RADIUS

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Deliverable D2.1

RADIUS Stakeholders' needs

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1 Executive Summary

This document describes/reports the key analysis elements used to represent Stakeholders' needs, with the aim of identifying a group of railway assets, monitoring and maintenance activities to pursue for future developments in the RADIUS project.

Primary key information has been extrapolated by adopting a proactive approach, aiming to identify and describe: **(1)** assets that can cause degraded railway system performances; **(2)** monitoring and maintenance activities IM usually deal with. In addition, qualitative and quantitative information for prioritize and rank the asset, monitoring and maintenance activities have been provided to support further analysis.

The characterisation of the type of stakeholders involved in the RADIUS has added, followed by the identification and description of needs, priorities and constraints to fit with the railway environment.

Finally, leveraging on the knowledge, feedbacks and contributions collected from the stakeholders, a group of the most interesting assets, monitoring and maintenance activities to pursue in RADIUS project has been identified.

This forms the pillar for the research to be presented in deliverable documents D2.2 and D2.3 of the RADIUS project WP2.

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2 Abbreviations and Acronyms

Abbreviation / Acronym	Description
RADIUS	Railway Digitalization Using DroneS
EU	European Union
WP	Work Package
STS	Hitachi Rail STS
IP	Infraestruturas de Portugal SA
IM	Infrastructure Managers
SP	Service Provider
CAA	Civil Aviation Authority
GoA	Grade of Automation
NOTAMS	Notice to Airmen
TBM	Time Based Maintenance
CBM	Condition Based Monitoring
PdM	Predictive Maintenance
QoS	Quality of Service
EM	Electro Magnetic
UIC	International Union of Railways
RUL	Remaining Useful Life

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3 Introduction

3.1 Background

Nowadays, the monitoring of railway signalling assets is based alternatively on:

a) On-demand or programmed human maintenance activities;
b) Wired solutions;
c) Active surveying by means of moving vehicles (e.g. trains equipped with monitoring technologies);
d) Working status information obtained from electronic interlockings.

Human maintenance activities are highly demanding in terms of direct costs (i.e. personnel labour costs) **and operational constraints**. On the other side, monitoring of signalling assets based on diagnostic data acquired by means of wired solutions is very expensive, since it requires extensive and costly cabling, which is also prone to failures throughout the years and needs maintenance itself. To partially overcome these limitations, some IMs have been obliged to make important investments for designing, developing, operating and maintaining diagnostic trains. These trains acquire diagnostic data during their runs, which are later elaborated off-line to discover trackside and signalling asset anomalies. However, diagnostic trains normally run at lower speed than commercial trains, thus implying temporary performance limitations on the assessed lines.

The objective of the RADIUS proposal is to develop a drone-based technology **(a)** to monitor the physical status and electronic functionality of both non-safety-critical and safety-critical railway signalling assets and **(b)** to execute specific maintenance activities to pave the road to efficient and reliable unmanned activities.

The rest of this document is organized as follows. In **Section 4**, the related works that contributes to enhance the quality of this deliverable are described. **Section 5** describes the agile and proactive methodology adopted for acquiring all the information useful for planning the activities concerning the task 2.1 and for better highlights the stakeholders' needs, requirements and priorities. **Section 6** describes the group of stakeholders identified for the RADIUS project and how needs and requirements are organized. Finally, **Section 7** a list of potential assets, monitoring and maintenance activities to pursue in the RADIUS project are identified and reported.

3.2 Purpose of this document

This document aims to identify the stakeholders' needs, priorities and constraints by adopting a fast and efficient approach for completing the activities related to the WP2 task 2.1, leveraging on the active cooperation of the involved partners.

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4 Related R&D works

In this section, a brief description about the European projects related to intelligent asset management systems investigated during these years has been performed. Such projects have contributed to enhance the quality of this deliverable and they will for the rest of the RADIUS project. In particular, this refers to Shift2Rail and some other related projects.

4.1 Shift2Rail

The EU project **Shift2Rail**[1] takes a **holistic approach to railway development in Europe**. The aim is to sustainably strengthen European industry, create jobs and develop the railway system to meet tomorrow's transport needs.

The work is organized around the following Technical Demonstrators (TDs) covering all R&I areas indicated in:

- Enhanced Switch & Crossing System;
- Next-Generation Switch & Crossing System;
- Optimized Track System;
- Next Generation Track System;
- Proactive Bridge and Tunnel Assessment;
- Repair and Upgrade;
- Dynamic Railway Information Management System;
- Railway Integrated Measuring and Monitoring System;
- Intelligent Asset Management Strategies;
- Smart Power Supply;
- Smart Metering for Railway Distributed Energy Resource Management System and Future Stations.

[1] https://shift2rail.org/

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4.2 In2Rail

The **In2Rail** project[2] (supported by the Horizon 2020 program) is to set the foundations for **a resilient, consistent, cost-efficient, high-capacity European network by delivering important building blocks that unlock the innovation potential that exists in Shift2Rail**.

Innovative technologies are explored and resulting concepts embedded in a systems framework where infrastructure, information management, maintenance techniques, energy, and engineering are integrated, optimized, shared and exploited. In2Rail makes advances towards Shift2Rail objectives: enhancing the existing capacity fulfilling user demand; increasing the reliability delivering better and consistent quality of service; reducing the LCC increasing competitiveness of the EU rail system. To achieve the above, a holistic approach covering Smart Infrastructures, Intelligent Mobility Management (I2M) and Rail Power Supply and Energy Management will be applied. In2Rail is one of the lighthouse projects of Shift2Rail and will contribute to Innovation Programs 2 and 3.

4.3 In2Smart and its successor In2Smart2

IN2SMART[3] represents the **first proposal of the Shift2Rail members referred**, according to MAAP (Multi Annual Action Plan), to the following Technology Demonstrators (TDs): TD3.7 Railway Information Measuring and Monitoring System (RIMMS), TD3.6 Dynamic Railway Information Management System (DRIMS) and TD3.8 Intelligent Asset Management Strategies (IAMS). These TDs have deployed an overall concept for Intelligent Asset Management based on the following three main interlinked layers:

- Measuring and Monitoring systems to collect data from the field related to the railway assets status: IN2SMART develops unmanned systems for "remote" monitoring; track geometry, switches & crossings and signalling monitoring systems; innovative measurement of train parameters and wheel defects combined with rolling stock identifications systems.
- Data management, data mining and data analytics procedures to process data from the field and from other sources: IN2SMART develops standard open interfaces to access heterogeneous maintenance-related data; analytic tools to automatic detect anomalies, discover and describe maintenance workflow processes and predict railway assets decay towards prescriptive maintenance.
- Degradation models and decision-making tools to support maintenance strategies and execution: IN2SMART lays the foundation of a generic framework for asset management and decision support process. This framework specifies the scope, objectives, workflow and outcomes of the decision-making process for maintenance interventions planning, and it is the enabler for the development of future decision support tools and systems. IN2SMART develops an optimized tamping tool and a robot platform for maintenance works. IN2SMART complements the work of the IN2RAIL lighthouse project to reach a homogeneous TRL4/5 demonstrator. IN2SMART reaches the final Integrated Technology Demonstrators that it deploys the overall concept of Intelligent Asset Management

[2] Innovative Intelligent Rail | http://www.in2rail.eu/
[3] In2SMART. Intelligent Innovative Smart Maintenance of Assets by integRated Technologies

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Starting from the results achieved in the In2Rail "lighthouse project" and in IN2SMART project, IN2SMART2 aimed at implementing specific demonstrators according to the IP3 Technological Demonstrators (TD):

Main objectives for TD3.6 – Dynamic Railway Information Management System (DRIMS):

- Asset status monitoring capabilities enrichment: automatic anomaly detection algorithms will allow discovering issues in a faster way;
- Operational reliability increase (less service disruption): railway asset decay prediction will lead to more targeted maintenance interventions and fewer interventions due to sudden failures;
- LCC reduction through condition-based maintenance of railway assets and continuous improvement of components/maintenance schedules.

