2023

Report on Public Transport

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 IRIS[2], 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 *Public Transport* community, reporting periodically the most up-to-date user needs and requirements in the *Public Transport* market 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 to 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.

This segment has been split into 3 sub-segments considering the previous report on Public Transport User Needs and Requirements (GSA-MKD-RL-UREQ-A11400 v1.0 dated 28 April 2021).

- Bus;
- Tram;
- Urban rail.

The focus of this report will primarily be on the bus sub-segment for two key reasons. Firstly, it is the only sub-segment not addressed in other sectors - urban rail and tram are covered in the rail sector. Secondly, the bus sub-segment involves a higher and more complex number of GNSS and EO applications. Finally, as the report is publicly available, it also serves as a reference for users and the 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

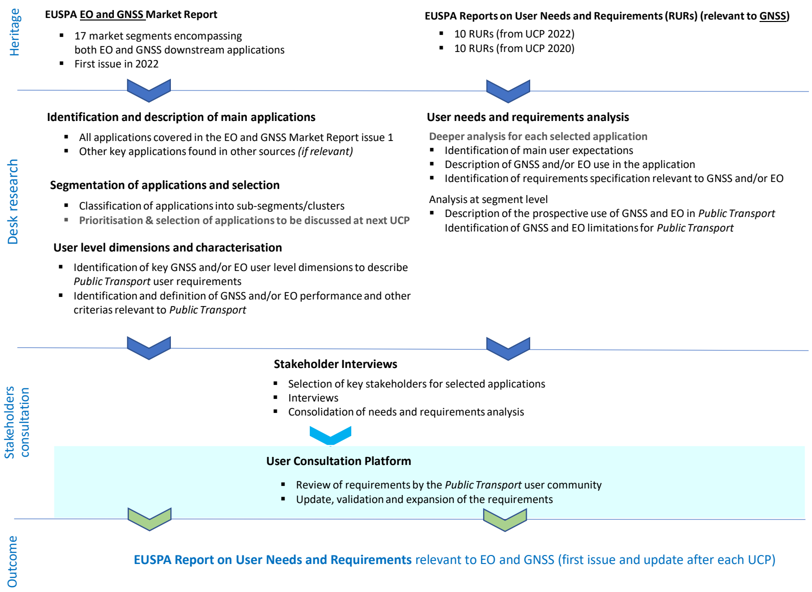

Figure 1: Public Transport user requirements analysis methodology

As presented in Figure 1, the work leverages on the latest EUSPA EO and GNSS Market Report, adopting the market segmentation for EO and GNSS downstream applications as starting point and 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 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 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 *Public Transport* user community. The outcomes of the *Public Transport* forum discussions were finally examined 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

This document is part of the User Requirements documents issued by the European Union Agency for the Space Programme for the market segments where Position Navigation and Time (PNT) and Earth Observation (EO) data play a key role. Its scope is to cover requirements on PNT and Earth Observation-based solutions from the strict user perspective and considering the market conditions, regulations, and standards that drive them.

The document starts with a market overview for *Public Transport* (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 standards and best practices (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 the depth of information available in the current version of the report for each application: 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 while providing a detailed overview of the related requirements at application level. A few key applications have been addressed during the UCP and are analysed more in detail.
- 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 *Public Transport* are addressed in section 5.3.
- Section 5.4 provides a synthesis of the main drivers for the user requirements in *Public Transport.*

Finally, section 6 summarises the main User Requirements for *Public Transport* 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 systems engineering and to shape the evolution of the European Union's satellite navigation systems, Galileo and EGNOS and the Earth Observation system, Copernicus.

2 EXECUTIVE SUMMARY

Key trends and market evolution

Public transportation solutions play a vital role in enhancing the well-being of urban communities and are currently experiencing rapid development in the use of GNSS (Global Navigation Satellite System). GNSS proves invaluable in aiding public transport operators (PTOs) across various aspects, including fleet management, passenger information, autonomous vehicles, driving advisory systems, and driving monitoring. Concurrently, Earth Observation contributes to transportation network planning and optimization for PTOs. Notably, European GNSS-based solutions have witnessed significant growth in public transport, with fleet management, passenger information, and autonomous vehicles emerging as the most widely adopted applications in buses, trams, and urban rails. It is noteworthy that, especially in the context of buses, GNSS serves as a key technology for driver advisory systems and driving monitoring, providing accurate positioning, navigation, and timing information.

Current and prospective use of GNSS and EO in Public Transport

In the contemporary context, GNSS finds extensive use in public transport, serving various purposes such as fleet management, passenger information, advanced driver assistance systems (ADAS), and autonomous vehicles, all thoroughly examined in this report. On the other hand, EO is somewhat limited in its application within public transport.

This report delves into a comprehensive analysis of user needs and requirements related to public transport applications, delineating the distinct roles and needs addressed by GNSS and EO. It identifies corresponding user requirements, with a specific focus on public transport, particularly buses in comparison to trams and trains, to minimize potential overlaps with applications in other market segments like rail and road. While GNSS and EO bring numerous advantages to public transport applications, there are still several limitations and challenges. To address GNSS limitations, other technologies can be utilized as complementary or substitute solutions. For instance, Galileo OSNMA and HAS can mitigate certain GNSS limitations, offering signals in multiple frequency bands, authentication for signal and data, and enhanced accuracy under nominal conditions.

Considering the future impact of GNSS and EO on public transport, it is pertinent to highlight the European Commission's strategy to achieve specific milestones by 2050, aiming for smart and sustainable mobility. This aligns seamlessly with the benefits that GNSS and EO can provide for public transport.

In the years ahead, GNSS and EO will play a pivotal role in the evolution of public transport. These technologies will enhance the availability of near-real-time information and improve location accuracy, integrity, and precision, facilitating accurate vehicle tracking, route optimization, and the development of more precise safety-critical solutions. Additionally, GNSS and EO will contribute to a deeper understanding of the public transport environment, enabling more accurate analysis and evidence-based decision-making. This data-driven strategy will rely on measurements encompassing vehicle speed, traffic patterns, landscapes, infrastructure, driving behaviours, and geographic information, all contributing to comprehensive traffic planning. Furthermore, the incorporation of GNSS and EO in public transportation will indirectly promote environmentally friendly travel habits and contribute to the development of more sustainable cities.

Examining the prospective applications of GNSS and EO in public transport, three emerge as potential game-changers for the sector:

- Autonomous shuttles.
- On demand public transport.
- Connected Driver Advisory Systems (C-DAS).

Drivers for users’ requirements

A set of 8 key drivers for user requirements in the public transport has been identified and described in section 5.4:

- Authentication and Robustness: ensuring secure and reliable authentication has become an important concern in safety-critical applications. Robust systems are necessary to mitigate risks effectively.
- Payment-Linked Features: features integrated with payment systems, like DRT (Demand Responsive Transport) services, are gaining popularity among users, enhancing convenience and accessibility.
- High Accuracy and Urban Availability: urban environments demand high accuracy and availability, particularly for applications such as autonomous shuttles, to ensure effective operations.
- Scalability: GNSS technology distinguishes itself from potential substitutes by offering scalable solutions, requiring minimal infrastructure for deployment.
- Intermodality Integration: users have expressed a need for seamless and continuous solutions that are not developed for a specific mode of transport.
- V2X Development: the growth of V2X applications, extending beyond cars to include motorcycles, cyclists, and road workers, is set to expand the utility of GNSS technology.
- Cybersecurity: given the sensitive data involved, robust cybersecurity measures are imperative for GNSS solutions. A breach in GNSS receivers could have significant consequences, especially for complex applications like autonomous shuttles.
- Environmental Impact: user requirements are influenced by the environmental impact of technologies and GNSS and EO can contribute to a more sustainable mobility.

3 MARKET OVERVIEW & TRENDS

3.1 Market Evolution and Key Trends

The Public Transport market plays an essential role in the well-being of urban communities and is currently undergoing rapid development. This sector is navigating a period marked by unique challenges and emerging opportunities, as it adapts to evolving demands of passengers, operators, and public authorities.

Significant advancements in this sector include the increasing integration of GNSS-based solutions in buses, trams, and urban rail systems. These innovations are revolutionizing the operations of these services by enhancing efficiency, safety, and reliability. The most popular applications for these modes of transport are fleet management, passenger information, and autonomous vehicles.

