2023

Report on **Rail**

User Needs and Requirements

#EUSpace

EUSPA European Union Agency for the Space Programme

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1 INTRODUCTION AND CONTEXT OF THE REPORT

The User Consultation Platform (UCP) is a periodic forum organised by the European Union Agency for the Space Programme (EUSPA), where users from different market segments meet to discuss their needs and application-level requirements relevant for Position, Navigation and Timing (PNT), Earth Observation (EO) and secure telecommunications. The event is involving end users, user associations and representatives of the value chain, such as receiver and chipset manufacturers and application developers. It also gathers organisations and institutions dealing, directly and indirectly, with the European Global Navigation Satellite System (EGNSS), encompassing Galileo and EGNOS and newly since 2020, also with the EU Earth Observation system, Copernicus, Space Situational Awareness (SSA) and with GOVSATCOM and IRIS², the upcoming system for EU Secure Satellite Constellation which offers enhanced communication capacities to governmental users and business. The UCP event is a part of the process developed at EUSPA to collect user needs and requirements and take them as inputs for the provision of user driven space data-based services by the EU Space Programme.

In this context, the objective of this document is to provide a reference for the EU Space Programme and for the Rail segment community, reporting periodically the most up-to-date user needs and requirements in the Rail segment. This report is a living and evolving document that will periodically be updated by EUSPA. It serves as a key input to the UCP, where it will be reviewed and subsequently updated and expanded in order to reflect the evolutions in the user needs, market and technology captured during the event.

The report aims to provide EUSPA with a clear and up-to-date view of the current and potential future user needs and requirements in order to serve as an input to the continuous improvement of the development of the space downstream applications and services provided by the EU Space Programme components. In line with the extended mandate of EUSPA, the Report on User needs and Requirements (RURs) previously focused on GNSS, have been revamped in order to also encompass the needs of Earth Observation (EO) commercial users and is now organised according to the market segmentation of the EUSPA EO and GNSS Market Report. As the EU Space components evolve continuously, the report now also includes references to the use of Space Surveillance and Tracking (SST) as part of the SSA programme.

Finally, as the report is publicly available, it also serves as a reference for users and industry, supporting planning and decision-making activities for those concerned with the use of PNT and of Earth observation technologies.

It must be noted that the listed user needs and requirements cannot usually be addressed by a single technological solution but rather by space downstream applications which combine several signals and sensors. Therefore, the report does not represent any commitment of the EU Space Programme to address or satisfy the listed needs and requirements in the current or future versions of the services and/or data delivered by its different components.

1.1 Methodology

The following figure details the methodology adopted for the analysis of the Rail segment user requirements at application level.

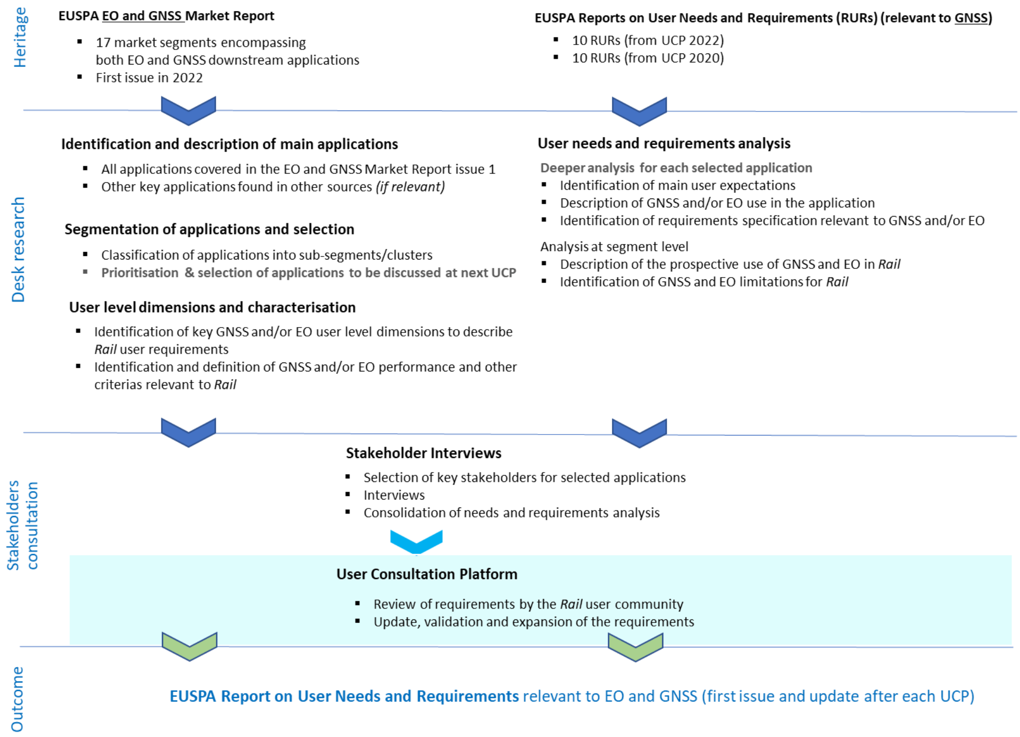

Figure 1: Rail user requirements analysis methodology

As presented in the figure 1, the work leverages on the latest EUSPA EO and GNSS Market Report, adopting as starting point the market segmentation for EO and GNSS downstream applications and takes on board the baseline of user needs and requirements relevant to GNSS compiled in the previous RURs published by the agency.

The analysis is split into two main steps, including a "desk research", aiming at refining and extending the heritage inputs and at gathering main insights, and a "stakeholders' consultation" to validate main outcomes.

More in details, the "desk research" was carried out to consolidate when required the list of applications and their classification, to identify the key parameters driving their performances or other relevant requirements together with the main requirements specification, etc. A deeper analysis was conducted for a set of applications prioritised for discussion at the last UCP event. The outcomes of this preliminary analysis were shared and consolidated prior to the UCP with a small group of key stakeholders, operating in the field of the selected applications.

These requirements analysis results were then presented and debated at the UCP with the Rail segment user community. The outcomes of the Rail segment forum discussions were finally examined in order to validate and fine-tune the study findings.

The steps described above have resulted in the outcomes that are presented in detail hereafter.

1.2 Scope

The document starts with a market overview for Rail segment (section 3), focusing on the market evolution and key trends applicable to the whole segment or more specific ones relevant to a group of applications or to the use of GNSS or EO. This section also presents the main market players and user communities. The report then provides a panorama of the applicable policies, regulations and standards (section 4). It then moves to the detailed analysis of user requirements (section 5). This section first presents an overview of the market segment downstream applications, and indicates for each application, the depth of information available in the current version of the report: i.e. broad specification of needs and requirements relevant to GNSS and EO, partial specification limited at this stage to needs and requirements relevant to GNSS, or limited to an introduction to the application and its main use cases at operational level. The content of this section will be expanded and completed in the next releases of the RUR.

Following its introduction, section 5 is organised as follows:

- Section 5.1 presents current GNSS and/or EO use and requirements per application, starting with a description of the application, presenting main user expectations and describing the current use of GNSS and/or EO space services and data for the application and providing a detailed overview of the related requirements at application level. A few key applications have been addressed at the UCP and are more detailed.
- Section 5.2 describes the main limitations of GNSS and EO to fulfil user needs in the market segment.
- Prospective use of GNSS and EO in Rail segment is addressed in section 5.3.
- Section 5.4 concludes the section with a synthesis of the main drivers for the user requirements in Rail segment.

Finally, section 6 summarises the main User Requirements for *Rail segment* in the applications domains analysed in this report.

The current version of the report will be expanded and completed through its future releases.

The RUR is intended to serve as an input to more technical discussions on system engineering and to shape the evolution of the European Union's satellite navigation systems, Galileo and EGNOS and the Earth Observation system, Copernicus, GovSatCom and IRIS2.

2 EXECUTIVE SUMMARY

This report aims to enhance the understanding of market evolution, limitations, key technological trends and main drivers related to the uptake of GNSS and EO data and services across the different rail application domains. These elements are crucial in shaping the appropriate development of technology and service offerings in accordance with the respective user needs.

Key trends and market evolution

The rail industry is increasingly using satellite data to improve its operations. Here are some of the main key trends and market evolution impacting this sector:

- Telematics: An increasing number of rail freight wagons are equipped with telematics, including GNSS. This allows for better tracking of the wagons and can help improve efficiency and visibility of freight, contributing to a level playing field with other modes of transport
- Infrastructure Monitoring: AI is being used to process GNSS and EO data and enhance infrastructure monitoring or predictive maintenance. It is helping to identify potential issues before they become major problems and improve safety

COVID-19 Recovery: The rail sector is recovering from the impact of COVID-19 and is expected to grow. The use of satellite data can help improve efficiency and reduce costs, which is especially important as the industry is expected to play a central role in the decarbonisation strategy of transportation in the EU.

Current and prospective use of GNSS and EO in Rail Segment

In the latest EUSPA Market Report, nine applications related to Rail have been identified and clustered into four different groups:

- "Attractiveness Enhancement" applications: including Passenger information systems and Public Transport – Tram and Light Rail;
- "Maintenance Improvement" applications: including Conidtion-based maintenance, Infrastructure monitoring and Predictive maintenance;
- "Safety Related" applications: including Enhanced Command & Control Systems (CCS) and Trackside personnel protection systems;
- "Train Driving Optimisation" applications: including Asset management and Driver Advisory Systems (DAS).

For each one of the identified applications, the present document describes the current contribution of GNSS (e.g. Enhanced Command & Control Systems) and/or EO (e.g. infrastructure monitoring – ground subsidence).

The report also discusses the limitations of GNSS and EO, including susceptibility to interference and multipath, sensibility to ambient humidity, cloud coverage in case of optical observation, vegetation cover, and distribution of measurement points in case of synthetic aperture radar interferometry. Additionally, it identifies potential uses of GNSS and EO, such as new capabilities being developed or combined use with existing technologies (e.g. ERTMS, digital maps, digital twins) .

As highlighted by the work from the EuropeanEnvironment Agency (EEA)[1], railway transportation has a lower environmental impact (in terms of greenhouse gas emissions) compared to other modes of mass transportation and has an important role to play in transport decarbonization. To support this ambition,

[1] EEA, Motorised transport: train, plane, road or boat — which is greenest?, 2021. Available at: https://www.eea.europa.eu/highlights/motorised-transport-train-plane-road

innovation and digitalization are essential. On one hand, digital rail freight will make rail freight more competitive and ensure smooth integration of rail freight in the logistics value chain, increasing the role of railway as a backbone of freight transport. On the other hand, systemic digitalization with the development of automation of operations will improve performance and capacity.

The use of GNSS-based applications in rail is expanding. Some applications have reached maturity: an increasing number of Rail freight wagons are now equipped with telematics including GNSS. The total number of EGNSS tracking devices is estimated to be more than 200 000 in the short term. The quantity of data collected opens the potential use of artificial intelligence to develop new infrastructure and track inspection and maintenance prediction methods. The present report has selected 10 GNSS-based applications, structured around 4 sub-segments (i.e. Maintenance improvement, Attractiveness enhancement, Safety related, and Train driving optimisation)

Ongoing and continuous developments should allow the integration of GNSS in the evolution of the ERTMS and GNSS shall also become part of the development of innovative solutions needed to decrease the cost of modern signalling solutions suitable for capillary lines and regional rail services.

Drivers for users' requirements

The document outlines the user needs for fifteen infrastructure-related applications and summarizes the drivers for user requirements. For GNSS, the identified drivers include high accuracy, time to first fix, time to convergence, redundancy, and robustness. For EO, the key elements considered for the requirements include spatial resolution, availability of historical data, and in some cases, the ability to cover large-scale areas, such as linear infrastructures.

For a subset of one selected EO application (Infrastructure monitoring) the document goes a step further by defining different operational scenarios for the use of EO and identifying in more details the corresponding user requirements.

User's requirements are driven differently depending on the application. A few applications without any safety critical needs will take benefits from performance offered by COTS receivers. The safety critical ones, on the other side, have a different context. Standards or technical specifications do not specify requirements for the localisation function directly but will be part of solutions or systems that will drive the requirements definition.

EGNSS service evolutions will contribute to reach some existing requirements and help define new services which will unlock future benefits for the Europeans (e.g. enhanced GNSS capabilities will further support an effective roll-out of ERTMS and will support the potential uptake of GNSS data for safety-related applications in rail).

Finally,there is also a need for increased awareness to expand stakeholder involvement and ensure a comprehensive understanding of the capabilities of EU Space components/services and technologies, such as available solutions and their uses and added value. This applies to GNSS, EO, and Satcom, coupled with more practical applications. This could enable the collection of more case uses or fine-tune needs and requirements, including feedback on the naming of the market segment/sub-segments and applications.

This report is built upon previous reports focusing on Rail User Needs and Requirements. It also includes insights gathered through interviews with various EU rail stakeholders, such as rail operators, service providers, and infrastructure managers. The findings have been thoroughly debated and questioned at the User Consultation Platform (UCP) 2023 in Sevilla. This event was attended by the user community, offering a solid foundation for comprehending the needs and requirements of users in the rail sector.

3 MARKET OVERVIEW & TRENDS

3.1 Market Evolution and Key Trends

Introduction to the Rail Market Segment

GNSS and EO serve the rail sector in many ways. First, GNSS plays a role in rail digitalization; from asset management to infrastructure monitoring and enhanced passenger information, GNSS is already largely deployed in non-safety critical applications. Moreover, a large number of initiatives are preparing for the introduction of GNSS in High- and Low-Density Command & Control Systems, paving the way for new train operations.

Furthermore, information derived from satellite-based imagery supports solutions around track deformation monitoring, vegetation encroachment detection and natural hazard risk assessments, allowing remote inspections and thus targeted on-site inspections.

GNSS and EO therefore both increase safety and reduce the cost of infrastructure management and operations compared to legacy solutions. The number of global initiatives demonstrates the consideration given to GNSS and EO-based developments in Rail (e.g. CLUG, EGNSS MATE, EO4Infrastructure, etc.). **EO** is utilized across all aspects of railway infrastructure, encompassing planning, construction, monitoring, disaster response to floods, and the assessment of risks and vulnerabilities.

Railway infrastructures are designed and constructed to ensure safe, efficient, and reliable transportation and include tracks, bridges and tunnels, key elements that are exposed to natural phenomena such as, ground deformations (e.g. landslides, subsidence, uplifts, sinkholes, fault and seismic displacements), extreme weather events, hazards induced by vegetation encroachment, anthropogenic activities in proximity (e.g. construction of new buildings or worksites) or other endogenous events that can lead to the end of service life (e.g. ageing of materials, raising traffic volumes).

EO can improve operations in terms of cost reduction, provision of a high-temporal-frequency that is crucial to ensure safe, efficient, and reliable transportation, to facilitate and predict maintenance, to prevent ground or structural failures, to assess geohazard susceptibly, and to create geohazard maps of the risks.

In comparison with traditional on-ground non-destructive inspections, based on routine campaigns and long inspection times required for data collection and their implementation into reliable infrastructure management systems, EO offers a cost-effective method for large-scale monitoring. This eliminates the requirement for costly equipment, cuts down on labour expenses and reduces logistical complexities. A complete overview of the application of railway infrastructure monitoring will be discussed in this User Requirement Analysis paragraph.

Additionally, it's crucial to emphasize the extensive availability of free and open-source imagery available (e.g. Sentinel Open Access Hub and USGS Earth Explorer). By tapping into existing archives of satellite data, historical images can be used for comparative analysis, further enhancing cost-effectiveness [RD2].

GNSS Key Market Trends

The following market trends drive user needs and requirements in the rail sector.

- The green and digital transition of the Rail sector

Reducing the impact of transport on global warming requires a further modal shift towards rail, which in turn requires innovation and digitalization to increase efficiency and attractivity. Digitalization in the rail industry takes different forms, including digital rail freight and systemic digitalization with the development of automation of operations [RD18]. Digital rail freight aims to make rail freight more competitive and ensure smooth integration of rail freight in the logistics value chain, increasing the role of railway as backbone for freight transportation. Systemic digitalization with the development of automation of operations improves performance and capacity. The European partnership on rail research and innovation - Europe's rail, has defined five priorities where digitalization plays an important role [RD33] . These priorities include digital and automated train operations, the development of a competitive digital green rail freight, and the development of sustainable and digital assets. These innovations are expected to transform the rail sector by providing truly customer-centric services, where mobility solutions fulfil passenger and logistic expectations, reducing costs and improving performance, and creating immediate customer satisfaction [RD33].

The rail industry has the potential to play a significant role in reducing the energy use and environmental impacts associated with transport. Rail is among the most energy-efficient modes of transport for freight and passengers, and it uses 80% less energy than road freight per ton of freight carried [RD18]. However, to fully realize this potential, the rail industry must continue to innovate and embrace digitalization. By doing so, it can increase its share of passengers and freight and help achieve net-zero goals.

- Rail sector recovering from COVID-19 impact and is expected to grow

The rail industry is recovering from the COVID-19 pandemic and has the potential to not only regain pre-COVID passenger numbers but also expand its market share. This aligns with the growing demand for sustainability, as rail travel offers a more environmentally friendly alternative to cars and planes. As new mobility options emerge, car usage for short to medium distances is projected to decrease by 20 to 70 percent over the next decade, creating an opportunity for rail to capture a larger share. Additionally, various regions are actively modernizing rail infrastructure and prioritizing decarbonization efforts. Notably, the European Green Deal aims to invest approximately €87.5 billion in rail-related infrastructure upgrades, including the use of GNSS-based technologies. The introduction of these technologies in signalling applications is growing in Europe and will be a change in future markets.

GNSS Market Evolution

- An increasing number of Rail freight wagons equipped with telematics including GNSS

The use of EGNSS tracking devices is increasing in the European rail freight market, with more trains and wagons being equipped with these devices. This is part of a strategy to shift freight from road to rail by enhancing the attractiveness of rail transportation. Fleet operators are also developing digital freight services and making wagons "smart" to offer customers a better view of their cargos. These smart wagons provide information such as temperature, pressure, estimated time of arrival, and accurate information about the transport itself. Additionally, they provide accurate information about the location of the cars, loading status, open/close condition of doors and hatches, and the health condition of bogies, braking system, and wheelsets. The use of EGNSS tracking devices and smart wagons has the potential to improve the efficiency and reliability of rail freight transportation. By providing customers with more accurate and detailed information about their cargos, rail operators can enhance the attractiveness of rail transportation and potentially shift more freight from road to rail. Additionally, the use of these devices can help reduce costs and improve safety by enabling more precise monitoring of the wagons and their contents.

The use of EGNSS tracking devices is becoming increasingly prevalent in the European rail freight market, with an estimated total number of more than 200,000 devices in the short term. These devices are now exchanging millions of messages each day, indicating that the technology has reached maturity. However, innovation in this area is ongoing, with new services being developed. For example, the 4F French coalition recently launched the MONITOR innovation project, which aims to support the development of digital freight trains. This project combines radio communication between wagons with brake and bogie monitoring sensors and automated brake testing to reduce the risks of derailments and untimely brake applications and to reduce train preparation time.

- Enhanced infrastructure monitoring now using AI for GNSS data processing

The use of satellite data in the rail industry has enabled more precise monitoring of track geometry condition and accurate location identification. This is achieved by equipping in-service trains with GNSS sensors, which allow for precise measurements [RD19]. By combining this technology with AI, rail operators can predict the emergence of defects and intervene proactively during the initial stages of deterioration. Implementing AI-driven automation in the rail system can enhance flexibility in managing varying peak travel times and mitigate operational disruptions caused by maintenance and staffing issues. This automation also enables upgrades to be carried out with minimal impact on rail services, optimizing overall efficiency and reliability. As a result, passengers benefit from an improved travel experience. Overall, the use of satellite data and AI in the rail industry has the potential to improve safety, reduce costs, and enhance the travel experience for passengers.

- Towards more cost-effective solutions for rail infrastructure monitoring with Drones, GNSS, AI

Railway infrastructure monitoring is an expensive task, and railway infrastructure managers are looking for more cost-effective solutions.

The SIA project is an example of a low-cost EGNSS solution being developed to provide a real-time monitoring system. This system provides high accuracy and high availability in the railway environment and feeds infrastructure degradation models and predictive algorithms. SIA components include several sub-systems which are monitoring several elements, including track, wheelset, pantograph and catenary, By doing so, it helps to reduce railway maintenance costs and maintenance unscheduled events. By showcasing its value to end-users, the project encourages the market uptake of EGNSS-based services to end-users.

Drones provide a cheaper alternative to traditional monitoring methods when combined with GNSS and AI as demonstrated by the RADIUS project. This enables efficient and advanced rail infrastructure monitoring, leading to improved maintenance, increased operational efficiency, and enhanced safety in the rail industry. Rail infrastructure managers such as SNCF Reseau and DB are already using drones to assist in their monitoring and maintenance activities.

The use of drones and other innovative technologies has the potential to improve the efficiency and safety of rail infrastructure monitoring. By providing more accurate and detailed information about the condition of rail infrastructure, rail operators can optimize their operations and potentially reduce costs. Additionally, the use of these technologies can help improve safety by enabling more precise monitoring of rail infrastructure and identifying potential issues before they become major problems.

EO Market Evolution

The European willingness to become the first continent to reach neutrality by 2050 drives the need for reducing the environmental footprint of infrastructures and strengthening their resilience to climate change. In this general context, the EO and GNSS EUSPA Market Report ([RD1]) and the previous Reports on User Needs and Requirements on surveying ([RD3]) have identified several key trends in the infrastructure market, which are relevant for the monitoring of railway infrastructures.

These key trends are the uptake of services based on InSAR for the identification of risks related to ground deformation, the increasing use of EO to better understand the impacts of climate change and support the design and construction of more resilient infrastructures.

In addition to the above-mentioned trends, the multiplication of commercial constellations of EO satellites and the increasing use of Artificial Intelligence are expected to have a significant impact on satellite-based applications, including in the infrastructure market. An overview of these profound evolutions is provided hereafter:

- Emergence of low-cost satellite technology that leads a multiplication of large constellations of small satellites (often referred to as “smallsats”).
- Lower launch and payload development costs that have opened the door to a commercial offer, even in domains like Synthetic Aperture Radars (SARs) which were previously limited to

institutional missions. This leads to a decrease of the price of SAR imagery as well improvements in performance.

- Increase of performance in terms of revisiting time, spatial and spectral resolution. In the domain of SAR, the revisit frequency being in the range of 1-3 hours because each constellation, has different satellites that observe a location at different times of the day rather than the more conventional dawn-dusk sun-synchronous orbit. SAR commercial constellations such as Iceye[2], Umbra[3], Capella Space[4] adopted very-high resolution (VHR) SAR sensors that provide a ground plane resolution until of 25 cm. The trend is similar for optical imagery, where commercial operators such as WorldView-3[5] provide revisiting time of one day, a spatial resolution until 30 cm in the panchromatic band (450 - 800 nm) and a spatial resolution of 1.3 m in the multispectral Visible Near Infrared (VNIR) band (860 to 1040 nm). Other operators such as Planet, Satellogic[6] are deploying constellations on the Low Earth Orbit (LEO) aiming to offer sub-meter resolution optical imagery with revisit times inferior to 1 hour. Some companies[7] are envisaging to deploy EO smallsats on the Very Low Earth Orbit (VLEO).
- Development of new applications based on the increased performance of the new constellation such as the near real time monitoring and tracking of rapid ground deformationt that can happen during and after the construction of the infrastructures or the applications of change detection provided in the near real time.

The increasing use of Artificial Intelligence and Machine Learning is also part of the trends which are changing the Earth Observation market and have direct impacts on applications relevant to the infrastructure market. These technologies enable the automation of processes which are usually costly and time-consuming and bring Earth Observation applications a step forward by enabling the identification of patterns, trends or correlations which would have remained invisible and unexploited with more traditional processing techniques. They are also facilitating the fusion of data from multiple sources and the integration with the Internet-of-Things (IoT). Moreover, the use of Artificial Intelligence[8] and Machine learning will increase the service providers' ability to deliver solutions for even for non-technical users.

The benefits and the interests of the use of EO in the infrastructures sector is shown by the growing volume of the market. When looking at the use of EO for monitoring infrastructure in general, the total revenue generated by the sales of EO data and EO-based services is expected to increase at a regular pace in the years to come. The chart below presents the estimations made in the EO & GNSS market report9 regarding the revenues for EO data & services at a global level. It should be noted that the values represent the general EO market for infrastructure and that EO for railway infrastructure is a subset of this. In the current version of the report it is not possible to subtract the values for railway infrastructure.

[2] https://www.iceye.com/

[3] https://umbra.space/

[4] https://www.capellaspace.com/

[5] https://worldview3.digitalglobe.com/

[6] E.g. Planet (www.planet.com) in the US or Satellogic (https://satellogic.com/) in Argentina

[7] E.g. Earth Observant Inc. (https://eoi.space/), a Californian start-up which aims to develop an optical imaging satellite constellation flying at 250 km above Earth

[8] Several providers already use Artificial Intelligence / Machine Learning as part as the solutions they offer (e.g. Overstory, Sobolt, Spacept, SpaceSense, SkyWatch, BlackSky, etc.)