Main objectives for TD3.7 – Railway Integrated Measuring and Monitoring System (RIMMS):

- Increase of operational reliability (less service disruptions) and safety (less incidents) through continuous and integrated monitoring of railway assets and rolling stocks impact;
- LCC reduction through condition-based maintenance of railway assets and continuous improvement of components/maintenance schedules;
- Safer and faster ways of monitoring the infrastructure assets based on innovative technologies;
- Straightforward, automatic and continuous monitoring of railway infrastructure through the equipment of many in-service trains with low-cost monitoring and processing components;
- Consideration of rolling stock impact on the railway infrastructure as a fundamental component in its overall monitoring.

Main objectives for TD3.8 – Intelligent Asset Management Strategies (IAMS):

- Shift towards a tailor-made maintenance approach by using the necessary tools for information management and decision support;
- A scalable framework for asset management systems, containing the static and dynamic data from all relevant components of the rail infrastructure enabling improved lifecycle management, efficient maintenance strategies and adequate operations planning which includes logistic preparation, deployment of staff, tools, equipment and plant and possessions;
- A holistic, system approach in combination with the new methodologies and data-driven concepts provided by TD3.6 and TD3.7;
- Using LEAN thinking to design new working methods and tools making significant steps forward in reducing time needed for maintenance and cost.

4.4 In2Track

The main objective of **IN2TRACK**[4] project is to set the **foundations for a resilient, consistent, cost-efficient, high-capacity European network by delivering important**

[4] In2TRACK. Research into enhanced tracks, switches and structures - https://projects.shift2rail.org/s2r_ip3_n.aspx?p=IN2TRACK

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building blocks that unlock the innovation potential that have been identified as part of the Shift2Rail Innovation Program 3. The specific objectives of IN2TRACK are divided into three parts:

- Enhancing and optimizing the switch & crossings and track systems in order to ensure the optimal line usage and capacity;
- Investigating novel ways of extending the life of bridges and tunnel assets through new approaches to maintaining, repairing and upgrading these structures;
- Development and adoption of a holistic, whole system-approach.

A whole-system approach, which is defined as the system boundaries extending from dynamic wheel-rail interaction (loading input) through to degradation of the S&C system, sub-systems, individual components, and underlying track foundation, will also be at the heart of IN2TRACK on how to reach the objectives.

4.5 In2track2

The **IN2TRACK2**[5] proposal addresses the topic of "Research into optimized and future railway infrastructure" of the 2018 HORIZON 2020 SHIFT2RAIL Call for proposals for the Joint Undertaking Members (S2R-CFM-IP3-01-2018). IN2TRACK2 **deals with rail infrastructure sub-system and covers all the works on Switch & Crossing (S&C), Track and Structures (Bridges and Tunnels) included in the SHIFT2RAIL Innovation Program 3 (including the project IN2TRACK) and contributes to the full longer-term SHIFT2RAIL objectives**. IN2TRACK2 represents the opportunity to choose some high-risk, innovative activities from the current SHIFT2RAIL work program for development under intensive collaboration as the right path for success.

IN2TRACK2 aims to reduce lifecycle costs, improve reliability and punctuality, whilst increasing capacity, enhancing interoperability and improving the customer experience. The structure of the work plan is designed around the development of a certain number of well-focused technological innovations in several areas (S&C, Track and Structures), each and all together, will contribute to achieve the desired impact at the overall railway system level. The IN2TRACK2 proposal is organized around three technical sub-projects, which are interconnected: S&C, Track and Structures. S&C activities aim at both improving the operational performance of existing S&C and providing radical new S&C system solutions that deliver a step-change in performance of the asset. The IN2TRACK2 Track activities aim at both exploring new track construction to optimize the today track system and improving the track system substantially to provide a step change in performance. The IN2TRACK 2 Bridges and Tunnels activities aim at improving methods and repair techniques to reduce costs improve quality and extend the service life of structures. By enhancing S&C, Track and Structures, IN2TRACK2 contributes to all of the expected impacts identified in the Shift2Rail Annual Work Plan.

[5]IN2TRACK2. Research into enhanced track and switch and crossing system 2 - https://projects.shift2rail.org/s2r_ip3_n.aspx?p=IN2TRACK2

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4.6 GAUSS H2020

The GAUSS project aims at fast and thorough achievement of acceptable levels in terms of performance, safety and security for both, current drone and future U-Space operations. The key element within GAUSS is the integration and exploitation of Galileo-EGNOS exceptional features for precise and secure positioning to enable U-Space operations, supporting the management and coordination of all drones in the VLL airspace.

4.7 RHINOS

RHINOS aims at increasing the use of EGNSS to support the safety-critical train localization function for train control in emerging regional and global markets. RHINOS adds value to EGNSS by leveraging the results from prior or existing projects, and develops a Railway High Integrity Navigation Overlay System to be used by the rail community.

RHINOS pillar is the GNSS infrastructure realized for the aviation application with additional layers that meet the rail requirements in the difficult railway environments.

RHINOS will feature an international cooperation with the Stanford University that has been involved in the aviation application since the birth of the GPS, gaining an undeniable knowledge of the GNSS performance and high-integrity applications.

4.8 CLUG

According to the ERAccording to the ERA 2015 Report on ERTMS Longer Term Perspective, GNSS could prove a game changer for the European railway network by enabling a significant reduction of trackside equipment and by improving localisation performance. The conclusions of the STARS project have confirmed this potential. However, fusion with other sensors will be necessary to mitigate the known impact of local effects on GNSS performance.

Capitalising on the achievements of EC and GSA funded projects, collaborating railway companies, i.e. SBB, DB and SNCF, would like to propose the project CLUG. This project will perform a mission analysis/needs identification and a preliminary feasibility study of an on-board localisation unit with the following characteristics:

- Failsafe on-board multi-sensor localisation unit consisting of a navigation core (IMU, tachometer, etc.) brought in reference using GNSS, track map and a minimal number of reference points;
- On-board continuous localisation system that provides location, speed and other dynamics of the train;
- Operational and interoperable across the entire European rail network;
- Compatible with the current ERTMS TSI or with its future evolutions.

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To achieve its objectives, the CLUG's management and the design and development of the localization unit will follow agile processes taking into account former projects results – especially STARS – as well as observations resulting from new test campaigns.

The CLUG consortium comprises railway companies (SNCF, DB Netz and SBB), railway signalling industries (CAF and Siemens), navigation specialists (Airbus Defense & Space, Naventik, FDC), a research institute (ENAC) and a certification expert (Navcert).

Ultimately, this project is the key enabling technology for the future-proof development of train digitalisation and automation to respond to the increased mobility needs of all European citizen and goods by leveraging the train, a green safe and efficient means of transport."

4.9 STARS

The STARS project paves the way for the future EGNSS deployment in safety relevant railway applications. By evolving the highly developed and deployed ERTMS standard through the implementation of the satellite positioning functionality, it will be possible to reduce the cost of the future railway signalling systems, especially for lines with lower traffic density. The project deals with three main topics: 1) The elaboration of reference data and characterization of the railway environment through a measurement campaign; 2) The assessment of the EGNSS performances achievable in the railway environment with the determination of the applicable requirements for the positioning system as well as the necessary evolutions of EGNSS services and ERTMS/ETCS functions and 3) Quantification of the economic benefits and specifying the possible implementation roadmap when applying the EGNSS on railways.