In Europe, the scale and impact of public transport are significant. Annually, 60 billion passenger journeys are made using public transport. The sector employs 2 million people at a local level and contributes between €130 and €150 billion to the economy, accounting for about 1% of the EU's GDP. Moreover, public transport is integral to the European Green Deal's ambition of reducing transport emissions by 90% by 2050. This reduction is crucial for achieving less congestion, cleaner air, more green spaces, and overall safer urban environments[1].

Challenges and Opportunities

In the realm of the public transport sector, key priorities include enhancing service quality, punctuality, and the overall accessibility of public transportation. One of the main challenges is integrating various modes of transport, such as micromobility options, with traditional public transport systems. This integration aims to provide a smooth and user-friendly experience for commuters, allowing easy transition between different transport modes. Additionally, the varied ticketing systems across different services present a hurdle, highlighting the need for more streamlined and user-centric ticketing solutions.

On the other hand, the rise in energy prices underscores the importance of public transport as a more energy-efficient option compared to private vehicles. This aspect is increasingly relevant in the context of global energy concerns and the drive towards environmental sustainability. The anticipated impact of digital advancements, including improved passenger information systems and more efficient booking processes, is expected to significantly enhance the appeal and usability of public transport. These technological innovations are set to simplify the travel experience, making public transport a more attractive option for a wider range of users.

[1] https://www.uitp.org/regions/europe/

The role of GNSS in Public Transport

The integration of GNSS has been transformative for the public transport sector, offering prospects for continued improvements. GNSS plays a pivotal role in various applications, ranging from safety-critical to smart mobility, and varying across different modes of public transport such as buses, trams, and urban rails. These applications encompass:

Type	Applications
Safety-critical applications	Driving Monitoring
	Autonomous vehicles
Smart mobility	Fleet Management
	Passenger Information
	Driver advisory systems

These GNSS-enabled features facilitate precise vehicle tracking, efficient route planning, and improved passenger information, significantly enhancing the overall public transport experience.

EO emerging role in Public Transport

EO applications in public transport are still evolving, and their role is expected to grow significantly in the short term. EO can enhance network planning and optimization by assessing parameters such as air quality, land use, traffic patterns, and infrastructure conditions. This information empowers transportation authorities and bus operators to evaluate existing services, pinpoint areas for potential improvement, and make well-informed decisions.

Key Trends

The public transport sector is rapidly evolving, with GNSS and EO technologies playing a pivotal role in shaping its future. Key trends emerging in this area include:

- **E-mobility**: Electric vehicles are increasingly becoming a significant part of the public transport landscape. Major European bus and coach groups, such as MAN and Daimler Buses, are transitioning their fleets to meet Euro 7 standards, with a plan to fully electrify their city buses by 2027[2]. GNSS and EO technologies are crucial in this shift, offering solutions to optimize the use of these vehicles. They help in planning routes considering battery life and charging station locations and facilitate predictive maintenance.
- **Turnkey solutions:** Turnkey solutions are gaining traction in the public transport sector, with OEMs providing comprehensive, integrated systems beyond just vehicles. These systems often include GNSS and EO technology features like passenger information systems, driving monitoring systems and air quality monitoring devices.
- **Multimodal, inclusive, and resilient public transport networks:** Future public transport networks aim to be more than just efficient and reliable. They seek to seamlessly integrate with other transport modes, creating an interconnected network. Additionally, these networks are gearing towards inclusivity, catering to diverse societal needs, including accessibility for people with disabilities and those living in remote areas. Safety against cyber threats and adaptability

[2] Strategy presented by MAN in 2023 UITP event.

to climate change are also vital aspects. GNSS and EO applications are instrumental in realizing these objectives.

3.2 Main User Communities

The Public Transport user community can be divided in 7 main categories:

- **Public transport authorities (PTAs)**: public transport authorities are the entities usually responsible for identifying the user requirements in terms of public transport in general, and more specifically in terms of PNT information, and translating them into conditions/requirements within the procurement of public transport service providers. Thus, although public transport authorities typically cannot decide on the specific technology to be used, they do have the responsibility to frame user needs, which then will be addressed by the operators by means of certain technologies.
- **Public transport operators (PTOs)** are companies that provide public transport services to end users. This group can be categorized based on the areas they cover local, regional/intercity, or national. Local PTOs are often smaller companies with fewer resources that face challenges in adopting innovative technologies, such as GNSS-based solutions.
- **End users**: the end user community is the beneficiary of public transport service that are designed by public transport operators covering their specific needs and requirements.
- **The industry**. This group is a highly important one, since they possess a significant technical and technological knowledge in terms of GNSS and EO. They also are the ones that will be developing the technologies and solutions to be included by the Original Equipment Manufacturers (OEMs) in their rolling stock and that ultimately respond to the user requirements identified and framed by the authorities or demanded by the market.
- **Tier 1 suppliers** constitute a particularly critical group as they are the ones developing the GNSS equipment itself. Furthermore, they act as a link between the component manufacturers and the OEMs in the development of GNSS equipment.
- **Standardisation bodies** are well-aware of the benefits of GNSS and EO in terms of performance and outcomes that can be beneficial for public transport (e.g., safety, punctuality, etc.). Also, they do play an important role defining the technology to be used to satisfy specific user requirements.
- **Research institutions** are an important reference when it comes to showcasing the benefits and performance of certain technologies being able to scientifically demonstrate those related to GNSS and EO in public transport.

3.3 Main Market Players

When it comes to the main market players, the PT (Public Transport) value chain has a first component composed by Public Transport Authorities and municipalities whose role consists in identifying, together with Public Transport Operators, passenger needs, issue regulation on the minimum requirements to be fulfilled and technology to be used by Public Transport Operators.

Public Transport Operators (PTOs) are companies, in some cases private contractors to the authorities and in others publicly owned companies, that are responsible for ensuring the availability and functioning of public transport in their domain, all while answering to the needs and regulations traced by the authorities, as well as the user needs. They typically own their own bus/tram/urban rail fleet and are also the ones that will procure the required technologies to fulfil user and authority needs and requirements.

Regarding GNSS supply side of the value chain, five main actors have been identified in the EO and GNSS EUSPA Market Report: Component manufacturers, Tier 1 suppliers, Vehicle Manufactures, Aftermarket device vendors, and Service providers:

- **Component manufacturers** produce elements used by Tier 1 suppliers and needed to build GNSS receivers and other GNSS-related products. This category of suppliers is mainly constituted by well-established market players.
- **Tier 1 suppliers** are in charge of the production of receivers and other products, which they supply to the vehicle manufacturers to be integrated into the vehicles (i.e., buses, trams, urban rail, etc.).
- **Vehicle Manufactures** are responsible for producing various types of vehicles, such as buses, trams and trains, and assembling and integrating components from Tier 1 suppliers into their vehicles.
- **Aftermarket device vendors**: these players market products or components that are sold separately from the primary device. These solutions are designed to enhance or extend the functionality of existing equipment.
- **Service providers**: service providers refer to organizations or companies that offer various services related to GNSS technology. This encompasses a variety of solutions, such as fleet management systems, Mobility as a Service (MaaS) platforms, on-demand transport apps, passenger information systems, driving monitoring tools, driving advisory systems, and transport planning software, etc.

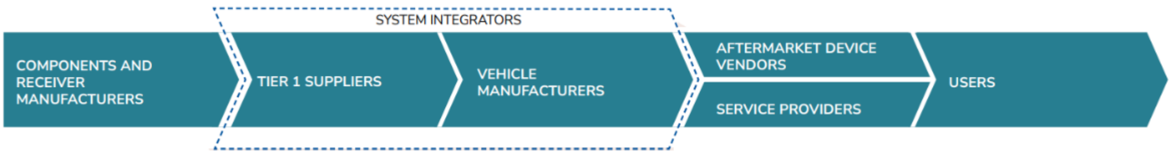

Figure 2 : GNSS Value Chain

When it comes to the EO supply side of the value chain, five main actors have been identified in the EO and GNSS EUSPA Market Report:

- **Data providers:** This group includes providers of unprocessed or pre-processed EO data. For the public transport segment, the most relevant types of data are Interferometric Synthetic Aperture Radar (InSAR) data and, in some cases, Optical Very High Resolution (VHR) images.
- **Infrastructure providers:** This refers to organizations offering various types of computing infrastructure and cloud storage. These facilities enable access, storage, distribution, and manipulation of EO data. Such organizations often collaborate with space agencies, research institutions, and private companies to support EO missions and data dissemination.
- **Platform providers:** These are companies offering online platforms and/or digital services, through which users can utilize tools and capabilities to analyze EO data, develop algorithms, and build applications.
- **EO products and service providers:** These companies provide products or services that fully utilize EO data and the processing capabilities offered by data and platform providers.
- **Information providers:** This group includes providers of sector-specific information that incorporates EO data along with non-EO data. As companies continually expand their portfolios, the distinction between "EO products and service providers" and "information providers" is becoming less clear. More broadly, there is a growing trend of vertical integration within the EO sector, with an increasing number of companies now managing the entire value chain.

