RADIUS: Railway signalling asset monitoring using UAS

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Abstract
Railway signalling assets monitoring is based on three alternative methods: a) human inspection, b) wired solutions, and c) monitoring trains. These methods impose severe limitations in terms of safety issues, initial investment, complexity, operating costs, limited diagnostic data, and track occupation. The result of these limitations is that the maintenance activities of railway lines are sub-optimal, resulting in preventable failures that require expensive and disruptive reparations that imply the temporal interruption of the service in the affected tracks. The project ”Railway digitalisation using drones” (RADIUS) proposes the use of Unmanned Aircraft Systems (UAS) to execute a large part of the inspection and maintenance tasks of signalling assets that improve on the current methods but require compliance with aviation standards and regulation besides those existing in the railway environment. To attain this goal, RADIUS has analysed the needs of the end users, to establish the system requirements, focusing its research in the communication links between the different elements of the solution, signalling asset modification to interact with the UAS, and image processing to process the visual information gathered by the UAS. A custom docking station was created to extend the range and ensure commercial viability of the solution. The individual elements and the solution as a whole have been validated in a railway relevant environment. The result of the project has been satisfactory, paving the way for the use of DRONE technology in the railway sector.

Keywords
Railway, Signalling Assets, Maintenance, UAS, GNSS

1 Introduction

Infrastructure Managers (IM) currently monitor their railway signalling assets using three methods:

- On-demand or programmed human maintenance activities.
- Wired solutions.
- Trains equipped with monitoring technologies.

Human maintenance activities demand high direct personnel labour costs and operational constraints. Maintenance teams comprise at least two or three people for safety purposes. In addition, maintenance activities require the protection of the affected trackside area from dangerous situations for the workers: train movements and speeds, power supply, etc. According to Eurostat (2020), during 2020 there were 31 deaths and 44 severe injuries amongst railway employees in EU-27 countries, some of them during inspections.

Monitoring of signalling assets based on diagnostic data acquired with wired solutions is expensive since it requires extensive and costly cabling. The limited bandwidth of existing cabling solutions only allow the transfer of a reduced set of diagnostic data, impacting the usefulness of this technology.

To overcome these limitations, some IM have made significant investments for designing, developing, operating, and maintaining diagnostic trains. These trains acquire diagnostic data during their runs, which are later elaborated offline to discover trackside and signalling asset anomalies. However, diagnostic trains run at lower speeds than commercial trains, thus imposing temporary performance limitations on the assessed lines. In addition, these solutions involve substantial additional budgets to maintain and update the on-board equipment of the diagnostic trains, as well as to train staff.

Railway maintenance activities require special verification checks of the maintained areas before restoring the nominal conditions. To overcome these limitations, RADIUS proposes to use Unmanned Aerial Systems (UAS) to execute a large part of the inspection and maintenance work on-site, including tuning, recalibration, activation of special functions, etc. SESAR (2016) acknowledges that using UAS could benefit the mobility sector through railway inspection. The RADIUS automation will also allow increased inspection frequency, defining a new paradigm for railway inspection and maintenance that limits the activities carried out by human teams and improves the global railway operational service in terms of availability, reliability, and performance.

The main benefits provided by UAS in inspection and maintenance activities are, therefore:

- Overcome many of the limitations mentioned above in inspection and maintenance of signalling assets.
- Contribute to the digitalisation of the railway sector, recognised as a key objective by GSA (2019a).
- Replace most of the human maintenance and visual inspection activities.
- Increase the safety of the maintenance operations by requiring fewer people in the field.
- Reduce the complexity and the cost of maintenance activities using autonomous systems.
- Increase the frequency of the inspections in a cost-effective way.