4.10 HELMET

The main objective of HELMET is to develop innovative EGNSS applications capable to impacting on eco-friendly and green transportations means. Target adopters of EGNOS and Galileo are the Connected and driverless cars, Train signalling, UAS for surveillance of roads and railways.

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5 Methodology

This chapter describes the approach used for characterizing and carrying out the RADIUS WP2 activities. The idea adapted for describing them have been shared and agreed with the entire consortium, which in turn cooperated for completing it. The contributions coming from each partner have been further included in an Excel file (see 10.1 RADIUS-WP2_activities_definition), which has been used further on for identifying the Stakeholders' needs, priorities and constraints.

The activities considered for the task 2.1 are the following ones:

- **Activity 2.1.1** - Identify and describe the railway signalling components/assets, installed in railway lines and in the remotely controlled railway stations that can cause degraded railway system performances when their operational behaviours deviate from the nominal ones. The manifestation of the symptoms associated with the deviations of the functional behaviours and their impacts on the general failure conditions such as Immobilising failure, Service failure, and Minor Failure shall also be described including all possible behaviours that deviate from the nominal status of railway signalling systems and assets (and the related symptoms to be detected) that without the appropriate maintenance activities may have an impact on railway system performances;
- **Activity 2.1.2** - Identify and describe the appropriate monitoring and maintenance activities that the Infrastructure Managers (IMs) normally do to cover cope with the above-identified abnormal behaviours that deviate from the nominal status. These descriptions will be used for understanding and then classifying the monitoring and maintenance activities in accordance with criteria such as "grade of automation", "severity", "criticality", "priority", "time-based maintenance", "condition-based maintenance". The list of criteria normally adopted in the railway's communities will be described;
- **Activity 2.1.3** - Define the prioritisation criteria (e.g. a Pareto Principle) for the above monitoring and maintenance activities based on a cost criticality function defined by the involved stakeholders and rank them;
- **Activity 2.1.4** - Out of the identified monitoring and maintenance activities, identify those that are potentially implemented within the RADIUS monitoring and maintenance framework; the identified activities will also be classified with respect to the type of required drones;
- **Activity 2.1.5** - Identify both (a) the constraints introduced by existing regulations, norms and standards from both the Unmanned Aerial Vehicles and railway application domains, and (b) the possible mitigations to cope with such constraints. If possible, suggestions for exporting some mitigations onto the regulation/standard/norm bodies shall also be provided.

The following sub-sections aim to explain the structure and give the content meaning of the whole Excel file (see 10.1 RADIUS-WP2_activities_definition). The Excel file is made of several sheets, each one characterizing the contents of the activities listed above.

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The information collected in each sheet has representation along columns and rows. The columns map the contents given/described for the activities of task 2.1, whereas the rows characterize each use case used for helping to identify the stakeholders' needs, priorities and constraints.

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5.1 Identification and description of the railway signalling components/assets Asset Identification

The contents provided in this sheet aims to identify and describe the railway signalling components/assets that can cause degraded railway system performances when their operational behaviours deviate from the nominal ones. For each identified asset, such information has been provided.

Bear in mind that for the purpose of this document, not all the following assets will be included in the future development of the RADIUS project but only few of them that satisfy certain criteria.

Asset Id	Railway Signalling Components Assets Name	Trackside Position	Functional/Operational Asset Behaviours	Normal Performance Description	Degraded Performance Description	Deviation Symptoms to be detected	Abnormal Behaviours Definition	Failure Conditions	Impact on Railway System Performances
Switch	Slide chair	Line side - Switch panel	The switch blades movement over the slide chairs must be as regular as possible, by minimizing any frictions, thus allowing the completion of the manoeuvre without any type of anomaly or abnormal behaviours.	1. An elapsed time is expected for the POM to complete the manoeuvre 2. A lower bound and upper bound amount of power and voltage is absorbed at different stage of the manoeuvre (according to POM model)	The degradation of such component is observed by an increase of the elapsed time for completing the manoeuvre /actuation as well as an increase of the absorbed power and voltage needed to the motor for completing the operation. Moreover, a squeaky sound produced during the manoeuvre and a lack of lubricant material along	1. The friction loads increases gradually 2. The elapsed time for completing the manoeuvre may increase (gradual increasing in the operating time) 3. The absorbed power and voltage may increase 4. The sound produced by rubbing the involved components becomes	**Dry/contaminated slide chair**: an incipient anomalous behaviour evolving over the time. It is caused by the increasing in the frictional resistance due to loss of lubrication and the effects of slide chair deterioration. It may either arise an out-of-control for the switch point or a technical discrepancy between the involved systems.	Service Failure	Changes in the railway itinerary and railway traffic management

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					with a contaminated composition may be noticed.	squeaky during the manoeuvre 5. The amount of lubrication fades out and its shininess decreases			

Table 1: Row example for the activity A2.1.1.

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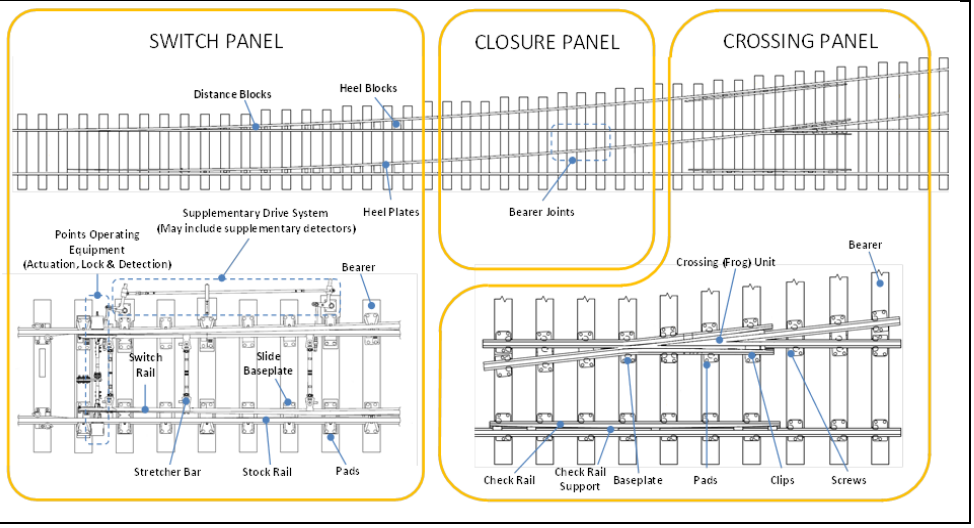
Each column referred in **Table 1** is described as follow:

1. **Asset identification**: Identify the asset of interest. For the stakeholder's needs analysis, the macro assets identified are show in **Table *2***.
2. **Railway signalling components assets name:** Identify the subcomponents for each asset. This information must be associated with item 1.
3. **Trackside position:** Identify the trackside position for each asset along the trackside.
4. **Function/Operational asset behaviours:** characterize the functional and operation behaviours for each asset, where a briefly description of the normal performance of an asset is given.
5. **Normal performance description:** Describe the asset performance during its normal functioning.
6. **Degraded performance description:** Describe the asset performance when a degradation behaviour is underway.
7. **Deviation symptoms to be detected:** Define the symptoms an asset exhibits when an early degradation process starts to begin, hence when its behaviours deviate from the nominal ones.
8. **Abnormal behaviours definition:** Define one or more abnormal behaviours for a given asset, giving descriptions (diagnosis) of such faulty behaviours.
9. **Failure conditions:** Characterize the type of failure condition in a railway application domain, as explained in EN 50126. The **Table *3*** shows RAM failure categorized by ascending cardinal numbers (e.g., 1, 2, and 3), referring to safety-critical and not critical railway aspects. Other critical safety aspects for classifying the RAMS failure categories have been considered:
   - Maintenance operation safety
   - Railway operation safety
   - General safety
10. **Impact railway system performances:** Define the impact on railway system performance when an abnormal behaviour arises. Changes in the railway itinerary and railway traffic management or similar consequences have been taken into account.