Figure 3: EO Value Chain

4 POLICY, REGULATION AND STANDARDS

This chapter presents regulations and standards that are relevant to Public Transport. As awareness of the climate change and environmental degradation are an existential threat to Europe and the world, governments have put in place new regulations to fight climate change and better protect the environment. The chapter also highlights the importance of defining standards ensuring the seamless integration and optimal utilization of GNSS and EO technologies in the public transport segment. This can be facilitated by organizations like ITxPT, which provide specifications for interoperable IT systems in the sector. These standards ensure a cohesive and interconnected public transport network, crucial for efficient and sustainable urban mobility.

With the whole transport sector (private and public transport) contributing to EU GDP for an amount of 5% and employing more than 10 million people in Europe, the transport system is critical to European businesses and global supply chains. The annual contribution of public transport to the economy is calculated in between 130 and 150 €bn which means 1% of EU GDP, with 2 million employees in the public transport sector at the local level.[3].

At the same time, transport implies costs for our society: greenhouse gas and pollutant emissions, noise, road crashes and congestion. Nowadays, transport represents almost a quarter of Europe's greenhouse gas emissions and is one of the main causes of air pollution in cities. The transport sector has not seen the same gradual decline in emissions as other sectors, with individual car usage and short distance flights being some of the problems. The fastest and most cost-efficient way to decarbonise people's daily mobility and reduce the carbon footprint of their mobility choices is to promote the use of public transport, and active modes (walking and cycling). Every year, public transport can help to avoid up 20 tonnes of CO2 in cities while only emitting one tonne[4]. Public transit users help reduce not only GHG emissions, but other air pollutants as well, thereby helping to improve air quality and public health (the EU Green Deal).

In light of this context, the European Commission has established the Green Deal, a strategic framework aiming for the European Union to become the first climate-neutral continent by 2050. This ambitious objective requires significant transformations across industries, particularly in transportation, to achieve a 90% reduction in transport-related greenhouse gas emissions by 2050. Here, public transport plays a crucial role in enhancing accessibility within cities by providing vital connections for daily urban and suburban commuting, ensuring access to education, employment, and essential services for all residents. Furthermore, investing in public transport presents an opportunity to decarbonize local mobility, offering substantial benefits such as cleaner air, reduced noise, safer roads, and an improved quality of life in cities. These advantages align with the goals of the EU Green Deal, generating significant benefits for both citizens and the European economy.

[3]https://ec.europa.eu/commission/presscorner/detail/ga/ip_20_2329

[4] https://ec.europa.eu/commission/presscorner/detail/ga/ip_20_2329

4.1 Applicable Regulations

In general terms, the Public Transport segment is informed by the legal framework that is summarised below:

1. EU Green Deal: The European Union's Green Deal is a comprehensive strategy aimed at making the EU climate-neutral by 2050. It includes initiatives to reduce greenhouse gas emissions in various sectors, including transportation.
2. Renewable Energy Directive (RED II): The RED II sets targets for the share of renewable energy in the transport sector, promoting the use of biofuels and other sustainable alternatives.
3. Urban Mobility Framework: As part of the EU's broader sustainable urban development policies, this framework provides guidance and support for cities to develop and implement sustainable urban mobility plans.

Different regulations are applicable depending on the application considered. For the road market segment which covers bus applications, several existing EU regulations are driving the use of GNSS:

1. Delegated regulation 886/2013 for the provision of road safety related minimum universal traffic information follow up of directive 2010/40/EU. Its focus is on the provision of minimum universal traffic information with a specific emphasis on road safety. The regulation likely establishes requirements and standards for the collection, dissemination, and exchange of traffic information that is essential for enhancing road safety across the European Union. Key aspects covered by the regulation may include defining the types of information to be collected, specifying technical standards for data exchange, and ensuring interoperability among different systems and services across EU member states. The intention is to create a standardized approach to traffic information that contributes to improved safety measures on European roads.
2. Delegated regulation 962/2015 supplementing Directive 2010/40/EU with regard to the provision of EU wide real time traffic information services. The regulation is part of the European Union's legislative framework related to intelligent transport systems. Specifically, it complements Directive 2010/40/EU, which aims to establish a framework for the deployment of Intelligent Transport Systems (ITS) in the field of road transport and focuses on the provision of EU-wide real-time traffic information service serving as a delegated regulation supplementing Directive 2010/40/EU. Its primary objective is to facilitate the provision of real-time traffic information services across the European Union. Real-time traffic information is crucial for improving the efficiency, safety, and sustainability of road transportation. The regulation likely outlines specific requirements, standards, and procedures that member states and relevant stakeholders must follow to ensure the effective implementation of EU-wide real-time traffic information services. This could include details on data formats, interoperability, and other technical specifications to promote a harmonized approach across the EU.
3. Regulation 2015/758 and 2017/78 concerning type approval requirements for the deployment of eCall in vehicle systems follow up of Directive 2010/40/REU in the stream of EU type approval, *Regulation (EU) 2015/758* covers type-approval requirements for the deployment of the eCall in-vehicle system based on the 112 service. The technical requirements and test procedures for the EC type-approval for vehicles referred to in this regulation are established in the Commission Delegated Regulation (EU) 2017/79. It establishes that all new passenger cars and light duty vehicles must be equipped with eCall, which makes use of European GNSS for precise positioning in case of an accident. It furthermore reports on the technical requirements for compatibility of eCall with EGNSS (Annex VI).
4. Intelligent Transport systems (ITS): Directive 2010/40/EU set the framework for the deployment of Intelligent Transport Systems (ITS) in the field of road transport and for interfaces with other

modes of transport. The Proposal for a Directive amending Directive 2010/40/EU in light of the 2020 Communication on a Sustainable and Smart Mobility Strategy, includes reference to the use of EO data from Copernicus to ensure the compatibility of ITS applications and services with navigation services (Annex II, j). *Disclaimer: The proposal was adopted in Parliament (1st reading) on 3rd October. Right now, it is awaiting Council's 1st reading position.*

4.2 Standards and Best practices

In the realm of public transport, the integration of Global Navigation Satellite Systems (GNSS) has become pivotal for enhancing operational efficiency, safety, and overall service quality. Standards and best practices play a crucial role in ensuring the seamless integration and optimal utilization of these technologies in the public transport segment. Standardization in the implementation of GNSS and EO technologies ensures interoperability among different systems, fostering a cohesive and interconnected public transport network. Best practices guide the responsible use of these technologies, addressing privacy concerns, and promoting sustainable and resilient urban mobility solutions. As cities continue to evolve, adherence to established standards and best practices becomes imperative for the successful integration of GNSS and EO in public transport, ultimately contributing to more efficient, reliable, and environmentally friendly transportation systems.

A notable example is ITxPT , a global organization with more than 120 members belonging to the public transport sector (including transport operators, authorities, manufacturers, and IT system integrators) whose mission is to enable interoperability between IT systems in public transport. They provide public transport authorities and operators with ITxPT specifications covering recommendations and requirements to support the purchase and integration of interoperable IT architecture. In addition, these specifications are used by industry suppliers to design ITxPT-compliant equipment and services. In particular, there is one ITxPT standard specification regarding GNSS Location (S02P03-GNSS Location) under on-board architecture which was updated in 2022 and recommends the adoption of multi-constellation GNSS receivers on-board.

In addition, the following list gathers the most relevant standardization bodies and working groups in the field of GNSS positioning that can influence R&D activities in GNSS performances:

- **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
- **CEN/CENELEC**
  - EN 16803-1 to EN 16803-4: Suite of 4 standard documents about GNSS performance, relevant for road applications. The documents deal with basic metrics, field and "Record and Replay" testing procedures, and a focus on spoofing and interferences. EN 16803-1 was published in October 2016, the other two documents are ongoing work. EN 16803-4 is to be added in the future and will define the methods for carrying out / designing performance test scenarios intended to be replayed in lab.
- **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 26262 Road Vehicles-Functional Safety: On the functional safety of electrical and/or electronic systems in production automobiles defined by the ISO in 2011.