The following table summarises the major limitations of each of the asset monitoring alternatives compared to the RADIUS approach:

Table 1: Asset monitoring alternatives

Inspection method	**Initial investment**	**Operating cost**	**Track possession**	**Other**
Human inspection	Low	Very high	Yes	Health & Safety
Wired solutions	Very high	Low	No	Limited features
Diagnostic trains	Very high	High	No, but reduced capacity	Staff training
RADIUS	Low	Low	No	Compliance with aviation standards

2 Key challenges

The only significant incident involving UAS and their interactions with the railway is the event happened in Stoke Gifford (UK), described in AAIB (2020). An UAS suffered a complete loss of control because of magnetic deviations of up to 140° observed over localised regions that were caused by the overhead high-voltage wires. Therefore, a commercial solution based on the RADIUS results should either shield the UAS against Electromagnetic Interference (EMI) or use EMI-immune on-board equipment.

Besides common operational limitations that affect UAS operations, a particular operational constraint with an impact on the system design was identified; train induced winds and vortexes. The magnitude of aerodynamic forces caused by a train in movement increases in proportion to the square of the train speed, Pan and Yang (2010) and depends on the horizontal and vertical distance to the train. Preliminary results have been estimated using the method described by Sebesan, Arsene (2015), extrapolating the results to the expected height of the flights, to establish a safe distance and height of the UAS for different train speeds.

A key component of the solution is an augmented positioning system, capable of providing accurate and safe positioning. The accuracy of conventional positioning systems may not guarantee the required accuracy to avoid unwanted interactions between the UAS and its surroundings. Therefore, an SBAS, is necessary for applications where accuracy, integrity, continuity, and availability of positioning information are critical. A solution based on EGNOS and GALILEO, as described by GSA (2019b) was investigated but proved insufficient, so it was decided to implement a commercially available Real Time Kinematics (RTK) solution.

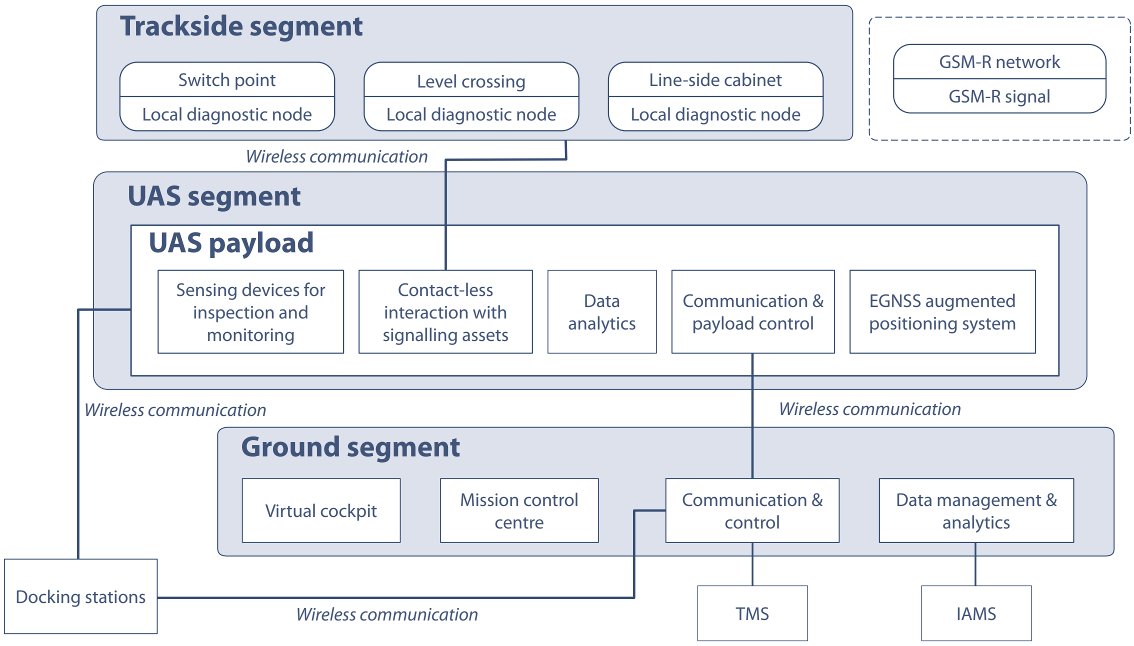


Figure 1: RADIUS architecture

3 High level objectives

The project explored potential uses of unmanned aerial technology for monitoring and maintenance of railway signalling assets and other ancillary systems and devices:

- **Inspection and monitoring** of the physical status and electronic functionality of railway signalling assets, including safety-critical assets.
- **Identification of vandalism** in assets and railway installations close to the tracks.
- **Wireless diagnostic data collection** to identify immediate maintenance actions required to restore operational conditions.
- **Software updates of signalling assets**. In many cases nominal performance can be restored by optimising the threshold settings of the signalling assets.

4 RADIUS architecture and design

The main outcome of the project is a UAS based solution for the monitoring of railway signalling assets. The architecture of the RADIUS system is shown in Figure 1. Customised signalling assets were developed during the project to take full advantage of the capabilities of UAS (see section 5.3). The Technology Readiness Level (TRL) achieved for the whole system and its key components was TRL6, implying the need for further research to produce a commercial-grade integrated solution, with individual components that can be marketed independently or as a whole (see section 6.1).

5 RADIUS methodology

To achieve its goals, RADIUS used the methodology described below, which is summarised in Figure 2:

- **System Specification**: In this preliminary task we identified stakeholders' needs, priorities and constraints introduced by aviation and railway regulations and standards, defined the system requirements and architectural specification and selected the use cases to be developed.

- **Communication, mission control and interaction with Traffic Management System (TMS)** involved the development of flight management procedures to perform asset monitoring and maintenance, avoiding or limiting railway possession.
- **Adaptation of signalling assets** to overcome the limitations of cabling solutions described in section 1, signalling assets were adapted to have wireless communication with the UAS.
- **Docking station**: To extend the range of the UAS, a docking station capable of recharging or replacing the batteries of the UAS was developed and tested.
- **Selection of UAS and payload design**: A commercially available UAS platform and sensors meeting the intended flight profiles and data requirements were selected and integrated.
- **Data management and analytics**: We complemented the on-board computation functionality of the UAS with the ground-segment platform, covering all data related aspects including cybersecurity, privacy, data management and analytics for predictive asset maintenance through a direct interface with the standard Intelligent Asset Management System (IAMS).
- **Tests and validation**: The individual components were tested in-lab and in-field, and the whole system was tested and validated in a relevant railway environment using a redesigned signalling asset for wireless communications.

5.1 Use cases

As part of the system specification task, RADIUS identified three use cases that were fully implemented during the project:

I. Cabinets
Lineside cabinets are placed on the wayside of the main track, and they play a key role in controlling signalling equipment at trackside.

The inspection of cabinets was carried out using RGB cameras, Infrared cameras (NIR) and Thermal cameras (LWIR). These sensors were able to store the state of the assets over time and detect modifications due to vandalism or normal tear and wear (See Figure 3a).

II. Crossings
A level crossing is an intersection at the same level between a railway track and a road or path. It is the mechanism used to regulate traffic. RADIUS proposes to carry out detailed monitoring to detect potential failures as early as possible to prevent fatal accidents that still occur every year.

Level crossings have a wide variety of components to regulate traffic, such as road traffic signals, barriers, technical shelter and pavements. It is necessary that all of them work optimally to avoid collisions between trains and vehicles.