Asset	Representation
1. Switch Point	

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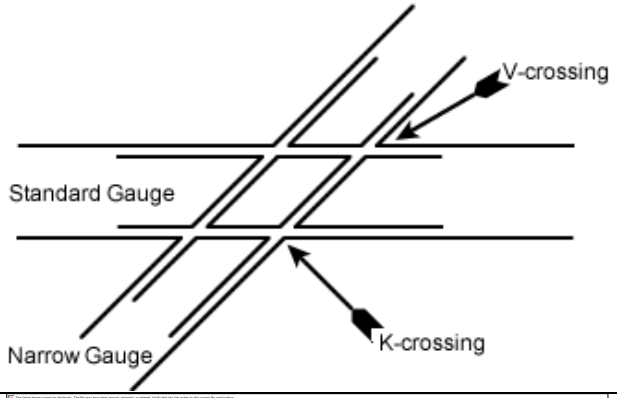
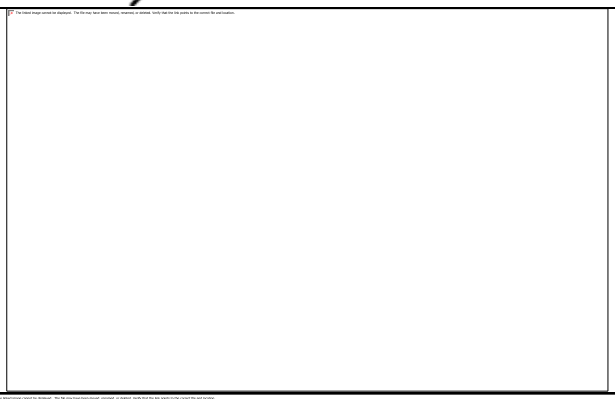
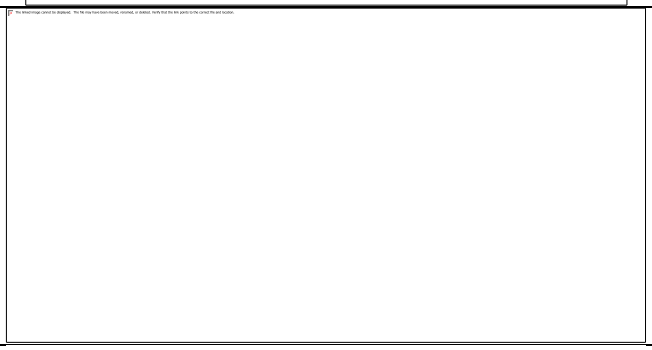
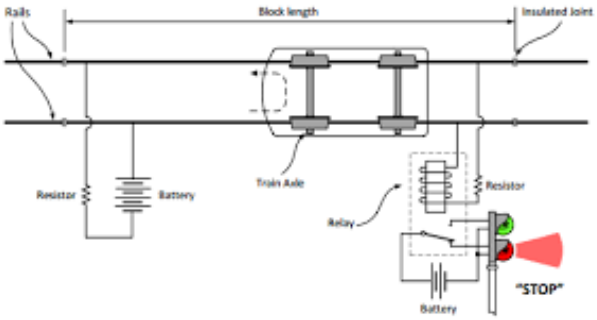
Asset	Representation
2. Crossing	
3. ATP beacon	
4. Axle counter	
5. Track Circuit JS HVIT	
6. Level Crossing	

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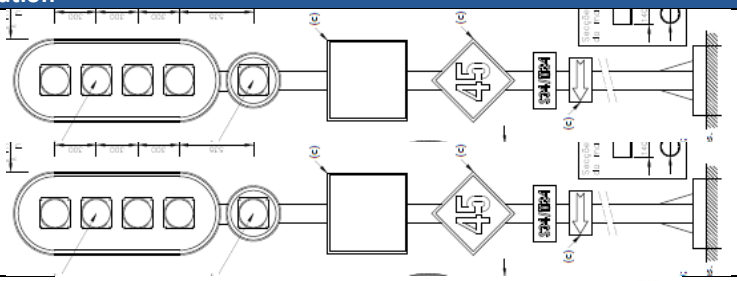
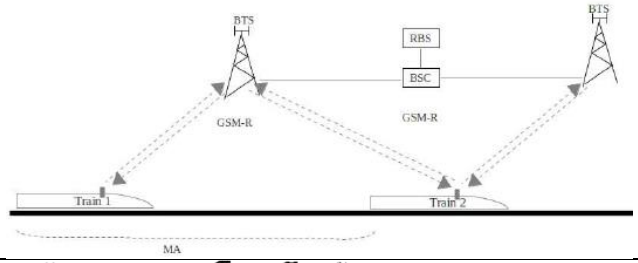
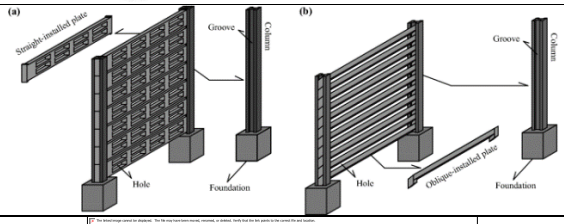
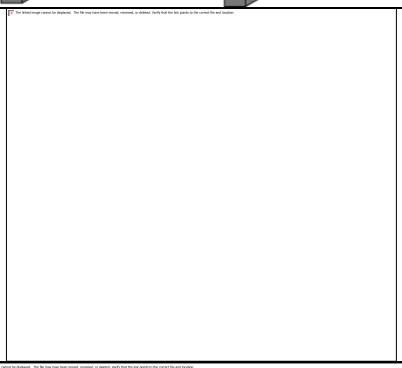
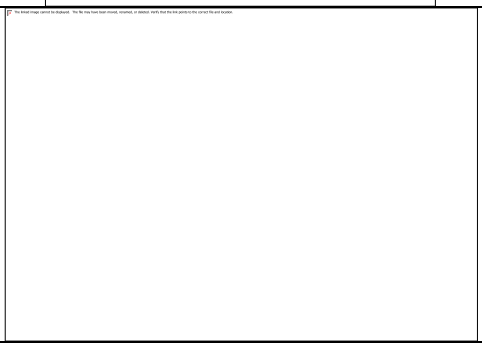
Asset	Representation
7. Main Signal	
8. GSM-R network	
9. Wayside fences	
10. Rail cable ducts	
11. Feeder pillar	

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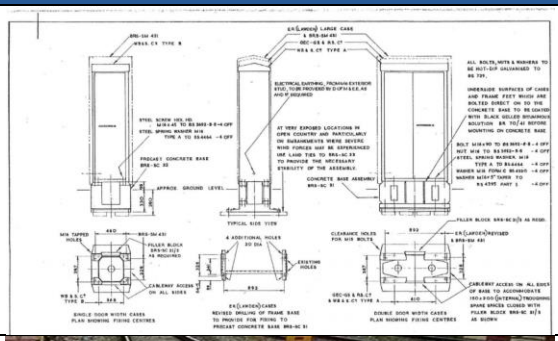
Asset	Representation
12. Lineside Cabinet	
13. Railway channel	

Table 2: List of interesting assets to monitor

RAMS severity category	Definition
Significant (Immobilising Failure)	A failure that: • prevents train movement or • causes a delay to service greater than a specified time • and/or generates a cost greater than a specified level
Major Service Failure	A failure that: • prevents the system from achieving its performance and • does not cause a delay or cost greater than the minimum threshold specified for a significant failure
Minor	A failure that: • does not prevent a system achieving its specified performance and • does not meet criteria for Significant or Major failures

Table 3: RAM failure categories as explained in EN 50126 §4.5.2.2

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5.2 Identification and description of the monitoring and maintenance activities

The contents provided in this sheet aim to identify and describe the monitoring and maintenance activities that the IM normally do to cope with the above-identified abnormal behaviours that deviate from the nominal status. For each identified asset, such information has been provided.