- 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:

- International Association of Geodesy (IAG): Commission 4 – Positioning and Applications: WG 4.1.4 (Robust Positioning for Urban Traffic): Specification and characterization of GNSS requirements, performance analysis for vehicles and pedestrians in urban areas, etc.
- ISO TC204 - Intelligent transport systems: New project titled "TS 21176 - Intelligent Transport Systems – Cooperative ITS – Position, Velocity and Time functionality in the ITS station". Collaboration between ISO TC204/WG18 (Cooperative systems) and CEN TC5/WG1.
- ISO 26262 Road Vehicles-Functional safety: functional safety of electrical and/or electronic systems in production automobiles defined by the ISO in 2011.
- ISO 5725 accuracy of measurements: Accuracy (trueness and precision) of measurements methods and results, to establish practical estimations of the various measurements. European Road Transport Research Advisory Council (ERTRAC): European Technology Platform (ETP) for Road Transport, recognized and supported by the European Commission. Even if ERTRAC is not a standardization organization, it has the relevant role to provide a strategic vision for road transport research and innovation; define strategies; stimulate effective public and private investment in road transport research and innovation.
- Open AutoDrive Forum (OADF): Initiative to harmonize the activities from NDS, TISA, ADASIS and SENSORIS created in 2015. The overarching objective is to generate an ecosystem of production-ready automotive standards including navigation and positioning.
- European Transport Safety Council (ETSC): Independent expert advice on transport safety matters to the European Commission, the European Parliament, and Member States. Recommendation document: "Prioritising the Safety Potential of Automated Driving in Europe", 2016.
- Cloud Large Scale Video Analysis (LSVA) project – Open Group: Focus on navigation data, maps, and support the development of suitable standards for video data set and video annotation, aim at developing a standard on video content annotation to be published by an existing appropriate SDO.

5 USER REQUIREMENTS ANALYSIS

Nowadays, GNSS is used in public transport for various applications such as Fleet management, Passenger Information, Advanced Driver Assistance Systems (ADAS) and Autonomous Vehicle. However, EO is slightly limited to a few public transport applications.

This chapter provides a detailed analysis of user needs and requirements pertaining to Public Transport applications, describing the different roles and needs covered by GNSS and EO and, ultimately, identifying the corresponding requirements from a user perspective. Due to potential overlaps with applications featured in other market segments such as rail and road, this chapter will primarily focus on those applications intrinsically related to public transport, with a specific emphasis on buses in comparison to trams and trains.

Table 1, Applications and level of investigation, depicts the main applications making use of GNSS and/or EO technologies in Public Transport. The list of applications is non-exhaustive and is expected to evolve to reflect the level of adoption of space technologies and the related innovations in the coming years.

This document recognizes that a variety of applications can gain advantages from GNSS and/or EO. However, the current edition does not provide an in-depth analysis of the needs and requirements for every application. To address this, 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.

● **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 have been identified and validated with the Public Transport 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 EO-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 matches **Public Transport**-related applications to the three above-mentioned categories. **The following list of applications and their categorisation are expected to evolve in the next versions of the document.**

Legend

EO only application

GNSS only application

Sub-segments	Applications	Types of Application/ Level of Investigation	
Bus	Fleet Management	A	●
	Passenger Information	A	●
	Driver advisory systems	A	●
	Driving monitoring	A	●
	Autonomous vehicle	A	●
	Transportation network planning and optimization	C	○
Tram	Fleet Management	B	◐
	Passenger Information	B	◐
	Autonomous vehicle	B	◐
	Driver advisory systems	B	◐
	Transportation network planning and optimization	C	○
Urban Rail	Fleet Management	B	◐
	Passenger Information	B	◐
	Autonomous vehicle	B	◐
	Driver advisory systems	B	◐

Table 1 Application and level of investigation.

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 least developed.

5.1 Current GNSS/EO use and requirements per application

5.1.1 Bus: fleet Management ●

Fleet Management Systems supervise vehicle operation and ensure service planning processes. These systems can offer a clear overview of all buses and their real-time locations throughout the city and along bus routes, improving transit service quality and enhancing operational efficiency.

Fleet Management Systems can contribute to optimising bus routes and resource management. These can lead to fuel consumption reduction which can have a substantial impact on operational costs. Moreover, these systems enhance security by providing real-time tracking and help decrease travel times.

In a more general perspective, public transport providers can use these systems to efficiently manage various modes of public transport, such as buses, trains, and trams, creating seamless connections and enhancing the overall public transport experience.

The core of a Fleet Management System is a GNSS tracking system used in combination with data transmission through the chosen communication system, such as 4G mobile networks. The combination of GNSS technology and 4G mobile networks monitors the positions of all vehicles, personnel, assets, and ongoing incidents. This information is then transmitted to a server, enabling visualisation through a Geographical Information System (GIS).

In this application, GNSS is used in the following contexts:

1. Real-Time Bus tracking: GNSS allows operators to track the real-time location of each bus.
2. Route Optimization: GNSS data is used to optimise bus routes and resource management by analysing historical travel patterns and real-time traffic conditions.
3. Maintenance: GNSS usage enables tracking of buses usage and performance, facilitating predictive maintenance scheduling.
4. Safety: real-time tracking improves passengers and drivers' safety. In the event of an incident, authorities can quickly locate and respond to the affected bus.

GNSS user requirements for Fleet Management (bus)		
Availability	Better than 99.9%	High
Position fix rate	-	<10Hz
Accuracy	Horizontal position	m-level
	Vertical position	m-level
	GNSS time	1us
Integrity	Position	Medium-High
Time to Alert	-	10-30s

Table 2 Description of GNSS user requirements for Fleet Management (bus).

5.1.2 Bus: Passenger information

Passenger Information System's main purpose is to provide passengers with real-time information about the status of public transport, in this case, bus services. This information can be communicated to passengers through various display systems, including mobile applications, multimedia panels for bus stops, LED panels for buses, and audio announcers informing passengers constantly. These systems can help reduce both actual and perceived waiting times, decrease overall travel time by assisting passengers in making route choices, and ultimately increase the use of transit. However, for an effective real-time passenger information system it is crucial to maintain consistent and accurate information across all the available channels to build and maintain passengers' trust in the service.

Real-Time Passenger Information Systems typically consist of multiple groups of components: among them, data collection systems where GNSS is used to collect information on the movement of vehicles (position, speed, time of arrival at the next stops, etc.) plays a prominent role.

In this application, GNSS is used in the following contexts:

1. Real-Time Bus Tracking: GNSS enables real-time communication of the vehicle's location to passengers, facilitating features such as dynamic trip planning through mobile apps.

2. Arrival and Departure Predictions: GNSS data helps to calculate real time arrival and departure predictions based on the current bus location and traffic conditions.

3. Service Alerts: GNSS is used to develop automated alerts in case of delays, detours, or service disruptions.
4. Bus Stop Announcements: inside the bus, GNSS is used to communicate automated announcements of upcoming bus stops.

GNSS user requirements for Passenger Information (bus)		
Availability	Better than 99.9%	High
Position fix rate	-	<10Hz
Accuracy	Horizontal position	m-level
	Vertical position	m-level
	GNSS time	1us
Integrity	Position	Medium-High
Time to Alert	-	10-30s

Table 3: Description of GNSS user requirements for Passenger Information (bus)

5.1.3 Bus: driver advisory systems

Driver advisory systems (DAS) provide information to bus drivers regarding the external and/or internal conditions of the vehicle facilitating decision-making regarding the optimal driving control of the bus. GNSS-based DAS applications have emerged as game-changers offering a myriad of benefits contributing for optimization of bus operations, improvement of safety, reduction of environmental impact and increase of passenger satisfaction.

These systems typically compute energy-efficient speed profiles to meet pre-planned or dynamically adjusted bus schedules and provide drivers with detailed guidance to follow these profiles and adhere to the schedules. Conflict detection and the calculation of new target timings are overseen by the control centre. GNSS serves as one of the sensors in the DAS equipment.

In this application, GNSS is used in the following contexts:

1. Real-time Bus Tracking: GNSS enables the tracking of buses' position contributing to calculating optimal driving routes and managing traffic congestion.
2. Energy-Efficient Driving: GNSS enables DAS to give advice on energy-efficient driving. With the analysis of the real-time bus information, such as speed and location, DAS will recommend the necessary adjustments to minimise fuel consumption and reduce emissions.
3. Safety: GNSS enables DAS to provide real-time alerts to drivers about potential hazards, accidents, and adverse weather conditions.
4. Data Analytics: GNSS contributes to the collection of driver behaviour data helping the identification of driving trends and areas for improvement.

