present) or particularly damage portions, could be interested by dedicated inspection flights.

6.4 Data management and inspection form

The UAS-based inspections of structures and infrastructures may result in a large amount of data, which needs to be managed appropriately, organised and stored to facilitate the post-mission consultation and interpretation.

Each survey should be supported by suitable inspection forms for the annotation of important information, such as:

- Identification of the survey (date) and inspection team.
- Identification and localisation (geographic coordinates) of the infrastructure.
- main geometry and structural typology characteristic (e.g., materials, average main dimensions, static scheme).
- schematic in-plane representation of the infrastructure with clear identification of the repeatable components and the verse and temporal progression of their inspection.
- extension, severity and typology of the detected damages.
- final assessment on the safety and usability condition of the infrastructure (with prescription about restrictions or retrofits, if needed).

The presence of appropriate inspection forms allows the comparison of surveys repeated over time.

For a bridge of relatively small dimensions (i.e. length ≈ 100-130 m, width ≈8-10 m, and height ≈ 10 m), a 3-member team can perform a visual inspection (including filling out the inspection form with fast damage assessment) within an hour, and a 3D reconstruction (including in-situ quality and completeness checks of the acquired data) within 2.5 hours. The times are strongly influenced by the local environmental conditions (e.g., access to the site, presence of obstacles, light conditions, GNSS converge, wind conditions).

6.5 References of Annex1

AASHTO (2018). 'The Manual for Bridge Evaluation', 3rd Edition, American Association of State Highway and Transportation Officials.

AASHTO (2019). 'Manual for Bridge Element Inspection', 2nd Edition, American Association of State Highway and Transportation Officials.

Bellotti, D. *et al.* (2019) 'Large-scale vulnerability analysis of girder railway bridges', in *Risk-based Bridge Engineering - 10th NewYork City Bridge Conference, 2019*. doi: 10.1201/9780367815646-20.

BIFM (2020). 'Bridge Inspection Field Manual', Chapter B of BSIPM. Minnesota Department of Transportation. Available online: http://www.dot.state.mn.us/bridge/inspection.html.

BSIPM (2020). 'Bridge and Structure Inspection Program Manual', Minnesota Department of Transportation. Available online: http://www.dot.state.mn.us/bridge/inspection.html.

CS 450 (2020). 'Inspection of Highway structures', Design Manual for Roads and Bridges.

Dorafshan, S. and Maguire, M. (2018) 'Bridge inspection: human performance, unmanned aerial systems and automation', *Journal of Civil Structural Health Monitoring*. doi: 10.1007/s13349-018-0285-4.

DRD (1994). 'Inspection of bridges'. Danish National Road Directorate, Copenhagen, Denmark.

Everett, T.D., Weykamp, P., Capers Jr, H.A., Cox, W.R., Drda, T.S., Hummel, L., Jensen, P., Juntunen, D.A., Kimball, T. and Washer, G.A., (2008). 'Bridge evaluation quality assurance in Europe' (No. FHWA-PL-08-016). Available online: https://international.fhwa.dot.gov/pubs/pl08016/pl08016.pdf

Fenwick, J.M., Graham, P., Best, J., Carse, A., Cole, D. and Keene, J. (2004). 'Bridge Inspection Manual', Second Edition. Issued by Queensland Department of Main Roads - Road System and Engineering.

Finnra (2004). 'Guidelines for Bridge Inspection'. Finnish National Road Administration. Available online: https://julkaisut.vayla.fi/sillat/julkaisut/sillantarkastusohje2004.pdf

Gillins, D.T., Parrish, C., Gillins, M. N, Simpson, C. (2018). 'Eyes in the sky: bridge inspections with unmanned aerial vehicles'. Oregon Department of Transportation. Available online: https://www.oregon.gov/ODOT/Programs/ResearchDocuments/SPR787_Eyes_in_the_Sky.pdf.

Gruber L. (1996). 'Bridge Inspection Manual, volume 1'. Swedish National Road Admin., Road & Traffic Management Division, Jonkoping, Sweden. Available online: https://www.putevi-srbije.rs/images/pdf/strategija/Bridges_inspection_Manuel.pdf

Hsien-Ke, L., Jallow, M., Nie-Jia, Y., Ming-Yi, J., Jyun-Hao, H., Cheng-Wei, S., & Po-Yuan, C. (2017). 'Comparison of Bridge Inspection Methodologies and Evaluation Criteria in Taiwan and Foreign Practices'. In *ISARC. Proceedings of the International Symposium on Automation and Robotics in Construction* (Vol. 34). IAARC Publications.