[9] https://www.euspa.europa.eu/newsroom/news/new-euspa-eo-and-gnss-market-report

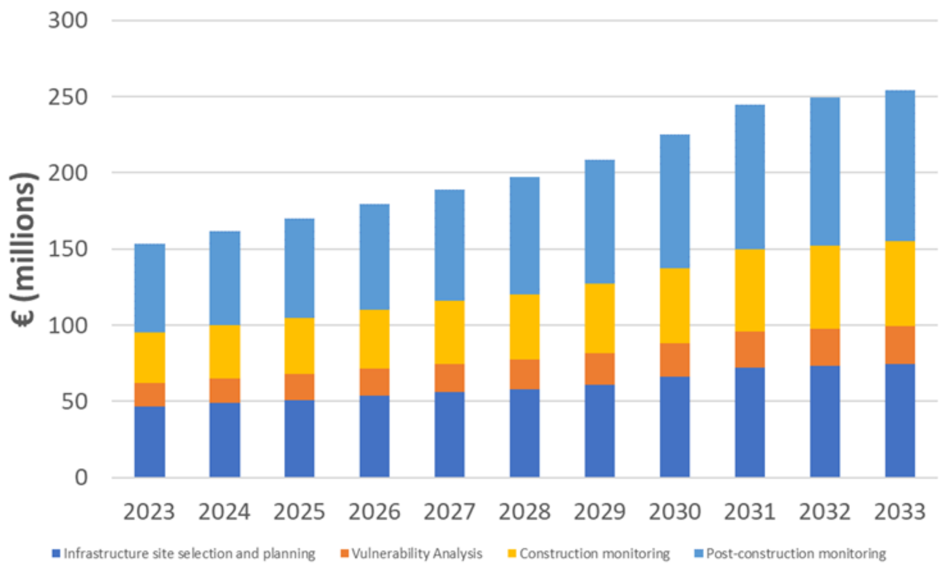

Figure 2: Revenue from EO data & services sales by application

Source: EUSPA, EO and GNSS Market Report, 2024

3.2 Main User Communities

The users' community can express very different needs. Beyond train owners, operators, industries, construction and public works companies including civil engineering companies who leverage space-enabled data to improve the safety, efficiency and comfort of the passengers and freight, there is a range of additional end users depending on the applications. Public authorities, logistics and insurance companies, research institute and universities have specific needs fulfilled by different GNSS-EO enabled applications or by their integration:

The **industry** is represented by the complex rail value chain, which, depending on the demand from train owners and operators, the train functions developed and the requirements of the associated operational scenario, develop requirements for positioning, timing and spatial information and decide on which information technologies to adopt to satisfy these. In the rail industry, train manufacturers drive a value chain involving tier 1 suppliers and component suppliers in the manufacturing of trains. The industry has set up multiple working groups to proceed jointly on specifications and requirements, in particular for safety relevant applications. Beyond the railway industry, the end user community include the companies (generally private) including civil engineering companies involved in the designing and construction of rail infrastructure.

The main user communities are listed below, which partly shape the rail users' needs and requirements.

- **Passengers (railway final users – passengers and freight)** are indirectly benefiting from satellite data in most cases. Railway passengers rely on satellite data for improving the efficiency and safety of railway transportation.
- **Train owners / operators** can use satellite data, including navigation and earth observation, for a variety of purposes, including monitoring and controlling moving rail cars, tracking hazardous rail freight, and improving train scheduling and maintenance practices.
- **Construction and public works companies** including civil engineering companies. They correspond to the (generally private) companies contracted by railway infrastructure owners and/or operators to design and construct the above-mentioned infrastructures. A wide range of

stakeholders are involved in infrastructure. Depending on the development stage, from planning until maintenance and even decommissioning, the roles, required expertise and responsibilities may greatly differ, and thus the usage and requirements for the use of space data.

- **Railway Undertakings and Infrastructure Managers** can use satellite data, including navigation and earth observation, for a variety of purposes, including monitoring railway infrastructure, improving maintenance practices, and enhancing safety and efficiency across the infrastructure lifecycle.
- **Public** authorities, including regulatory authorities, at local (e.g. municipalities), regional, national or European level. This includes authorities responsible for spatial planning and authorities entrusted with the verification that infrastructures comply with applicable legislation and regulations.
- **Infrastructure owners and/or operators**, referred to as "infrastructure managers" can be public or private entities.
- **International development organisations** (e.g. World Bank), when development projects involving the construction of large infrastructures such as transport networks are at stake.
- **Financial institutions** including large international development organisations are involved in the funding of railway infrastructures and are interested in the exposure to risk of the concerned infrastructures and in the progress of construction works.
- **Insurance companies** can be relevant from two standpoints. For GNSS, driving insurers offering telematics insurance schemes, for Earth Observation, insurance companies cover the risk related to issues to the railway infrastructure.
- **Standardization bodies** like ISO, ETSI and CEN/CENELEC, are active on GNSS performance criteria to better specify the positioning and timing in the standards. Moreover, ISO is active on standards for monitoring relevant for the use of Earth Observation. Since 2017, the Geoscience and Remote Sensing Society (GRSS) formed the Standards for Earth Observations (GSEO) Technical Committee to support the development and promotion of technical standards related to the generation, distribution, and utilization of interoperable data products from remote sensing systems. By 2020 five standards development projects, sponsored by the GRSS Standards Committee (GRSS/SC), had been initiated with the IEEE Standards Association (IEEE-SA).
- **Industry associations** are active in coordinating and shaping practices in the rail and infrastructure sectors. For example the UIC and CIRIA have acknowledged the potential for satellite data in their respective sector and are aiming to disseminate best practices.
- **Research institutes and universities** active in the fields of navigation and positioning for automotive industry with a particular focus on signal processing, in order to demonstrate the benefits of augmentation and multi-frequencies, in particular in urban environment, to mitigate multipath effects. Some institutes involved in legal metrology can also participate. In EO, research institutes and universities are active in the development of more sophisticated methods and techniques for the InSAR images processing, and in the development of fine analysis of InSAR multi-temporal time series. Indeed, the determination of more accurate displacements of the ground can be obtained from removal of the atmospheric contribution and the periodic variations related to Earth's rotational and environmental factors like the water cycle. Another field of research in EO, is the application of machine learning for change detection and classification.

3.3 Main Market Players

The value chains for GNSS-based applications and for EO-based applications are significantly different and are therefore addressed separately in this document. From a user-customer perspective, the main difference originates from the fact that GNSS and EO data are supporting different set of applications. Train localization, supported by GNSS data, is pertinent for applications related to signalling and logistics, while EO data is mostly relevant for applications related to the maintenance of the railway infrastructure.

3.3.1 GNSS Market Players

GNSS-based solutions first rely on component and receiver manufacturers. Most of the chips embedded in GNSS-based railway solutions today rely on COTS components most of them not specifically developed for the rail. They are integrated in rail systems by system integrators developing railway components. Some of the solutions developed for onboard systems can then be integrated by train manufacturers. These user communities also play an important role in the definition of user requirements: Component manufacturers, system integrators and train manufacturers.

As presented in the EO and GNSS EUSPA Market Report [RD1], the main market players in the GNSS value chain are:

- Components and receiver manufacturers
- System integrators: Tier 1 suppliers and train manufacturers
- Train manufactures
- Train operators that will use the service to offer better services to their clients and increase their efficiency and attractivity. Some examples: Fleet operators will offer customers a better view on their cargos such as temperature, pressure, estimate time of arrival as well as accurate information of the transport itself. Passenger information will benefit from revitalized capillary lines and regional rail services.
- Infrastructure managers to reduce costs and improve performance
- Users, beyond the railway industry, the end user community includes companies (generally private) such as civil engineering companies involved in the designing and construction infrastructures.

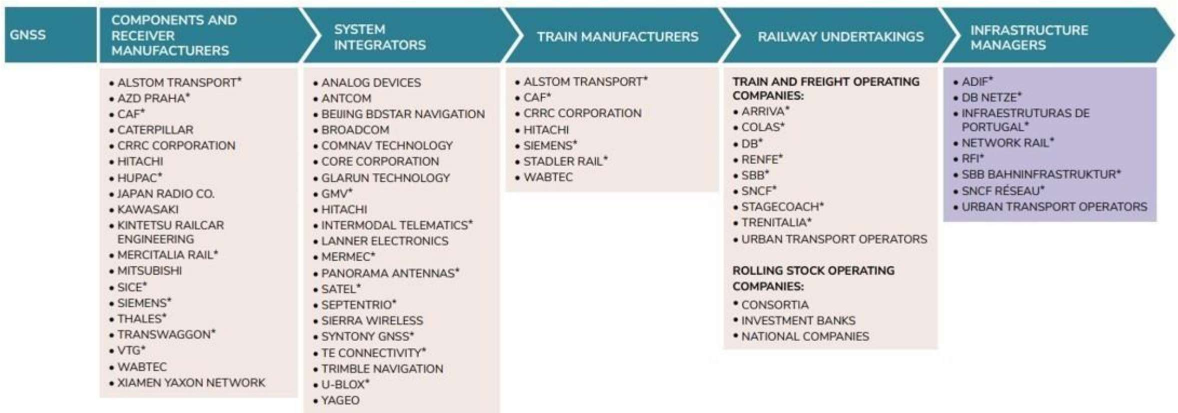

Figure 3: Rail GNSS Value Chain

Source: EUSPA Market Report, 2024

The rail industry is concentrated in Europe and North America. European GNSS companies have a market share of roughly one-third among components and receivers and the top 3 companies in the continent are Septentrio, Hexagon (Leica Geosystems) and U-blox.

The main industry stakeholders in the Rail GNSS market value chain are system integrators, component manufacturers, train manufacturers, train owners and operators as well as Railway Undertakings and infrastructure managers.

- The main component manufacturers (receivers and others) are Hitachi Rail STS, Trimble, GMV, Glarun Technology, Sierra Wireless.
- System integrators are involved whenever key operators have strong exports both to North America and Asia. The top 3 companies are VTG, Alstom and CRRC, but this category also includes: Thales, Siemens, Hitachi, .
- We can cite among train and rolling stock manufacturers: Siemens, Alstom, Hitachi, and China South Locomotive.
- Train owners and operators include train operating companies and freight operating companies, such as Deutsche Bahn, Trenitalia, SNCF, Arriva, Colas, Renfe, Stagecoach and urban transports operators. There are also rolling stock operating companies as investment banks, consortia and national companies.
- The Railway Undertakings and infrastructure managers include Deutsche Bahn, RFI, RFF, Network Rail, ADIF and urban transport operators.

3.3.2 EO Market Players

As far as the EO-related value chain is concerned, the main market players identified in the EO and GNSS EUSPA Market Report[10] are:

- **Data providers**: Providers of unprocessed or pre-processed EO data from multiple sources (i.e. satellites and in-situ (non-space) measurements). Typically operating a data-as-a-service business model.
- **Infrastructure providers**: Providers of various types of computing infrastructure upon which EO data can be accessed, stored, distributed or manipulated. Typically operating an infrastructure-as-a-service business model.
- **Platform providers**: Providers of online platforms and/or digital services, through which users can utilise tools and capabilities to analyse EO data, develop algorithms and build applications. Typically, operating platform-asa-service and/or software-as-a-service business models.
- **EO products and service providers**: Providers of products (e.g. land cover classifications) or services (e.g. ground motion monitoring) that make full use of EO data and processing capabilities offered by data and platform providers. Typically operating an analytics-as-a-service business model.
- **Information providers**: Providers of sector-specific information that incorporates EO data along with non-EO data. Typically operating an insights-as-a-service business model.
- **End Users:** Final users benefitting in their decision making or operations from the solutions offered by EO services and/or information providers.

The entities listed in the value chains of the different segments are to be considered as representative examples and non-exhaustive of the entire market.

[10] https://www.euspa.europa.eu/newsroom/news/new-euspa-eo-and-gnss-market-report

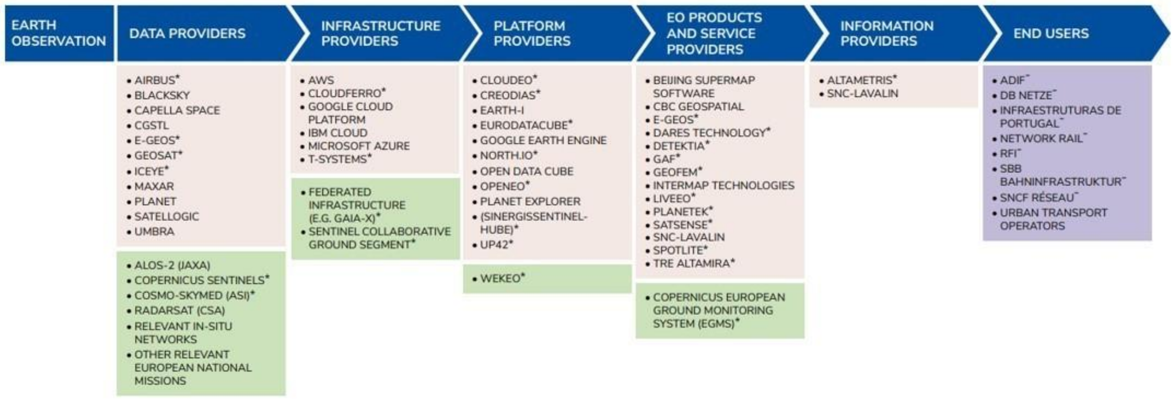

Figure 4: Rail EO Value Chain

Source: EUSPA, EO and GNSS Market Report, 2024

European companies analysing EO data account for half of the global Analysis, Insights & Decision Support market in 2019. Companies in this market make use of EO data to provide information and intelligence to their clients seeking to solve complex geospatial challenges.

The main players in the EO Rail segment value chain are:

- **Infrastructure providers**: refers to organisations offering various types of computing infrastructure and cloud storage upon which EO data can be accessed, stored, distributed or manipulated. These organizations often collaborate with space agencies, research institutions, and private companies to support EO missions and data dissemination. Some key European infrastructure providers are:
  - Cloudferro
  - T-Systems
  - Copernicus Collaborative Ground Segment
- **Data providers**: includes providers of unprocessed or pre-processed EO data. Of all the types of data that EO encompasses, one of the most relevant for the Rail sector is Interferometric Synthetic Aperture Radar (InSAR) data.
  - Sentinel-1 (Copernicus Programme, EU): Sentinel-1A and Sentinel-1B provide free and open SAR data, including InSAR data globally with archives back to 2015.
  - TerraSAR-X (German Aerospace Center, DLR) and TanDEM-X: radar satellites provide high-resolution SAR data TanDEM-X, in particular, was used in a ground-breaking mission to create a global digital elevation model (DEM) through interferometry.
  - Cosmo-SkyMed (ASI, Italy): The Cosmo-SkyMed constellation consists of four radar satellites (CSK-1, CSK-2, CSK-3, and CSK-4) that offer SAR data suitable for InSAR applications.
  - X-band constellations from ICEYE, Umbra and Capella Space
  - ALOS PALSAR L-band used for soil moisture and SAR interferometry in lightly vegetated areas
- **Platform providers**: refers to those companies that offer online platforms and/or digital services, through which users can utilise tools and capabilities to analyse EO data, develop algorithms and build applications. Some of the main platform providers include:
  - Copernicus Data Space Ecosystem

- Cloudeo
- Exolabs
- CreoDIAS

- **EO products and service providers**: these are companies that provide products or services that make full use of EO data and processing capabilities offered by data and platform providers. Some European EO products and service providers relevant to the Rail sector are:
  - Vaisala (meteorological and environmental monitoring solutions)
  - Terramonitos (satellite imagery and data analytics services)
- **Information providers**: providers of sector-specific information that incorporates EO data along with non-EO data. Due to companies continually expanding their portfolios, the distinction between 'EO Products and Service Providers' and 'Information Providers' is becoming less clear. In a broader sense, there is a growing trend of vertical integration within the EO sector, with an increasing number of companies now managing the entire value chain. Within the Rail segment, some relevant EO information providers are:
  - Copernicus Program
  - DEIMOS Imaging
  - Airbus Defence and Space
- **End Users**: the final users who benefit from the applications and services offered by information providers.

The community is mainly divided in regional, local authorities and state in charge of the deployment of transport infrastructures and the private sector in charge of deploying and maintaining these civil works [RD17].

4 POLICY, REGULATION AND STANDARDS

4.1 Applicable regulations

In addition to the rules described in legal texts (i.e., directives, decisions, regulations), the design and operating conditions of railway systems in Europe are today subject to a normative framework that requires the demonstration of the system's safety. This framework is composed of specific European standards derived from the generic functional safety standard IEC 61508: 2011 [RD5].

The railway sector is distinguished by the existence of three safety standards (EN 50126: 2017, EN 50128: 2011, and EN 50129: 2018]). Each of them addresses a particular safety aspect and can be applied depending on the considered subsystem.

- The EN 50126 standard describes a systematic RAMS management process (starting from the design phase until the system decommissioning) in order to specify and demonstrate reliability, availability, maintainability, and safety. Part 1 of this standard focuses on the generic RAMS process, while part 2 addresses the systems approach to safety.
- The EN 50128 standard specifies the process requirements and techniques applicable to the development of software for programmable electronic systems used in railway Control-Command and protection applications.
- The EN 50129 standard addresses safety-related electronic systems (including subsystems and equipment) for railway signalling applications.

Finally, the EU's rail transport policy is geared towards the creation of a single European railway area. The policy includes the harmonization of technical, administrative, and safety rules, which is essential for interoperability between national rail systems.

4.1.1 Critical Infrastructure protection policy

There is no regulatory authority dedicated to infrastructures in general but in the European Union, the European Commission plays an increasingly important transversal role with respect to Critical Infrastructure protection (see following section).

4.1.2 Telecommunications Regulations

In the specific case of telecommunications, the Body of European Regulators of Electronic Communications (BEREC) is the regulating agency of the telecommunication market in the European Union. Besides, each Member State has set up its own National Regulatory Authorities (NRA) in charge of regulating telecommunications. However, neither BEREC nor the NRAs are directly involved in the definition of the Timing & Synchronization architecture. Finally, spectrum regulation agencies (ITU-R world agreement, national agencies for enforcement) and telecom network regulation agencies (CCITT/ITU-T, national agencies for enforcement) are also involved in particular through their participation in Standardization forums (see [RD4]).

4.1.3 Space Policy and Regulations

The Regulation (EU) 2021/696 of 28 April 2021 "*establishing the Union Space Programme and the European Union Agency for the Space Programme*" (EUSPA) ([RD5]) is the main Space policy document for the European Union. Although the regulation highlights the role that Copernicus should play in supporting the Union's capacity to achieve independent decision-making and actions in a certain number of fields, among which infrastructure monitoring, it does no impose any regulatory obligations with regard to the use of space-based systems for infrastructure management.

Except for "critical infrastructures", there is in general no EU policy or regulatory document which directly addresses the infrastructure market. There are however a number of policy or regulatory documents which may have an indirect impact on the infrastructure market. An overview of these documents is provided in the Annex.

4.1.4 European Rail User Requirements Specification – ERTMS/ ETCS RAM

Further specifications on ERTMS are provided by UNISIG on the design, certification and application of ERTMS equipment. Those considered to be more related to GNSS applications are commented in this section.

Railway requirement criteria are usually qualified in terms of reliability, availability, maintainability and safety (RAMS). They differ from the GNSS quality criteria. Railway definitions according to the EN 50126 standard are:

- Reliability: the probability that an item can perform a required function under given conditions for a given time interval.
- Availability: the ability of a product to be in state to perform a required function under given conditions at a given instant in time or over a given time interval assuming that the required external resources are provided.
- Maintainability: the probability that a given maintenance action, for an item under given conditions of use can be carried out within a stated time interval when the maintenance is performed under stated conditions and using stated procedures and resources. It means the ability of a system being maintained or restored after a failure to operational status over a given time interval assuming that the maintenance is made under given conditions with prescribed procedures and means.
- Safety integrity: the probability of a system satisfactory performing the required safety functions under all stated conditions within a stated period of time.

PERFORMANCE REQUIREMENTS

This section contains an analysis of the required technical performances of ERTMS/ETCS equipment that could include a GNSS component inside.

Accuracy

- Position accuracy measured on-board: For every travelled distance s the accuracy shall be better or equal to ± (5m + 5% s). The fixed ± 5m tolerance is intended to cover the longitudinal uncertainty of the balise reader in detecting the balise reference location. Also, in case of malfunctioning, the on-board equipment shall evaluate a safe confidence interval.

- Accuracy of speed known on-board: ± 2km/h for speeds lower than 30km/h, then increasing linearly up to ± 12km/h at 500km/h.
- Age of location measurement for position report to trackside: The location of the train head indicated in a position report shall be estimated less than 1 sec before the beginning of sending of the corresponding position report.

Clock

- Safe clock drift: 0.1 %. This value is not only a performance but also a safety related requirement as it refers to clock information used for time-stamping of messages and for supervision of time-outs, the magnitude of which is a few minutes.

For more information about performance requirements, please refer to [RD7].

Performance Requirements for Interoperability define possible values for technical performance requirements of ERTMS on-board equipment.

Reliability requirements consist of quantitative requirements in terms of Mean Time Between Failures (MTBF); and differentiates in reason of the criticality (Immobilizing, Service or Minor) of such failures. They are also called ERTMS RAM (for Reliability, Availability and Maintenance) requirements and are stated as follows (these are all defined for on-board equipment).

- The MTB Immobilizing hardware Failures shall be not less than 2,7x106 hours.
- The MTB Service hardware Failures MTBF-SONB shall be not less than 3,0x105 hours.
- The MTB Minor hardware Failures MTBF-MONB shall be not less than 8,0x103 hours.

Availability must be not less than 99.973%, in order to assure compatibility with the ERTMS availability.

Maintainability is also standardized by European Standards. Apart being designed in order to minimize periodical maintenance and to control hazard levels, the equipment installation must not interfere with the access to other systems and devices on-board the train. The system supplier must specify the needed and forbidden maintenance procedures, it must also present auto test systems to verify periodically the correct operation and include a “maintenance mode” for the maintenance operation, including interfaces maintenance.

SAFETY REQUIREMENTS

According to [RD9], the Railway Safety philosophy is based on three main principles:

- Avoidance, and as far as possible exclusion, the transformation of the inherent human non-intended errors into wrong-side failures (= failures, technical or human, susceptible to develop into hazards, to produce harm). Prevention of imaginable non-intended failures of the human operator to become wrong-side failures => the railway system is not designed to protect against intended wrong-side human failures.
- The controlled reliability, mainly applicable to the vital components.
- Detection and identification of any possible random critical technical failure (= any technical non functionality which has the potential to produce a non-safe response) and immediate enforcement of a safe state.

The railway safety standards (EN 50126…EN 50129) clearly prescribe the methodology to be followed over the whole life cycle of a sub-system or component to assure that its safety integrity risk is controlled and maintained under the prescribed level.

The classification of the safety integrity is prescribed on 5 levels (from EN 50129):

Safety Integrity	On Demand Mode (Low demand mode)		Continuous Mode (High demand mode)	Consequence of a failure
Level	Availability	Probability of failure on Demand (failure/demand)	Tolerable Hazard Rate per hour and function	
SIL4	> 99.99%	$\geq 10^{-5}$ to $<10^{-4}$	$\geq 10^{-9}$ to $<10^{-8}$	Several possible dead people in surrounding community
SIL3	99.99%	$\geq 10^{-4}$ to $<10^{-3}$	$\geq 10^{-8}$ to $<10^{-7}$	Several possible dead people
SIL2	99% -99.99%	$\geq 10^{-3}$ to $<10^{-2}$	$\geq 10^{-7}$ to $<10^{-6}$	Possible serious wounded people or one dead person
SIL1	90% -99%	$\geq 10^{-2}$ to $<10^{-1}$	$\geq 10^{-6}$ to $<10^{-5}$	Possible minor wounds
SIL0		No requirement		N/A

Figure 5: Safety integrity classification (EN 50129)

This table indicates the probability of failure, the safety integrity risk allocated to each of the levels (the figures represent probabilities expressed in events/hour).

The classification of SIL makes a distinction between the continuous (high demand) mode of operation and the operation on demand. This distinction considers that the operation on demand shall be preceded by an initial check of the element's fail-less state. In this study we will be interested exclusively in the continuous mode.

Note:

- The "on demand mode" is reserved for systems used in intermittent/sporadic way.
- The "continuous mode" concerns systems permanently used for a period of time.

In the framework of the generic high-level quantitative safety requirements for ETCS operating either in Level 1 or Level 2, requirements are presented here to illustrate the magnitude order of Tolerable Hazard Rates of the transmission systems. This information is important if we consider that, to replace balises by virtual balises, the GNSS-based equipment must provide a performance as good as the existing equipment.

A dangerous failure is an undetected failure of the positioning system leading to the position provided being out of the accuracy range.

The safety integrity level will be derived from the different tolerable hazard rates, taking into consideration the specified environment. For Hazard Rates of < 10-9 failures/hour, a SIL 4 process will be applicable. It is important to notice only failures that cause the ETCS hazard need to be considered.

Considering ETCS onboard equipment without the transmission system, the hazard rate for the ETCS onboard system excluding those parts forming part of the transmission paths shall be shown not to exceed a THR of 0.67x10-9 dangerous failures/hour. The process of confirmation that the train data is correctly stored on-board must be of a quality commensurate with a SIL 4 system.

For more information about safety requirements, please refer to [RD6].

4.2 Non-regulatory sources

The Green Deal is a set of initiatives proposed by the European Commission to make the European Union climate-neutral by 2050. The rail industry is expected to play a significant role in achieving this goal. Here are some relevant initiatives under the Green Deal that will impact the rail industry:

- Improving rail infrastructure management: The European Commission is proposing measures to make freight transport more efficient and sustainable by improving rail infrastructure management, optimizing the use of rail tracks, improving cross-border coordination, increasing punctuality and reliability, and ultimately attracting more freight companies to rail

- Supporting the expansion of zero-emission power sources: The Federal Railroad Administration (FRA) is committed to reducing rail's carbon footprint by supporting the expansion of zero-emission power sources, such as electric locomotives
- Reducing GHG emissions from rail operations, maintenance, and construction: The FRA is committed to reducing GHG emissions from the operations, maintenance, and construction of the rail system
- Decarbonizing rail operations: Railway companies are pursuing sustainability agendas, particularly surrounding decarbonizing operations
- Increasing efficiency within the sector: The European Commission aims to increase efficiency within the sector, helping it to contribute to the target of cutting transport emissions by 90% by 2050, as set out in the European Green Deal
- Enhancing railway security: Satellite data can be used to enhance railway security, improving safety and efficiency across the infrastructure lifecycle

4.3 Other (standards, practices…)

Within the European Union, the following organisations are involved in the roll-out of standards, rules and practices:

- Product related standards are developed and published by the UIC on behalf of stakeholders that are constituents of the railway operating Community (ROC) in Europe, and also represented in UIC European regional Assembly
- UNIFE has been representing the European rail manufacturing industry since 1992. UNIFE and its members work on setting standards for the rail industry, including standards for rail vehicles, rail infrastructure, and rail operations.
- Europe's rail (ERJU), the European Committee for Standardization (CEN), and the European Committee for Electrotechnical Standardization (CENELEC) are the leading organisation providing standards and practices for the EU Rail sector. In 2021, ERJU, CEN and CENELEC have signed a Memorandum of Understanding (MoU) to accelerate European rail standardization work. The aim is to accelerate European rail standardization work and formalize the existing collaboration between the three organizations. The agreement is expected to foster innovation in the railway sector and maintain the EU's position as a world leader.