The inspection of level crossings was carried out by using RGB cameras allowing the operators to inspect the asset using the real-time video feed provided by the UAS since visual image recognition provides

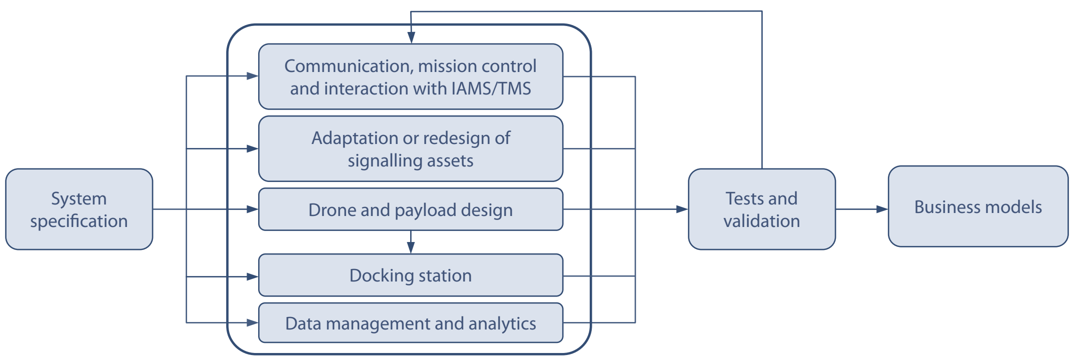
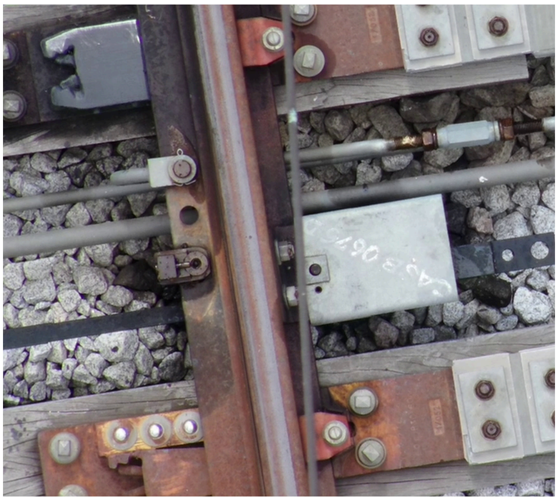


Figure 2: RADIUS methodology

(a) Detection of vandalism in cabinets



(b) High definition image of a switch

Figure 3: RADIUS use cases

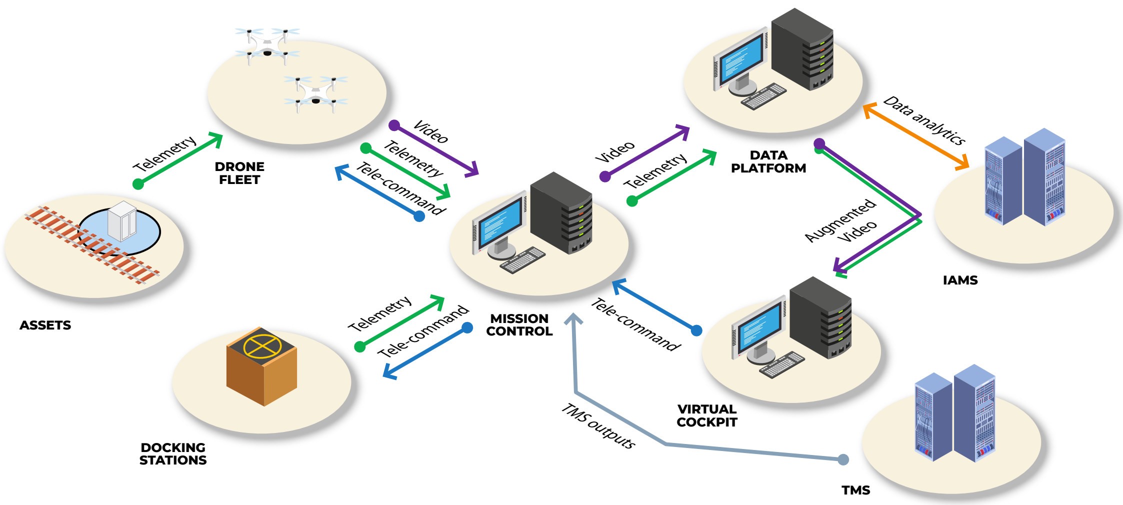


Figure 4: RADIUS Data flows

a valid tool for both diagnostic and maintenance by monitoring the movement and timing of the barrier, detecting obstacles, etc.