INDOT (2000).'Handbook for the post-earthquake safety evaluation of bridges and roads", Indiana Department of Trasportation. Available online: https://docs.lib.purdue.edu/cgi/viewcontent.cgi?article=3103&context=jtrp.

ITSEOA (2010). 'Instruction Technique pour la Surveillance et l'Entretien des Ouvrages d'Art'. Ministère de l'Écologie du Développement durable, des Transports et du logement. Available online: http://dtrf.cerema.fr/pdf/pj/Dtrf/0005/Dtrf-0005954/DT5954.pdf?openerPage=notice

LLGG (2020). 'Linee guida per la classificazione e gestione del rischio, la valutazione della sicurezza ed il monitoraggio dei ponti esistenti', allegate al parere del Consiglio Superiore dei Lavori Pubblici n.88/2019, espresso in modalità "agile" a distanza dall'Assemblea Generale in data 17.04.2020. Available online: http://www.mit.gov.it/comunicazione/news/mit-approvate-le-linee-guida-per-la-sicurezza-dei-ponti.

Morandi P., Manzini C.F., Borzi B., A. Mauro, A. Vecchi, M. Tisalvi, F. Iacobini, (2019) *"Simplified seismic vulnerability assessment of railway masonry arch bridges*", Proceedings of the 10th New York City Bridge Conference, New York, USA, 26-27 August 2019.

NCHRP, N. S. (2007). 375: Bridge Inspection Practices. *Washington DC: National Cooperative Highway Research Program*.

NPRA (1998). 'Guidelines for the management of bridges'. Norwegian Public Roads Administration. Ministry of Transport of the Republic of Latvia, LATVIAN ROAD ADMINISTRATION. Available online: https://vegvesen.brage.unit.no/vegvesen-xmlui/bitstream/handle/11250/189807/guidelines_management_bridge.pdf?sequence=1&isAllowed=y

NYSDOT (2017). 'Bridge inspection manual', New York State Department of Transportation. Available online: https://www.dot.ny.gov/divisions/engineering/structures/manuals/bridge-inspection.

NZTA (2001). 'Bridge inspection and maintenance manual', NZ Transport Agency, New Zealand Government. Available online: https://www.nzta.govt.nz/resources/bridge-inspection-maintenance-manual/.

ODOT (2017). 'Post-earthquake bridge inspection manual', Oklahoma Department of Trasportation. Available online: https://www.odot.org/pontis_files/Post-Earthquak%20Insp.pdf.

Ryan, T. W. *et al.* (2012) 'Bridge Inspector's Reference Manual' (BIRM), U.S. Department of Trasportation, Federal Highway Administration. Pubblication No. FHWA NHI 12-049. Available online: https://www.fhwa.dot.gov/bridge/nbis/pubs/nhi12049.pdf.

Wells, J. and Lovelace, B. (2018) *Improving the Quality of Bridge Inspections Using Unmanned Aircraft Systems (UAS), Minnesota Department of Transportation*. Available online: https://www.dot.state.mn.us/research/reports/2018/201826.pdf.

WisDOT (2020). "Structure Inspection Field Manual", Wisconsin Department of Transportation. Available online (also the "Part2-Bridges" updated at August 2017): https://wisconsindot.gov/Pages/doing-bus/eng-consultants/cnslt-rsrces/strct/inspection-manual.aspx.

7 ANNEX 2: Drone-based Railway inspection

7.1 Introduction

The railways are a very complex infrastructure the maintenance of the functional integrity of the railway is of paramount importance both for safety and for economical reasons.

We identify 3 different areas where a drone-based inspection can dramatically improve the efficiency of the maintenance process:

- Overhead power lines inspection
- Track deformation
- Obstacles On Track (OO, which may also include the whole railbed and its surroundings, for example vegetation encroaching, flooding, landslides, etc)

The traditional approach foresees the use of specialized personnel and some special vehicles (4-D platforms, inspection trains, etc.).