It is also worth noting that the International Organization for Standardization (ISO) is also the leading international organization focused on worldwide standards across practically every industry. It produces standards for the rail industry, including standards for rail vehicles, rail infrastructure, and rail operations.

The following list gathers a non-exhaustive list of relevant standardization bodies working groups, and related standards and initiatives in the field of GNSS positioning that influence implementation of GNSS and required performance, in particular for safety-critical applications.

4.3.1 Relevant Standards for GNSS

ETSI TC SES/SCN

TS 103 246-1 to TS 103 246-5: Satellite Earth Stations and Systems, GNSS based location systems. Setting out functional requirements, reference architecture, performance requirements, requirements for location data exchange protocols, and performance test specifications.

ISO

ISO TC204: The ISO's Technical Committee 204 is developing a new project titled "TS 21176 – Intelligent Transport Systems – Cooperative ITS – Position, Velocity and Time functionality in the ITS station". This is a collaboration between ISOTC204/WG18 (cooperative systems) and CEN TC5WG1.

ISO 5725 Accuracy of Measurements: On the accuracy (trueness and precision) of measurements methods and results, to establish practical estimations of the various measurements.

ISO/TC20/SC14 – WG8: *Downstream space services and space-based applications*: a dedicated WG established to cover downstream standards.

Other relevant working groups

IAG – WG 4.1.4.: The International Association of Geodesy has a commission (4) focussing on positioning and applications. Within this commission, WG 4.1.4. (Robust Positioning for Urban Traffic) is concerned with the specification and characterization of GNSS requirements, and performance analysis for vehicles and pedestrians in urban areas.

TISA: The Traveller Information Services Association (TISA) follows the development of the TPEG protocol family, covering the broadcast of traffic and transport information to end users. Recently, TISA has developed the TPEG2 Emergency Alerts and Warnings (EAW) technology, supporting the distribution of official Emergency Alerts and Warnings as issued by public authorities and/or authorized agencies, without language barriers.

OADF: The Open Auto Drive Forum is an initiative to harmonize the activities from NDS, TISA, ADASIS and SENSORIS created in 015. The overarching objective is to generate an ecosystem of production-ready automotive standards including navigation and positioning.

Cloud LSVA (Large Scale Video Analysis) project – Open Group: This project focusses on navigation data and maps and supports the development of suitable standards for video data sets and video annotation. It aims to develop a standard on video content annotation to be published by an existing appropriate SDO.

4.3.2 Relevant Standards for EO

Techniques for observing the Earth are frequently criticized due to inconsistencies in various areas such as sensor calibration, data structure and formats, precision in terms, and pricing systems. This has led to slow adoption rates and challenges in ensuring the correct interpretation of these techniques. This sluggishness may be attributed to apparent inconsistencies and bewildering jargon. The implementation of international standards can provide effective solutions to these issues, and these guidelines are intended to enhance the accessibility of Earth Observation products and technologies.

At present, there is a noticeable lack of standards or regulatory documents in Earth Observation, regarding both data quality and processing or products. The internationally accepted data format and metadata standards for digital spatial data have been set by organizations such as ISO, IEEE, OGC, GRSS, and SEOAH. Appropriate Earth Observation standards for railway infrastructure can be categorized into various classes:

- **EO data standards:**
  - The International Organization for Standardization (ISO); EO collection metadata: ISO 19115 Geographic Information - Metadata.
  - The Open Geospatial Consortium (OGC) provides Standards and Schemas (XSD, JSON Schema, etc) for the geospatial information interoperability and implementation used by international organizations.

- EO product metadata: OGC's GML Application Schema for EO Products
- Collection and service discovery: OGC's Cataloguing of ISO Metadata using the ebRIM profile of CS-W.
- Catalogue Service: OGC's Catalogue Services Specification 2.0 Extension Package for ebRIM Application Profile: EO Products.
- Order: OGC's Ordering Services for EO Products
- Feasibility Analysis: OGC's Sensor Planning Service Application Profile for EO Sensors
- Online Data Access: OGC's WMS EO Extension
- Identity (User) Management: OGC's User Management Interfaces for EO Services.
- Geoscience and Remote Sensing Society (GRSS) created the Standards in Earth Observations (GSEO) Technical Committee to support the development and promotion of technical standards related to the generation, distribution, and utilization of interoperable data products from remote sensing systems.
- The Standards in Earth Observations Ad Hoc Committee (SEOAH) is the managing organizational unit within GRSS to handle standards development within the IEEE.

- **Standards for Geotechnical investigation:**

The Geotechnical Monitoring by Field Instrumentation Panel (ISO TC 182/WG2) is currently working on a new draft document that includes several annexes for new technologies, one of them being satellite InSAR. While this is an important step, given the increasing use of EO technologies, there is a general consensus throughout the industry that a unified set of EO international standards is required.

The Geotechnical investigation and testing – Geotechnical monitoring by field instrumentation, (ISO18674), establishes a set of methodologies for measuring pore water pressures and piezometric levels in saturated ground through the use of piezometers as part of geotechnical monitoring. These general monitoring rules are applicable to different geological scenarios, including ground levels, structures interacting with the ground, geotechnical fills, and geotechnical works as specified in ISO 18674-1. The guidelines are versatile, finding relevance in various scenarios including monitoring water pressures in and around geotechnical structures like dikes, excavation walls, foundations, dams, tunnels, and slopes.

4.3.3 Relevant Organisations

International regulators

Access to the railway infrastructure is granted only to railway undertakings that hold a valid single safety certificate. The single safety certificate gives evidence that the railway undertaking has established its safety management system and is able to comply with its legal obligations. The main policy and regulatory European stakeholders involved in the user requirement definition process are the **ERA, CER, EIM, EUG and UNIFE.**

European Commission

The European Commission, due to the high interest on transport and mobility,strongly focuses on the rail sector. Railways related policies and initiatives look towards addressing several aspects of transportation within the Union. The overall goal is to ensure safe, sustainable and efficient transportation.

Due to the overarching nature of this sector, policies, regulations and other initiatives are developed and implemented through several Directorates-General within the Commission.

Some key aspects relevant to the rail segment in which the European Commission intervenes are, on a general basis the development of a transport policy, train approval and certification processes, Intelligent Transport Systems technologies (ITS) and sustainable mobility through EVs. More particularly, the Commission also focuses on enhancing the industry's competitiveness through innovation, research and development. Regarding this, it is worth highlighting the development and deployment of digital infrastructure, including high-speed broadband networks and 5G communication systems. These technologies are essential for enabling the connectivity required for connected and automated vehicles to communicate with each other and with infrastructure.

European Parliament

The European Parliament's work in the railway segment encompasses legislative oversight, railway safety initiatives, emission standards, trains regulation, infrastructure development, sustainability and budget allocation. MEPs involved in these topics contribute to shaping European policies and actions with the aim of creating safer, more environmentally friendly and efficient transportation systems within the European Union.

Access to the railway infrastructure is granted only to railway undertakings that hold a valid single safety certificate. The single safety certificate gives evidence that the railway undertaking has established its safety management system and is able to comply with its legal obligations. The main policy and regulatory European stakeholders involved in the user requirement definition process are the **ERA, CER, EIM, EUG and UNIFE.**

European Railway Agency

The European Railway Agency was set up to help create an integrated railway area within the EU, by reinforcing safety and interoperability. ERA is responsible for managing common European railway rules and specifications through different legal texts composed of directives, decisions and regulations.

The Agency also acts as the system authority for the European Rail Traffic Management System (ERTMS), which has been set up to create a unique signalling environment throughout Europe. Since 2020 the European Union Agency for Railways (ERA) has become the EU's sole authority for the certification and authorisation of rolling stock for vehicle authorisation, safety certification, and ERTMS trackside approval, replacing the EU's previous national certification agencies.

The **Community of European Railway** and Infrastructure Companies (CER) brings together close to 70 railway undertakings, their national associations as well as infrastructure managers and vehicle leasing companies. CER's role is to represent the interests of its members on the EU policy-making scene, in particular to support an improved business and regulatory environment for European railway operators and railway infrastructure companies.

European Rail Infrastructure Managers (EIM) is a sector association that represents the interests of European rail infrastructure managers. It represents the common interests of the railway infrastructure managers at European level.

ERTMS Users Group (EUG) members are railway companies with large investments in ERTMS. The ERTMS Users Group offers a platform for railways peers to share experiences and to consolidate their views and focuses its activities on ETCS and the ETCS related part of the radio-based communication system. They work with ERA, UNISIG and advise the previously mentioned CER or EIM. A specific working group is devoted to localisation.

European Rail Industry Association (UNIFE) represents European train manufacturers and rail suppliers, SMEs and major industries, from rolling stock manufacturers and infrastructure suppliers to system integrators and engineering companies. Under the umbrella of UNIFE, UNISIG (Union industry of signalling) actively contributes to the activities of the European Union Agency for Railways in the field of

ERTMS/ETCS technical specifications. UNISIG is composed of nine UNIFE Member companies: Alstom ,Hitachi, AŽD, CAF, Siemens Mobility, GTS Deutschland and MerMEc.

UNISIG is involved in the definition of user requirements for safety relevant applications, and in particular for ERTMS user requirements. The application for certificate is made to the safety certification body. The process is the same no matter if the European Railway Agency (ERA) or a National Safety Authority (NSA) is the safety certification body (single European process). In the case of rail operations in more than one Member State, ERA will be the safety certification body. Otherwise, the applicant can choose whether to apply to ERA or to the relevant NSA [RD8].

Four parties are thus involved when assessing the safety of a system [RD16]:

- the proposer of the new system,
- (one or several) independent assessment body (ISA – Independent Safety Assessor),
- a rail notified body (NoBo),
- a National Railway Safety Authority (NSA).

The aim of an ISA is to audit, assess and review processes and safety evidence generated along the life cycle of a project, to ensure and demonstrate compliance to safety standards and suitable techniques and to assess the adequacy of the evidence. Notified bodies by the different member states to the EU Commission are third parties, independent of organization or product. They assess and perform conformity assessment pursuant to the European texts and give certificate of conformity. The NSA gives the final authorization to use the product in operation.

5 USER REQUIREMENTS ANALYSIS

This chapter provides analysis of user needs and requirements pertaining to *Rail segment* applications introduced before, describing the different roles and needs covered by GNSS and EO and, ultimately, identifying the corresponding requirements from a user perspective.

Table 1 below depicts the main applications making use of GNSS and/or EO technologies in *Rail segment.* The list of applications is non-exhaustive and is expected to potentially grow and adapt according to the expected adoption of space technologies in the coming years and the innovations that should come with it. The current report being the first version of the Rail segment Needs and Requirements relevant to EO in addition to GNSS, it is a living and evolving document that will periodically be updated and expanded by EUSPA in its next releases.

While each one of the applications addressed in this document can benefit from GNSS and/or EO, the current issue the RUR does not cover in detail the needs and requirements of all applications. A categorisation was performed prioritising some applications based on their maturity level and relevance to the market trends and drivers. Other applications are foreseen to be covered in more detail in future versions of this RUR.

The following applications categorisation reflects the depth of information available in section 5:

Application Type A: these applications correspond to those for which an in-depth investigation is presented and for which needs and requirements relevant to GNSS and/or EO have been identified and validated with *Rail segment* user community at the UCP.

Application Type B: these applications correspond to those not selected for in-depth investigation in the current version of the RUR, for which a partial specification of needs and requirements is provided, limited at this stage to the ones relevant to GNSS.

Application Type C: these applications correspond to GNSS-based applications, not selected for in-depth investigation in the current version of the document. A high-level description of the application is included considering that they will be further analysed and developed in next versions of the RURs.

The table below maps the Rail segment-related applications to the three above-mentioned types. **The following list of applications and their categorisation are expected to evolve in the next versions of the document.**

Legend (signs included when applicable for rail)
EO only application
GNSS only application - ; ;
Hybrid/synergetic application (combined use of EO and GNSS)

Sub-segments	Applications	Types of Application/ Level of Investigation	
MAINTENANCE IMPROVEMENT	Condition-based maintenance	A	
	Infrastructure monitoring	A	
	Predictive maintenance	A	
	Passenger information systems	A	

Sub-segments	Applications	Types of Application/ Level of Investigation	
ATTRACTIVENESS ENHANCEMENT	Public Transport – Tram and Light Rail	C	
SAFETY RELATED	Enhanced Command & Control Systems (CCS)	A	
	Trackside personnel protection systems	A	
	Hazardous cargo monitoring	B	
	Door Control supervision	B	
TRAIN DRIVING OPTIMISATION	Rail fleet management	A	
	Driver Advisory Systems (DAS)	A	

Table 1 Applications and level of investigation

Note 1: Fleet management, Condition-based maintenance and Predictive maintenance are non-safety related applications relying on the position of fixed and moving elements of the railway environment (from the infrastructure to the track-side equipment, and also rolling stock, wagons…). On the charts, these applications are grouped under the name "Asset management".

Note 2: "Infrastructure monitoring" includes the more mature EO applications - monitoring of trackside vegetation, landslide and track deformation.

The next section 5.1 addresses first "type A" applications, then "type B" applications and finally "type C" applications, for which the level of provided information is currently the less developed.]

Each EO-based "Type A" application will cover the needs and requirements for potentially several operational scenarios. For each scenario, a table summarises the EO related needs and requirements. The table template is illustrated below in Table 2 and explains the various inputs.

ID	Identifier
Application	Application covered.
Users	Common users of the product/service.
User Needs	
Operational scenario	**Describes the operational scenario faced by the user, which requires a solution.**
Size of area of interest	Describes the area of interest (e.g. a rail infrastructure manager is interested to monitor the status of a 150m bridge).
Scale	Describes the scale of interest (e.g. a rail infrastructure manager is interested to see at mm level the ground subsidence for the bridge piers).
Frequency of information	How often the user requires the information.
Other (if applicable)	Other user needs such as contextual information (weather data) or file formatting requirements.
Service Provider Offer	
What the service does	Description of the service that satisfies the user's needs.

How does the service work	(Technical) description of how the service works.
Service Provider Satellite EO Requirements	
Spatial resolution	Spatial resolution of the satellite imagery/data required by the service provider to realise the service.
Temporal resolution	Frequency of satellite data (revisit time) over the area of interest.
Data type / Spectral range	Type of data (e.g. RGB, SAR) and spectral range (if relevant).
Other (if applicable)	Other data requirements.
Service Inputs	
Satellite data sources	Type of required data and examples of operational satellites that can provide these data.
Other data sources	Other sources of data that the service provider uses to realise the service.

Table 2: Description of needs and requirements relevant to EO table[11]

5.1 Current GNSS use and requirements per application

5.1.1 Condition-based maintenance and predictive maintenance

Condition Based Maintenance is a maintenance strategy to monitor the real-time condition of tracks and trains. These results are large data sets that give away key information to support decision-making and enable efficiency gains. If GNSS is not the main information to be collected, localization of the data is of main importance. The goal is to reduce maintenance costs significantly compared to today's corrective maintenance schemes.

[11] See key EO performance parameters (detailed) definition in annex A.1.2.

GNSS user requirements for Condition-based maintenance		
Accuracy	Horizontal	10-20 m-level longitudinal
	Vertical	Non-applicable
Availability	Urban canyon	Yes
	Natural canyon	Yes
	Canopy	Yes
	Indoor	Yes
	Better than 95%	High
	Better than 99%	Medium
Robustness		Low
Integrity and reliability		Low
Size, weight, autonomy (when smartphone or handheld based)	Relevance	Yes
	Time a device can run	The device needs to run for long period but does not need to run full continuous time
TTFaF	In hot start	depending on the mode used for energy saving, hot start may be needed (if periods of short power on, long power off...)
Service area	Geographical coverage	Over the whole railway network
Update Rate		–From 1-30 min
TTA	Time between the occurrence of the failure and its presentation to the user	30s

5.1.2 Trackside personnel protection systems

The maintenance and upgrade of the infrastructure is a major activity involving movements of personnel, equipment and materials. Personnel working on or close to the track must be protected from trains using the network. Speed restrictions may apply, or the train may be prevented from entering the work zone completely. Alternatively, personnel working must be warned when a train is approaching the working area. Main applications related to protection and emergency management are described in this section.

GNSS applied to trackside personnel protection will improve current manual or semiautomatic procedures. This application can monitor the location of the working team, the assets (rail construction machinery, etc.) and the trains. The system, knowing the position of the elements, could issue warnings to the trains for slowing speed or event stop, and orders to the working equipment and teams to abandon working areas when trains are approaching.

GNSS user requirements for trackside personnel protection		
Accuracy	Horizontal	1 to 10 m-level The PNT shall provide a small relative accuracy
	Vertical	Non-applicable
Availability	Urban canyon	Yes
	Natural canyon	Yes
	Canopy	Yes
	Indoor	Yes
	Better than 95%	High
	Better than 99%	High
Robustness		Low
Integrity and reliability		High
Size, weight, autonomy (when smartphone or handheld based)	Relevance	Yes
	Time a device can run	8-10h (daily service of a worker)
TTFaF	In hot start	Some minutes
Service area	Geographical coverage	available over the whole EU Rail network
Update rate		5 - 10s
TTA	Time between the occurrence of the failure and its presentation to the user	10 - 30s
SIL	For ATO application	SIL2 corresponding to a failure rate of 10^{-7}/hr

5.1.3 Rail fleet management

The tracking of assets (rolling stock, wagons) is crucial to achieve an optimised use of the fleet. Fleet operators develop digital freight services and make wagons smart, that offer customers a better view on their cargos such as temperature, pressure, estimate time of arrival as well as accurate information of the transport itself: location of the cars, loading status, open/close condition of doors and hatches and health condition of bogies, braking system and wheelsets.

The technology has reached maturity with an increasing number of trains and wagons equipped but innovation is up and running for even more services.

GNSS user requirements for fleet management		
Accuracy	Horizontal	10 to 20 m-level longitudinal after track identification
	Vertical	Non-applicable
Availability	Urban canyon	Yes
	Natural canyon	Yes
	Canopy	Yes

	Indoor	Yes
	Better than 95%	High
	Better than 99%	High
Robustness		Low
Integrity and reliability		Low
Size, weight, autonomy (when smartphone or handheld based)	Relevance	Yes
	Time a device can run	Long term
TTFaF	In hot start	depending on the mode used for energy saving, hot start may be needed (if periods of short power on, long power off…)
Service area	Geographical coverage	Over the whole EU rail network
Update Rate		60s or more
TTA	Time between the occurrence of the failure and its presentation to the user	30s

5.1.4 Passenger information systems

Different applications can be included in the application bundle “Passengers information”:

- On-train ticketing, retail & authentication
- On-train reservations
- On-train catering and services
- Train Crew information services
- Customer Information Systems
- On-board Passenger Information systems
- Personal Journey Assistant
- Location Based Services & Points of Interest
- Passenger Broadband (Internet Access Caching)

GNSS user requirements for Passenger information		
Accuracy	Horizontal	100 m-level
	Vertical	Non-applicable
Availability	Urban canyon	Yes, 95%
	Natural canyon	Yes, 95%
	Canopy	Yes, 95%
	Indoor	Yes, 95%
	Better than 95%	High
	Better than 99%	Medium

Robustness		Low
Integrity and reliability		Low
Size, weight, autonomy (when smartphone or handheld based)	Relevance	Yes when relying on tablets
	Time a device can run	1 day if tablet is used to collect positions
TTFaF	In hot start	Less than 10s
Service area	Geographical coverage	Over the whole EU network
Update rate		1s

5.1.5 Enhanced Command & Control Systems (CCS)

Control, command and signalling' (CCS) refers to the on-board and trackside structures and equipment designed to ensure the safe operation and movement of trains, directing rail traffic, and keeping trains clear of each other. It includes lineside signals, but also a whole range of technology designed to control and manage the way train movements are managed. Control, command and signalling are at the core of railway operations – they essentially determine safety and performance of a network.

Automatic Train Protection aims to prevent a train proceeding beyond the point of danger and to prevent the speed of the train exceeding the permissible limit in the event of a driver error. It consists of the safe determination of position, speed and direction of train movement in order to supervise the safe movement of the train up to its stopping point (End of Movement Authority).

In Europe, the ERTMS, which stands for 'European Railway Traffic Management System', is the European standard for the Automatic Train Protection (ATP) and command and control systems. It is a single European signalling and speed control system that ensures interoperability of the national railway systems, reducing the purchasing and maintenance costs of the signalling systems as well as increasing the speed of trains, the capacity of infrastructure and the level of safety in rail transport. ERTMS comprises of the European Train Control System (ETCS), i.e. a cab-signalling system that incorporates automatic train protection (ATO), the Global System for Mobile communications for Railways (GSM-R) and operating rules.

Since 2012, EUSPA provides strong support to railway industry, infrastructure managers and railway operators to adopt EGNSS and EGNOS for the complex signalling applications and integrate GNSS within the evolution of European Rail Traffic Management System (ERTMS).

This application requires the combination of several functions (or lower-level applications) which in turn are strongly dependent of the accurate and safe determination of position and speed of the trains:

- Calculation of End of Movement Authority
- Calculation the emergency braking curve to get to the EOA
- Train Location / Train Position Report
- Speed profile calculation
- Train spacing
- Supervision to buffer stops (in particular Calculation on board the release speed for the approach to buffer stop)

There are many ATP applications where GNSS could be used, among them: Enhanced Odometry, Absolute Positioning, Cold Movement Detection, Train integrity and train length monitoring, Track Identification, Odometer Calibration, and Level Crossing Protection.

The use of GNSS for the following applications are still under definition. As the requirements for GNSS will strongly depend on the way it will be integrated in the developed solutions, the requirements proposed below are excluding these use cases of GNSS: Train integrity and train length monitoring, Odometer Calibration, and Level Crossing Protection.

Most of the EU projects currently plan the use of an absolute position to be provided by an onboard localisation unit. Some requirements are available in [RD3] but some more and refinements are under definition in the context of the X2R4 and R2DATO projects that will be delivered in the next months.

GNSS user requirements for Track Identification		
Accuracy	Horizontal	1.9 or 2.25m maximum depending on the inter-track distance
	Vertical	Non-applicable
Availability	Urban canyon	Yes, 99.99%
	Natural canyon	Yes, 99.99%
	Canopy	Yes, 99.99%
	Indoor	Yes, 99.99%
	Better than 95%	High
	Better than 99%	High
Robustness		High
Integrity and reliability		Very high
Size, weight, autonomy (when smartphone or handheld based)	Relevance	No
	Time a device can run	Not relevant
TTFaF	In hot start	5s
Service area	Geographical coverage	Over the whole EU network
Update rate		1s
TTA	Time between the occurrence of the failure and its presentation to the user	10-30s
SIL		SIL 2-4

The requirements presented in the following table result from previous discussions. The cold detector is expected to initiate operations once the train has halted and been turned off. Following this, it ought to verify that the train has remained stationary upon startup.These devices are therefore expected to operate without a battery within a certain period. During the UCP 2023 dialogue, doubts concerning the application's use case and the viability of a GNSS-based solution were brought to light. These aspects need to be properly fleshed out and refined ahead of the forthcoming improvements to these requirements.

GNSS user requirements for Cold Movement Detection		
Accuracy	Horizontal	Longitudinal accuracy < 1m As long as track identification is ensured The PNT shall provide a relative accuracy < 1m
	Vertical	Non-applicable
Availability	Urban canyon	Yes, 99.99%
	Natural canyon	Yes, 99.99%
	Canopy	Yes, 99.99%
	Indoor	Yes, 99.99%
	Better than 95%	High
	Better than 99%	High
Robustness		High
Integrity and reliability		Very high
Size, weight, autonomy (when smartphone or handheld based)	Relevance	No
TTFaF	In hot start	5s
Service area	Geographical coverage	Over the whole EU network
Update rate		1s
TTA	Time between the occurrence of the failure and its presentation to the user	< 10s
SIL		SIL 4 that corresponds to a failure rate of 10^{-9}/hr

The requirements for enhanced odometry are specified by the subset 41 [RD13] and [RD12].

GNSS user requirements for Enhanced Odometry		
Accuracy	Horizontal	Travelled distance ±5m + 5% of the distance since the last balise
	Vertical	Non-applicable
Availability	Urban canyon	Yes, 95%
	Natural canyon	Yes, 95%
	Canopy	Yes, 95%
	Indoor	Yes, 95%
Robustness		High
Size, weight, autonomy (when smartphone or handheld based)	Relevance	No
	Time a device can run	Not relevant

Service area	Geographical coverage	Over the whole EU network
TTA	Time between the occurrence of the failure and its presentation to the user	< 5s

5.1.6 Driver Advisory Systems (DAS)

The DAS (Driver Advisory System) allows the exchange of information between the railway system and the human operator (the driver), with the purpose of optimizing the driving of the train. The on-train system calculates an energy efficient speed profile to achieve the pre-planned or dynamically updated train timings and generates detailed driver advice to follow the profile and achieve the timings. The control centre is responsible for conflict detection and calculation of new target train timings. GNSS is used as one of the sensors in the DAS equipment. The main applications targeted by the DAS system are:

- Real time location allowing traffic management by conflict detection and providing accurate location report.
- Speed management enabling low energy driving, increasing reliability on arrivals time and allowing proper management of braking before conflict.

The DAS systems can be classified into two main categories:

- Standalone DAS (S-DAS) has all data downloaded to train at or prior to journey start. It realises a static exchange of information.
- Connected DAS (C-DAS) realises a communications link to the Control Centre (or Traffic Management Centre) in each controlled area in which the train operates. This enables the provision of schedule, routing and speed restriction updates to trains in near real time, and also receipt of information from trains to the Infrastructure Manager control centre to improve regulation decisions. It aims to optimise the traffic flow of the railways as a whole by dynamic re-planning of the timetable to avoid conflicts.