III. Switches

A switch is a device that allows trains to change from one track to another. Their correct operation is vital for rail traffic to function perfectly, thus avoiding incidents such as delays or, in more serious cases, accidents. For this reason systems that verify their correct operation are key.

RADIUS improves the way checks are performed on switches. Operators can inspect the asset using the real-time video supplied by the UAS, and construct 3D models of the switch surroundings using technologies such as LIDAR, SFM, etc. Such 3D models can be further used for providing either quantitative or qualitative analysis.

The high definition images that can be obtained with current RGB cameras provide enough resolution to inspect and detect anomalies, (see Figure 3b) specially when using AI algorithms to spot differences between the images captured at different times.

(a) Modified signalling asset test (b) Docking station placed at the demonstration site

Figure 5: Key components of the solution

5.2 Communications and data flow

The RADIUS solution integrates a set of different links for the interaction of the several actors and subsystems that comprise the solution. Figure 4 depicts the different data flows involved, which are hosted by two different kinds of data links:

- Wireless links
  - Long range
    * Ground segment and docking stations
    * Ground segment and UAS
  - Short range
    * UAS and asset diagnostic nodes
    * UAS and docking stations
- Wired links
  - Ground segment and docking stations
  - Ground segment and UAS

5.3 Modified assets

To introduce UAS-based technology into the railway infrastructure environment, assets should be able to communicate with the UAS to exchange the information needed for monitoring activities. These communication devices can be easily integrated in newly designed products, but the upgrade of existing assets is much more difficult since they usually have a minimal set of measurements and any modification in their design usually involves the need to repeat the type tests for certification purposes.

With these considerations in mind, we decided to focus on the adaptation of existing assets. We designed the adaptation as a native UAS compatible device attached to, but not interacting with, the existing asset. To be able to perform the adaptation of vital assets and safety critical systems, the design was based on a hard separation between the asset and the communication device.

To demonstrate the application of these principles we developed a use case applied to the switch point machinery. The communication device, shown in operation in Figure 5a, was developed and tested in a flight test carried out as described in section 5.5.

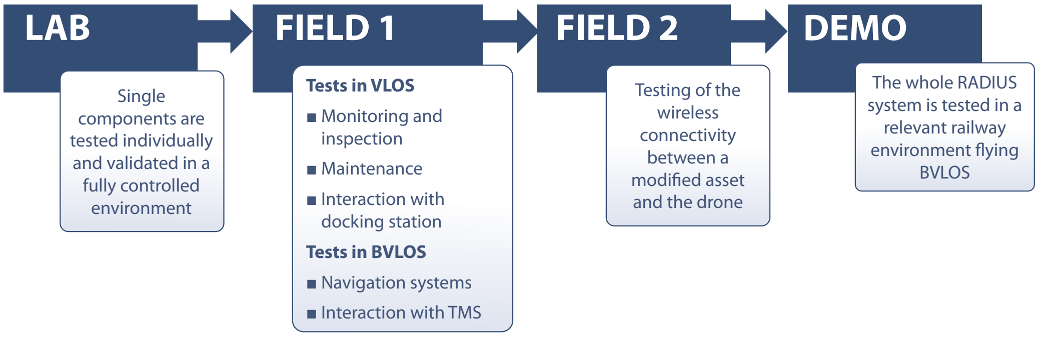


Figure 6: Test and validation campaigns

5.4 Docking station

The RADIUS docking station is a key component of the RADIUS solution since it enhances the autonomy of UAS, thereby enabling commercially viable operations.