GNSS user requirements for DAS (bus)		
Availability	Better than 99,9%	High
Position fix rate	-	<10Hz
Accuracy	Horizontal position	m-level
	Vertical position	m-level
	GNSS time	1us
Integrity	Position	Medium-High
Time to Alert	-	10-30s

Table 4 Description of GNSS user requirements for DAS (bus).

5.1.4 Bus: driving monitoring

Driving monitoring systems on buses are used to track and evaluate a bus driver's performance. These systems collect drivers' data related to speed, braking, and fatigue. These data are then used to evaluate the driver's safety practices and compliance with driving guidelines. Overall, driving monitoring systems can improve safety and the overall bus operation efficiency.

In this application, GNSS is used in the following contexts:

1. Driver Behaviour Analysis: GNSS equipped systems continuously monitor driver behaviour, including speed, acceleration and braking. With the analysis of these data, operators can identify unsafe driving practices.
2. Route Compliance: the use of GNSS ensures that bus drivers comply with predefined routes. If a driver deviates from the designated path, the system can generate alerts.
3. Safety: GNSS equipped monitoring systems can send real-time alerts to the driver and the central control centre in the event of unsafe driving behaviours, such as speeding.
4. Emergency: in the event of an accident, GNSS data can provide information related, for example, to the location and speed of the bus at the time of the event.
5. Reporting: with GNSS data operators can develop reports on driver performance, evaluating variables like routes and schedules compliance, and fuel consumption.

GNSS user requirements for Driving monitoring (bus)		
Availability	Better than 99,9%	High
Position fix rate	-	<10Hz
Accuracy	Horizontal position	m-level
	Vertical position	m-level
	GNSS time	1us
Integrity	Position	Medium-High
Time to Alert	-	10-30s

Table 5 Description of GNSS user requirements for Driving monitoring (bus)

5.1.5 Bus: autonomous vehicles

An autonomous bus is a vehicle that can carry passengers without needing human intervention. It does this by using sensors to understand its surroundings and make driving decisions. These vehicles typically follow predefined routes or operate within geofenced areas, which can include corporate headquarters, university campuses, or providing last-mile transportation between transportation hubs and final destinations. This type of vehicle offers numerous potential advantages, including improved safety, efficiency, accessibility, and reliability, along with lower labour expenses and reduced traffic congestion. Autonomous buses combine a variety of techniques to perceive its environment. GNSS when integrated with complimentary technology such as, ultrasonic, inertial motion, digital maps, radar/LiDAR and cameras, acts as the sixth sense to deliver the positioning performance required by autonomous vehicles.

In this application, GNSS is used in the following contexts:

1. Bus Positioning: GNSS provides high-precision location data, allowing autonomous buses to know their exact position on the road.
2. Operational conditions: GNSS can help analyse the bus surroundings, helping to prevent collisions through data on road layouts, traffic signs, vehicles, pedestrians, etc.
3. Geofencing: GNSS allows autonomous buses to stay within predefined operational areas.

GNSS user requirements for Autonomous Vehicles (bus)		
Availability	Better than 99,9%	High
Position fix rate	-	<10Hz
Accuracy	Horizontal position	m-level
	Vertical position	m-level
	GNSS time	1us
Integrity	Position	Medium-High
Time to Alert	-	10-30s

Table 6 Description of GNSS user requirements for Autonomous Vehicles (bus)

5.1.6 Bus: transportation network planning and optimization

Using Earth Observation (EO) for transportation network planning and optimization in public bus transport is a valuable strategy for evaluating various factors like air quality, land use, traffic patterns, and infrastructure conditions along bus routes. These insights empower transportation authorities and bus operators to assess existing bus services, identify areas for potential improvement, and make informed decisions.

EO can be used in the following contexts:

1. Route Planning and Optimization: EO data offers insights related to land use, building density, traffic, population distribution, and even predictions of extreme weather conditions. These insights help guide decision-makers in expanding or optimizing bus routes effectively.
2. Infrastructure Monitoring: EO data provides valuable information about the condition of existing infrastructure, including roads, bridges, tunnels, and bus stop. These data contribute to identifying areas that require maintenance to ensure efficient bus services.

3. Urban Heat Island: EO data can detect urban heat islands. When identified, mitigation measures, such as enhancing bus services in these areas and encouraging bus usage. This can be achieved by providing incentives to users and simultaneously implementing restrictions on car usage.
4. Air Quality: EO technology can monitor air quality in urban areas. This information is valuable for public transport operators and authorities, enabling them to offer incentives for bus usage in areas with higher pollution levels.

5.1.7 Tram: fleet management ◑

Fleet Management Systems supervise vehicle operation and ensure service planning processes. These systems can offer a clear overview of the real-time locations of the trams throughout the city/tram lines, improving transit service quality and enhancing operational efficiency.

Fleet Management Systems can contribute to the optimisation of the overall transport system. Moreover, these systems enhance security by providing real-time tracking and help decrease travel times. Additionally, the trams position information is combined with speed and lateral acceleration sensors to report potential track, switches and catenaries damages and need for maintenance

In a more general perspective, public transport providers can use these systems to efficiently coordinate various modes of public transport, such as buses, trams and trains, creating seamless connections and enhancing the overall public transport experience.

The core of a Fleet Management System is a GNSS tracking system used along with data transmission through the chosen communication system, such as GSM or GPRS. The combination of GNSS technology and GSM/GPRS wireless coverage monitors the positions of all vehicles, personnel, assets, and ongoing incidents. This information is then transmitted to a server, enabling visualisation through a Geographical Information System (GIS).

In this application, GNSS is used in the following contexts:

1. Real-Time Tram tracking: GNSS allows operators to track the real-time location of each tram.
2. Optimization: GNSS can contribute to the optimization of tram traffic by providing data on tram locations.
3. Maintenance: GNSS usage enables tracking of tram usage and performance, facilitating predictive maintenance scheduling.
4. Safety: with real-time tracking the safety of passengers and drivers is improved. In the event of an incident, authorities can quickly locate and respond to the affected tram.

GNSS user requirements for Fleet Management (tram)		
Availability	-	High
Position fix rate	-	1Hz
Accuracy	Horizontal position	m-level
	GNSS time	1s
Integrity	Position	High
Time to Alert	-	10-30s

Table 7 Description of GNSS user requirements for Fleet Management (tram)

5.1.8 Tram: passenger information ◑

A Passenger Information System's main purpose is to provide passengers with real-time information about the status of public transport, in this case, tram services. This information can be communicated to passengers through various display systems, including mobile applications, multimedia panels for tram stops, LED panels, and audio announcers informing passengers constantly. These systems can help reduce both actual and perceived waiting times, decrease overall travel time by assisting passengers in making route choices, and ultimately increase the use of transit. However, for an effective real-time passenger information system, it is crucial to maintain consistent and accurate information across all available channels to build and maintain passengers' trust in the service.

Real-Time Passenger Information Systems typically consist of multiple groups of components, with one of those being the data collection systems where GNSS is used to collect information on the movement of vehicles (position, speed, time of arrival at the next stops, etc.).

In this application, GNSS is used in the following contexts:

1. Real-Time Tram Tracking: GNSS enables real-time communication of the vehicle's location to passengers, facilitating features such as dynamic trip planning through mobile apps.
2. Arrival and Departure Predictions: GNSS data helps to calculate real time arrival and departure predictions based on the current tram location and traffic conditions.
3. Service Alerts: GNSS is used to develop automated alerts in case of delays, detours, or service disruptions.
4. Tram Stop Announcements: inside the tram, GNSS is used to communicate automated announcements of upcoming stops.

GNSS user requirements for Passenger Information (tram)		
Availability	-	High
Position fix rate	-	1Hz
Accuracy	Horizontal position	m-level
	GNSS time	1s
Integrity	Position	High
Time to Alert	-	10-30s

Table 8 Description of GNSS user requirements for Passenger Information (tram)

5.1.9 Tram: autonomous vehicles ◑

An autonomous tram is a vehicle that can carry passengers without needing human intervention. It does this by using sensors to understand its surroundings and make driving decisions. This type of vehicle offers numerous potential advantages, including improved safety, efficiency, accessibility, and reliability, along with lower labour expenses.
Autonomous trams combine a variety of techniques to perceive its environment. GNSS when integrated with complimentary technology such as, ultrasonic, inertial motion, digital maps, radar/LiDAR and cameras, acts as the sixth sense to deliver the positioning performance required by autonomous vehicles.