Asset Identification	Railway Signalling Components Assets Name	Abnormal Behaviours Definition	Monitoring Activity Identification Definition	Monitoring Activity Description	Maintenance Activity Identification Definition	Maintenance Activity Description	Maintenance Activity Classification ["grade of automation", "severity", "criticality", "priority", "Time Based Maintenance", "Condition Based Maintenance"]
Switch	Slide chair	**Dry/contaminated slide chair**: an incipient anomalous behaviour evolving over the time. It is caused by the increasing in the frictional resistance due to loss of lubrication and the effects of slide chair deterioration. It may either arise an out-of-control for the switch point or a technical discrepancy between the involved systems.	Visual inspection	The maintenance team inspects the grease condition of the slide chairs along the track-side	1.Cleaning 2.Proper lubrication	The maintenance team proceeds by cleaning and lubricating the slide chairs.	**Grade of automation**: Low **Severity**: Medium **Criticality**: High **Priority**: High **Time Based Maintenance**: Yes **Condition Based Maintenance**: No

Table 4: Row example for activity A2.2.

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Each column referred in **Table 4** is described as follow:

1. **Monitoring Activity Identification Definition and Description**: Define the type of monitoring activities and descriptions carried out by the IM.
2. **Maintenance Activity Identification Definition and Description**: Define the type of maintenance activities and give their descriptions carried out by the IM.
3. **Maintenance Activity Classification**: Classify the maintenance activities relaying on information reported in **Table 5**. The rating of such information is represented as Low, Medium or High, or with cardinal numbers, that is, 1, 2 and 3 respectively.

Type	Definition
Grade of automation (GoA)	Level of automated maintenance activities considering the needed applications.
Severity	Measure the impact that an abnormal behaviour has on the business costs and availability of railway service
Criticality	Refers to the (consequences of) abnormal behaviour of a system. The more serious the expected direct and indirect effects of abnormal behaviour, the higher the criticality level.
Priority	Measure the level of (business) importance towards stakeholders for a specific activity.
Time Based Maintenance (TBM)	Time-based maintenance (TBM) is maintenance performed on equipment based on a calendar schedule. This means that time is the maintenance trigger for this type of maintenance. TBM maintenance is planned maintenance, as it must be scheduled in advance.
Condition Based Maintenance (CBM)	Condition-based maintenance (CBM) is a maintenance strategy that monitors the real-time condition of an asset to determine what maintenance needs to be performed. CBM dictates that maintenance should only be performed when certain indicators show signs of decreasing performance or upcoming failure.

Table 5: Maintenance Activity Classification

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5.3 Definition of the prioritisation criteria

The contents provided in this sheet aim at define the prioritisation criteria for the monitoring and maintenance activities referred in section 5.2, based on a criticality function defined by the involved stakeholders and rank them.

Asset Identification	Railway Signalling Components Assets Name	Maintenance Activity Description	Grade of Automation	Severity	Criticality	Priority	Intervention cost	RIMMA
Switch	Slide chair	The maintenance team proceeds by cleaning and lubricating the slide chairs.	1	2	3	3	1	2

Table 6: Row example for activity A2.1.

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Each column referred in **Table 6** is described as follow:

1. **Monitoring & Maintenance Cost Value**: Define a qualitative metrics identifying the monitoring and maintenance cost value as shown in **Table 7**.
2. **Ranking Index for Monitoring and Maintenance Activity (RIMMA)**: Define a quantitative index for prioritizing the monitoring and maintenance activities. The index has been computed by combining monitoring and maintenance cost value and information rating values described in **Table *7*** and **Table 5,** respectively.

Rating	Description
1	Costs for monitor and maintain activities are low due to the cost of the materials used, type and frequency of intervention and the number of people involved in the intervention.
2	Costs for monitor and maintain activities are discrete. The activities may request asset subcomponent repairs and the involvement of people with different expertise.
3	Costs for monitor and maintain activities are high. The activities may request either full or partial replacement of certain asset subcomponent, involvement of people with different expertise and high time-consuming interventions

Table 7: Monitoring and maintenance cost

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5.4 Identification of the monitoring and maintenance activities in RADIUS framework

The contents provided in this sheet aim to identify the monitoring and maintenance activities that can be potentially implemented within the RADIUS infrastructure.

Asset Identification	Railway Signalling Components Assets Name	Maintenance Activity Description	RADIUS Monitoring & Maintenance Framework Apportionment	Type Required Drones Identification	Level of automated Drone Inspection
Switch	Slide chair	The maintenance team proceeds by cleaning and lubricating the slide chairs.	Yes	**Drone equipment:** RGB camera Infrared camera (NIR)	**Low.** Operators inspect the asset using the real-time video feed provided by the drone. Operating time could be measured using specific algorithms.

Table 8: Row example for activity A2.1.4

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Each column referred in **Table 8** is described as follow:

1. **Monitoring & Maintenance Framework Apportionment**: Define the feasibility for monitoring and maintenance activities in the RADIUS framework.
2. **Type Required Drones Identification**: Define a drone equipment required for carrying out the monitoring and maintenance activities on the identified asset.
3. **Level of automated Drone Inspection**: Define the degree of drone automation level on the identified asset.

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5.5 Regulations in UAS and railway application domains

Several interviews with Normative Agencies and European IMs (i.e. IP, RFI, etc.) have shown that there are not norms in force about flying drone in railway infrastructures.

This implies the RADIUS project will refer to the current rules and procedures for the operation of unmanned aircraft (Commission Delegated Regulation (EU) 2019/945 & Commission Implementing Regulation (EU) 2019/947), putting in evidence, in the operational scenarios' definition the loading gauge concept, which defines a free virtual area obstacle, where the drone could fly without a train running on the related track.

In the UIC framework, some standard shapes have been defined as a European limit template, and often identified as a standard "Gabarit" (see **Figure 1**), depending on the total height starting from the plane of the iron and the width starting from the central axis of the track.

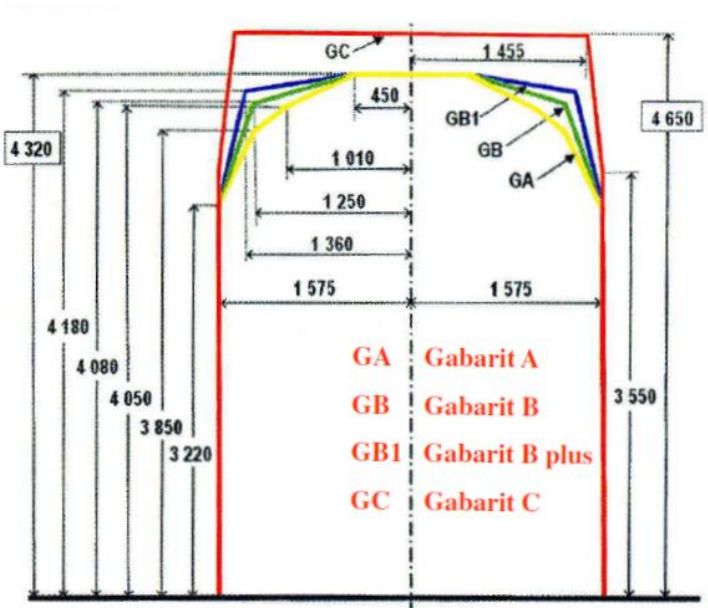

Figure **1:** UIC loading gauges

Actually, a continuous monitoring of forthcoming standards, norms and regulations will be carried out during the RADIUS lifetime, also with the support of Euro Control as Advisory Board member.