The docking station serves as a hub, where UAS can safely land, recharge, and eventually upload data collected during their monitoring missions (thus solving the need to store the whole set of data captured during a whole testing campaign). It was designed to be integrated with existing railway signalling facilities, and equipped with wireless technologies that enable secure and efficient communication with the UAS. The main components of the RADIUS docking station are:

- The **landing pad** is the surface where the UAS takes off and lands.
- The **charging station** handles the recharging of the UAS batteries.
- The **navigation system** aids the UAS during the landing and take-off phases, guaranteeing the necessary precision for safe landings.
- The **control unit** is the brain of the docking station and manages all its operations.
- **Safety mechanisms** include barriers, cameras and sensors to prevent collisions and ensure a safe landing.

The docking station prototype tested during the final demonstration is shown on Figure 5b.

5.5 Validation activities

A comprehensive test and validation campaign was carried out, as shown in Figure 6. The three locations selected were:

- Field 1: The railway station of Casa Branca (Portugal) and a corresponding piece of track on the Alentejo railway line.
- Field 2: The Hitachi Rail industrial plant in Naples (Italy), that includes a private rail ring.
- Demonstration site: The railway station of Ourique (Portugal) and the surrounding piece of track on the Alentejo railway line.

The Field 1 site enabled all tests and validation of the preliminary RADIUS prototype and to acquire data of switches and cabinets for the development of post-processing of the data. The Field 2 site was used to test and validate the wireless communication between the UAS and the specially designed signalling asset described in section 5.3. Both the Field 1 and the Demonstration site had all the characteristics necessary for the RADIUS project, including the validation of the Beyond Visual Line of Sight (BVLOS) Concept of Operations (CONOPS) of the RADIUS prototype, since:

- They are sections of a real railway track allowing tests and validation up to TRL6.

- Train traffic is limited to a few slots during the day, offering several traffic-free windows and providing the opportunity to test the coordination protocols with the TMS.
- The sections included tracks with and without catenaries.
- Key assets of RADIUS interest (i.e. cabinets, switches and crossings) were present and could be inspected.

Safety analysis and privacy issues
To support the test and validation campaigns, we performed a Specific Operations Risk Assessment (SORA) complying with the regulatory requirements, identifying the robustness level of each safety objective and the mitigations prescribed by SORA. The assessment included the risk for third parties on the ground (ground risk) and in the air (air risk).

To safeguard privacy concerns, we conducted a manual check after the automatic phase of detection and cancellation of personal information to verify if images related to any person (or any personally identifiable item) external to the project were recorded accidentally and these images allowed the individual recognition of the person (or item). Based on the analysis performed, we concluded that the automatic detection algorithms used were sufficient to comply with privacy requirements.

BVLOS proof of concept
Some flights were conducted outside the Visual Line of Sight (VLOS) boundary. The objective was to demonstrate the BVLOS CONOPS, complying with regulatory limitations. We placed observers that kept the UAS in sight during all phases of the flights and were ready to intervene in case of an incident. The test was functionally a success because the process was carried out completely autonomously, without the need for intervention by the observers or the pilot in command, thus demonstrating the feasibility of BVLOS operations, when they become routinely approved.

6 Conclusions

This paper presented a proposal for a complete system to monitor signalling assets in the railway environment using UAS. A comprehensive review of the existing solutions was conducted. The needs of the potential users of the technology were considered, resulting in the definition of the requirements of the system that were used to design and implement it. The validation of the solution included simulated exercises and a series of flights in which the different components were tested. A final demonstration of the whole system was carried out to check the interoperability of the different components in a relevant railway environment. The following conclusions can be drawn from the RADIUS project:

6.1 Conclusions on maturity of the solution

RADIUS has demonstrated its ability to improve rail safety, but there are still steps to be taken to make it a commercially viable technology.