Driver Advisory Systems (DAS) are a mean of reducing energy consumption in the rail freight sector. They provide train drivers with continuous or selective feedback on the most energy-efficient speeds to adopt while driving the train. They rely on timetable information and train characteristics as well as topographic data and, where possible, dynamic (real-time) traffic information (e.g. to prevent conflicts with passenger trains sharing the same line). By modifying the train drivers' behaviour, DAS technology enables a smoother and more efficient rail traffic flow, thereby reducing the overall energy consumption.

GNSS user requirements for Driver Advisory System		
Accuracy	Horizontal	1m for track distinction
	Vertical	Non-applicable
Availability	Urban canyon	Yes
	Natural canyon	Yes
	Canopy	Yes
	Indoor	Yes
	Better than 95%	High
	Better than 99%	High

Robustness		Low
Integrity and reliability		Low
Size, weight, autonomy (when smartphone or handheld based)	Relevance	Yes
	Time a device can run	8-10h (daily service of a driver)
TTFaF	In hot start	1 min
Service area	Geographical coverage	Over the whole EU network
Update rate		1s
TTA	Time between the occurrence of the failure and its presentation to the user	10s

5.1.7 Hazardous Cargo monitoring ◑

Some of the goods carried by Rail freight operators can damage the environment if they are spilt in transit and/or pose a threat to society if they are stolen. These include crude petroleum and petroleum products; compressed, liquefied and refrigerated gases; flammable/corrosive/toxic chemicals and chemical/nuclear hazardous wastes. GNSS can be used to provide an alarm and alert system when used in conjunction with satellite or terrestrial communications and geofencing technologies. This solution allows managers to remotely monitor, track and communicate with their cargoes in real-time. Furthermore, this application provides updates on location, speed, mapping directions, security, etc. It also helps in archiving of vital condition data and an ability to track stolen cargoes.

GNSS user requirements for Hazardous cargo monitoring		
Accuracy	Horizontal	1-10 m-level
	Vertical	Non-applicable
Availability	Urban canyon	Yes
	Natural canyon	Yes
	Canopy	Yes
	Indoor	Yes
	Better than 95%	High
	Better than 99%	Medium
Robustness		Low
Integrity and reliability		High
Size, weight, autonomy (when smartphone or handheld based)	Relevance	Yes
	Time a device can run	Years
TTFaF	In hot start	if power on/off for energy management, 1s
Service area	Geographical coverage	Over the whole EU network
Update rate		15 min

TTA	Time between the occurrence of the failure and its presentation to the user	10 - 30s

5.1.8 Door control supervision

The purpose of this application is to enable the opening of specific doors at particular stations. GNSS is used to locate the train within a station. Some stations have short platforms or platforms on both sides, it is required that only the correct doors (i.e. those with a platform next to them) are opened when a train stops at a station. This application requires knowledge of the train location within the station and identification of the train at a specific platform. Location data can also be used by passenger information systems to alert passengers for the need to move to other vehicles, e.g. long trains at short platforms.

GNSS user requirements for Door Control Supervision		
Accuracy	Horizontal	1-10 m-level When using ATO: 1m
	Vertical	Non-applicable
Availability	Urban canyon	Yes
	Natural canyon	Yes
	Canopy	Yes
	Indoor	Yes
	Better than 95%	High
Robustness		Low
Integrity and reliability		High
Size, weight, autonomy (when smartphone or handheld based)	Relevance	No
	Time a device can run	Not relevant
Service area	Geographical coverage	Over the whole EU network
TTA	Time between the occurrence of the failure and its presentation to the user	10 - 30s

5.2 Current EO use and requirements per application

For a long time, the rail infrastructure sector has been employing EO to carry out tasks such as surveying, mapping, monitoring, and disaster response. In addition to this, many recent developments in satellite technologies, data analytics and machine learning have been expanding EO's role.

Nowadays, EO is integrated with the classical geotechnical technologies that consist of sensors and in-situ surveys and inspections providing fundamental information for planning, design, construction, monitoring of the state and the structural health of existing railway infrastructures and for the prediction of maintenance and the reduction of geohazard risks. EO has already become the mean technology applied for the continuous monitoring and alerting systems of large infrastructure and limited areas. EO is still playing an important role in reducing the environmental impact by promoting and boosting the development of sustainable infrastructures by providing the following information:

- **Identifying Environmental Risks**: EO involves assessing the potential environmental impacts of proposed infrastructure projects before they are implemented. This includes evaluating the potential effects on ecosystems, biodiversity, air and water quality, and communities. By identifying these risks early on, developers can take steps to mitigate or avoid them altogether.
- **Optimizing Design and Location**: Through EO, developers can explore alternative designs and locations that minimize environmental impact. For example, they may choose to build infrastructure in less ecologically sensitive areas or use sustainable materials and construction techniques that reduce resource consumption and pollution.
- **Mitigating Environmental Damage**: EO strategies often include measures to mitigate any unavoidable environmental damage. This might involve creating green infrastructure to replace lost habitat, implementing pollution control measures, or restoring ecosystems affected by construction activities.
- **Incorporating Sustainability**: EO encourages the incorporation of sustainability principles into infrastructure development. This could include designing buildings with energy-efficient features, integrating renewable energy sources into transportation projects, or implementing green infrastructure solutions like rain gardens and permeable pavements to manage stormwater runoff.
- **Engaging Stakeholders:** EO typically involves engaging stakeholders, including local communities, environmental groups, and government agencies, in the decision-making process. By considering their input and concerns, developers can better understand the potential environmental impacts of their projects and identify ways to address them.

An additional use of EO is enhancing the climate resilience of infrastructures. Using EO data, a deeper understanding of evolving climate conditions can be obtained and thus, the safeguarding of infrastructures can be improved [RD2].

We cluster EO-based applications in five main groups that follow the stages of infrastructure life cycle:

- **Infrastructure planning and designing, finance planning -** applications related to the selection of sites for the construction of new infrastructures and the assessment of the impact that said railway infrastructure may have on the surrounding environment and the economic trade-off. Those applications support decision making to identify construction techniques and the determination of costs.
- **Infrastructure construction -** applications for the monitoring of the ground movements even induced during the construction phases, applications for the monitoring of the construction progress.
- **Infrastructure monitoring** - applications related to the post-construction phase for the maintenance, for the mitigation of geological process that can affect the infrastructure and to strengthen the resilience and the safety of railways. A continuous monitoring is required for the monitoring of the growth of vegetation surrounding the railways and the identification for the presence of diseased trees is valuable for the maintenance of the infrastructures and avoid incidents. A continuous monitoring is even required to identify the presence of new buildings built at a certain distance from the most nearby railway tracks. Moreover, continuous monitoring is the base of the condition and predictive-based maintenance, a strategy that monitors the real-time condition of tracks and trains and allows triggering maintenance activities only when potential asset degradation is detected.
- **Disaster response to flood** - applications related to the identification of railway infrastructures that are involved in flood, helping the authorities to monitor the evolution of the situation, and in the management of the closing or reopening of the railways.
- **Risk and vulnerability assessments** – applications related to assessment of the risks and vulnerability related to the climate change and extreme weather events such as flooding, severe storms, landslides, rock fall, avalanches can have a devastating impact on the safety and the

expected lifetime of infrastructures which are becoming unreliable, unpredictable, inadequate and unsafe.

Note: Several terms used in this document refer to technologies, domain or activities which are relevant to several applications related to the monitoring/management of infrastructures. The corresponding definitions are provided in Annex A1.3.

Table 3: User needs and EO Applications

User needs	EO Applications
Infrastructures Planning and Designing, Finance Planning	• Determination of surface ground movements • Weather Impact Assessments and Adaptation to Climate Change • Determination of soil moisture
Infrastructure construction	• Geotechnical and structural monitoring during the construction
Infrastructure monitoring	• Determination of surface ground movements • Vegetation monitoring • Monitoring for the construction of new buildings • Control of railway tracks located in places hard to reach
Flood monitoring	• Flood monitoring for disaster response
Risk and vulnerability assessments	• Weather Impact Assessments and Adaptation to Climate Change

Attribute of applications

The main user needs for railway infrastructure monitoring are:

- **Spatial and Temporal Resolution**: To effectively monitor railway infrastructures high-resolution imagery are requested. Traditional EO satellites may not provide the necessary level of detail and obtaining high-resolution data can be expensive.
- **Long-Term Monitoring**: For railway infrastructure projects that span many years or even decades, long-term monitoring using EO data can be challenging due to satellite lifetimes and changes in sensor technology.
- **Cost**: EO systems, especially high-resolution satellite systems, can be costly to develop, launch, and maintain. This can limit the availability of data for railway infrastructure monitoring.
- **Accuracy and Calibration**: Ensuring the accuracy and calibration of EO instruments is crucial for reliable railway infrastructure monitoring. This requires regular maintenance and calibration, which can be difficult in remote or inaccessible areas.
- **Data from different sensors**: The availability of different sensors such as SAR bands C, X ,L would increase the quality of the monitoring of the railway infrastructure, for instance, C-band can provide a few information in vegetated areas compared to L-band .
- **Data latency**: the delay between the image acquisition and their availability and the delay in the determination of precise orbits that are demanding for InSAR are crucial aspects for near-real-time monitoring and they have to be decreases at low as possible.

5.2.1 Infrastructure planning and design, finance planning

Description

The planning phase is focused on the surveying of the areas to understand the site characteristics, which include site topography, geology, land cover/land use on the site and its vicinity, terrain stability, exposure to risks and exposure to climate change impacts.

The phase includes the evaluation of environmental and economic trade-off and provides all the information for the identification of the route and infrastructures elements to be build.

After the planning phase of an infrastructure, the design phase is performed with the scope to establish to identify construction techniques and provide the determination of the costs useful for the financial planning of the railway infrastructures.

Overview of user needs

The main site characteristics requested by the users are the following ones:

- **Topography**: determine the elevation and slope of the site to assess if it is well-adapted to the type of infrastructure to be built;
- **Geology**: analyze soil characteristics (e.g. density, depth of bedrock) to identify possible complications and design plans to remediate these complications ([RD30]);
- **Land cover/land use**: be informed about the natural and manmade characteristics of the site land cover and land use characteristics of the potential site and of its surroundings (e.g., presence of built areas, agricultural lands, natural areas, rivers, railways, railways, etc.);
- **Terrain stability**: be informed about the extent to which the potential site is subject to ground deformation and if so, be informed about the associated subsidence risk;
- **Exposure to risks**: be informed about the natural risks the potential site is exposed to , such as floods, landslides, subsidence, wildfires, avalanches, earthquakes, tsunami;
- **Exposure to climate change impacts**: be informed about the long-term impacts of climate change the potential site will be exposed to (e.g., higher risk of exposure to droughts).
- **Environmental impact assessment:** be informed about the potential environmental effects of a proposed project, development, or policy before it is implemented.

The planning phase mainly consists in surveying activities, which as mentioned in the previous Reports on User Needs and Requirements on surveying ([RD3]) involve the staking out of reference points and markers that will guide the execution of the construction project. These activities include establishing basic lines, grade control and principal points, positioning for corners, delineating the working areas, determining ground profiles and the placement of utilities, and preparing large-scale topographic maps for drainage and site design. The establishment of the coordinate framework for a construction site involves both high-order control surveys and low-order control surveys. During this phase, users (inc. engineering and construction companies, public land authorities, etc.) need to perform the construction surveying activities with a sufficient level of accuracy to guarantee that construction operations benefit from a high-quality reference framework.

The infrastructure designing phase is a critical stage in the development of any infrastructure project and it is essential for ensuring financial viability and securing funding for the project. Typically the design phase involves several key steps and considerations:

- Project Definition: Clearly defining the objectives, scope, and requirements of the infrastructure project. This includes identifying the purpose of the infrastructure, target users, expected capacity, and performance criteria.

- Site Selection and Analysis: Assessing potential sites for the infrastructure project, considering factors such as geographical features, land use, environmental sensitivity, accessibility, and existing infrastructure networks.
- Feasibility Studies: Conducting feasibility studies to evaluate the technical, economic, environmental, and social viability of the proposed infrastructure project. This involves analyzing costs, benefits, risks, and potential impacts to determine whether the project is feasible and worth pursuing.
- Design Concept Development: Developing conceptual designs and layouts for the infrastructure project, considering factors such as functionality, safety, efficiency, aesthetics, and sustainability. This may involve brainstorming sessions, workshops, and consultations with stakeholders to explore different design options.
- Engineering Design: Detailed engineering design of the infrastructure project, including structural design, civil engineering, electrical systems, mechanical systems, and other technical aspects. This phase involves creating detailed drawings, specifications, and plans that will guide the construction and implementation of the project.
- Environmental Assessment: Conducting environmental assessments to identify and mitigate potential environmental impacts of the infrastructure project. This may involve Environmental Impact Assessments (EIAs), as discussed earlier, as well as other studies and analyses to ensure compliance with environmental regulations and standards.
- Stakeholder Engagement: Engaging with stakeholders, including government agencies, local communities, businesses, and other relevant parties, to gather input, address concerns, and build support for the infrastructure project. Effective stakeholder engagement is essential for ensuring the project's success and minimizing conflicts.
- Regulatory Approvals: Obtaining necessary permits, licenses, and approvals from regulatory authorities for the infrastructure project. This may include obtaining planning permissions, environmental permits, zoning approvals, and other regulatory clearances required for construction and operation.
- Risk Management: Identifying and managing risks associated with the infrastructure project, including technical, financial, environmental, and social risks. This involves developing risk management plans and strategies to mitigate or address potential threats to project success.
- Cost Estimation and Budgeting: Estimating the total cost of the infrastructure project, including design, construction, land acquisition, permits, contingencies, and other expenses. Establishing a realistic budget is essential for ensuring financial viability and securing funding for the project.
- Value Engineering: Evaluating design options and construction methods to optimize project performance, quality, and cost-effectiveness. Value engineering involves finding ways to maximize value and minimize waste while meeting project objectives.

Table 4: User needs for Railway Infrastructures Planning and Designing, Finance Planning

User needs	Description
Determination of surface ground movements	Determination of surface ground movements derived by geological processes such as landslides, subsidence, ground failures, sinkholes, uplifts, faults and seismic displacements poses significant challenges for the planning and projecting of new infrastructures.
Determination of soil moisture	Determination of soil moisture, the total amount of water, including the water vapor in a land surface

User needs	Description
	provides a basic information for the geotechnical engineering
Weather Impact Assessments and Adaptation to Climate Change	Climate change and extreme weather events such as flooding, severe storms, landslides, rock fall, avalanches can have a devastating impact on the safety and the expected lifetime of infrastructures which may become nreliable, unpredictable, inadequate, and unsafe.

Table 5: EO requirements for "Determination of surface ground movements"

ID	EUSPA-EO-UR-RAI-0001
Application	Determination of surface ground movements
Users	Railway infrastructure owners and/or operators.
User Needs	
Operational scenario	Railways tracks can be affected by any movement taking place on the ground such as landslides, subsidence, uplifts, sinkholes, faults and seismic displacements. Avoiding or mitigating the consequences of such events poses significant challenges for planning, building and maintenance of railways infrastructures.
Size of area of interest	In general, a buffer of 500 m around the rail infrastructure is sufficient but it can be incremented depending on the geomorphology of the area to monitor and by the origin of ground movements.
Scale	From local to national
Frequency of information	From weekly to monthly
Other (if applicable)	Not applicable
Service Provider Offer	
What the service does	Provide information on ground displacements in the surroundings of the infrastructure. The risk assessment can take different forms depending on what users need (e.g. map, reports)
How does the service work	The service uses the MT-InSAR technique to determine time series of the surface ground displacements, velocities, accelerations and strains. The variation of the velocity (acceleration) and the strain rate identify areas affected by active surface ground movements.
Service Provider Satellite EO Requirements	
Spatial resolution	From 1 m up to 100 m
Temporal resolution	Weekly
Data type / Spectral range	SAR (C,X,L bands)
Other (if applicable)	Not applicable
Service Inputs	
Satellite data sources	Sentinel-1, TerraSAR X, ALOS, Cosmo SkyMed
Other data sources	GNSS and precise levelling measurements for the determination of the movements of ground reference points. Piezometers for the

	determination of the level of ground water and pluviometers. Historical archives.

Table 6: EO requirements for “Determination of soil moisture”

ID	EUSPA-EO-UR-RAI-0002
Application	Determination of soil moisture
Users	Infrastructure owners and/or operators.
User Needs	
Operational scenario	Determination of soil moisture, the total amount of water, including the water vapor in a land surface provides a basic information for the geotechnical engineering.
Size of area of interest	A buffer until 2000m around the railway infrastructure
Scale	From local to regional scale
Frequency of information	Ad-hoc
Other (if applicable)	Not applicable
Service Provider Offer	
What the service does	Information provision
How does the service work	The service analyses InSAR and optical images to determine the soil moisture.
Service Provider Satellite EO Requirements	
Spatial resolution	From 10 m up to 100 m
Temporal resolution	From daily to weekly
Data type / Spectral range	SAR (C,X,L bands), multi and hyper spectral images
Other (if applicable)	Not applicable
Service Inputs	
Satellite data sources	Sentinel 1 and 2, TerraSAR-X, ALOS, Cosmo SkyMed
Other data sources	In-situ inspection and sensors such as piezometers.

Table 7: EO requirements for "Weather Impact Assessments and Adaptation to Climate Change"

ID	EUSPA-EO-UR-RAI-0003
Application	Weather Impact Assessments and Adaptation to Climate Change
Users	Railway infrastructure owners and/or operators.
User Needs	
Operational scenario	Determination of the risk and of the vulnerability for the planning of safety, durable and resilient infrastructures and to minimizes damage to railway infrastructure assets. Climate change and extreme weather events such as flooding, severe storms, landslides, rock fall, avalanches can have a devastating impact on the safety and the expected lifetime of infrastructures. The assesment is based with natural hazard management under today's weather conditions and develop solutions and strategies to prepare for the changed weather and climate conditions of the future.
Size of area of interest	Mainly the whole railway network
Scale	From regional to national
Frequency of information	Ad-hoc
Other (if applicable)	Not applicable
Service Provider Offer	
What the service does	The service develops predictive models and maps of risks, to support the identification of solutions and strategies to prepare for the changed weather and climate conditions of the future and prioritize key actions to reduce asset exposure to damage and disruption.
How does the service work	The service combines EO observations, atmospheric, geomorphological and geographical data and models to develop predictive models and maps of risks.
Service Provider Satellite EO Requirements	
Spatial resolution	From 10 m up to 100 m
Temporal resolution	From weekly to monthly
Data type / Spectral range	SAR (C,X,L) Multi and hyper spectral, Meteosat
Other (if applicable)	Not applicable
Service Inputs	
Satellite data sources	Sentinel 1 and 2, TerraSAR-X, ALOS, Cosmo SkyMed
Other data sources	Atmospheric, geomorphological and geographical data and models. Historical archives.

5.2.2 Infrastructure construction

Description

Construction operations cover the activities carried out between the end of the "site selection and planning" phase and the time at which the infrastructure enters its operational phase. They include activities such as earth-moving, excavation, concrete work, installation work, etc. Depending on the type of infrastructure, they may also include activities such as tunnelling and boring.

Overview of user needs

The monitoring of construction progress aims at verifying that construction operations are progressing in line with the foreseen schedule and with design plans. Users need to identify delays and deviations as soon as possible in the process while minimising inspection costs.

Table 8: User needs for Railway Infrastructures Construction

User needs	Description
Geotechnical and structural monitoring during the construction	Continuous geotechnical and structural monitoring to control slopes and works to be built during the construction of a railway infrastructure such as the excavation of tunnels, the construction of viaducts, bridges, and railway sections.

Table 9: EO requirements for "Geotechnical and structural monitoring during the construction

ID	EUSPA-EO-UR-RAI-0004
Application	Geotechnical and structural monitoring during the construction
Users	Railway infrastructure owners and/or operators, construction and public works companies, financial institutions financing the construction that can include international organisations.
User Needs	
Operational scenario	Geotechnical and structural monitoring as part of the completion of a rail section. Continuous geotechnical and structural monitoring to control slopes and works to be built during the excavation of tunnels and the construction of railways.
Size of area of interest	The entire area susceptible to ground shifts caused by the construction or excavation of an infrastructure project.
Scale	Local
Frequency of information	From daily to weekly
Other (if applicable)	Not applicable
Service Provider Offer	
What the service does	Provide information on ground displacements in the surroundings of the infrastructure. The risk assessment can take different forms depending on what users need (e.g. map, reports)
How does the service work	The service uses the MT-InSAR technique to determine time series of the surface ground displacements, velocities, accelerations, and strains. The variation of the velocity (acceleration) and the strain rate identify areas affected by active surface ground movements
Service Provider Satellite EO Requirements	
Spatial resolution	From 1 m up to 100 m
Temporal resolution	From daily to weekly
Data type / Spectral range	SAR (C,X,L bands), Multi and hyper spectral
Other (if applicable)	Not applicable
Service Inputs	

Satellite data sources	Sentinel-1 and 2, ALOS, TerraSAR X, Cosmo SkyMed
Other data sources	GNSS and precise levelling measurements for the determination of the movements of ground reference points. Piezometers for the determination of the level of ground water and pluviometers.

5.2.3 Infrastructure monitoring

Description

Built infrastructures can suffer from natural phenomena (e.g. ground deformation, vegetation encroachment, extreme weather events, natural hazard) or anthropogenic activities (e.g. construction works in the vicinity of existing infrastructures). In this document, post-construction operations refer to the monitoring of the state (mainly the structural health) of existing infrastructures once their construction is completed.

Overview of user needs

Users need to ensure the protection of their infrastructures, to optimise maintenance operations and possibly to extend the infrastructure lifecycle within safety margin. To achieve this, they need to monitor aging damages, to improve maintenance effectiveness in terms of planning and cost reduction, reduce risks notably from more frequent extreme weather events and predict possible failures ([RD11][RD22][RD23]).

GNSS contribution and related requirements

Concerning GNSS, the stability of built infrastructure can be monitored via high-precision GNSS methods, e.g. by post-processing of static relative GNSS observations at field control points (established directly into or in the vicinity of the object) with station data from local or global CORS networks. In addition, GNSS data may be utilised to feed various smart sensors, mounted into the infrastructure body for real-time stability monitoring (see [RD1]).

EO contribution and related requirements

As far as EO is concerned, it is considered very cost-effective for monitoring infrastructure on a large scale and with high frequency ([RD12]).

For the infrastructure monitoring, several user needs have been considered and are described in the table below.

Table 10: User needs for Railway Infrastructures Monitoring

User needs	Description
Determination of surface ground movements	Determination of surface ground movements derived by geological processes such as landslides, subsidence, ground failures, sinkholes, uplifts, faults, and seismic displacements poses significant challenges for the for the maintenance and mitigation of existing ones. A continuous monitoring is almost requests for the identification of new geological processes and for controlling their evolution.
Vegetation monitoring	The monitoring of vegetation growth and the identification of diseased trees surrounding the railways can be useful to the maintenance of railway infrastructures and avoid incidents.
Monitoring for the construction of new buildings, quaries and the broader environment	Monitoring the construction of new buildings within a certain distance from a railway track is crucial for safety and regulatory compliance. Satellite imagery can contribute to the identification of new buildings close the railways can create problems with the trains. In addition, users have reported the use of EO data to monitor quaries and other elements surrounding the railway tracks to better assess the impact of human surrounding activities on railway tracks.

User needs	Description
of the railway tracks	Automated alerts and notifications to inform relevant stakeholders, including railway operators, local authorities, and regulatory agencies, when new construction is detected within the restricted area. Regulatory guidelines and safety standards regarding the distance between railways and buildings may vary from one jurisdiction to another.
Control of railway tracks located in places hard to reach	Controlling railway tracks located in hard-to-reach places presents unique challenges due to the remote and sometimes harsh environments in which they are situated. Effective control of deformation of tracks and maintenance are essential to ensure the safety, efficiency of rail transportation and avoid incidents to the trains in these areas.
Condition and Predictive-based Maintenance	Condition and predictive-based maintenance are a strategy that implies a proactive approach to maintenance, achievable through continuous monitoring of an asset's conditions of tracks and trains, which allows triggering maintenance activities only when potential asset degradation is detected in the case of condition based maintenance. On the other hand, Predictive Maintenance uses condition-based monitoring to optimize equipment performance and lifespan by continually assessing its health in real time.

Table 11: EO requirements for "Vegetation monitoring"

ID	EUSPA-EO-UR-RAI-0005
Application	Vegetation monitoring
Users	Railway infrastructure owners and/or operators
User Needs	
Operational scenario	The presence of vegetation along and close to the railway tracks can create obstacles and impact the trains. The monitoring of the status and growth of vegetation along the railway corridor can prevent hazards such as fallen trees or overgrown branches that can disrupt rail operations. The goal is the determination of the distance between vegetations and tracks. Identification of the types of vegetation, and determination of height and volume of trees.
Size of area of interest	In general, a buffer of 100 m around the railway infrastructure is sufficient but it can be incremented depending on the geomorphology of the area to monitor. In the case of slope stability monitoring a wider buffer could be needed (>100m) to effectively monitor the surroundings.
Scale	From local to national
Frequency of information	Monthly
Other (if applicable)	Not applicable
Service Provider Offer	
What the service does	Information provision and alert in case of presence of diseased and dead trees that can fall on the railway tracks.
How does the service work	The service analyses InSAR and optical images to determine the presence of vegetation and identify diseased and dead trees.
Service Provider Satellite EO Requirements	
Spatial resolution	From 1 m up to 100 m
Temporal resolution	Weekly
Data type / Spectral range	SAR (C,X,L bands), Multi and hyper spectral
Other (if applicable)	Not applicable
Service Inputs	
Satellite data sources	Sentinel-1 and 2, ALOS, TerraSAR X, Cosmo SkyMed
Other data sources	Aerial and drone imagery.