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6 Stakeholders' needs, priorities and constraints

This section describes the group of stakeholders identified for the RADIUS project and how needs and requirements are organized. The approach adopted to identify stakeholders' need, priorities and constraints is based on a full engagement with stakeholders and, in general, with the entire RADIUS consortium.

The stakeholders identified for the purpose of the project are divided in the following categories:

[1] **Railway Infrastructure Manager:** anybody or undertaking that is responsible in particular for establishing and maintaining railway infrastructure. This may also include the management of infrastructure control and safety systems. The functions of the infrastructure manager on a network or part of a network may be allocated to different bodies or undertakings. This includes mainly railway track and catenary and can also include the stations and power supply network.

[2] **Service Provider:** companies offering fully integrated, rail solutions across rolling stock, signalling, operation, service & maintenance, digital technology and turnkey.

[3] **Others:** any other company, organization, association, etc., which could be potentially involved as stakeholder. For instance, CAAs' norms and regulations may indirectly establish needs and requirements to be applied to RADIUS.

For the RADIUS project, as primary stakeholders, IMs have provided the major contributions in providing needs, requirements and priorities but other stakeholders have also been considered.

Stakeholders' needs, requirements and priorities are listed in ***Table 9**: Stakeholders' needs, priorities and constraints. Degree of importance is categorized as High (H), Medium (M) and Low (L).*

ID	Role	Impact	Influence	Interest	Needs/Expectations	Requirements
1	IM	H	H	H	Verify the integrity and working status of the asset	Visual Inspection of the asset
2	IM	H	H	H	Reduction of scheduled human inspections and make them more effective	Periodic monitoring and maintenance procedure on a specific time schedule (monthly, quarterly, yearly) or inspection per condition (failure)
3	SP	H	H/M	H	Implementation of corrective actions	Analysis of the monitoring and maintenance procedure used for the maintenance and correct functioning of railway assets
4	SP	H	H/M	H/M	Simplify the maintenance operations and make them more effective	The periodic monitoring and maintenance procedure for a specific target (monthly, quarterly, yearly)

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ID	Role	Impact	Influence	Interest	Needs/Expectations	Requirements
5	SP	H	H	H	Verify the integrity and functioning of the asset	Mechanical check and visual inspection of the railway asset components.
6	SP	M	M	M	Identification of new procedures based on new monitoring and maintenance procedure	Measurement of parameters (physical, mechanical, electrical, etc.)
7	SP	H	H	H	Allow the new technology to be applicable in the Railway domain	The monitoring and maintenance procedures of the railway asset has to be modified on the basis of the technologies used for maintenance purposes
8	SP	H	H	H	Interaction between drones and the asset	Allowing the monitoring of assets located in areas that are either difficult to get to (e.g., excessive distance, etc.) or accessible by maintenance personnel
9	SP	H	H	H	Implementation of the logics for the risk detection	Monitoring and control of risky situations for the railway asset
10	SP	M	M	M	Implementation of prognostic approach	Reduction of the number of periodic maintenance interventions, scheduling of corrective actions, and prevention of unexpected equipment failures.
11	Others	L	M	L	1. Approving NOTAMs which segregate the airspace 2. Approving the Operational Risk Assessment 3. Requiring more stringent requirements for more complex operations (operational and design) design and/or operational characteristics.	Constraints introduced by existing regulations, norms and standards from the CAAs to be complied with

Table **9**: Stakeholders' needs, priorities and constraints. Degree of importance is categorized as High (H), Medium (M) and Low (L).

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7 Identification of assets, monitoring and maintenance activities

In this section, it is provided a list of potential assets, monitoring and maintenance activities to pursue in the RADIUS project. According to the Grant Agreement, Annex 1 (part A), a criterion based on a defining a criticality function to better understand which asset, monitoring and maintenance activity must be prioritized from the stakeholders' point of view. The RIMMA index defined in see section 5.3 along with failure conditions referred in ***Table 3***, have been used for prioritizing assets, monitoring and maintenance activities, as shown in **Table 10.**

Asset	Asset sub-components	Monitoring activity	Maintenance activity	Stakeholders needs (Ref. Table 9)	Failure conditions	RIMMA
Switch Point	Fastening elements	Visual inspection	1. Refastening elements 2. Redundancy of the fastening elements 3. Ultrasound checks	3,4,5,6,7,8,9,10	2	2,6
Switch Point	Stretcher bar	Visual inspection	1. Geometry checks 2. Measured inspection tasks	3,4,5,6,7,8,9,10	3	2,4
Switch Point	Drive rod	Visual inspection	Geometry checks	3,4,5,6,7,8,9,10	1	2,4
Switch Point	External locking device	Visual inspection	1. Refastening elements 2. Redundancy of the fastening elements 3. Ultrasound checks	3,4,5,6,7,8,9,10	1	2,4
Switch Point	Switch and stock rail	Visual inspection	Geometry checks	3,4,5,6,7,8,9,10	3	2,4
Switch Point	Motor	Visual inspection	1. Cleaning 2. Proper lubrication 3. Removing and replacing the brushes 4. Functional test of actuation, locking and detection mechanisms	3,4,5,6,7,8,9,10	1	2,2

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Asset	Asset sub-components	Monitoring activity	Maintenance activity	Stakeholders needs (Ref. Table 9)	Failure conditions	RIMMA
Switch Point	Clutch	Visual inspection	1. Re-calibration 2. Proper lubrication 3. Functional test of actuation, locking and detection mechanism	3,4,5,6,7,8,9,10	1	2,2
Switch Point	Slide chair	Visual inspection	1. Cleaning 2. Proper lubrication	3,4,6,7,8,9,10	1	2
Switch Point	Switch and stock rail	Visual inspection	1. Removing obstructive elements 2. Cleaning 3. Proper lubrication of switch components	3,4,5,6,7,8,9,10	1	1,8
Switch Point	Switch and stock rail	Visual inspection	1. Deburring 2. Replacement of switch and stock rail assembly 3. Track geometry 4. Correct adjustment of DLD system (Driving and Locking Device) 5. Correct adaptation of distance blocks	3,4,5,6,7,8,9,10	2	1,8
Level Crossing	Road Traffic Signals	Visual inspection	1. Correction of position and/or fastenings defects 2. Retighten screws 2. Electrical values measures 3. Dusting of optical systems (lanterns) inside and out 4. Check for locks and hinges status on lantern doors 5. Check for bell	1, 2	2	1,2

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Asset	Asset sub-components	Monitoring activity	Maintenance activity	Stakeholders needs (Ref. Table 9)	Failure conditions	RIMMA
Railway Channel	Obstacles	Visual inspection	Visual inspection	1, 2	1	1,2
Railway Channel	Work Group	Visual inspection	Visual inspection	1, 2	1	1,2
GSM-R network	GSM-R signal	Electro-Magnetic Field analysis	Action or repair	1, 2	2	1,2
Level Crossing	Barriers	Visual inspection	1. Correction of position and/or fastenings defects 2. Retighten screws 3. Test of up and down movements (timing and synchronicity) 4. Electrical measures 5. Mechanical adjustments 6. Gear lubrication 7. Cleaning and vegetation removal	1, 2	2	1
Level Crossing	Pavement	Visual inspection	1. Correction of position and/or fastenings defects 2. retighten screws	1, 2	3	1
Railway Channel	Fences	Visual inspection	Visual inspection	1, 2	1	1
Feeder Pillar	N/A	Visual inspection	Action or repair	1, 2	1	0,8
Level Crossing	Technical Shelter	Visual inspection	1. Removing obstructive elements, namely vegetation in a 1m radius 2. Cleaning 3. Correction of small defects	1, 2	1	0,8
Railway Channel	Vegetation Control	Visual inspection	Visual inspection	1, 2	1	0,8
Railway Channel	Track	Visual inspection	Visual inspection	1, 2	1	0,8
Wayside cabinet/enclosure	Cabinet/enclosure	Visual inspection	Repair		1	0,8