From prototype to commercial solution
RADIUS has managed to reach TRL6 level, but more research is required to reach TRL9. The project conducted successfully validation campaigns in relevant environments of a prototype that integrated all the components of a whole solution, but the next step is to convert these prototypes into economically viable commercial products on the market.

Improved navigation
RADIUS currently relies on proprietary RTK positioning systems. It would be desirable to remove this dependency. One possible solution would be to use Open-Source solutions based on EGNOS, OSNMA and GALILEO, possibly complemented with AI algorithms exploiting the visual information captured by the same sensors used to conduct the missions.

Asset management platform
Reconnaissance flights generate huge amounts of data that needs to be processed and archived efficiently to be exploited to the full. Therefore, further steps need to be taken to develop and integrate a specialised and

customised digital asset management system interfacing the existing IAMS.

Other research objectives

An UAS can measure malicious and non-malicious radio frequency interference that are above given thresholds and have the capability of disturbing the signalling communications. They can be caused by unauthorised radio transmissions, degradation of devices that cause emitting outside the usual spectrum, intentional disturbances, etc.

In addition to fine tuning signalling assets parameters as described in section 3, UAS could perform firmware updates using wireless technology. This requires handling the security risks inherent to firmware upgrades which was outside the scope of the project.

6.2 Conclusions on technical design, feasibility and architecture

The technology works in the railway environment

The RADIUS project has succeeded in demonstrating that its technology is technically feasible and allows the use of UAS to monitor the correct functioning of critical infrastructures for railway safety. UAS make it possible to carry out more frequent inspections, reduce costs and increase the safety of maintenance operations by avoiding displacing manual work. Moreover, the flights do not interfere with rail traffic.

The docking station makes monitoring of long railway tracks feasible

RADIUS has developed the docking station, a platform strategically distributed along the tracks that allows UAS to land automatically, recharge their batteries and synchronise the information collected during their inspection flights. By extending the range and flight time of the UAS, the efficiency of the inspections is improved, reducing costs, and increasing coverage by being able to work in BVLOS, making it a commercially viable solution.

6.3 Conclusions on performance and benefit assessments

Valuable data acquisition

RADIUS has proven not only to be technically and commercially feasible, but also that the data obtained during its reconnaissance flights is useful and suitable for assessing and monitoring the state of preservation of the crucial signalling assets. RADIUS makes it possible to detect efficiently problems or defects in the monitored assets, ensuring train safety. The Business Model of a service based on the RADIUS solution was developed and described in Oñate et al. (2023).

Other applications in the rail sector

RADIUS has demonstrated its viability for monitoring the status of a selection of elements that are vital to ensure the safety of railway traffic: cabinets, crossings and switches, but the technology has the potential to be extended to other categories of assets and to other uses cases within the rail sector itself.

Applicability to other linear infrastructures

RADIUS is a project with great potential to be extended to other industries or linear infrastructures, with common characteristics with the railway sector. Many of the technologies developed could be extrapolated to other applications, such as the docking station, wireless communications with sensors on the ground and the image processing algorithms.

6.4 Recommendations for standardisation and regulation

UAS applications in any particular domain have to comply with the regulation and standards that are applicable in that domain, but also to the regulation and standards that are unique to the airspace.

Given that aviation requirements are generally more stringent that those applicable in ground based operations, it is recommended that the regulatory and standardisation bodies take this circumstance into account in order to not impose excessive requirements that would burden the operations of drones in their respective domains with no increase in the safety of the operations.

In the context of a research project we were able to successfully demonstrate the BVLOS concept of operations (see section 5.5), but commercially viable operations will require expedite flight approvals. The

European UAS Regulatory Framework CIR EU 2019/947 (2019) was created with the explicit goal of enabling the development of a highly promising market, but the reality of its application is that five years after its publication there are considerable obstacles to operate legally, even after demonstrating the safety of the proposed operations to other users of the airspace and people and property on the ground.

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