In this application, GNSS is used in the following contexts:

1. Tram Positioning: GNSS provides high-precision location data, allowing autonomous trams to know their exact position.

2. Operational conditions: GNSS can help analyse the tram surroundings, helping to prevent collisions through data on track layouts, vehicles, pedestrians, etc.
3. Geofencing: GNSS allows autonomous trams to stay within predefined operational areas ensuring they remain on designated tram tracks.

GNSS user requirements for Autonomous vehicles (tram)		
Availability	-	High
Position fix rate	-	1Hz
Accuracy	Horizontal position	m-level
	GNSS time	1s
Integrity	Position	High
Time to Alert	-	10-30s

Table 9 Description of GNSS user requirements for Autonomous vehicles (tram)

5.1.10 Tram: driver advisory systems

Driver advisory systems (DAS) provide information to tram drivers regarding the external and/or internal conditions of the vehicle facilitating decision-making regarding the optimal driving control of the tram. GNSS-based DAS applications have emerged as game-changers offering a myriad of benefits contributing for optimization of tram operations, improvement of safety, reduction of environmental impact and increase of passenger satisfaction.

These systems typically compute energy-efficient speed profiles to meet pre-planned or dynamically adjusted tram schedules and provide drivers with detailed guidance to follow these profiles and adhere to the schedules. Conflict detection and the calculation of new target timings are overseen by the control centre. GNSS serves as one of the sensors in the DAS equipment.

In this application, GNSS is used in the following contexts:

1. Energy-Efficient Driving: GNSS enables DAS to give advice on energy-efficient driving. With the analysis of the real-time tram information, such as speed and location, DAS will recommend the necessary adjustments to minimise fuel consumption and reduce emissions.
2. Safety: GNSS enables DAS to provide real-time alerts to drivers about potential hazards, accidents, and adverse weather conditions.
3. Data Analytics: GNSS contributes to the collection of driver behaviour data helping the identification of driving trends and areas for improvement.

GNSS user requirements for DAS (Tram)		
Availability	Better than 99,9%	High
Position fix rate	-	<10Hz
Accuracy	Horizontal position	m-level
	Vertical position	m-level
	GNSS time	1us
Integrity	Position	Medium-High
Time to Alert	-	10-30s

Table 10: Description of GNSS user requirements for DAS (Tram).

5.1.11 Tram: transportation network planning and optimisation

Using Earth Observation (EO) for transportation network planning and optimization in trams is a valuable strategy for evaluating various factors like air quality, land use, traffic patterns, and infrastructure conditions along tram lines. These insights empower transportation authorities and operators to assess the existing services, identify areas for potential improvement, and make informed decisions.

EO can be used in the following contexts:

1. Route Planning and Optimization: EO data offers insights related to land use, building density, traffic, population distribution, and even predictions of extreme weather conditions. These insights help guide decision-makers in planning and expanding tram lines effectively.
2. Infrastructure Monitoring: EO data provides valuable information about the condition of existing infrastructure, including tram lines, bridges, tunnels, and tram stops. These data contribute to identify areas that require maintenance to ensure efficient and safe tram services.
3. Urban Heat Island: EO data can detect urban heat islands. When identified, mitigation measures can be implemented, such as expanding tram services in these areas and encouraging public transport while restricting car usage through incentives for users.
4. Construction monitoring: EO can be used to monitor the construction of new elements of tram lines.
5. Air Quality: EO technology can monitor air quality in urban areas. This information is valuable for public transport operators and authorities, enabling them to offer incentives for tram usage in areas with higher pollution levels.

5.1.12 Urban rail: fleet management

Fleet Management Systems supervise vehicle operation and ensure service planning processes. These systems can offer a clear overview of the real-time locations of the trains throughout the city/train lines, improving transit service quality and enhancing operational efficiency.

Fleet Management Systems can contribute to the optimisation of the overall transport system. Moreover, these systems enhance security by providing real-time tracking and help decrease travel times. Additionally, the trains position information is combined with speed and lateral acceleration sensors to report potential track, switches and catenaries damages and need for maintenance.

In a more general perspective, public transport providers can use these systems to efficiently coordinate various modes of public transport, such as buses, trams and trains, creating seamless connections and enhancing the overall public transport experience.

The core of a Fleet Management System is a GNSS tracking system used along with data transmission through the chosen communication system, such as GSM or GPRS. The combination of GNSS technology and GSM/GPRS wireless coverage monitors the positions of all vehicles, personnel, assets, and ongoing incidents. This information is then transmitted to a server, enabling visualisation through a Geographical Information System (GIS).

In this application, GNSS is used in the following contexts:

1. Real-Time Tram tracking: GNSS allows operators to track the real-time location of each train.
2. Optimization: GNSS can contribute for the optimization of train traffic by providing data on train locations.
3. Maintenance: GNSS usage enables tracking of train usage and performance, facilitating predictive maintenance scheduling.
4. Safety: with real-time tracking the safety of passengers and drivers is improved. In the event of an incident, authorities can quickly locate and respond to the affected train.

GNSS user requirements for Fleet Management (Urban Rail)		
Availability	-	High
Position fix rate	-	1Hz
Accuracy	Horizontal position	m-level
	GNSS time	1s
Integrity	Position	High
Time to Alert	-	10-30s

Table 11: Description of GNSS user requirements for Fleet Management (urban rail).

5.1.13 Urban Rail: passenger information ◑

A Passenger Information System's main purpose is to provide passengers with real-time information about the status of public transport, in this case, train services. This information can be communicated to passengers through various display systems, including mobile applications, multimedia panels for train stops, LED panels, and audio announcers informing passengers constantly. These systems can help reduce both actual and perceived waiting times, decrease overall travel time by assisting passengers in making route choices, and ultimately increase the use of transit. However, for an effective real-time passenger information system, it is crucial to maintain consistent and accurate information across all available channels to build and maintain passengers' trust in the service.

Real-Time Passenger Information Systems typically consist of multiple groups of components, with one of those being the data collection systems where GNSS is used to collect information on the movement of vehicles (position, speed, time of arrival at the next stops, etc.).

In this application, GNSS is used in the following contexts:

1. Real-Time Train Tracking: GNSS enables real-time communication of the vehicle's location to passengers, facilitating features such as dynamic trip planning through mobile apps.

2. Arrival and Departure Predictions: GNSS data helps calculate real time arrival and departure predictions based on the current train location and traffic conditions.
3. Service Alerts: GNSS is used to develop automated alerts in case of delays, detours, or service disruptions.
4. Train Stop Announcements: inside the train, GNSS is used to communicate automated announcements of upcoming stops.

GNSS user requirements for Passenger information (Urban Rail)		
Availability	-	High
Position fix rate	-	1Hz
Accuracy	Horizontal position	m-level
	GNSS time	1s
Integrity	Position	High
Time to Alert	-	10-30s

Table 12: Description of GNSS user requirements for Passenger Information (urban rail)

5.1.14 Urban rail: autonomous vehicles ◑

An autonomous train is a vehicle that can carry passengers without needing human intervention. It does this by using sensors to understand its surroundings and make driving decisions. This type of vehicle offers numerous potential advantages, including improved safety, efficiency, accessibility, and reliability, along with lower labour expenses.

Autonomous trains combine a variety of techniques to perceive its environment. GNSS when integrated with complimentary technology such as, ultrasonic, inertial motion, digital maps, radar/LiDAR and cameras, acts as the sixth sense to deliver the positioning performance required by autonomous vehicles. In this application, GNSS is used in the following contexts:

1. Train Positioning: GNSS provides high-precision location data, allowing autonomous trains to know their exact position.
2. Operational conditions: GNSS can help analyse the tram surroundings, helping to prevent collisions through data on track layouts, vehicles, pedestrians, etc.
3. Geofencing: GNSS allows autonomous trains to stay within predefined operational areas ensuring they remain on the designated train tracks.

GNSS user requirements for Autonomous Vehicles (Urban Rail)		
Availability	-	High
Position fix rate	-	1Hz
Accuracy	Horizontal position	m-level
	GNSS time	1s
Integrity	Position	High
Time to Alert	-	10-30s

Table 13: Description of GNSS user requirements for Autonomous vehicles (urban rail)

5.1.15 Urban Rail: driver advisory systems ◑

Driver advisory systems (DAS) provide information to train drivers regarding the external and/or internal conditions of the vehicle facilitating decision-making regarding the optimal driving control of the train. GNSS-based DAS applications have emerged as game-changers offering a myriad of benefits contributing for optimization of train operations, improvement of safety, reduction of environmental impact and increase of passenger satisfaction.