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Asset	Asset sub-components	Monitoring activity	Maintenance activity	Stakeholders needs (Ref. Table 9)	Failure conditions	RIMMA
Rail Cable Ducts	N/A	Visual inspection	Action or repair	1, 2	1	0,8
Slopes/cuttings	N/A	Visual inspection	Action	1, 2	1	0,6
Lineside cabinet	Cabinet Doors	Visual inspection	1. Cleaning 2. Tightness check of doors 3. Functional test of doors, locks and hinges 4. Proper lubrication	1, 2	1	0,6
Axle Counter	Equipment box	Visual inspection	1. Correction of position and/or fastenings defects 2. Check for tightness integrity on the box cover 3. Electrical values measures 4. Functional test with auxiliary test case 5. Retighten screws on cable terminals	1, 2	3	0,6
Axle Counter	Cable	Visual inspection	1. Correction of position and/or fastenings defects	1, 2	3	0,6
Track Circuit JS HVIT	Cable Connections	Visual inspection	1. Correction of position and/or fastenings defects 2. Retighten screws on cable terminals	1, 2	1	0,6
Track Circuit FTGS	Equipment box	Visual inspection	1. Correction of position and/or fastenings defects 2. Electrical values measures	1, 2	2	0,6
Main Signal	Head / Lamps	Visual inspection	1. Correction of position and/or fastenings defects 2. Retighten screws 3. Electrical values measures 4. Dusting of optical systems (lanterns) inside and out 5. Check for locks and hinges status on lantern doors 6. Signal visibility at 350m	1, 2	2	0,6
Railway Channel	Photovoltaic supply	Visual inspection	1. Correction of position and/or fastenings defects 2. retighten screws	1, 2	1	0,6

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Asset	Asset sub-components	Monitoring activity	Maintenance activity	Stakeholders needs (Ref. Table 9)	Failure conditions	RIMMA
Wayside cabinet/enclosure	Air vent grilles	Visual inspection	Cleaning	1, 2	2	0,6
Wayside cabinet/enclosure	Access doors	Visual inspection	Action or repair		1	0,6
Wayside Fences	N/A	Visual inspection	Repair	1, 2	1	0,6
Lineside cabinet	Cabinet	Visual inspection	1. Removing obstructive elements, namely vegetation in a 1m radius 2. Cleaning 3. Correction of small defects	1, 2	2	0,4
Lineside cabinet	Cabinet vents	Visual inspection	1. Cleaning	1, 2	2	0,4
ATP Beacon	Beacon	Visual inspection	1. Correction of fastening defects 2. Check of sealing integrity 3. beacon replacement if needed	1, 2	3	0,4
ATP Beacon	Cable connection to beacon	Visual inspection	1. Correction of fastening defects 2. Check of sealing integrity 3. Beacon replacement if needed	1, 2	3	0,4
Axle Counter	Detection device	Visual inspection	1. Correction of position and/or fastenings defects	1, 2	3	0,4
Track Circuit JS HVIT	Impedance Bonds	Visual inspection	1. Correction of position and/or fastenings defects 2. Check for tightness integrity on the box cover 3. Electrical values measures	1, 2	1	0,4
Track Circuit JS HVIT	Insulated Joints	Visual inspection	1. Electrical values measures	1, 2	3	0,4
Track Circuit FTGS	Cable Connections	Visual inspection	1. Correction of position and/or fastenings defects 2. Retighten screws on cable terminals	1, 2	3	0,4

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Asset	Asset sub-components	Monitoring activity	Maintenance activity	Stakeholders needs (Ref. Table 9)	Failure conditions	RIMMA
Main Signal	Mast	Visual inspection	1. Correction of position and/or fastenings defects 2. Retighten screws 3. Electrical values measures	1, 2	2	0,4
Railway Channel	Drainage	Visual inspection	Visual inspection	1, 2	1	0,4

Table 10: Asset, monitoring and maintenance activity rankings, based on a prioritisation criterion identified by RIMMA index and failure conditions ratings.

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Asset	Network (km)	Network (km) single track equivalent	#asset	assets/10km Single track equivalent
Switch point	1440	2075	12401	59,8
Switch/Crossing	1440	2075	7249	34,9
Lineside Cabinet	1440	2075	4402	21,2
ATP Beacon	1440	2075	3714	17,9
Axle Counter	1440	2075	2625	12,7
Track Circuit JS HIVT	1440	2075	1955	9,4
Track Circuit Jointless	1440	2075	830	4,0
Level Crossing	2535	3145	204	0,6
Main Signal	1440	2075	49	0,2
GSM-R Network	224,967	250,417	5	
Technical Shelters	1440	2075	1	0,0

Table 11: Asset distribution on IP Railway networking

On the basis of the ranked asset, monitoring and maintenance activities shown in **Table 10**, those ones considered to be of greatest importance for RADIUS stakeholders needs, turn out to be:

[1] Switch Point
[2] Level crossing
[3] Lineside cabinet
[4] GSM-R Network

This choice will allow to:

- Focus the research developments on the key innovation of the RADIUS project, i.e., the inspection and monitoring of assets on/in the proximity of the tracks with UAVs.
- Include in the payload of the RADIUS UAV all the key monitoring technologies (visual inspection and electromagnetic field analysis) to potentially cover all the remaining assets by further developing software modules only (e.g., dedicated image processing modules). This will ease future exploitation of the results.

As a reinforcement in the selection of these assets, **Table 11** reports the approximate quantities and density of the assets in service on IP's railway network, whereas **Figure 2** reports the frequency of corrective maintenance interventions on quarterly basis on switch point components at Rome Metro C subway line.

Beside from the specific application of the drones for the monitoring and diagnosis the status of an asset, its usage may be applied transversally to the railway domain, aiming at the safe management of maintenance interventions and train circulation along the line. Some examples may involve the warning of danger to people along the track or the detection of obstructive objects and abandoned maintenance items, etc.

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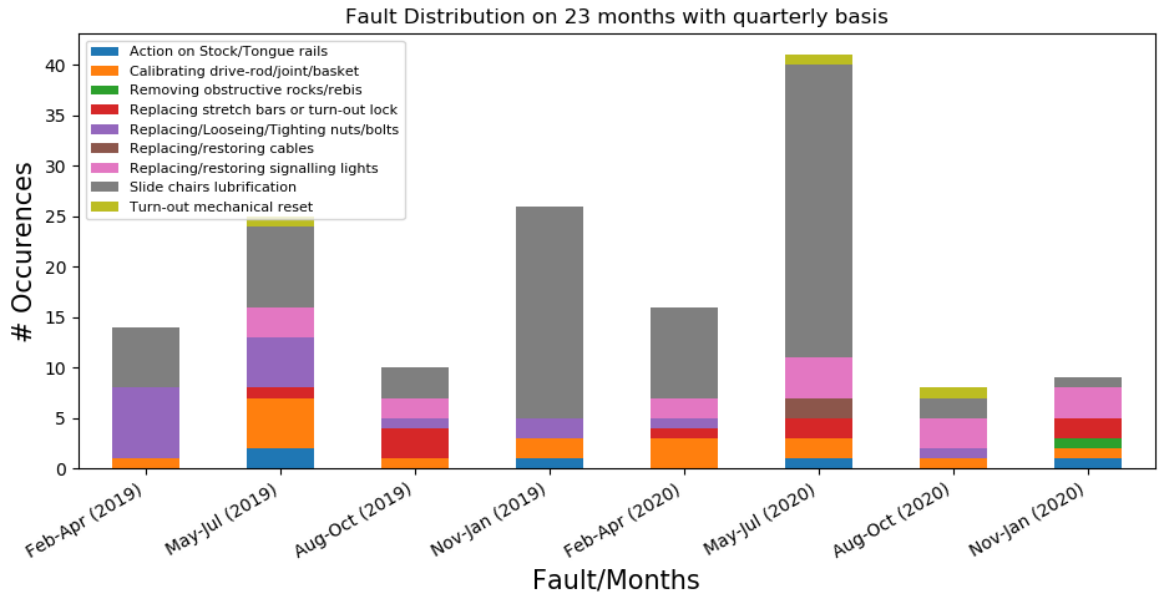

Figure **2**: Frequency of corrective maintenance interventions on quarterly basis on switch point components at Rome Metro C subway line

7.1 Switch Point

The choice of identifying the switch point as one of the assets to pursue during the RADIUS project is mainly linked to safety critical aspects, maintenance cost reduction and the degree of automation of monitoring and maintenance activities.