The use of drones equipped with different camera and sensor technologies may represent an efficient and cost-effective support, or in some cases an alternative, to the visual inspection methods. Please refer also to Annex 1, because several similarities can be found in bridge and railway inspections: payloads, flight conditions limitations, etc.

The present document focuses on the three main aspects related to the use of drones for the condition assessment and damage inspection of power lines and track and quick response to detect and assess the presence of obstacles on track.

7.2 Railway inspection framework

The power line inspection is a periodic process but can also be triggered by Unexpected damaging Events (UE, e.g., earthquackes or landslides) or system alarms (power anomalies).

The track deformation inspection is a periodic process as well, the use of sensor equipped vehicle is a standard and efficient procedure even if the inspection vehicle is a valuable resource allocated periodically.

Periodic drone-based inspection can be programmed to assess track deformation or risk of OOT using drones with long endurance flight and advanced photogrammetry and/or LIDAR technologies

In case of UE, the inspection vehicle could be inavaialble and a quick drone-based inspection will be the best option.

The line is continuosly monitored to prevents OOTs, not only the periodic inspection with sensor equipped vehicle, but the personnel is instructed to communicate the possible risk of OOT. In case of damaging UE (or a risk signaled by anybody) the UAV inspection could be the standard procedure when the track is not easy inspectionable.

7.2.1 Periodic Inspections

The periodic inspection using drones requires the definition of a standard protocol and pre-design of the flight plan. Thermal camera inspection has to be planned (for power line examination). Photogrammetry and LIDAR techonologies are required to accurately measure track deformation. The protocol shall address the survey of an entire line. The interaction of the pilot with the maintenance manager is minimal since the maintenance manager will examine a posteriori the data (thermal and visual) collected during the flight. The flight will be largely authonomous.

The number and the detailed characteristics of the flight paths (e.g, distance from the target, the amount of the data acquired) have to be defined using standard parameters, the awareness about surrounding environment (terrain morphology or obstacles like vegetation) can be left mostly to the pilot and his assistant and/or to the onboard collision avoidance sensors. The duration of the operations is proportional to the track lenght,

7.2.2 Post Damaging Unexpected Events inspections

The drone-based visual survey post damaging UE assessment requires the presence of the Maintenance Manage. After a UE, a quick visual preliminary assessment of the safety and serviceability conditions of the infrastructure network is crucial in order to rapidly highlight the most critical cases and support the technical emergency management. The employment of drones during this fast structural condition screening may reduce both time consuming and first responders' risks, compared to traditional methods.

In this scenario the time factor is determinant, a proper order of priority for inspections should be considered according to the strategic role of the structure in the transportation system and its vulnerability (if known from existing studies) exactly in the same way of the bridge inspections.

The flight plan cannot be established a priori. The interaction of the maintenance manager with the Drone Pilot is mandatory, since a specific know how is required to evaluate during the flight the need for further inspection. The data collection is mandatory for further analysis for maintenance/repair operation planning, but the maintenance manager shall be allowed for continuos visual examination during the flight.

The number and the detailed characteristics of the flight paths (e.g, distance from the target, angle of view) have to be defined in the collaboration of the two main actors (pilot and maintenance manager), the awareness about surrounding environment (terrain morphology or obstacles like vegetation) can be left mostly to the pilot and his assistant. The duration of the operations cannot be defined a priori.

7.3 Data management and inspection form

The drone-based inspections of structures and infrastructures may result in a large amount of data, which needs to be managed appropriately, organised and stored to facilitate the post-mission consultation and interpretation.

7.3.1 Periodic Inspections

Each survey should be supported by suitable inspection forms for the annotation of important information, such as:

- Identification of the survey (date) and inspection team.
- Identification and localisation (geographic coordinates) of the infrastructure.

For periodic inspection it is mandatory to have a predefined flight plan and the data collected have to be examined a posteriori by the maintenance manager.

7.3.2 Post Damaging Unexpected Events inspections

the time factor is determinant, the usual information have to be stored with the collected data:

- Identification of the survey (date) and inspection team (including maintenance manager)
- Identification and localisation (geographic coordinates) of the infrastructure.

The maintenance manager is mandatory required to prepare an in-flight inspection report, taking note of any anomaly. In a subsequent phase the corrective action will be activated.