Table 12: EO requirements for “Monitoring for the construction of new buildings”

ID	EUSPA-EO-UR-RAI-0006
Application	Monitoring for the construction of new buildings
Users	Railway infrastructure owners and/or operators.
User Needs	
Operational scenario	Monitoring construction activities, especially related to earthworks activities, of new and existing buildings within a certain distance from a railway track is crucial for safety and regulatory compliance. Satellite imagery can contribute to the identification of new buildings close the railways can create problems with the trains. Automated alerts and notifications to inform relevant stakeholders, including railway operators, local authorities, and regulatory agencies, when new construction is detected within the restricted area. Regulatory guidelines and safety standards regarding the distance between railways and buildings may vary from one jurisdiction to another.
Size of area of interest	In general, a buffer of 100 m around the railway infrastructure is sufficient but it can be incremented depending on the geomorphology of the area to monitor.
Scale	From local to national
Frequency of information	Monthly
Other (if applicable)	Not applicable
Service Provider Offer	
What the service does	Information provision and alert in case of the identification of new buildings
How does the service work	The service analyses InSAR and optical images to determine the presence of new buildings.
Service Provider Satellite EO Requirements	
Spatial resolution	From 1 m up to 100 m
Temporal resolution	Weekly
Data type / Spectral range	SAR (C,X,L bands), Multi and hyper spectral
Other (if applicable)	Not applicable
Service Inputs	
Satellite data sources	Sentinel-1 and 2, ALOS, TerraSAR X, Cosmo SkyMed, Planet
Other data sources	Aerial and drone imagery.

Table 13: EO requirements for "Control of railway tracks located in places hard to reach"

ID	EUSPA-EO-UR-RAI-0007
Application	Control of railway tracks located in places hard to reach"
Users	Railway infrastructure owners and/or operators.
User Needs	
Operational scenario	Controlling railway tracks located in hard-to-reach places presents unique challenges due to the remote and sometimes harsh environments in which they are situated. Managing the deformation of rail tracks and regular maintenance are crucial to maintain the safety and efficiency of rail transportation, and to prevent train incidents. These practices are key to keeping rail infrastructure functioning at its highest level.
Size of area of interest	The entire area susceptible to geohazards.
Scale	From local to national
Frequency of information	From weekly to monthly
Other (if applicable)	Not applicable
Service Provider Offer	
What the service does	Provide information on ground displacements in the surroundings of the infrastructure, focusing on places difficult to reach (e.g. mountain environment, sea-side, etc.). The risk assessment can take different forms depending on what users need (e.g. map, reports).
How does the service work	The service uses the MT-InSAR technique to determine time series of the surface ground displacements, velocities, accelerations and strains. The variation of the velocity (acceleration) and the strain rate identify areas affected by active surface ground movements. The service is integrated with the optical and SAR images for change detection.
Service Provider Satellite EO Requirements	
Spatial resolution	From 1 m up to 100 m
Temporal resolution	Weekly
Data type / Spectral range	SAR (C,X,L bands)
Other (if applicable)	Not applicable
Service Inputs	
Satellite data sources	Sentinel-1, TerraSAR X, ALOS, Cosmo SkyMed
Other data sources	Aerial and drone surveys.

Table 14: EO requirements for "Condition and Predictive-based Maintenance"

ID	EUSPA-EO-UR-RAI-0008
Application	Condition and Predictive-based Maintenance
Users	Railway infrastructure owners and/or operators.
User Needs	

Operational scenario	Controlling the real-time condition of railway tracks and trains for detecting potential asset degradation and provide a pointed maintenance. CBM is a proactive approach to maintenance that uses condition-based monitoring to optimize equipment performance and lifespan by continually assessing its health in real time.
Size of area of interest	The entire railway networks
Scale	From local to national
Frequency of information	From weekly to monthly
Other (if applicable)	Not applicable
Service Provider Offer	
What the service does	Provide information on asset degradation of railway tracks and trains.
How does the service work	The service is an integrated system that analyses optical, SAR images both from satellites, drones and on-board train cameras, and sensors.
Service Provider Satellite EO Requirements	
Spatial resolution	From 1 m up to 100 m
Temporal resolution	Weekly
Data type / Spectral range	SAR (C,X,L bands), Multi and hyper spectral
Other (if applicable)	Not applicable
Service Inputs	
Satellite data sources	Sentinel-1, TerraSAR X, ALOS, Cosmo SkyMed
Other data sources	Aerial, drone surveys and on-board train cameras and sensors.

5.2.4 Flood monitoring

Description

Flood monitoring is typically performed using a combination of technologies, data sources, and processes to detect, track, and respond to potential or ongoing flooding events. This specific application is covered under the Report on User Requirement related to Emergency Management, however it was deem relevant to include a snapshot of this application under the Rail Report on User Requirement considering the interest of end-users for this application.

Overview of user needs

The key components of flood monitoring are:

- **Remote Sensing and Satellite Imagery:** Remote sensing technologies, including satellites, are used to monitor weather patterns, precipitation levels, and changes in water bodies such as rivers and lakes. This data can help predict and monitor potential flood events.
- **Radar Systems:** Weather radars are used to detect heavy rainfall and storm systems. Doppler radar, for instance, can measure the speed and direction of precipitation, helping forecasters determine if a weather event may lead to flooding.
- **Aerial and Drone Surveillance:** Drones and aerial surveys can be used to assess the extent of flooding and damage in real-time. They are particularly valuable for accessing areas that are difficult to reach.
- **Weather Forecasting:** Meteorological data and computer models are used to predict weather conditions and potential rainfall amounts. These forecasts can help authorities anticipate flood events and take preventative measures.
- **Flood Modelling**: Computer models are used to simulate potential flooding scenarios based on various factors, such as rainfall, snowmelt, topography, and land use. These models can help predict the extent and impact of floods.
- **GIS** (Geographic Information Systems): GIS technology is used to create floodplain maps, which show areas prone to flooding. These maps help in planning and response efforts.
- **River Gauges:** River gauges are instruments placed in rivers and streams to monitor water levels. They provide real-time data on water height and can trigger flood warnings if levels rise significantly.
- **Ground Sensors:** Ground-based sensors can monitor various environmental parameters, such as soil moisture and water quality, which can provide early warning signs of potential flooding.

For the Flood monitoring, several user needs have been considered and are described in the table below.

Table 15: User needs for Disaster Respond to Floods

User needs	Description
Flood monitoring	During floods it is necessary to identify the area and the railways that are involved in the flood, helping the authorities to monitor the evolution of the situation, and in the management of the closing or reopening of the railways.

Table 16: EO requirements for "Flood monitoring"

ID	EUSPA-EO-UR-RAI-0009
Application	Flood monitoring
Users	Railway infrastructure owners and/or operators.
User Needs	
Operational scenario	During floods can be useful to identify railways that are involved in flood, helping the authorities to monitor the evolution of the situation, and in the management of the closing or reopening of the railways. Creation of flood maps to identify the areas to be checked before the re-activation of the railways.
Size of area of interest	Section of the railway infrastructure network involved in the flood
Scale	From local to regional
Frequency of information	Ad-hoc, continuous monitoring
Other (if applicable)	Not applicable
Service Provider Offer	
What the service does	Map of flooded areas and alert provision
How does the service work	The service analyses InSAR and optical images to determine the areas affected by flood or disaster.
Service Provider Satellite EO Requirements	
Spatial resolution	100 m
Temporal resolution	From daily to weekly
Data type / Spectral range	SAR (C,X,L bands) Multi and hyper spectral
Other (if applicable)	Not applicable
Service Inputs	
Satellite data sources	Sentinel-1 and 2, ALOS, TerraSAR X, Cosmo SkyMed
Other data sources	Aerial and drone imagery.

5.2.5 Risk and vulnerability assessments

Description

Risk and vulnerability assessments related to climate change are essential tools for understanding the potential impacts of climate change on infrastructures and help to develop strategies for adaptation and mitigation and reduce the economic impact. Continuous monitoring and review of climate risks and vulnerabilities are critical to assess the effectiveness of adaptation and mitigation strategies and make adjustments as needed.

The main types of risks to be considered include:

- Flooding.
- Extreme temperatures and theirs impact on tracks and railway infrastructures. In high temperature conditions, railway tracks can experience "sun kinks" or buckling because heat causes the steel to expand.
- Extreme forest fires: particularly relevant for energy grids in countries such as Chile. This has a direct impact on infrastructures.
- Sea level rising and quality of water (most important for the desalinization plants).
- Sea level and the temperature of water (relevant for desalinization plants and the physical resilience of the infrastructure itself). Also, water temperature, has an impact on the chemical process of the desalinization. The higher the temperature the more expensive the process.

Overview of user needs

The key components of risk and vulnerability assessments monitoring are:

- Climate data collection and analysis: Assessors gather historical climate data and future climate projections to understand temperature changes, precipitation patterns, sea-level rise, and extreme weather events in the region.

Table 17: User needs for "Weather Impact Assessments and Adaptation to Climate Change"

User needs	Description
Weather Impact Assessments and Adaptation to Climate Change	Natural hazard management related weather and climate such as flooding, severe storms, landslides, rock fall, avalanches etc in a way that keeps and improves railway infrastructure performance and avoids or minimizes damage to railway infrastructure assets. It starts with natural hazard management under today's weather conditions and develops solutions and strategies to prepare for the changed weather and climate conditions of the future.

Table 18: EO requirements for "Weather Impact Assessments and Adaptation to Climate Change"

ID	EUSPA-EO-UR-RAI-0010
Application	Weather Impact Assessments and Adaptation to Climate Change
Users	Railway infrastructure owners and/or operators.
User Needs	
Operational scenario	Natural hazard management related weather and climate such as flooding, severe storms, landslides, rock fall, avalanches etc in a way

	that keeps and improves railway infrastructure performance and avoids or minimizes damage to railway infrastructure assets. It starts with natural hazard management under today's weather conditions and develops solutions and strategies to prepare for the changed weather and climate conditions of the future.
Size of area of interest	Mainly the whole railway network
Scale	From regional to national
Frequency of information	Ad-hoc
Other (if applicable)	Not applicable
Service Provider Offer	
What the service does	The service develops predictive models and maps of risks, to support the identification of solutions and strategies to prepare for the changed weather and climate conditions of the future and prioritize key actions to reduce asset exposure to damage and disruption.
How does the service work	The service combines EO observations, atmospheric, geomorphological and geographical data and models to develop predictive models and maps of risks.
Service Provider Satellite EO Requirements	
Spatial resolution	From 10 m up to 100 m
Temporal resolution	From weekly to monthly
Data type / Spectral range	SAR (C,X,L), multi and hyper spectral, Meteosat
Other (if applicable)	Not applicable
Service Inputs	
Satellite data sources	Sentinel 1 and 2, TerraSAR-X, ALOS, Cosmo SkyMed
Other data sources	Atmospheric, geomorphological and geographical data and models. Historical archives.

5.3 Limitations of GNSS and EO

5.3.1 GNSS performance in the railway environment

Rail is a very safety-sensitive environment and this why there are still limitations to use GNSS technology in Rail applications. The main limitations for Rail GNSS applications concern obscuration, which might take place in tunnels, deep cuttings and in the shade of high hills/mountains, and at high latitudes or out of coverage of EGNOS in case of signalling/safety relevant applications. Such environments create local propagation effects impacting accuracy, availability and integrity that must be considered to meet performance requirements regardless of the track environment.

5.3.2 GNSS accuracy for track identification

A direct limitation is GNSS accuracy regarding positioning a train on parallel tracks or in train stations. The PNT solution shall provide an accuracy of 1,9m or 2,25m maximum depending on the inter-track distance and be available with a 99,99% probability.

5.3.3 GNSS integrity for safety-critical applications

In order to prevent the use of a GNSS-based position when the required performance cannot be reached, location units under development will embed some protection mechanisms that will detect and mitigate failures from one side and bound residual errors on the other side with the computation of confidence interval, following approaches developed in the GNSS domain under the acronym RAIM (Receiver Autonomous Integrity Monitoring). These mechanisms intend to qualify the integrity of the position and prevent dangerous use of erroneous outputs.

The development of integrity concepts for railway applications is investigated by the scientific community and addressed in several on-going projects. Among the challenges, let's mention:

- Measurement errors for all the relevant sensors need to be analysed and modelled to establish realistic positioning error characteristics, especially in challenging environments
- The confidence interval (CI) is the interval within which the error on a given state parameters must be contained within the Integrity Risk probability. Its computation, to be fully efficient and protective, must cover the true error with a very high probability in any of the reception conditions and ideally would be tangent to the error at every moment, tightly bounding the error [RD6].

5.3.4 Safety demonstration

When used as a component of the CCS on-board architecture, the on-board location unit shall be certified according to CENELEC safety standards [RD3].

The railway standards require a RAMS evaluation for safety-critical application like train control and signalling. Before obtaining the authorisation of service, an equipment has to produce a safety documentation conformed to these standards that describe the degree of confidence that the user can place in the delivered service is needed for the establishment of a safety documentation in order to put the satellite-based train localisation into service.

When dealing with a GNSS application, performance strongly vary in time and space because on one hand, the presence of local effects varies with the train moving along the track, on the other hand, the satellite positions vary with time and thus their conditions of propagation to the train.

The safety demonstration must then consider both the global failures of the system as well as the local events, that are more difficult to quantify.

5.3.5 GNSS power consumption

When the positioning system must be installed on wagons or on some assets without any power source, power consumption has to be considered in the development of the sensor.

5.3.6 Jamming and spoofing of GNSS signals affecting safety and security

The presence of interference signal along the track is today still relatively few investigated for railways but will also be a limitation if non-detected at least, and if not mitigated.

Jamming refers to deliberate transmission of malicious signal in the GNSS band to block the receiver from acquiring the satellite signal by inducing noise hiding the useful signal. Jamming may degrade positioning performance but almost availability.

Spoofing is the transmission of synthetic GNSS-like signals compelling receiver to provide a false position. Spoofing could misinform on the train position and create potential along or across track errors that could be critical in terms of safety.

The localization unit shall be included in the cyber security considerations made at CCS on-board and/or vehicle level [RD3]. The solution shall be able to detect spoofing or jamming signals and to react accordingly to be robust to such attacks.

5.3.7 Optical imagery limitations

The use of optical imagery is limited in the presence of clouds above the area of interest, which can be a problem for applications related to infrastructure in areas prone to bad weather, particularly if these applications require frequent revisits. In Europe, for instance, the average cloud coverage is around 70%. For applications requiring weekly updates, it may be necessary to have daily revisits of the satellites in areas prone to cloudy weather to ensure that an image without cloud coverage can be captured during the period. In some specific cases, such as rails located under a tree canopy, optical imagery cannot be used either. However, there are other satellite-based technologies that can be used in such cases, such as Synthetic-Aperture Radar (SAR) technology, which can penetrate clouds and provide high-resolution images of the ground. SAR technology can be used to detect snow cover, monitor land use, and track changes in the environment. Overall, satellite technology has the potential to revolutionize the rail sector by providing reliable and secure communication, optimizing logistics, and enhancing overall efficiency and safety.

5.3.8 SAR imagery limitations

Contrary to optical imagery, SAR imagery can be obtained night and day and is not affected by the cloud coverage. Nevertheless, it also suffers limitations [RD20] among which:

- Depending on the frequency used, vegetation can limit data acquisition. For instance, the C-band SAR used in Sentinel-1 cannot capture image of the ground in vegetated areas while L-band SAR (e.g. ALOS mission) can penetrate vegetation;
- SAR interferometry is based on measurements of the phase difference between the signal emitted by the sensor and the signal backscattered by "objects" on the surface (see Annex A1.2 and 1.4). The distribution of measurement points is therefore depending on land cover and on the presence of natural or man-made "objects", generally referred to as "reflectors", able to reflect the radar signal (such as rocks, buildings, rail, etc.). In case of unsuitable land cover (e.g. dense vegetation, insufficient number of natural or man-made reflectors) the use of SAR interferometry requires that dedicated artificial reflectors are installed on site to enable measurements;
- SAR interferometry measures movements in the line-of-sight of the satellite and cannot measure displacement parallel to the orbit of the satellite (i.e. in the North-South direction in the case of near-polar, sun-synchronous orbits like for Sentinel-1)). The discrimination between vertical and horizontal (West-East) movements is only possible if several geometries (ascending and descending orbits) are used (see [RD21]);
- The actual technical features of SAR sensors and constellations permit the detection only of slow ground movements that not exceed few cm/year.
- Performance/Cost balance of EO data

The performance of EO satellite missions and constellations may vary significantly from a mission/constellation to another. The data relevant to infrastructure applications (mainly optical and SAR data) and made available by public missions generally have lower performances than commercial missions in terms of spatial resolution and revisit frequency. The best commercially available imagery has a spatial resolution in the range of 30cm and an update frequency in the range of 12-24 hours but few commercial constellations have been announced which once completed should offer similar or slightly lower spatial resolutions (~50cm) but with higher revisit frequency (1-4 hours). Several operators have announced the launch of constellations with spatial resolutions in the range of 30cm but targeting revisit every 2 hours (e.g. Planet Pelican constellation, Umbra, Whitney -Capella Space). Main limitations are therefore related to finding the balance between cost and performance. For applications requiring the acquisition of a high number of images (e.g. in case of line infrastructure spreading over several hundreds of kilometres) or in case of applications requiring frequent updates, the price of satellite imagery can become relatively significant.

Accessibility to EO data, cut-off times and timeliness of data delivery such as images and precise orbits, represent services high added value services with consequent improvement in performance. Another aspect concerning the complexity of the language associated with EO that arises from the need to describe and understand various aspects, including the technology, data processing, and the underlying scientific principles. Given the technical nature of EO language, it can be challenging for individuals outside the field to understand the nuances and details, especially for SAR.

5.3.9 Absence of certification process for EO data

According to the FIRE Focus Group on Infrastructure[12], the absence of certification process or quality "label" enabling to assert the quality of satellite-derived monitoring products and services limits the penetration of EO-based applications in the infrastructure sector. The Focus Group has underlined that infrastructure managers are convinced of the business case of using EO (e.g. for replacing manual surveys and inspections with satellite-based monitoring) but need some kind of certification of both the data source and the processing algorithms. In other words, a proof is needed that EO-based methods are equally accurate or better as current alternatives. The Focus Group suggests that infrastructure managers, contractors, governments, and other stakeholders agree together to accept the measurement results derived from satellite data as an objective representation of the reality, but underlines that this would require "contracts, regulations, and laws" to accept certain EO-based methods as valid alternatives to the currently prescribed methods.

5.3.10 EO key challenges

The EO-based monitoring of railway infrastructures requires a multidisciplinary approach, involving remote sensing experts, data scientists, engineers, and policymakers. These players can encounter a series of challenges in using EO, including:

- **Data Processing and Analysis**: Copious amounts of data are generated by EO systems. Processing and analysing these data to detect changes or damage to infrastructure can be time-consuming and resource intensive.
  Data processing and analysis are a huge challenger especially for SAR data. The setting of parameters applied to the SAR processing of images, and the time-series analysis of displacements, can influence and provide different results. For this reason, the analysis of results requires multidisciplinary approach to be conducted with the supervision of experts and considering the geotechnical and geomorphological features of the monitored area.
- **Weather Conditions**: Weather conditions can impact the quality of EO data. Cloud cover, for instance, can obscure the view of the Earth's surface. Overcoming this challenge may require the use of radar or other sensors that can penetrate clouds.

[12] https://fire-forum.eu/fire-focus-groups/

- **Data Integration**: railway infrastructure monitoring often requires the integration of data from multiple sources, including aerial photography, and ground-based sensors. Ensuring compatibility and accuracy in such integrated systems is a challenge.
- **Data Accessibility**: While there is a wealth of EO data available, accessing and using this data can be challenging. It may require special software and expertise, which is not always readily available to those who need it.
- **Data Privacy and Security**: Railway networks data can be sensitive, and there are privacy and security concerns related to collecting and using EO data.
- **Legal and Regulatory Issues**: There can be legal and regulatory challenges related to using EO data, especially when it comes to issues like privacy, data ownership, and international cooperation.
- **Human Error**: Interpreting EO data and identifying changes or issues in infrastructure can be subject to human error, which underscores the need for automation and machine learning techniques to assist in analysis.

5.4 Prospective use of GNSS and EO

5.4.1 Prospective use of GNSS

The following considerations depend on the railway use case. For applications where safety is not an issue and where cost and/or size and/or power autonomy of the system are limited, GNSS COTS chip will be the only sensor embedded. For safety critical applications such as control and command and when the localization solution is part of the train equipment, other technologies can be used as a complement.

Integrated solutions with complementary technologies

Most of the developments performed for GNSS integration in high demanding level of performance, investigate the use of multi-sensor solutions with, at least an IMU (Inertial Measurement Unit) but also other sensors among:

- speed sensor,
- a Digital Map,
- ERTMS balise reader...

Architectures under discussions also investigate the use of sensor fault detection and exclusion barriers as well as integrity monitoring concept that will be required to reach performance in all use cases and environments [RD16].

Evolutions of EGNSS services and components

Railway stakeholders will benefit from the different evolutions of the GNSS. Multi-frequency and multi-constellation as every segment of application.

Precise Point Positioning (PPP)

PPP is becoming an attractive alternative technique to RTK and its use in rail applications could be one of the technologies to be embedded in a hybridized GNSS/INS solution.

Interference mitigation

If interference impact is still rarely investigated up-to-now, robustness is part of the requirements expressed for a certain number of applications. Jamming effects will increase unavailability of the GNSS solution. Spoofing could induce dangerous impacts on signalling if not detected and not mitigated.

Interference mitigation techniques, integrated in receivers or as a result of the system (thanks to detection mechanisms, redundancy...) will be of importance in particular for safety critical applications.

Integrity monitoring

Accuracy and integrity are complementary but different requirements. For some of the applications listed in this report, integrity will be a priority compared to accuracy. CCS use cases associate to the position estimate a confidence interval, which role is to bound uncertainty. Some use cases can accept up to 20m inaccuracy but a very low integrity risk. The integrity monitoring algorithm, guaranteeing that this CI correctly bound uncertainty is of prime importance.

Over the past years, work has been performed to extend the Advanced Receiver Autonomous Integrity Monitoring (ARAIM) to the rail sector. The objective is to support GNSS-related rail applications with integrity techniques aimed to protect multi-constellation users , by relying on robust user algorithms. For those using rail services, integrating the SBAS with ARAIM could offer safety measures against local impacts. Additionally, combining this with an Inertial Measurement Unit (IMU) and/or an odometer could help meet the demanding integrity requirements and challenging conditions common in Rail Safety Of Life (SoL) applications. Several GNSS-related rail applications (e.g. Fleet management, Cargo monitoring, Virtual balise, Level crossing protection, etc.) have been investigated under the ARAIMTOO and ARAIMFUSE projects funded by the European Commission.

Multi-frequency and multi-constellation solutions

The multi-constellation era has brought surveyors several benefits, including increased availability, faster ambiguity resolution, and better coverage, especially for northern latitudes. Most receivers used in the surveying sector can track at least two constellations, and around 80% of surveying GNSS receivers already support Galileo, with around 98% being EGNOS-capable. In Europe, the majority of RTK providers have already upgraded or started to upgrade to Galileo. The introduction of Galileo High Accuracy Service on E6 and GPS L5 is expected to significantly reduce convergence time for PPP and differential techniques, allowing surveyors to benefit from triple frequency solutions.

High accuracy service

The Galileo High Accuracy Service E6-B signal is suitable for transmitting PPP information, allowing an adequate update rate for achieving centimetre-level accuracy. The HAS allows for the transmission of different bits from different satellites, which can highly increase the total bandwidth and lead to better performance, reducing the PPP receiver convergence time when combined with other factors. HAS offers triple frequency, enabling faster convergence time for surveying applications and accuracy comparable to RTK. GNSS raw phase measurements of Galileo signals via Android-based devices are an intriguing future high-accuracy prospect for mapping and surveying. The signal authentication service (SAS) of Galileo would be particularly interesting in sectors where volumetric surveys take place, i.e., where one measures the work performed by contractors against their contractual arrangements.

RTK VS PPP uptake

The landscape of RTK is changing with the proliferation of RTK GNSS receiver "boards" such as the Trimble BD series, Novatel OEM series, Hemisphere GNSS P series, and Septentrio AsteRx series. Additionally, there has been a massive uptake of RTK solutions in fast-growing markets such as China, which lies in the so-called GNSS hotspot of satellite visibility. Several national mapping agencies and commercial vendors have developed active and passive reference stations and network RTK reference station networks. Furthermore, the price of RTK GNSS receivers has significantly decreased due to a congested market and competitive pressure from emerging PPP solutions. These changes are expected to have a significant impact on the RTK landscape.

5.4.2 Prospective use of EO

Although the benefits of using EO for rail infrastructure related applications are recognised, the operational use of EO products and services in the infrastructure market remains relatively low. It is therefore a bit premature to talk about “prospective” use while the main target remains to achieve full adoption in the market.

Yet, a few elements can be mentioned:

- The clear trend towards very high spatial resolutions (~30cm) and very high revisit frequencies (~1 hour or less) might be well adapted to the monitoring of construction progress in Near-Real-Time.
- A few constellations are already offering “video from space” services (e.g. Vivid-I constellation from Earth-I, Skysat constellation from Planet or Satellogic constellation) with 1m spatial resolution. Even though the sequence duration remains relatively short (from 60s to 120s in general), it potentially opens the door to new opportunities:
  - Coupled with artificial intelligence techniques, it can allow a faster and more accurate recognition of objects, sites and infrastructures, which can be of key value for construction and post construction operations;
  - Giving various angle of view of infrastructures, it can allow 3D models to be created to much higher precision than from a single stereo pair;
  - Providing more contextual information to analysts and researchers by capturing movement, it can allow a better assessment of the surroundings of key infrastructures and thus a more accurate change detection including detection of 3D changes over time;
  - Providing the ability to mitigate patchy cloud and haze in a scene, it can allow to derive clearer images and thus improve the revisit time of the system.
- Data offered by EO can be coupled with observation data provided by other means such as drones or High-Altitude Pseudo Satellites (HAPS). Being closer to the ground, they can offer way more defined images than what satellites can do, and in the case of drones, they can also move around or under infrastructure to observe areas not visible from above. This enables complementary use of earth observation and ground data by allowing to use EO data as a first mean to identify areas of interest, and then reduce the perimeter to be assessed and subsequently the amount a ground data required by the end user (“tip and cue” paradigm).
- Digital twins are going to be increasingly used in infrastructure-related applications, in particular to simulate how infrastructures evolve when time passes and when their surroundings change (e.g. due to climate change). Earth observation will provide environmental data that will feed digital twin models.