These systems typically compute energy-efficient speed profiles to meet pre-planned or dynamically adjusted tram schedules and provide drivers with detailed guidance to follow these profiles and adhere to the schedules. Conflict detection and the calculation of new target timings are overseen by the control centre. GNSS serves as one of the sensors in the DAS equipment.

In this application, GNSS is used in the following contexts:

1. Energy-Efficient Driving: GNSS enables DAS to give advice on energy-efficient driving. With the analysis of the real-time train information, such as speed and location, DAS will recommend the necessary adjustments to minimise fuel consumption and reduce emissions.
2. Safety: GNSS enables DAS to provide real-time alerts to drivers about potential hazards, accidents, and adverse weather conditions.
3. Data Analytics: GNSS contributes to the collection of driver behaviour data helping the identification of driving trends and areas of improvement.

GNSS user requirements for DAS (Train)		
Availability	Better than 99,9%	High
Position fix rate	-	<10Hz
Accuracy	Horizontal position	m-level
	Vertical position	m-level
	GNSS time	1us
Integrity	Position	Medium-High
Time to Alert	-	10-30s

Table 14: Description of GNSS user requirements for DAS (urban rail).

5.2 Limitations of GNSS and EO

This section provides an overview of the limitations that act as constraints, curbing the expansion of GNSS and EO use in the public transport segment. The most relevant limitations, which significantly impact GNSS and EO applications are outlined below:

Legend

EO only application
GNSS only application

Type of Limitation	Limitations
Technical limitations	**No indoor penetration** - Poses challenges for tracking vehicles within public transport terminals, tunnels, and other indoor areas.
	Low robustness against interference - GNSS signals can be easily disrupted by interference from buildings or other electronic devices, leading to inaccuracies in tracking and navigation, impacting safety related applications, fare calculation and validation on payment systems.
	Natural obstructions and accessibility in rural areas - Mountains, valleys, and dense foliage can obstruct GNSS signals, leading to inaccuracies or temporary loss of signal. In remote or rural areas with less dense infrastructure, the availability and accuracy of GNSS signals might be reduced due to the lack of nearby reference stations.
	Urban environments (high buildings): Buildings may block the signal and reduce the number of visible satellites.
	No direct signal from the satellites: Signals from satellites must travel from satellite to final receiver being affected by multipath effects (signal reflected or diffracted from buildings or structures).
	Spatial and temporal resolution: The limitation of spatial and temporal resolution is closely tied to the specific use case, such as mapping certain infrastructure elements like bridges and roads. When a need arises for higher resolution in certain use cases, it may be necessary to consider commercial providers overusing ESA open data. Commercial providers offer Very High-Resolution imagery, with details down to the centimetre level, and a revisit time that allows for nearly 10 images a day. However, it's important to note that accessing such commercial data can be quite expensive and may not be viable for most public transport authorities.
Safety and integrity limitations	**Low robustness against spoofing and jamming**- Malicious actors can manipulate the signals to provide false information about vehicle locations or overpower the signal by other RF signals.
Accuracy and precision limitations	**Position Fix Rate –** The rate at which GNSS provides accurate position fixes might not meet the necessary requirements for some applications within dynamic and rapidly changing environments.

Table 15: List of limitations of GNSS and EO in Public Transport.

If GNSS and EO within public transport applications can bring many added values, several limitations and challenges still exist. To mitigate GNSS limitations, other technologies can be used either as complementary or substitute. For example, when it comes to GNSS, new services like Galileo OSNMA and HAS can mitigate some of these limitations. Galileo offers signals transmitted in four frequency bands (E1, E5a, E5b, and E6) and modern signals that are more resistant to multipath. OSNMA provides signal and data authentication, offering reliability thanks to an additional safety layer that reassures users about the authenticity of the information received from Galileo satellites. HAS provides an accuracy of less than 20 cm in nominal conditions, further enhancing the capabilities of GNSS in public transport applications.

5.3 Prospective use of GNSS

When we consider how GNSS and EO will shape the future of public transport, it is relevant to mention the European Commission strategy to achieve specific milestones by 2050. The main objective is simple: our mobility should be smart and sustainable; this strategy perfectly aligns with the benefits that GNSS and EO can determine for public transport.

In the upcoming years, GNSS and EO will play an important role in the development of public transport. By enhancing the availability of near-real-time information and the improvement of location accuracy, integrity, and precision, accurate vehicle tracking, route optimization, and the development of more precise safety-critical solutions will be facilitated. Moreover, GNSS and EO will enable a broader understanding of the public transport environment allowing a more accurate analysis and evidence-based decision-making. This data-driven strategy will rely on measurements of vehicle speed, traffic patterns, physical surroundings like landscapes and infrastructure, individual driving behaviors, and geographic information; all these factors will contribute to a more complete traffic planning. Additionally, the incorporation of GNSS and EO in public transportation will indirectly encourage more environmentally friendly travel habits and, consequently, more sustainable cities.

When we look at the GNSS and EO prospective applications in public transport, three stand out as potential game-changers for the public transport sector:

- Autonomous shuttles.
- On demand public transport.
- Connected Driver Advisory Systems (C-DAS).

5.3.1 Autonomous shuttles

For some years now, several European cities have been testing autonomous shuttles on test tracks, closed circuits, and pilot programs on public roads. Back in 2015, a handful of cities initiated the first tests with autonomous shuttles, and this number has steadily increased as more cities join in. Simultaneously, the number of companies involved in the development of autonomous shuttles has also been increasing.

Oslo, Geneva, Lyon, Luxembourg, Copenhagen, Helsinki, and Tallinn are some of the cities that served or are serving as test beds for the autonomous shuttles within various EU-funded projects. Among these projects, ULTIMO stands as the most recent with the goal of developing a business model that addresses the economic, legal and security issues of an autonomous electric minibus service. With resources allocated across a 4-year span, ULTIMO aims to deploy 45 autonomous electric minibuses over the course of a year, operating across three European cities.

Most of the shuttles being tested have a capacity of approximately 10 to 15 passengers. However, a significant development occurred in 2021 when the city of Malaga introduced Europe's first driverless normal sized electric bus service with a total number of 60 seats.

In 2021, EasyMile achieved an important milestone in the history of autonomous vehicles being the first driverless vehicle maker in Europe with permission to run an autonomous shuttle among other vehicles, pedestrians and cyclists without on-board supervision on a public road. In 2022, this company made another big move by getting the first commercial contract for autonomous shuttles. This 10-year contract involves a fleet of fully autonomous shuttles, operated without the presence of a human supervisor on board for guest transport at the Terhills tourist site in Belgium.

Similar to EasyMile, other European companies like 2Get-There and Navya, established manufacturers such as VDL Bus&Coach and Renault Group, and Siemens are actively engaged in the development of autonomous shuttles within the public transport market. More frequently, this development involves partnerships with transport operators such as Transdev, Arriva or Keolis, as well as collaborating with local and regional public entities. The implementation of pilots is commonly carried out in partnership with public transport authorities.

Some of the pros of autonomous shuttles are listed below:

- Decrease in the rate of accidents caused by human error, such as driver fatigue, distraction, or misjudgment.
- Labor costs decrease, by removing the need for human drivers.
- Reliability and punctuality of public transport services improvement.
- Without driver rest time or working hour limitations, there's more flexibility in bus route planning.

Nevertheless, despite the continuous testing of autonomous shuttles, some challenges still need to be addressed. Some of these challenges are of a physical nature mainly due to complex weather conditions (i.e., heavy rain, fog or snow), which complicate the accurate readiness of the environment. Understanding the details of public infrastructure also presents a challenge. Tatu Nieminen, CEO of REMOTED, highlights that autonomous shuttles face difficulties due to instances of other drivers illegally overtaking and making dangerous maneuvers. Still, regulatory aspects continue to be the most commonly identified challenges when discussing autonomous shuttles. The strict safety standards that apply on European roads include, for example, monitoring vehicle systems and integrating emergency plans. While Levels 1 and 2 of autonomous driving already cover assistance systems in vehicles and are approved in all European countries, regulations for Levels 3 and 4 vary across the different countries, with Level 4 having unique safety design demands.