Regarding the first point, as is well known, the number of switch points present on the railway lines are so many as well as are very frequent the monitoring and maintenance activities carried out on them (see ***Figure 2***). This implies the operators to expose themselves to a high safety risk during these activities.

Regarding the second point, some of the interventions are not very cost effective, especially when carried on a time-based schedule, hence, even when not necessary. The use of a drone for the inspection of the switch point may lead to new and effective ways to perform maintenance, thanks especially to his ability to fly over asset subcomponents, therefore to monitor its status. For example, by using visual image recognition, the drone could recognize the degree of lubrication for specific asset sub-components (i.e., slide chairs) and predict the RUL, so that a preventive intervention could be scheduled before a failure happens.

Operators can also inspect the asset using the real-time video provided by the drone, which can provide 3D models of the scene by using technologies such as LIDAR, SFM, etc. Such 3D models can be further used for providing either quantitative or qualitative analysis. Operating time could also be measured using specific algorithms. Some of the great benefits of using drones for inspecting the switch point are:

[1] Simplifying and maximizing the monitoring and maintenance activities by reducing the frequency of the interventions on wayside;

[2] Reducing the impact on Railway system performance and providing a prognostic tool for predicting and diagnosing in advance interventions on a specific component.

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7.2 Level crossing

Level crossings are provided on the railway lines to pass the road traffic across the track. As the road traffic passes at the same level on that of the railway track, the crossing is termed as level crossing.

The level crossing main components are road traffic signals, barriers, technical shelter and pavements. For these ones, the functional/operational behaviours are verified by monitoring the correctness of emitted sound and light signals (according to the defined rules), state and movements of the barriers and the state of the road surface, which provides a mean to road traffic across the line.

The use of drones for inspecting the level crossing may be carried out by using RGB camera and operators could inspect the asset using the real-time video feed provided by the drone. Visual image recognition can be used as double-edged weapon, providing both a valid tool for diagnostic and maintenance (i.e., monitoring the movements behaviour and time of the barrier, detecting obstacle, etc.), enhancing the availability and the safety of the railway infrastructure.

Other applications will concern automatic signalling detection, evaluation of traffic signals on/off time, evaluation of visibility, etc. Operators can also inspect the asset using the real-time video provided by the drone, which can provide 3D models of the scene by using technologies such as LIDAR, SFM, etc. Such 3D models can be further used for providing either quantitative or qualitative analysis.

Some of the great benefits of using drones for inspecting level crossing ranges from critical safety aspects to the increasing of the cost/time availability ratio.

7.3 Line Side Cabinet

Line side cabinet are placed on the wayside of the main track and they play key role in controlling signalling equipment at trackside. They whole cabinet consist of doors, cable plates and/or active equipment and air vents. They in turn play key roles in giving access to the cabinet, protecting the signalling equipment and maintaining inside temperature and moisture in acceptable limits

The use of drones for inspecting line side cabinet may be carried out by using RGB camera, Infrared camera (NIR) and Thermal camera (LWIR). The use of such sensors may help to detect the healthy status of the asset, for instance by detecting changes in colour (due to vandalism or weather, rust), open doors or lack of them, rusty key locks and changes in temperature or moisture inside the cabinet.

Some benefits in monitoring line side cabinet are to provide systems on safe principle and maximize the line availability by preventing conflict movement on trains.

The choice of the line side cabinets will also allow testing the feasibility of the following monitoring and maintenance aspects foreseen in the DoA:

[1] Contactless diagnostic data collection;
[2] Software updates of signalling assets.

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7.4 GSM-R Network

The Global System for Mobile Communications-Railway (GSM-R) delivers digital, secure and dependable communications between drivers and signallers. It aims to improve reliability and deliver the foundation for a digitally enabled railway network.

Although such new system has reduced operating cost by replacing the patchwork of increasingly inefficient and expensive legacy systems, maintenance and monitoring activities are still based on TBM, where maintenance team scan the EM spectrum with specific devices to assess QoS and detect EM interferences.

The use of drones for inspecting GSM-R Network may be carried out by using EM-scanner, whose collected data can be further analysed to obtain a signal coverage or interference map. Online processing could be also possible.

Some benefits in monitoring such asset with drones are:

[1] Simplifying and maximizing the monitoring and maintenance activities by reducing the frequency of interventions on wayside;
[2] Increasing the safety of the personnel during their activities;
[3] Decreasing the maintenance and monitoring activities cost.

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8 Conclusion

The contents presented in this document is the outcome of a carefully designed methodology, research upon industrial and with an active contribution by all the partners.

This deliverable brings information about the identification and description of railway signalling components/assets, which in turn can cause degraded railway system performance, affecting railway traffic management in several ways. The identification and description of monitoring and maintenance activities that IM normally performs to cope with, will be useful for next work packages deliveries to better define the RADIUS system specification. In saying so, through a pragmatic approach, this document defines a prioritisation criterion for ranking the monitoring and maintenance activities, based on a criticality function defined by the involved stakeholders, thus identifying a group of interesting asset, monitoring and maintenance activities that can be potentially implemented within the RADIUS infrastructure.
Switch points, level crossing, lineside cabinet and GSM-R network will be the main assets addressed throughout RADIUS because of their importance and impact for end-users.
Moreover, based on the content reported in the document, this deliverable tackles down the common IM problems by reducing costs for human preventive and corrective maintenance and increasing the health and safety of workers as well as the railway reliability and availability.

In the forthcoming steps, based on the outcomes of D2.1, this information will be mainly used to define, design and describe the system requirements and architectural specifications, for the deliverable D2.2 and D2.3. Nevertheless, all the information provided in this document must be intended to support the activity development of the other RADIUS WPs.

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9 References

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[7] IN2TRACK – Research into enhanced track, switches and structures. S2R-CFM-IP3-01-2016

[8] IN2TRACK2 - Research into enhanced track, switches and crossing system 2. S2R-CFM-IP3-01-2018

[9] GAUSS H2020 – Galileo-EGNOS as an Asset for UTM Safety and Security

[10] RHINOS – Railway High Integrity Navigation Overlay System will define a GNSS-based System to support the localization of trains respecting the challenging requirements of the Railway safety standards

[11] CLUG - Certifiable Localisation Unit with GNSS in the Railway Environment

[12] STARS - Satellite Technology for Advanced Railway Signalling

[13] HELMET - High integrity EGNSS Layer for Multimodal Eco-friendly Transportation

The project leading to this application has received funding from the European GNSS Agency under the European Union's Horizon 2020 research and innovation programme under grant agreement No 101004192

10 Appendix A

10.1 RADIUS-WP2_activities_definition

RADIUS-WP2_activities_definition.xlsx

The project leading to this application has received funding from the European GNSS Agency under the European Union's Horizon 2020 research and innovation programme under grant agreement No 101004192