5.5 Summary of drivers for user requirements

5.5.1 Drivers for GNSS-related user requirements

Drivers for the integration of GNSS in the various railway applications strongly vary between applications. When safety is not engaged and when investments are limited, applications developed take advantage of COTS components and their performance.

When safety is critical, requirements are driven by safety rules, specifications or standards that may require performance that cannot be offered by COTS today neither by GNSS-only.

The on-going and future developments of new EGNSS services will help, on one hand, to increase usages of COTS components for higher level of services and, on the other hand, help the stringent requirements to be met.

EGNOS FOR RAIL

Originally specified by aviation users, EGNOS provides safe augmentation information for GNSS, composed of navigation data corrections (orbits and time) and integrity information. Usable by any other type of users, the availability of EGNOS is however limited in railway environments that are more stringent, due to RF masking, multi-paths and interferences and do not offer the required service to guaranteed data integrity [RD15].

The definition of EGNOS requirements for rail users is progressing thanks to the railway community involvement and help EU space programmes to develop additional service dedicated to railways to allow these concrete expectations to be met. An EGNOS rail service would allow EGNSS-based safety services to reach their requirements.

HAS and OS-NMA

The Galileo OSNMA is an authentication mechanism that allows GNSS receivers to verify the authenticity of GNSS information, making sure that the data they receive are indeed from Galileo and have not been modified in any way. Possible use cases of HAS in rail could be public transport ticketing and liability critical applications such as e-logistics that might require anti-spoofing.

Galileo HAS will offer real-time improved user positioning performances with accuracy less than two decimetres (in nominal conditions) and may contribute to reach requirements for identified applications such as:

- Cold Movement Detection,
- Door control supervision,
- Infrastructure surveying,
- Gauging surveys and
- Structural monitoring
- Digital Automatic Coupling

5.5.2 Drivers for EO-related user requirements

Except in a few specific cases where other types of satellite imagery (e.g. thermal infrared) may be required, most infrastructure-related EO-based applications require optical (visible) and/or SAR imagery. The main drivers are:

- Spatial resolution (several applications require Very High Resolution imagery, with meter-level or submeter-level resolution);

- The availability of historical data (to enable change detection or to identify trends);
- For line infrastructure, the ability to cover large-scale areas (e.g. several hundreds of square kilometres).

Except for construction progress monitoring, the frequency at which the information provided to users must be updated is not that critical (monthly or above in most cases) and can therefore not be considered as a main driver.

In addition to the above-mentioned performance-related drivers, other aspects can be considered as drivers for the uptake of EO in the infrastructure market:

- Legislation/regulation, which is a main driver for the adoption of EO-based applications related to the monitoring of the rail infrastructures to ensure safe, efficient, and reliable transportation. In general, managers provide monitoring of rail infrastructures if there is a legal/regulatory obligation to do so, for example if exists the obligation to verify the structural health of bridges and tunnels at regular intervals;
- Willingness to optimise maintenance costs, notably by reducing the number of on-site inspection (which by the same occasion contributes to increase worker safety by reducing the risk of accidents related to on-site inspections). In this perspective, the availability of cost/benefits analyses demonstrating the gains that EO can bring to the sector would be helpful.

Without really being a "driver", the definition/availability of best practices for the use of EO in the sector would support the uptake of EO-based services for infrastructure management. It is expected that market drivers (i.e. related to the cost of performing in-situ measurement on an extended and aging network) and environmental (i.e; environmental and ESG requirements) will support further uptake of EO data in the railway sector.

5.6 Synergies with SATCOM

Satellite communication is being used in the railway industry, and its use is expected to increase in the future, especially considering that the railway sector has been characterized by important innovations regarding digital technologies for train-to-ground communications [RD23]. In addition, satellite communication can provide reliable and secure communication for rail operations, including train control, signalling, and safety-critical applications [RD24]. It is estimated that satellite connectivity is currently being used on over 2,000 locomotives worldwide and in some of the most remote regions in the world where natural coverage is limited [RD25].

Most demanding criteria for SATCOM solutions are 1) Reliability for critical applications, 2) Transfer delay between SATCOM remote terminals and 3) The use of handhelds (when needed). Capacity from geostationary satellites is available and forecast to remain available in all major frequency-bands being used to support voice and data streams, enabling various applications. Such capacity is limited in certain locations (especially outside European Union) and might be not sufficient to cover the whole aggregated expected demand. Capacity from assets located in NGSO (Non-GeoStationary Orbit) is currently available from an EU company through a single constellation of satellites operating in MEO (Medium Earth Orbit), in Ka-band, whose services are planned to be enhanced in 2024+. Moreover, the multi-orbit constellation IRIS² shall complement and integrate the existing and future capacities of the SATCOM (for governmental usage) component of the European Union Space programme for the provision of secure satellite communications.

From a preliminary technical and business-related analysis, if only safety-critical data and voice services are considered, the most competitive value propositions are narrowband solutions, whereas broadband solutions expand the possibility to open new markets for the rail users generating multiple sources of revenue and being able to recover the strong initial investments required to provide the service.

Accordingly, potential solutions could be based on GEO (Ka-band, L-band, S-band, C-band, X-band), MEO (S-band reaching end of life, C-band being a theoretical as this solution is neither in development nor planning stage, but has been analysed since it was the most suitable candidate of the Satcom4Rail study [RD31]. In particular, Low Earth Orbit (LEO) High Throughput Satellites (HTS) can play a significant role in the adaptable communication system for train-to-ground communication. This technology can provide continuous communication for train control, voice communication (including railway emergency communications), passenger information systems, and real-time video capabilities. LEO satellite connectivity offers faster speeds, real-time conversations, and reliable connections even over remote regions. The use of satellites and other space-based technologies is helping railway operators to improve their services, increase safety, security, reliability, and enhance their overall efficiency. From improving train scheduling to enhancing maintenance practices, space technology is providing solutions that were previously unimaginable. Overall, satellite communication has the potential to revolutionize the rail sector by providing reliable and secure communication, optimizing logistics, and enhancing overall efficiency and safety for both passenger and freight trains.

The potential of SATCOM in regional railway lines should be further explored, it might be playing a crucial role in proffering cost-efficient strategies for digitalization and modernization. In addition, the utilization and seamless integration of SATCOM into intelligent rail infrastructure elements such as capacity management, energy management, and maintenance should also be considered. This integration conveys how SATCOM can significantly accelerate the advancement of rail systems, thereby transforming the railway industry toward greater efficiency and sustainability.

SATCOM could have a great potential when it comes to supporting the Future Railway Mobile Communication System (FRMCS), since there is a potential of FRMCS to leverage satellite communication technology [RD26]. The transition to FRMCS is expected to require a significant increase in data capacity and bandwidth, which can be achieved through the use of satellite communication. The FRMCS will also require the need for interoperability between different communication technologies, including satellite and terrestrial networks, to ensure seamless communication across the railway network. [RD27]

The technical specifications of the FRMCS are defined in several documents and standards. The FRMCS will be based on 3GPP building blocks and will provide overall technical conditions for the successor of GSM-R. [RD28] The UIC has already structured and gather user requirements related to the FRMCS by classifying applications in the following four different groups [RD29]:

- Critical Communication Applications, for example: On-train outgoing voice communication from the driver towards the controller(s) of the train, Trackside maintenance voice communication, Automatic train control communication, Data recording and access, etc.
- Performance Communication Applications, for example: On-train voice communication, Station public address, On-train telemetry communications, Non-critical Real time video, Wireless on-train data communication for train staff, etc. Business Communication Applications, for example: Information help point for public, Emergency help point for public, Wireless internet on-train for passengers, etc.
- Business communication applications, for example: help points for public, internet for passengers, billing information, etc.
- Critical Support Applications, for example: Multi-user talker control, Location service, Safety application key management communication, etc.

The initial three versions of only terrestrial 5G FRMCS will be founded on 3GPP standards. As for Satellite Communications, their integration in commercial solutions will commence with the release 17 of 3GPP standards. Regardless, it is still uncertain if these 3GPP standards will be designed or compatible with IRIS2.

According to [RD29] identifies main communication attributes for the above-mentioned categories, where:

- Link type could be:

- Bi-directional voice: like a user-to-user communication
- Uni-directional voice: like a “broadcast” communication (e.g. PA)
- Bi-directional data: like an application sending and receiving data
- Uni-directional data: like an application sending or receiving data

- Latency, i. e. the delay between action and reaction could be classified as:
  - Normal: there is no explicit requirement from the user, there is no need for immediate and the delay does not harm the use of the application by the user
  - Low: immediate action (order of seconds)
- Bandwidth, i.e. an indication of the anticipated rate of data transfer when using the application which could be:
  - High (order of > 1MB/s)
  - Medium (order of 100 KB/s)
  - Low (order of KB/s)
- Reliability: a qualitative indication of the reliability required of the communications system when the application is in use which could be:
  - High
  - Normal
- Setup: a qualitative indication of the time to establish a voice or data communication session with the application that would be acceptable to a user, and is sufficient to perform the railway operation:
  - Normal: there is no explicit requirement from the user, there is no need for immediate and the delay does not harm the use of the application by the user
  - Immediate (order of hours)
- Speed: the speed that a user is travelling in, maximum value:
  - Low ≤40 Km/h, including stationary users
  - Normal >40 Km/h, <250 Km/h
  - High ≥250 Km/h, ≤500 Km/h

Accordingly, the following table provides a first iteration of high-level requirements at the level of the sections. Note: due to the high level of discrepancy between applications a range has been included

	Link Type	Latency	Bandwidth	Reliability	Setup	Speed
Critical Communication Applications	*Bi-directional and Uni-directional voice/data*	*Low*	*Low*	*High*	*Normal-Immediate*	*High-Normal*
Performance Communication Applications	*Bi-directional and Uni-directional voice/data*	*Low-Normal*	*Medium-Low*	*High-Normal*	*Normal*	*High-Normal-Low*
Business Communication Applications	*Bi-directional data*	*Normal*	*Low*	*High-Low*	*Normal*	*High-Low*

Critical Support Applications	*Bi-directional data*	*Normal-Low*	*Low*	*High*	*Normal*	*High-Normal*

Table 19: Average user requirements for the FRMCS applications per category

Identification of limitations for the use of SatCom in Rail

FRMCS will operate alongside GSM-R (until approximately 2035).Taking into account the timeframe for replacing the current GSM-R, **GSM-R voice requirements become the main barrier for SATCOM**, due principally to the fact that their values are out of the scope of any current SATCOM solution (in terms of reliability, latency and even bandwidth for the whole European demand). Therefore, it is important to consider the safety cases for these scenarios where SATCOM could be working standalone (e.g. remote/rural areas).

When only safety data applications (i. e. ETCS) are considered, most of the SATCOM solutions become technically feasible. This is because of more challenging criteria for SATCOM are easier to reach when applications data rates are lower, and when the most demanding type of terminal (i. e. the handheld) is not required anymore (since pedestrian users do not use ETCS data applications). When voice applications are not considered, **data rate decreases and, therefore, link reliability and latency are largely increased**. Moreover, SATCOM communications will only consist of **single hop connections** (between ground stations and on-board SATCOM terminals). In this way, the transfer delay is reduced compared to with that of the double hop connectivity required for user-to-user (voice) connections. In the long term, the concept of operation in railways could change and voice services could be replaced by data applications, making possible the use of SATCOM solutions to support services currently provided by voice and data applications using only data.

Moreover, it is very important to remark that nowadays **it does not exist a regulatory framework supporting the certification and homologation of the SATCOM solutions** (even if good candidate to support FRMCS designed to be a multi-bearer system) for the railway domain. Therefore, solutions technically compliant with railway criteria shall be upgraded to comply with these future established regulations. Due to the stringent requirements from safety railway applications, it is well understood that the future railway communication architecture will be composed of several communications systems, i. e. multilink system, as the Next Generation Networks tend. In order to successfully deploy a SATCOM solution as part of the multi-technology railway architecture, several aspects have to be considered, such as the **regulatory framework, railway certifications, the use of communication standards, geographical constraints** and some other technical implications because of introducing SATCOM technologies into the railway field and in a multi-technology architecture.

From the economic point of view of satellite solutions compared with terrestrial ones, it is worth mentioning that two main scenarios can be analysed: Brownfield (when considering terrestrial solutions deployed re-using current GSM-R infrastructure) and Greenfield (when deploying future terrestrial solutions from scratch). In this sense, **SATCOM economic feasibility raises when deploying a railway communication system in a new line (Greenfield)**, since it is much cheaper (in terms of CAPEX) and faster to deploy than terrestrial solutions. This is because of ground infrastructure is not required in SATCOM solutions (except for those areas to be covered by alternatives terrestrial solutions due to the lack of satellite coverage).

Identification of the prospective use of Satcom in Rail

The main key technological factor to support the usage of SATCOM technology in rail domain refers to the i**nteroperability 5G communication protocol**. The landscape of radio protocols in satellite communication encompasses several key standards and technologies. In commercial SATCOM, two primary protocols are widely used: 5G and DVB-S2X. The DVB-S2X standard currently serves as a prevalent choice for commercial satellite communication. DVB-S2X is mainly used as a current standard in commercial SATCOM, however over the long term, it could be anticipated that the upcoming non-terrestrial 5G (which will be updated soon) is estimated to pave the way and become another important standard. Indeed, it will benefit from the **5G terrestrial eco-system**. **Interoperability** between satellite gateways and user terminals including terrestrial networks) enabling roaming and full mobility and dynamic tracking. **Non-terrestrial 5G** terminals is a relatively new concept which is expected to still evolve in the coming years. This evolution is likely to prompt SATCOM terminal manufacturers to transition from DVB-S2X to 5G, driven by the advantages offered by non-terrestrial 5G's integration with the terrestrial 5G ecosystem. Although there are differences in the air interfaces, the efficiency disparity from a radio efficiency standpoint is relatively small. The key benefit of non-terrestrial 5G lies in its ability to facilitate seamless integration between non-terrestrial 5G SATCOM terminals and the terrestrial 5G infrastructure. Terrestrial 5G modem chipsets will have to be modified to accommodate SATCOM links. Nevertheless, it is expected that the integration of non-terrestrial 5G will enable some cost saving, ease of roaming capabilities for mobile terminals among different geographical regions, and easier handover from terrestrial network to SATCOM network (some mobile terminals already offer this feature, but the engineering is rather complex as the air interface is not the same, e.g.: 4G to DVB-S2X etc.).

Indeed, Key stakeholders in the railway industry have a clear preference for utilizing 5G technology in FRMCS up to version 3. 5G's capability to fully address the mission-critical communication needs essential for rail operations to replace GSM-R. 5G MNOs (Mobile Network Operator) are considered in FRMCS version 3. According to the FRMCS roadmap, the **potential utilization of SATCOM could be considered in FRMCS Version 4**.

6 USER REQUIREMENTS SPECIFICATION

The chapter provides a synthesis of the requirements described in section 5.1 respectively on GNSS in section 6.1 and on EO in section 6.2. The content of this section will be updated, completed and expanded by EUSPA in the next releases of the RUR based on the results of further investigations discussed and validated in the frame of the UCP.

6.1 Synthesis of Requirements Relevant to GNSS

Condition-based maintenance and predictive maintenance (based on previous requirements defined for cargo monitoring)

Id	Description	Type	Source
EUSPA-GN-UR-RAI-0640	The PNT solution shall provide the train position with a longitudinal accuracy of 10-20m after track identification.	Performance (Accuracy)	[RD10] [RD11]
EUSPA-GN-UR-RAI- 0680	The PNT solution shall provide the train position with a horizontal accuracy of 10m or even more	Performance (Accuracy)	[RD10] [RD11]
EUSPA-GN-UR-RAI-0650 and 0690	The availability of the location information provided by the PNT solution fulfilling its performance requirements shall be High.	Performance (Availability)	[RD10] [RD11]
EUSPA-GN-UR-RAI-0660 and 0700	The ability of the 0365 PNT solution to provide timely warnings to the user when data provided by the solution should not be used shall be Low.	Performance (Integrity)	[RD10] [RD11]
EUSPA-GN-UR-RAI-0710 and 0670	The maximum allowable time between the occurrence of the failure in the PNT solution and its presentation to the user shall be 30s or even more.	Performance (Time To Alarm)	[RD10] [RD11]
EUSPA-GN-UR-RAI-0991	The PNT solution shall be available over the whole EU Rail network	Performance (Availability)	[RD10] [RD11]
EUSPA-GN-UR-RAI-0992	The PNT solution shall be available in urban canyon with a high probability	Performance (Availability)	[RD10] [RD11]
EUSPA-GN-UR-RAI-0993	The PNT solution shall be available under canopy with a high probability	Performance (Availability)	[RD10] [RD11]

EUSPA-GN-UR-RAI-0994	The PNT solution shall be available indoors with a high probability	Performance (Availability)	[RD10] [RD11]
EUSPA-GN-UR-RAI-0995	The PNT solution shall have a TTFF that will depend on the mode used for energy saving (alternance of short power on/long power off periods). Hot start may be needed.	Performance (TTFF)	[RD30]
EUSPA-GN-UR-RAI-0996	The PNT solution shall have an update rate of 1-30 min	Performance (update rate)	[RD10] [RD11]
EUSPA-GN-UR-RAI-1110	Size, weight and autonomy shall be considered.	Function (size, weight, autonomy, time a device can run)	[RD30]

Trackside Personnel Protection

Id	Description	Type	Source
EUSPA-GN-UR-RAI-0360	The PNT solution shall provide the train position with a horizontal accuracy within a range of 1-10m.	Performance (Accuracy)	[RD10] [RD11]
EUSPA-GN-UR-RAI-0365	The PNT solution shall provide a small relative accuracy.	Performance (Accuracy)	[RD10] [RD11]
EUSPA-GN-UR-RAI-0370	The availability of the location information provided by the PNT solution fulfilling its performance requirements shall be High.	Performance (Availability)	[RD10] [RD11]
EUSPA-GN-UR-RAI-0380	The ability of the PNT solution to provide timely warnings to the user when data provided by the solution should not be used shall be High.	Performance (Integrity)	[RD10] [RD11]
EUSPA-GN-UR-RAI-0921	The PNT solution shall be available over the whole EU Rail network	Performance (Availability)	[RD10] [RD11]
EUSPA-GN-UR-RAI-0922	The PNT solution shall be available in urban canyon with a high probability	Performance (Availability)	[RD10] [RD11]
EUSPA-GN-UR-RAI-0923	The PNT solution shall be available under canopy with a high probability	Performance (Availability)	[RD10] [RD11]

EUSPA-GN-UR-RAI-0924	The PNT solution shall be available indoors with a high probability	Performance (Availability)	[RD10] [RD11]
EUSPA-GN-UR-RAI-0925	The PNT solution shall have a TTFF of some minutes.	Performance (TTFF)	[RD10] [RD11]
EUSPA-GN-UR-RAI-0926	The PNT solution shall have an update rate of 5-10s	Performance (Update rate)	[RD10] [RD11]
EUSPA-GN-UR-RAI-0390	The maximum allowable time between the occurrence of the failure in the PNT solution and its presentation to the user shall be between 10s and 30s.	Performance (Time To Alarm)	[RD10] [RD11]
EUSPA-GN-UR-RAI-0391	For ATO application, the PNT solution shall achieve a Safety Integrity Level 2, that corresponds to a failure rate of 10-7/hr.	Performance (Safety Integrity Level)	[RD10] [RD11]
EUSPA-GN-UR-RAI-1120	Size, weight and autonomy shall be considered.	Function (size, weight, autonomy, Time a device can run)	[RD30]
EUSPA-GN-UR-RAI-1121	The device shall run 8-10 hours (daily service of a driver)	Performance (size, weight, autonomy, Time a device can run)	[RD30]

Rail fleet management

Id	Description	Type	Source
EUSPA-GN-UR-RAI-0640	The PNT solution shall provide the train position with a longitudinal accuracy of 10-20m after track identification.	Performance (Accuracy)	[RD10] [RD11]
EUSPA-GN-UR-RAI-0650	The availability of the location information provided by the PNT solution fulfilling its performance requirements shall be High.	Performance (Availability)	[RD10] [RD11]
EUSPA-GN-UR-RAI-0660	The ability of the PNT solution to provide timely warnings to the user when data provided by the solution should not be used shall be Low.	Performance (Integrity)	[RD10] [RD11]
EUSPA-GN-UR-RAI-0981	The PNT solution shall be available over the whole EU Rail network	Performance (Availability)	[RD10] [RD11]
EUSPA-GN-UR-RAI-0982	The PNT solution shall be available in urban canyon with a high probability	Performance (Availability)	[RD10] [RD11]
EUSPA-GN-UR-RAI-0983	The PNT solution shall be available under canopy with a high probability	Performance (Availability)	[RD10] [RD11]
EUSPA-GN-UR-RAI-0984	The PNT solution shall be available indoors with a high probability	Performance (Availability)	[RD10] [RD11]
EUSPA-GN-UR-RAI-0985	The PNT solution shall have a TTFF that will depend on the mode used for energy saving (alternance of short power on/long power off periods). Hot start may be needed.	Performance (TTFF)	[RD30]
EUSPA-GN-UR-RAI-0986	The PNT solution shall have an update rate of 60s or more	Performance (Update rate)	[RD10] [RD11]
EUSPA-GN-UR-RAI-0670	The maximum allowable time between the occurrence of the failure in the PNT solution and its presentation to the user shall be 30s.	Performance (Time To Alarm)	[RD10] [RD11]
EUSPA-GN-UR-RAI-1130	Size, weight and autonomy shall be considered.	Function (size, weight, autonomy, Time a device can run)	[RD30]

Passenger Information System

Id	Description	Type	Source
EUSPA-GN-UR-RAI-0840	The PNT solution shall provide the train position with a horizontal accuracy of less than 100m.	Performance (Accuracy)	[RD10] [RD11]
EUSPA-GN-UR-RAI-0850	The availability of the location information provided by the PNT solution fulfilling its performance requirements shall be of 95%.	Performance (Availability)	[RD10] [RD11]
EUSPA-GN-UR-RAI-1031	The PNT solution shall be available over the whole EU Rail network	Performance (Availability)	[RD10] [RD11]
EUSPA-GN-UR-RAI-1032	The PNT solution shall be available in urban canyon with a 95% probability	Performance (Availability)	[RD10] [RD11]
EUSPA-GN-UR-RAI-1033	The PNT solution shall be available under canopy with a 95% probability	Performance (Availability)	[RD10] [RD11]
EUSPA-GN-UR-RAI-1034	The PNT solution shall be available indoors with a 95% probability	Performance (Availability)	[RD10] [RD11]
EUSPA-GN-UR-RAI-1035	The PNT solution shall have a TTFF of less than 10s.	Performance (TTFF)	[RD10] [RD11]
EUSPA-GN-UR-RAI-1036	The PNT solution shall have an update rate of 1s.	Performance (Update rate)	[RD10] [RD11]
EUSPA-GN-UR-RAI-0830	The maximum allowable time between the occurrence of the failure in the PNT solution and its presentation to the user shall be less than 10s.	Performance (Time To Alarm)	[RD30]

Enhanced Command & Control Systems (CCS) is a group of several functions with different requirements.

- Enhanced Command & Control Systems (CCS) – Cold Movement Detection

Id	Description	Type	Source
EUSPA-GN-UR-RAI-0070	The PNT solution shall provide the train position with a longitudinal accuracy lower than 1m (as long as track identification is ensured).	Performance (Accuracy)	[RD10] [RD11]

EUSPA-GN-UR-RAI-0075	The PNT solution shall provide a relative accuracy of less than 1m.	Performance (Accuracy)	[RD10] [RD11]
EUSPA-GN-UR-RAI-0080	The availability of the location information provided by the PNT solution fulfilling its performance requirements shall be High.	Performance (Availability)	[RD10] [RD11]
EUSPA-GN-UR-RAI-0090	The ability of the PNT solution to provide timely warnings to the user when data provided by the solution should not be used shall be Very High.	Performance (Integrity)	[RD10] [RD11]
EUSPA-GN-UR-RAI-0100	The PNT solution shall achieve a Safety Integrity Level 4, that corresponds to a failure rate of 10-9/hr.	Performance (Safety Integrity Level)	[RD10] [RD11]
EUSPA-GN-UR-RAI-0861	The PNT solution shall be available over the whole EU Rail network	Performance (Availability)	[RD10] [RD11]
EUSPA-GN-UR-RAI-0862	The PNT solution shall be available in urban canyon with a 99.99% probability.	Performance (Availability)	[RD10] [RD11]
EUSPA-GN-UR-RAI-0863	The PNT solution shall be available under canopy with a 99.99% probability	Performance (Availability)	[RD10] [RD11]
EUSPA-GN-UR-RAI-0110	The maximum allowable time between the occurrence of the failure in the PNT solution and its presentation to the user shall be less than 10s.	Performance (Time To Alarm)	[RD10] [RD11]

- Enhanced Command & Control Systems (CCS) – Track Identification

Id	Description	Type	Source
EUSPA-GN-UR-RAI-0220	The PNT solution shall provide an accuracy of 1.9m or 2.25m maximum depending on the inter track distance.	Performance (Accuracy)	[RD10] [RD11]
EUSPA-GN-UR-RAI-0230	The availability of the location information provided by the PNT solution fulfilling its performance requirements shall be High.	Performance (Availability)	[RD10] [RD11]
EUSPA-GN-UR-RAI-0240	The ability of the PNT solution to provide timely warnings to the user when data	Performance (Integrity)	[RD10] [RD11]

	provided by the solution should not be used shall be Very High.		
EUSPA-GN-UR-RAI-0250	The PNT solution shall achieve a Safety Integrity Level 2-4.	Performance (Safety Integrity Level)	[RD10] [RD11]
EUSPA-GN-UR-RAI-0891	The PNT solution shall be available over the whole EU Rail network	Performance (Availability)	[RD10] [RD11]
EUSPA-GN-UR-RAI-0892	The PNT solution shall be available in urban canyon with a 99,99% probability	Performance (Availability)	[RD10] [RD11]
EUSPA-GN-UR-RAI-0893	The PNT solution shall be available under canopy with a 99,99% probability	Performance (Availability)	[RD10] [RD11]
EUSPA-GN-UR-RAI-0894	The PNT solution shall be available indoors with a 99,99% probability	Performance (Availability)	[RD10] [RD11]
EUSPA-GN-UR-RAI-0895	The PNT solution shall have a TTFF of 5s	Performance (TTFF)	[RD10] [RD11]
EUSPA-GN-UR-RAI-0896	The PNT solution shall have an update rate of 1s	Performance (Update rate)	[RD10] [RD11]
EUSPA-GN-UR-RAI-0260	The maximum allowable time between the occurrence of the failure in the PNT solution and its presentation to the user shall be between 10s and 30s.	Performance (Time To Alarm)	[RD10] [RD11]

- Driver Advisory System to be completed during the UCP

Id	Description	Type	Source
EUSPA-GN-UR-RAI-1140	The PNT solution shall provide an accuracy of 1m maximum for track identification.	Performance (Accuracy)	[RD30]
EUSPA-GN-UR-RAI-1141	The PNT solution shall be available over the whole EU Rail network	Performance (Availability)	[RD30]
EUSPA-GN-UR-RAI-1142	The PNT solution shall be available in urban canyon with a 95% probability	Performance (Availability)	[RD30]
EUSPA-GN-UR-RAI-1143	The PNT solution shall be available under canopy with a 95% probability	Performance (Availability)	[RD30]
EUSPA-GN-UR-RAI-1144	The PNT solution shall be available indoors with a 95% probability	Performance (Availability)	[RD30]

EUSPA-GN-UR-RAI-1145	The ability of the PNT solution to provide timely warnings to the user when data provided by the solution should not be used shall be Low.	Performance (Integrity)	[RD30]
EUSPA-GN-UR-RAI-1146	Size, weight and autonomy shall be considered if a handheld device is used to collect positions.	Function (Size, weight, autonomy, Time a device can run)	[RD30]
EUSPA-GN-UR-RAI-1152	The device shall run 8-10 hours (daily service of a driver)	Performance (Size, weight, autonomy, Time a device can run)	[RD30]
EUSPA-GN-UR-RAI-1147	The PNT solution shall have a TTFF of 1s	Performance (TTFF)	[RD30]
EUSPA-GN-UR-RAI-1148	The PNT solution shall have an update rate of 1s	Performance (Update rate)	[RD30]
EUSPA-GN-UR-RAI-1149	The maximum allowable time between the occurrence of the failure in the PNT solution and its presentation to the user shall be 10s.	Performance (Time To Alarm)	[RD30]

Hazardous Cargo Monitoring

Id	Description	Type	Source
EUSPA-GN-UR-RAI-0800	The PNT solution shall provide an accuracy of 1-10m.	Performance (Accuracy)	[RD10] [RD11]
EUSPA-GN-UR-RAI-0810	The availability of the location information provided by the PNT solution fulfilling its performance requirements shall be High.	Performance (Availability)	[RD10] [RD11]
EUSPA-GN-UR-RAI-0820	The ability of the PNT solution to provide timely warnings to the user when data provided by the solution should not be used shall be High.	Performance (Integrity)	[RD10] [RD11]
EUSPA-GN-UR-RAI-1021	The PNT solution shall be available over the whole EU Rail network	Performance (Availability)	[RD10] [RD11]
EUSPA-GN-UR-RAI-1022	The PNT solution shall be available in urban canyon with a high probability	Performance (Availability)	[RD10] [RD11]

EUSPA-GN-UR-RAI-1023	The PNT solution shall be available under canopy with a high probability	Performance (Availability)	[RD10] [RD11]
EUSPA-GN-UR-RAI-1024	The PNT solution shall be available indoors with a high probability	Performance (Availability)	[RD10] [RD11]
EUSPA-GN-UR-RAI-1025	The PNT solution shall have a TTFF 1s if If power is switched on/off for energy management	Performance (TTFF)	[RD30]
EUSPA-GN-UR-RAI-1026	The PNT solution shall have an update rate of 15min	Performance (Update rate)	[RD10] [RD11]
EUSPA-GN-UR-RAI-0830	The maximum allowable time between the occurrence of the failure in the PNT solution and its presentation to the user shall be between 10s and 30s.	Performance (Time To Alarm)	[RD10] [RD11]
EUSPA-GN-UR-RAI-1150	Size, weight and autonomy shall be considered.	Function (Size, weight, autonomy, Time a device can run)	[RD30]
EUSPA-GN-UR-RAI-1151	The device shall run on long periods (years).	Performance (Size, weight, autonomy, Time a device can run)	[RD30]

Door Control Supervision

Id	Description	Type	Source
EUSPA-GN-UR-RAI-0320	The PNT solution shall provide an accuracy of 1-10m.	Performance (Accuracy)	[RD10] [RD11]
EUSPA-GN-UR-RAI-0321	When using ATO, The PNT solution shall provide the train position with a horizontal accuracy within a range of 1m.	Performance (Accuracy)	[RD10] [RD11]
EUSPA-GN-UR-RAI-0330	The availability of the location information provided by the PNT solution fulfilling its performance requirements shall be High.	Performance (Availability)	[RD10] [RD11]

EUSPA-GN-UR-RAI-0340	The ability of the PNT solution to provide timely warnings to the user when data provided by the solution should not be used shall be High.	Performance (Integrity)	[RD10] [RD11]
EUSPA-GN-UR-RAI-0350	The maximum allowable time between the occurrence of the failure in the PNT solution and its presentation to the user shall be between 10s and 30s.	Performance (Time To Alarm)	[RD10] [RD11]

Infrastructure monitoring (previously entitled infrastructure surveying in [RD10][RD11])

Id	Description	Type	Source
EUSPA-GN-UR-RAI-0480	The PNT solution shall provide the train position with a horizontal accuracy within a range of 0.01-1m.	Performance (Accuracy)	[RD10] [RD11]
EUSPA-GN-UR-RAI-0490	The availability of the location information provided by the PNT solution fulfilling its performance requirements shall be Low.	Performance (Availability)	[RD10] [RD11]
EUSPA-GN-UR-RAI-0500	The ability of the PNT solution to provide timely warnings to the user when data provided by the solution should not be used shall be High.	Performance (Integrity)	[RD10] [RD11]
EUSPA-GN-UR-RAI-0510	The maximum allowable time between the occurrence of the failure in the PNT solution and its presentation to the user shall be 30s or even more.	Performance (Time To Alarm)	[RD10] [RD11]
EUSPA-GN-UR-RAI-0941	The PNT solution shall be available over the whole EU Rail network	Performance (Availability)	[RD10] [RD11]
EUSPA-GN-UR-RAI-0942	The PNT solution shall be available in urban canyon with a low probability	Performance (Availability)	[RD10] [RD11]
EUSPA-GN-UR-RAI-0943	The PNT solution shall be available under canopy with a low probability	Performance (Availability)	[RD10] [RD11]
EUSPA-GN-UR-RAI-0944	The PNT solution shall be available indoors with a low probability	Performance (Availability)	[RD10] [RD11]

6.2 Synthesis of Requirements Relevant to EO

This section only addresses the applications of Type A (identified in Chapter 5 introduction). The applications of Type B and C, which will not be covered in the current version of the RUR will be explicitly identified in the introduction of §6.2

ID	Application	Users	User Needs					Service Provider Offer		Service provider Satellite EO Requirements				Service inputs	
			Operational Scenario	Size of Area of Interest	Scale	Frequency of Information	Other (if applicable)	What the service does	How does the service work	Spatial resolution	Temporal resolution	Data Type / Spectral Range	Other (if applicable)	Satellite data sources	Other data sources
EUSPA-EO-UR-RAI-0001	Determination of surface ground movements	Railway infrastructure owners and/or operators.	Railways tracks can be affected by any movement taking place on the ground such as landslides, subsidence, uplifts, sinkholes, faults and seismic displacements. Avoiding or mitigating the consequences of such events poses significant challenges for planning, building and maintenance of railways infrastructures.	In general, a buffer of 500 m around the rail infrastructure is sufficient but it can be incremented depending on the geomorphology of the area to monitor and by the origin of ground movements.	From local to national	From weekly to monthly	Not applicable	Provide information on ground displacements in the surroundings of the infrastructure. The risk assessment can take different forms depending on what users need (e.g. map, reports)	The service uses the MT-InSAR technique to determine time series of the surface ground displacements, velocities, accelerations and strains. The variation of the velocity (acceleration) and the strain rate identify areas affected by active surface ground movements.	From 1 m up to 100 m	Weekly	SAR (C,X,L bands)	Not applicable	Sentinel-1, TerraSAR X, ALOS, Cosmo SkyMed	GNSS and precise levelling measurements for the determination of the movements of ground reference points. Piezometers for the determination of the level of ground water and pluviometers. Historical archives.
EUSPA-EO-UR-RAI-0002	Determination of soil moisture	Infrastructure owners and/or operators.	Determination of soil moisture, the total amount of water, including the water vapor in a land surface provides a basic information for the geotechnical engineering.	A buffer until 2000m around the railway infrastructure	From local to regional scale	Ad-hoc	Not applicable	Information provision	The service analyses InSAR and optical images to determine the soil moisture.	From 10 m up to 100 m	From daily to weekly	SAR (C,X,L bands), multi and hyper spectral images	Not applicable	Sentinel 1 and 2, TerraSAR-X, ALOS, Cosmo SkyMed	In-situ inspection and sensors such as piezometers.
EUSPA-EO-UR-RAI-0003	Weather Impact Assessments and Adaptation to Climate Change	Railway infrastructure owners and/or operators.	Determination of the risk and of the vulnerability for the planning of safety, durable and resilient infrastructures and to minimizes damage to railway infrastructure assets. Climate change and extreme weather events such as flooding, severe storms, landslides, rock fall, avalanches can have a devastating impact on the safety and the expected lifetime of infrastructures. The assesment is based with natural hazard management under today's weather conditions and develop solutions and strategies to prepare for the changed weather and climate conditions of the future.	Mainly the whole railway network	From regional to national	Ad-hoc	Not applicable	The service develops predictive models and maps of risks, to support the identification of solutions and strategies to prepare for the changed weather and climate conditions of the future and prioritize key actions to reduce asset exposure to damage and disruption.	The service combines EO observations, atmospheric, geomorphological and geographical data and models to develop predictive models and maps of risks.	From 10 m up to 100 m	From weekly to monthly	SAR (C,X,L) ; Multi and hyper spectral, Meteosat	Not applicable	Sentinel 1 and 2, TerraSAR-X, ALOS, Cosmo SkyMed	Atmospheric, geomorphological and geographical data and models. Historical archives.

EUSPA-EO-UR-RAI-0004	Geotechnical and structural monitoring during the construction	Railway infrastructure owners and/or operators, construction and public works companies, financial institutions financing the construction that can include international organisations.	Geotechnical and structural monitoring as part of the completion of a rail section. Continuous geotechnical and structural monitoring to control slopes and works to be built during the excavation of tunnels and the construction of railways.	The entire area susceptible to ground shifts caused by the construction or excavation of an infrastructure project.	Local	From daily to weekly	Not applicable		The service uses the MT-InSAR technique to determine time series of the surface ground displacements, velocities, accelerations, and strains. The variation of the velocity (acceleration) and the strain rate identify areas affected by active surface ground movements	From 1 m up to 100 m	From daily to weekly	SAR (C,X,L bands), Multi and hyper spectral	Not applicable	Sentinel-1 and 2, ALOS, TerraSAR X, Cosmo SkyMed	GNSS and precise levelling measurements for the determination of the movements of ground reference points. Piezometers for the determination of the level of ground water and pluviometers.
EUSPA-EO-UR-RAI-0005	Vegetation monitoring	Railway infrastructure owners and/or operators	The presence of vegetation along and close to the railway tracks can create obstacles and impact the trains.The monitoring of the status and growth of vegetation along the railway corridor can prevent hazards such as fallen trees or overgrown branches that can disrupt rail operations. The goal is the determination of the distance between vegetations and tracks. Identification of the types of vegetation, and determination of high height and volume of trees .	In general, a buffer of 100 m around the railway infrastructure is sufficient but it can be incremented depending on the geomorphology of the area to monitor. In the case of slope stability monitoring a wider buffer could be needed (>100m) to effectively monitor the surroundings.	From local to national	Monthly	Not applicable	Information provision and alert in case of presence of diseased and dead trees that can fall on the railway tracks.	The service analyses InSAR and optical images to determine the presence of vegetation and identify diseased and dead trees.	From 1 m up to 100 m	Weekly	SAR (C,X,L bands), Multi and hyper spectral	Not applicable	Sentinel-1 and 2, ALOS, TerraSAR X, Cosmo SkyMed	Aerial and drone imagery.
EUSPA-EO-UR-RAI-0006	Monitoring for the construction of new buildings	Railway infrastructure owners and/or operators.	Monitoring the construction activities, especially related to earthworks activities, of new and existing buildings within a certain distance from a railway track is crucial for safety and regulatory compliance. Satellite imagery can contribute to the identification of new buildings close the railways can create problems with the trains.Automated alerts and notifications to inform relevant stakeholders, including railway operators,	In general, a buffer of 100 m around the railway infrastructure is sufficient but it can be incremented depending on the geomorphology of the area to monitor.	From local to national	Monthly	Not applicable	Information provision and alert in case of the identification of new buildings	The service analyses InSAR and optical images to determine the presence of new buildings.	From 1 m up to 100 m	Weekly	SAR (C,X,L bands), Multi and hyper spectral	Not applicable	Sentinel-1 and 2, ALOS , TerraSAR X, Cosmo SkyMed, Planet	Aerial and drone imagery.

			local authorities, and regulatory agencies, when new construction is detected within the restricted area. Regulatory guidelines and safety standards regarding the distance between railways and buildings may vary from one jurisdiction to another.												
EUSPA-EO-UR-RAI-0007	Control of railway tracks located in places hard to reach"	Railway infrastructure owners and/or operators.	Controlling railway tracks located in hard-to-reach places presents unique challenges due to the remote and sometimes harsh environments in which they are situated. Managing the deformation of rail tracks and regular maintenance are crucial to maintain the safety and efficiency of rail transportation, and to prevent train incidents. These practices are key to keeping rail infrastructure functioning at its highest level.	The entire area susceptible to geohazards.	From local to national	From weekly to monthly	Not applicable	Provide information on ground displacements in the surroundings of the infrastructure, focusing on places difficult to reach (e.g. mountain environment, sea-side, etc.). The risk assessment can take different forms depending on what users need (e.g. map, reports) .	The service uses the MT-InSAR technique to determine time series of the surface ground displacements, velocities, accelerations and strains. The variation of the velocity (acceleration) and the strain rate identify areas affected by active surface ground movements. The service is integrated with the optical and SAR images for change detection.	From 1 m up to 100 m	Weekly	SAR (C,X,L bands)	Not applicable	Sentinel-1, TerraSAR X, ALOS, Cosmo SkyMed	Aerial and drone surveys.
EUSPA-EO-UR-RAI-0008	Condition and Predictive-based Maintenance	Railway infrastructure owners and/or operators.	Controlling the real-time condition of railway tracks and trains for detecting potential asset degradation and provide a pointed maintenance. CBM is a proactive approach to maintenance that uses condition-based monitoring to optimize equipment performance and lifespan by continually assessing its health in real time.	The entire railway networks	From local to national	From weekly to monthly	Not applicable	Provide information on asset degradation of railway tracks and trains.	The service is an integrated system that analyses optical, SAR images both from satellites, drones and on-board train cameras, and sensors.	From 1 m up to 100 m	Weekly	SAR (C,X,L bands), Multi and hyper spectral	Not applicable	Sentinel-1, TerraSAR X, ALOS, Cosmo SkyMed	Aerial, drone surveys and on-board train cameras and sensors.
EUSPA-EO-UR-RAI-0009	Flood monitoring	Railway infrastructure owners and/or operators.	During floods can be useful to identify railways that are involved in flood, helping the authorities to monitor the evolution of the situation, and in the management of the closing or reopening of the railways. Creation of flood maps to identify the areas to be checked before the re-activation of the railways.	Section of the railway infrastructure network involved in the flood	From local to regional	Ad-hoc, continuous monitoring	Not applicable	Map of flooded areas and alert provision	The service analyses InSAR and optical images to determine the areas affected by flood or disaster.	100 m	From daily to weekly	SAR (C,X,L bands) ; Multi and hyper spectral	Not applicable	Sentinel-1 and 2, ALOS, TerraSAR X, Cosmo SkyMed	Aerial and drone imagery.

EUSPA-EO-UR-RAI-0010	Weather Impact Assessments and Adaptation to Climate Change	Railway infrastructure owners and/or operators.	Natural hazard management related weather and climate such as flooding, severe storms, landslides, rock fall, avalanches etc in a way that keeps and improves railway infrastructure performance and avoids or minimizes damage to railway infrastructure assets. It starts with natural hazard management under today's weather conditions and develops solutions and strategies to prepare for the changed weather and climate conditions of the future.	Mainly the whole railway network	From regional to national	Ad-hoc	Not applicable	The service develops predictive models and maps of risks, to support the identification of solutions and strategies to prepare for the changed weather and climate conditions of the future and prioritize key actions to reduce asset exposure to damage and disruption.	The service combines EO observations, atmospheric, geomorphological and geographical data and models to develop predictive models and maps of risks.	From 10 m up to 100 m	From weekly to monthly	SAR (C,X,L), multi and hyper spectral, Meteosat	Not applicable	Sentinel 1 and 2, TerraSAR-X, ALOS, Cosmo SkyMed	Atmospheric, geomorphological and geographical data and models. Historical archives.

6.3 Synthesis of Requirements Relevant to SatCom

This section provides the general requirement for the railway telecom signal application called FRMCS, as defined by the UIC. Any system, regardless of its components and distribution architecture, aimed to support applications based on the following requirements will have to fulfil these requirements. These requirements could potentially be supported by any communication modes, whether terrestrial, mobile or satellite (examples of radio access technology includes LTE, UMTS, Wi-Fi, GSM-R, Satellite, etc.).

Application	Sub-Application	Distribution	Latency	Bandwidth	Reliability	Setup	Speed
Critical Communication Applications	On-train outgoing voice communication from the driver towards the controller(s) of the train	User-to-User/ Multi-user	Low	Low	High	Normal	High
	On-train incoming voice communication from the controller towards a train driver	User-to-User	Low	Low	High	Normal	High
	Multi-train voice communication for drivers including ground user(s)	Multi-user	Low	Low	High	Normal	High
	Banking voice communication	User-to-User/Multi-user	Low	Low	High	Normal	Normal
	Trackside maintenance voice communication	User-to-User/Multi-user	Low	Low	High	Normal	Normal
	Shunting voice communication	User-to-User/Multi-user	Low	Low	High	Immediate	Low
	Public emergency call	User-to-User	Low	Low	High	Normal	High
	Ground to ground voice communications	User-to-User	Low	Low	Normal	Normal	Low
	Automatic train protectionl communication	User-to-User/Multi-user	Low	Low	High	Immediate	High
	Automatic train operation communication	User-to-User/Multi-user	Low	Low	High	Immediate	High
	Data communication for Possession Management	User-to-User	Normal	Low	High	Normal	Low
	Trackside maintenance warning system communication	User-to-User/Multi-user	Low	Low	High	Immediate	Normal
	Remote control of engines communication	User-to-User	Low	Low	High	Normal	Normal
	Monitoring and control of critical infrastructure	User-to-User	Low	Low	High	Normal	Normal
	Railway emergency communication	User-to-User/Multi-user	Low	Low	High	Immediate	High
	On-train safety device to ground communication	User-to-User	Low	Low	High	Immediate	High
	Platform train interface alert	User-to-User/Multi-user	Low	Low	High	Immediate	Normal
	Working alone	User-to-User	Low	Low	High	Immediate	Low
	Voice Recording and access to the recorded data	N/A	N/A	N/A	Normal	N/A	Low
	Data recording and access	N/A	N/A	N/A	Normal	N/A	Low
	Shunting data communication	User-to-User/Multi-user	Low	Low	High	Normal	Low
	Train integrity monitoring data communication	User-to-User/Multi-user	Normal	Low	High	Immediate	High

	Public emergency warning	Multi-user	Low	High	High	Immediate	High
	On-train outgoing voice communication from train staff towards a ground user	User-to-User/Multi-user	Low	Low	Normal	Normal	High
	On-train incoming voice communication from a ground user towards train staff	User-to-User/Multi-user	Low	Low	Normal	Normal	High
	Railway staff emergency communication	User-to-User/Multi-user	Low	Low	High	Immediate	High
	Critical real time video	User-to-User/Multi-user	Low	High	High	Normal	High
	Critical Advisory Messaging services- safety related	User-to-User/Multi-user	Normal	Low	High	Immediate	High
	Virtual Coupling data communication	User-to-User/Multi-user	Low	Low	High	Normal	High
	Train parking protection	User-to-User	Normal	Low	High	Normal	Normal
	Safety application key management communication	User-to-User	Normal	Low	High	Immediate	High
Performance Communication Applications	Multi-Train voice communication for drivers excluding ground user(s)	Multi-user	Low	µLow	High	Normal	High
	On-train voice communication	User-to-User/Multi-user	Low	Low	Normal	Normal	High
	Lineside fixed telephony	User-to-User	Low	Low	High	Normal	Low
	On-train voice communication towards passengers (Public Address)	User-to-User/Multi-user	Low	Low	Normal	Normal	High
	Station public address	User-to-User/Multi-user	Low	Low	Normal	Normal	Low
	Communication at stations and depots	User-to-User/Multi-user	Low	Low	Normal	Normal	Low
	On-train telemetry communications	User-to-User	Normal	Low	High	Normal	Low
	Infrastructure telemetry communications	User-to-User	Normal	Low	High	Normal	Low
	On-train remote equipment control	User-to-User	Normal	Low	Normal	Normal	High
	Monitoring and control of non-critical infrastructure	User-to-User	Normal	Low	Normal	Normal	Low
	Non-critical real time video	User-to-User	Low	High	Normal	Normal	High
	Wireless on-train data communication for train staff	User-to-User	Normal	Low	High	Normal	Low
	Wireless on-train data communication for train staff	User-to-User	Normal	Low	High	Normal	Low
	Train driver advisory train performance	User-to-User	Normal	Low	High	Normal	Low
	Train departure data communications (voice and data)	User-to-User	Normal	Low	Normal	Normal	Low
	Messaging services	User-to-User/Multi-user	Normal	Low	Normal	Normal	High
	Transfer of data	User-to-User	Normal	Medium	Normal	Normal	High
	Record and broadcast – controller to driver(s)	User-to-User/Multi-user	Normal	Medium	Normal	Normal	High

	Transfer of CCTV archives	User-to-User	Normal	High	Normal	Normal	Low
	Non-critical real time video communication	User-to-User/Multi-user	Low	Medium	Normal	Normal	High
	Augmented reality data communication	User-to-User	Low	Medium	Normal	Normal	High
	Real time translation of languages data communication	User-to-User	Low	Medium	Normal	Normal	High
Business Communication Applications	Information help point for public	User-to-User	Low	Low	Normal	Normal	Low
	Emergency help point for public	User-to-User	Low	Low	Normal	Normal	Low
	Wireless internet on-train for passengers	User-to-User	Normal	High	Normal	Normal	High
	Wireless internet for passengers on platforms	User-to-User	Normal	High	Normal	Normal	High
Critical Support Applications	Assured Voice Communication (voice and data)	User-to-User/Multi-user	Low / Normal	Low	High	Normal	Normal
	Multi user talker control	User-to-User/Multi-user	Low	Low	High	Normal	High
	Role management and presence	User-to-User/Multi-user	Normal	Low	High	Normal	High
	Location services	User-to-User/Multi-user	Low	Low	High	Normal	High
	Authorisation of communication	User-to-User	Low	Low	High	N/A	High
	Authorisation of application	User-to-User	Normal	Low	High	Normal	High
	QoS and priority	User-to-User	Normal	Low	High	N/A	High
	Assured data communication	User-to-User/Multi-user	Normal	Low	High	Normal	Normal
	Inviting-a-user messaging	User-to-User	Normal	Low	Normal	Normal	High
	Authorisation of application	User-to-User	Normal	Low	High	N/A	High
	Distribution of synchronised time	User-to-User/Multi-user	High	Low	High	N/A	High

Source: UIC - Future Railway Mobile Communication System User Requirements Specification - v5.1.0

6.4 Sources for the requirements

As this document is mostly based on interviews, the requirements come from the feedback from experts and various UCP participants. The sources vary with the specific application. The majority of input came from the persons listed below while the community participated as well via the UCP.

Many of the EO and GNSS requirements were discussed during previous UCPs. The new proposed requirements come from interviews with SNCF for the DAS application and Alstom for the Enhanced Odometry. Regarding EO, this document is the first edition of the report on user requirements featuring EO-related applications. Literature review, stakeholder consultations and discussions via the UCP have supported the current editions for EO-related user requirements.

7 ANNEXES

A.1 Definition of key GNSS performance parameters

This annex provides a definition of the most commonly used GNSS performance parameters, taken from 99[RD2]**Error! Reference source not found.** and includes additional details which are relevant for Rail segment community.

Availability: the percentage of time the position, navigation or timing solution can be computed by the user. Values vary greatly according to the specific application and services used, but typically range from 95-99.9%. There are two classes of availability:

- System availability: the percentage of time the system allows the user to compute a position - this is what GNSS Interface Control Documents (ICDs) refer to.
- Overall availability: takes into account the receiver performance and the user's environment. Values vary greatly according to the specific use cases and services used.

Accuracy is the difference between true and computed solution (position or time). This is expressed as the value within which a specified proportion – usually 95% – of samples would fall if measured. This report refers to positioning accuracy using the following convention: centimetre-level: 0-10cm; decimetre level: 10-100cm; metre-level: 1-10 metres.

Continuity is the ability of a system to perform its function (deliver PNT services with the required performance levels) without interruption once the operation has started. It is usually expressed as the risk of discontinuity and depends entirely on the timeframe of the application. A typical value is around 1*10-4 over the course of the procedure where the system is in use.

Indoor penetration is the ability of a signal to penetrate inside buildings (e.g. through windows). Indoor penetration does not have an agreed or typical means for expression. In GNSS this parameter is dictated by the sensitivity of the receiver, whereas for other positioning technologies there are vastly different factors that determine performance (for example, availability of WiFi base stations for WiFi-based positioning).

Integrity is a term used to express the ability of the system to provide warnings to users when it should not be used. It is the probability of a user being exposed to an error larger than the alert limits without timely warning. The way integrity is ensured and assessed, and the means of delivering integrity-related information to users are highly application dependent. Throughout this report, the "integrity concept" is to be understood at large, i.e. not restricted to safety-critical or civil aviation definitions but also encompassing concepts of quality assurance/quality control as used in other applications and sectors.

Latency is the difference between the reference time of the solution and the time this solution is made available to the end user or application (i.e. including all delays). Latency is typically accounted for in a receiver, but presents a potential problem for integration (fusion) of multiple positioning solutions, or for high dynamics mobile devices.

Robustness relates to spoofing and jamming and how the system can cope with these issues. It is a more qualitative than quantitative parameter and depends on the type of attack or interference the receiver is capable of mitigating. Robustness can be improved by authentication information and services.

Authentication gives a level of assurance that the data provided by a positioning system has been derived from real signals. Radio frequency spoofing may affect the positioning system, resulting in false data as output of the system itself.

Power consumption is the amount of power a device uses to provide a position. It will vary depending on the available signals and data. For example, GNSS chips will use more power when scanning to identify signals (cold start) than when computing a position. Typical values are in the order of tens of milliwatts (for smartphone chipsets).

Time To First Fix (TTFF) is a measure of time between activation of a receiver and the availability of a solution, including any power on self-test, acquisition of satellite signals and navigation data and computation of the solution. It mainly depends on data that the receiver has access to before activation: cold start (the receiver has no knowledge of the current situation and must thus systematically search for and identify signals before processing them – a process that can take up to several minutes.); warm start (the receiver has estimates of the current situation – typically taking tens of seconds) or hot start (the receiver understands the current situation – typically taking a few seconds).

Time To First accurate Fix (TTFaF) is a measure of a receiver's/solution's performance covering the time between activation and output of a position within the required accuracy bounds.

A.2 Definition of key EO performance parameters

This annex provides a definition of the most commonly used EO performance parameters and includes additional details which are relevant for Rail segment community.

Spatial resolution relates to the level of detail that can be retrieved from a scene. In the case of a satellite image, which consists of an array of pixels, it corresponds to the smallest feature that can be detected on the image. A common way of characterising the spatial resolution is to use the Ground Sample Distance (GSD) which corresponds to the distance measured on the ground between the centres of two adjacent pixels. Thus, a spatial resolution of 1 meter means that each pixel represents a 1 by 1 meter area on the ground.

Spectral resolution refers to the ability of a sensor to differentiate electromagnetic radiation of different wavelengths. In other words, it refers to the number and “size” of wavelength intervals that the sensor is able to measure. The finer the spectral resolution, the narrower the wavelength range for a particular channel or band. In remote sensing, features (e.g. water, vegetation) can be characterised by comparing their “response” in different spectral bands.

Radiometric resolution expresses the sensitivity of the sensor, that is to say its ability to differentiate between different magnitudes of the electromagnetic energy. The finer the radiometric resolution, the more sensitive it is to small differences in the energy emitted or reflected by an object. The radiometric resolution is generally expressed in bit, e.g. an 8-bit image has a scale of 2^8=256 nuances.

Temporal resolution relates to the time elapsed between two consecutive observations of the same area on the ground. The higher the temporal resolution, the shorter the time between the acquisitions of two consecutive observations of the same area. In absolute terms, the temporal resolution of a remote sensing system corresponds to the time elapsed between two consecutive passes of the satellite over the exact same point on the ground (generally referred to as “revisit time” or “orbit cycle”). However, several parameters like the overlap between the swaths of adjacent passes, the agility of the satellites and in case of a constellation, the number of satellites mean that some areas of the Earth can be reimaged more frequently. For a given system, the temporal resolution can therefore be better than the revisit time of the satellite(s).

Geolocation accuracy refers to the ability of an EO remote sensing platform to assign an accurate geographic position on the ground to the features captured in a scene. An accurate geolocation makes easier the combination of several images (e.g. combination of a Synthetic Aperture Radar image with a cadastral map and a vegetation map).

Spectral range refers to the wavelength range of a particular channel or band over in which remote sensing data must be collected.

Latency is the difference between the reference time of the satellite measurement and the time the final product is made available to the user (here the service provider).

A.3 Other performance parameters

Size, weight, autonomy and power consumption. Power consumption and size are not strictly GNSS performance parameters, however they are also considered in this analysis, especially for GIS and Mapping-related applications.

- **Autonomy**. Power consumption is the amount of power a device uses to provide a position. The power consumption of the positioning technology will vary depending on the available signals and data. For example, GNSS chips will use more power when scanning to identify signals (cold start) than when computing a position. Typical values are in the order of tens of mW (for smartphone chipsets). GNSS is considered one of the heaviest drains on smartphones batteries
- **Size, weight**. Most GIS devices used by NGOs are handheld or rugged tablets/phones, which implies that they must remain small and lightweight.

Resiliency is the ability to prepare for and adapt to changing conditions and withstand and recover rapidly from disruptions; including the ability to recover from deliberate attacks, accidents, or naturally occurring threats or incidents. A resilient system will change its way of operations while continuing to function under stress, while a robust (but non-resilient) system will reach a failure state at the end, without being able to recover.

Connectivity refers to the need for a communication and/or connectivity link of an application to be able to receive and communicate data to third parties. Connectivity relies on the integration with both satellite and terrestrial networks, such as 5G, LEO satellites, or LPWANs.

Interoperability refers to the characteristic of a product or system, whose interfaces are completely understood, to work with other products or systems, in either implementation or access, without any restrictions (e.g. ability of GNSS devices to be combined with other technologies and the possibility to merge the GNSS output with the output coming from different sources).

Traceability is the ability to relate a measurement to national or international standards using an unbroken chain of measurements, each of which has a stated uncertainty. For Finance applications, knowledge of the traceability of the time signal to UTC is essential to ensure regulatory compliance of the time-stamp.

Agility corresponds to the ability of a satellite to modify its attitude and to point rapidly in any direction in order to observe areas of interest outside its ground trace. High agility can improve the temporal resolution compared with the revisit time of the satellite.

Swath corresponds to width of the portion of the ground that the satellite "sees" at each pass. The larger the swath, the bigger the observed area at each pass.

Off-nadir angle corresponds to the angle at which images are acquired compared with the "nadir", i.e. looking straight down at the target. In practice, objects located directly below the sensor only have their tops visible, thus making it impossible to represent the three-dimensional surface of the Earth. High resolution images are therefore generally not collected at nadir but at an angle. A large off-nadir angle enables a wider ground coverage at each pass and the identification of features not visible at nadir, but it reduces the spatial resolution. For optical imagery, typical off-nadir angles are in the range of 25-30 degrees.

Sun-elevation angle corresponds to the angle of the sun above the horizon at the time an image is collected. High elevation angles can lead to bright spots on the imagery while low elevation angles lead to darker images and longer shadows. The most appropriate angle depends on the type of application: a high sun elevation is appropriate for spectral analysis since the objects to be observed are well illuminated while a lower elevation angle is better suited to interpretation of surface morphology (e.g. the projected shadows can enable a better image interpretation).

A.4 Additional definitions

Ground deformation monitoring is the process which consists in tracking the vertical and horizontal movements of the land surface and their dynamics, whatever these movements are caused by natural phenomena (e.g. volcanic activity) or by human activities (e.g. aquifer exploitation).

Change detection is the process which aims at identifying difference in the state of "objects" (e.g. bridges, constructions, urban areas) or of a phenomenon (e.g. deforestation, soil sealing) by comparing snapshots of the situation at different times. In Earth Observation, change detection is extensively based on satellite imagery obtained through a wide variety of sensors (e.g. optical, radar, infrared, microwave, etc.

Interferometric Synthetic Aperture Radar (InSAR) is a technique enabling to generate surface deformation maps based on the processing of SAR images captured at different moments in time. The processing uses the fact that if the ground has moved between the times of two SAR images of the same area, a slightly different portion of the wavelength is reflected back to the satellite resulting in a measurable phase shift that is proportional to displacement. The processing therefore consists in obtaining information about the vertical movements of the ground surface by calculating the phase difference between the emitted radar signal and the signal backscattered by the surface for successive images. InSAR can potentially measure deformations of millimetre-scale during periods ranging from days to years.

A.5 Overview of InSAR techniques

Brief description of EO for ground movement detection – Interferometric Synthetic Aperture Radar (InSAR)

One of the most common techniques used to measure ground motion around the infrastructures from the space is the Interferometric Synthetic Aperture Radar (InSAR) by using radar-equipped satellites that emit radar waves towards the Earth's surface and records the reflected signals [RD34].

Differential Interferometry Synthetic Aperture Radar (DInSAR) works by comparing SAR images from two or more radar acquisitions. It relies on the coherence of radar signals, which is a measure of how well the radar waves reflect from the same point on the Earth's surface over multiple acquisitions.

The technique consists of the measurement of the signal phase variation between images acquired on the same section at different times. Changes in the phase between two acquisitions indicate changes in the distance between the satellite and the Earth's surface. This phase difference can be converted into ground displacement measurements. One of the main advantages of InSAR is that radar images can penetrate through clouds and are suitable for nighttime as they do not rely on visible or infrared light.

DInSAR exploits SAR acquisition sequences measured and collected over long periods of time over the same geometry. The combination of these factors allows for the obtention of relevant details concerning the spatial and temporal patters in ground motion over time. However, this technique can present decorrelation due to ground cell noise, coming mostly from the vegetation surrounding the area of interest which can move and lead to the false identification of ground movement.

To overcome the limitations of DInSAR, Multi-Temporal InSAR (MT-InSAR) has been developed. MT-InSAR is an advanced technique that extends the capabilities of traditional InSAR by stacking and analysing a series of SAR images acquired over multiple time periods and to remove the atmospheric disturbances that could distort the observations.

MT-InSAR is particularly useful for monitoring ground deformation and surface changes over longer time spans ranging from weeks to years, it is highly effective in capturing slow-moving deformation processes that may not be apparent in single-pair InSAR acquisitions and can provide more comprehensive insights into the evolution of deformation phenomena. MT-InSAR is crucial for assessing the stability and the surveillance of critical infrastructure over an extended period.

Persistent Scatterers Interferometry (PSI) is one of the most important techniques applied to satellite MT-InSAR that produce Persistent Scatterers (PS), which are sparse ground point-wise radar benchmarks characterized by long-term stability of the electromagnetic backscattered signal and high reflectivity. These radar targets allow retrieving estimates of movement in terms of mean yearly velocity and single displacement measures at each acquisition date, along the satellite LOS (Line Of Sight) with millimetric accuracy. When a LOS diversity and much higher temporal sampling are needed for specific applications, ground-based SAR sensors can be used.

The number of PS can change between different regions, depending on the number of available SAR images and on the presence of reflecting elements on the ground, both artificial (e.g. buildings, bridges, pylons, street lights, above-ground pipelines, any rectilinear structure that can create a dihedral signal reflection back to the satellite) and natural (e.g. rocky outcrops, hard unvegetated surfaces, boulders). Given that the PSI technique is based on a differential method, i.e. multi-temporal interferometric approach, PS time-series analysis is a powerful technique for detecting and monitoring surface movements of unstable areas at a detailed scale (e.g., buildings and landslides).

A.6 Policy and regulation relevant to infrastructure

As mentioned in section 4.1, there are a number of policy or regulatory documents which may have an indirect impact on the infrastructure market.

The first of them is the Communication from the Commission on the European Green Deal ([RD6]) which ambitions to achieve climate neutrality by 2050 and indicates that efforts will have to be strengthened in several domains among which climate-proofing, resilience building, prevention and preparedness. All of them apply to the infrastructure sector and the Communication from the Commission recommends that all the actors across the EU develop instruments to integrate climate change into their risk management practices. Applied to infrastructures, this would mean in particular to take climate change into account when selecting new sites for construction, when designing new infrastructures and when operating/maintaining infrastructures. Interestingly, the Communication from the Commission mentions a number of digital technologies considered to be a critical enabler for attaining the sustainability goals of the Green deal (e.g. artificial intelligence, 5G, cloud and edge computing and the internet of things) but does not mention GNSS or Earth Observation.

The European Green Deal refers in turn to two other potentially relevant documents: the Communication from the Commission on the EU Biodiversity Strategy for 2030 ([RD7]) and the EU Action Plan: 'Towards Zero Pollution for Air, Water and Soil', formalised later in 2021 through another Communication from the Commission ([RD8]).

The EU's Biodiversity Strategy for 2030 is a comprehensive, ambitious and long-term plan to protect nature and reverse the degradation of ecosystems. The strategy aims to put Europe's biodiversity on a path to recovery by 2030, and contains specific actions and commitments. In particular, it aims at stopping loss of green urban ecosystems and recommends to systematically integrate the promotion of healthy ecosystems, green infrastructure and nature-based solutions into urban planning, including in public spaces, infrastructure, and the design of buildings and their surroundings.

The EU Action Plan: 'Towards Zero Pollution for Air, Water and Soil' aims to improve public health protection. It indicates among others that the Commission will introduce stricter requirements to tackle air pollution at source in several sectors including agriculture, industry, transport, energy and also buildings, this latter aspect being directly related to the construction sector and therefore to infrastructure. The EU Action Plan mentions Copernicus as major building block for the EU's Destination Earth Initiative. The EU action plan identifies a number of "Flagships", one of them being dedicated to "showcasing zero pollution solutions for buildings" (Flagship 6). Through this flagship, the Commission aims to showcase from the renovation wave strategy and New European Bauhaus initiative how building projects and the use of Local Digital Twins can also contribute to zero pollution objectives.

Another potentially relevant document is the "new Circular Economy Action Plan For a cleaner and more competitive Europe" ([RD9]). This Communication from the Commission indicates that the Commission will launch a new comprehensive Strategy for a Sustainable Built Environment, which will ensure coherence across the relevant policy areas such as climate, energy and resource efficiency, management of construction and demolition waste, accessibility, digitalisation and skills. The document mentions Copernicus as a source of data to improve circularity metrics.

As mentioned previously, the case of "critical infrastructures" is subject to a specific policy/regulatory framework.

In December 2008, the European Commission issued a Directive on the "identification and designation of European Critical Infrastructures and the assessment of the need to improve their protection" ([RD14]). The Directive, also known as "ECI Directive" distinguishes the "critical infrastructure" from "European critical infrastructure" and mentions that "There are a certain number of critical infrastructures in the Community, the disruption or destruction of which would have significant cross-border impacts [...]. The evaluation of security requirements for such infrastructures should be done under a common minimum approach." Although the Directive applies only to the energy and transport sectors ("The sectors to be used for the purposes of implementing this Directive shall be the energy and transport sectors."), it mentions that "if deemed appropriate, subsequent sectors to be used for the purpose of implementing the Directive may be identified. Priority shall be given to the ICT sector". The ECI Directive also sets out specific protection requirements on ECI operators and competent Member State authorities.

In December 2020, the European Commission issued a proposal for a Directive on the resilience of critical entities ([RD10]) to replace the ECI Directive. In this document, the European Commission proposes to switch from the approach consisting in protecting specific assets toward an approach aiming at reinforcing the resilience of the critical entities that operate these assets. The proposed directive has a much wider sectoral scope, covering ten sectors, namely energy, transport, banking, financial market infrastructure, health, drinking water, waste water, digital infrastructure, public administration, and space. It defines obligations for Member States (e.g. obligation to identify critical entities and to define a strategy for reinforcing the resilience of these critical entities) and for critical entities (e.g. obligation to assess at least every four years the risks that may disrupt their operations). The proposed directive also requires that measures to prevent incidents from occurring are defined and explicitly mentions the need for "disaster risk reduction and climate adaptation measures". However, the proposed directive does not impose any obligation on the means or type of information to be used by Member States and critical entities to implement the Directive and does not refer either to Earth Observation or to GNSS. It therefore does not impose any obligation on the use of EO and GNSS in the Infrastructure sector.

A.7 List of of Acronyms

Acronym	Definition
ATO	Automatic Train Operation
ATP	Automatic Train Protection
CCS	Command and Control System
CI	Confidence Interval
CMD	Cold Movement Detection
DAS	Driver Advisory System
EC	European Commission
EGNOS	European Geostationary Navigation Overlay Service
EGNSS	European Global Navigation Satellite System
EO	Earth Observation
EOA	End of Movement Authority
ERA	European Union Agency for Railways
ETCS	European Train Control System
ERTMS	European Rail Traffic Management System
ESA	European Space Agency
EU	European Union
EUSPA	European Agency for the Space Programme
FRMCS	Future Railway Mobile Communication System
GNSS	Global Navigation Satellite System
HAS	High Accuracy Service
MR	Market Report
EUSPA	European Union Agency for the Space Programme
OSNMA	Open Service Navigation Message Authentication
PNT	Positioning, Navigation and Timing
RAIM	Receiver Autonomous Integrity Monitoring
RAMS	Reliability Availability Maintainability Safety
R&D	Research and development
RUR	Report on User needs and Requirements
R&I	Research and Innovation
SATCOM	Satellite communications
SME	Small and Medium-sized Enterprise

Acronym	Definition
ATO	Automatic Train Operation
ATP	Automatic Train Protection
SIL	Safety Integrity Level
SoL	Safety of Life Service
SST	Space Surveillance and Tracking
UCP	User Consultation Platform
UNISIG	UNion Industry of SIGnalling

A.8 Reference Documents

Id.	Reference	Title	Date
[RD1]	EUSPA Market Report	EUSPA EO and GNSS Market Report (Issue 1)	Jan. 2022
[RD2]	Spottitt	SAR and Optical Satellite Images for Advanced Asset Monitoring. Available at: https://spottitt.com/industry-news/sar-and-optical-satellite-images-for-advanced-asset-monitoring/	2023
[RD3]	OCORA-TWS01-101	Localisation-On-Board-(LOC-OB) Requirements	June 2023
[RD4]	GRAIL-2 D4.2	GRAIL-2 project report D4.2, Safety approval process, V. Antón, Tech. Rep.	2013.
[RD5]	Himrane PhD Thesis	Himrane, O. Contribution to safety and operational performance evaluation of GNSS-based railway localization systems using a formal model-based approach (Doctoral dissertation, Université de Lille).	2022
[RD6]	IEEE Access journal paper	P. Zabalegui, G. De Miguel, A. Pérez, J. Mendizabal, J. Goya and I. Adin, "A Review of the Evolution of the Integrity Methods Applied in GNSS," in IEEE Access, vol. 8, pp. 45813-45824, 2020, doi: 10.1109/ACCESS.2020.2977455.	2020
[RD7]	ESSP-TN-11715 v01-00	Report on the use of EGNOS V2 for Railway safety and non-safety applications (not public)	08.05.2014
[RD8]	ERA website	https://www.era.europa.eu/	2023
[RD9]	SATLOC	Impact of the EGNOS and Galileo integrity on the design of railway on board fail-safe positioning equipment George BARBU, UIC (SATLOC project)	2008
[RD10]	GSA-MKD-RL-UREQ-250286	Report on User Needs and Requirements, Outcome of the EUSPA User Consultation Platform	2021
[RD11]	EUSPA-MKD-RL-UREQ-A11383	Annex 7 to the Report on User Needs and requirements for Rail	2021
[RD12]	GRAIL-WP3	GNSS Subsystem Requirements Specification for Enhanced Odometry Application	2008
[RD13]	SUBSET-041	UNISIG SUBSET-041 Performance Requirements for Interoperability, Issue 3.2.0	2015
[RD14]		Interview with Sebastien Dislaire, SNCF Réseau	29.09.2023

Id.	Reference	Title	Date
[RD15]	CLUG_D3.1.1	GNSS augmentation usage for CLUG, CLUG D3.1.1	07.06.2021
	CLUG_D5.7	Preliminary definition of the system performances and interfaces, CLUG D5.7	29.06.2022
[RD16]	Marzoni	M. G. Marzoni, A. Lippi, F. Rispoli, F. Senesi, and A. Rapaccini, “On the certification process for satellite-based applications in the ERTMS ETCS train control system,” in Proc. Eur. Navigat. Conf., Apr. 2015, p. 7–10.	2015
[RD17]	Tsunashima	Tsunashima, H.; Ono, H.; Takata, T.; Ogata, S. Development and Operation of Track Condition Monitoring System Using In-Service Train. Appl. Sci. 2023, 13, 3835. https://doi.org/10.3390/app13063835	2023
[RD18]	IEA, Future of Rail	IEA, The Future of Rail, January 2019. Available at: https://www.iea.org/reports/the-future-of-rail	01.2019
[RD19]	EC – User Needs Copernicus Programme	COMMISSION STAFF WORKING DOCUMENT Expression of User Needs for the Copernicus Programme. Available at: https://www.copernicus.eu/sites/default/files/2019-10/STAFF_WORKING_PAPER_2019-394-Expression_of_User_Needs_for_the_Copernicus_Programme.pdf	10.2019
[RD20]	ITAtech	ITAtech Report n°3-v2, May 2015. ITAtech Guidelines for Remote Measurements Monitoring Systems	05.2015
[RD21]	United Nations UN SPIDER Portal	United Nations UN-SPIDER portal. Data Application of the Month: Land Deformation Mapping Using DInSAR https://www.un-spider.org/links-and-resources/data-sources/daotm-land-deformation	2023
[RD22]	EUSPA URD Infra 2022	EUSPA, Report on Infrastructure User Needs and Requirements, 2022.	2022
[RD23]	Vizzari	Vizzarri A, Mazzenga F, Giuliano R. Future Technologies for Train Communication: The Role of LEO HTS Satellites in the Adaptable Communication System. Sensors (Basel). 2022 Dec 21;23(1):68. doi: 10.3390/s23010068. PMID: 36616666; PMCID: PMC9823863.	2023

Id.	Reference	Title	Date
[RD24]	ERA - SatCom	ERA, Study on feasibility of SATCOM for railway communication by Indra and ALG for the European Union Agency for Railways over the period June 2016 – February 2017.	02.2017
[RD25]	Inmarsat	Inmarsat, Defining the Future of Rail Operations, 2022. Available at : https://www.inmarsat.com/content/dam/inmarsat/corporate/documents/enterprise/insights/Inmarsat_WP_Defining_the_future_of_rail_connectivity.pdf.coredownload.inline.pdf	2022
[RD26]	UNIFE	UNIFE, Successful Transition to FRMCS UNIFE Position Paper on the Key Success Factors for the transition to FRMCS. September 2021. https://www.unife.org/wp-content/uploads/2021/09/UNIFE-Postion-Paper_Successful-Transition-to-FRMCS_v28092021Final.pdf	9.2021
[RD27]	Nicholas Shrimpton	Nicholas Shrimpton, Unleashing the potential of FRMCS together, Global Railway Review. November 2022. https://www.globalrailwayreview.com/article/137315/unleashing-the-potential-of-frmcs-together/	11.2022
[RD28]	Dan Mandoc	Dan Mandoc, UIC FRMCS Project Manager, FRMCS Definition, Specification and Standardization Activities, 2022. https://www.era.europa.eu/system/files/2022-11/4-3_dan_mandoc_era_uic_frmcs_definition_16102019_en.pdf	2022
[RD29]	UIC	UIC, Future Railway Mobile Communication System User Requirements Specification. 2019. https://uic.org/IMG/pdf/frmcs_user_requirements_specification_version_4.0.0.pdf	2019
[RD30]	EUSPA-MKD-UM-MOM-v_1.0_UCP 2023_RAIL_session MOM - FINAL - 14122023 - EY	UCP 2023 MINUTES OF MEETING OF THE RAIL MARKET SEGMENT PANEL	2023
[RD31]	ESA – SATCOM4rail	SATCOM4rail, Final report: Specification of a Certification Framework for Satellite Communication in Railway Safety Applications (ESA Contract N.: 4000107663/13/NL/CLP	2014

Id.	Reference	Title	Date
[RD32]	GNSS Technology Report	GSA GNSS Technology Report (Issue 3)	Sept. 2020
[RD33]	IEA	https://www.iea.org/reports/the-future-of-rail	Jan. 2019
[RD34]	Edward Hoppe and al.	Edward Hoppe and al. Bridge Remote Sensing Using TerraSAR-X Satellite, SMAR 2019 – Fifth Conference on Smart Monitoring, Assessment and Rehabilitation of Civil Structures. Available at: https://www.ndt.net/article/smar2019/papers/Tu.2.A.8.pdf	2019

EUSPA Mission Statement

The mission of the European Union Agency for the Space Programme (EUSPA) is defined by the EU Space Programme Regulation. EUSPA's mission is to be the user-oriented operational Agency of the EU Space Programme, contributing to sustainable growth, security and safety of the European Union.

The EU Agency for the Space Programme:

- Provides state-of-the-art, safe and secure positioning, navigation and timing services based on Galileo and EGNOS, cost-effective satellite communications services for GOVSATCOM and soon IRIS², and Front Desk services of the EU Space Surveillance Tracking whilst ensuring the systems' service continuity and robustness.
- Promotes and maximises the use of data and services offered by Galileo, EGNOS, Copernicus, GOVSATCOM and soon IRIS² across a broad range of domains.
- Fosters the development of a vibrant European space ecosystem by providing market intelligence, and technical know-how to innovators, academia, start-ups, and SMEs. The agency leverages Horizon Europe, other EU funding, and innovative procurement mechanisms.
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