5.3.2. On demand public transport

For many years, Demand Responsive Transit (DRT), also known as micro-transit services, have been introduced in different countries as a potential solution to some challenges faced by the traditional public transport. However, DRT quickly proved to be costly and unable to deliver the anticipated advantages. Only in more recent years, thanks to smartphones and the use of real-time vehicle information, DRT became popular again.

In Europe, cities like Barcelona, Vienna and Madrid rely on DRT services. But it is in small and medium size cities and low-density suburbs that these services are progressing more. Some European-funded projects, such as MULTIDEPART, have been specifically focusing on the development of the DRT market. Additionally, projects like ULTIMO want to set the foundations and deploy the very first economically viable large-scale, on-demand, and passenger-oriented Automated Vehicle public transportation services.

There are different types of operational DRT models, from the least flexible to the most flexible options, such as door to door services. However, what can truly unlock the full potential of DRT is the use of GNSS. The usage of smart algorithms that perfectly align with the real-time vehicle locations can determine the optimal routes and schedules based on the passengers' needs, facilitating efficient ride-sharing among multiple passengers.

Companies like Ioki, Clever Shuttle, Shotl, Padam Mobility, Door2door, UbiGo, Via and Ne-mi offer on demand services across Europe leveraging on different business models. Frequently, these services are mostly funded by governments, with some companies working on more viable and profitable business models. Finally, public-private partnerships, involving a collaboration between established entities like public transport authorities, operators, and DRT providers are gaining pace.

When talking about DRT challenges, in the past they were mostly related to technical limitations in booking, routing and trip ordering technologies. However, nowadays the biggest problems are related to the characteristics of the vehicles, regulatory frameworks, financing scheme and operating costs, as well as the operator and community culture. The Kutsuplus service is a clear example of these challenges. It was operational in Helsinki from 2013 to 2015 and gained great popularity, with over 70,000 trips taken in 2014. However, despite its positive impact, the service was discontinued in December 2015 due to its excessive costs compared to the number of passengers.

5.3.3. Connected Driver Advisory Systems (C-DAS)

Driver Advisory Systems (DAS) offer substantial advantages by decreasing energy expenses and carbon emissions. Yet, it is becoming evident that the benefits of DAS can be further enhanced through its integration with a Traffic Management System (TMS), giving rise to the concept of C-DAS, or Connected Driver Advisory Systems.

In this integrated system, the Traffic Management System (TMS) establishes real-time timing requirements for scheduling and adherence to the timetable, while the Driver Advisory System (DAS) determines the most efficient driving style within the bounds of these requirements. Real-time updates related to scheduling, routing, and speed restrictions are then communicated to the vehicle. Simultaneously, information gathered from the vehicle contributes to traffic regulation decisions made within the TMS.

When implemented in trains some of the advantages of C-DAS include:

- Less time in red signals.
- Decreased energy consumption.
- Better recovery during disruptions.
- Improved driver guidance and incident investigation.

However, one of the primary challenges that hinders the broader adoption of C-DAS is the interaction between DAS and TMS systems. Establishing standards and protocols for communication between these two systems can be a costly and time-consuming process. SFERA Project (Smart communications For Efficient Rail Activities), a collaboration among 11 major European railway companies between 2016 and 2020, aimed to reduce train energy consumption and set common principles for live traffic optimisation. One of the outcomes of this project was the provision of means to facilitate the use of C-DAS systems for all trains by standardizing data exchange between on-board and traffic management systems.

In Europe, companies such as Siemens Mobility, Trapeze Group, Alstom, and Hitachi offer C-DAS solutions. While these systems are currently predominantly implemented in trains, there is potential for future development in vehicles like buses and trams.

5.4 Summary of drivers for user requirements

In this section a set of key drivers for user requirements in the public transport segment is presented below:

- Authentication and Robustness: ensuring secure and reliable authentication has become an important concern in safety-critical applications. Robust systems are necessary to mitigate risks effectively.
- Payment-Linked Features: features integrated with payment systems, like DRT (Demand Responsive Transport) services, are gaining popularity among users, enhancing convenience and accessibility.

- High Accuracy and Urban Availability: urban environments demand high accuracy and availability, particularly for applications such as autonomous shuttles, to ensure effective operations.
- Scalability: GNSS technology distinguishes itself from potential substitutes by offering scalable solutions, requiring minimal infrastructure for deployment.
- Intermodality Integration: users have expressed a need for seamless and continuous solutions that are not developed for a specific mode of transport.
- V2X Development: the growth of V2X applications, extending beyond cars to include motorcycles, cyclists, and road workers, is set to expand the utility of GNSS technology.
- Cybersecurity: given the sensitive data involved, robust cybersecurity measures are imperative for GNSS solutions. A breach in GNSS receivers could have significant consequences, especially for complex applications like autonomous shuttles.
- Environmental Impact: user requirements are influenced by the environmental impact of technologies and GNSS and EO can contribute to a more sustainable mobility.

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

REQUIREMENTS FOR BUS APPLICATIONS

Id	Description	Type	Source
EUSPA-GN-UR-PUB-0210	The positioning system shall provide an availability better than 99,9 %	Performance (availability)	Validated at UCP 2023 Identified in [RD 3]
EUSPA-GN-UR-PUB-0220	The positioning system shall be able to provide a fix rate accuracy less than 10 Hz	Performance (position fix rate)	Validated at UCP 2023 Identified in [RD 3]
EUSPA-GN-UR-PUB-0230	The positioning system shall provide a horizontal accuracy at meter level	Performance (accuracy)	Validated at UCP 2023 Identified in [RD 3]
EUSPA-GN-UR-PUB-0270	The positioning system shall provide a vertical accuracy at meter level	Performance (accuracy)	Validated at UCP 2023 Identified in [RD 3]
EUSPA-GN-UR-PUB-0240	The timing system shall provide an accuracy within range of 1us	Performance (accuracy)	Validated at UCP 2023 Identified in [RD 3]
EUSPA-GN-UR-PUB-0250	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 Medium-High	Performance (integrity)	Validated at UCP 2023 Identified in [RD 3]

EUSPA-GN-UR-PUB-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 Alert)	Validated at UCP 2023 Identified in [RD 3]

Table 15: GNSS requirements for bus applications.

REQUIREMENTS FOR TRAM APPLICATIONS

Id	Description	Type	Source
EUSPA-GN-UR-PUB-0310	The availability of the location information provided by the positioning system shall be High	Performance (availability)	Validated at UCP 2023 Identified in [RD 3]
EUSPA-GN-UR-PUB-0320	The positioning system shall be able to provide a fix rate accuracy of 1 Hz	Performance (position fix rate)	Validated at UCP 2023 Identified in [RD 3]
EUSPA-GN-UR-PUB-0330	The positioning system shall provide a horizontal accuracy at meter level	Performance (accuracy)	Validated at UCP 2023 Identified in [RD 3]
EUSPA-GN-UR-PUB-0340	The timing system shall provide an accuracy within range of 1s	Performance (accuracy)	Validated at UCP 2023 Identified in [RD 3]
EUSPA-GN-UR-PUB-0350	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)	Validated at UCP 2023 Identified in [RD 3]
EUSPA-GN-UR-PUB-0360	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 Alert)	Validated at UCP 2023 Identified in [RD 3]

Table 16: GNSS requirements for tram applications.

REQUIREMENTS FOR URBAN RAIL APPLICATIONS

Id	Description	Type	Source
EUSPA-GN-UR-PUB-0410	The availability of the location information provided by the positioning system shall be High	Performance (availability)	Validated at UCP 2023 Identified in [RD 3]
EUSPA-GN-UR-PUB-0420	The positioning system shall be able to provide a fix rate accuracy of 1 Hz	Performance (position fix rate)	Validated at UCP 2023 Identified in [RD 3]
EUSPA-GN-UR-PUB-0430	The positioning system shall provide a horizontal accuracy at meter level	Performance (accuracy)	Validated at UCP 2023 Identified in [RD 3]
EUSPA-GN-UR-PUB-0440	The timing system shall provide an accuracy within range of 1s	Performance (accuracy)	Validated at UCP 2023 Identified in [RD 3]
EUSPA-GN-UR-PUB-0450	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)	Validated at UCP 2023 Identified in [RD 3]
EUSPA-GN-UR-PUB-0460	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 Alert)	Validated at UCP 2023 Identified in [RD 3]

Table 17: GNSS requirements for urban rail applications.

6.2 Synthesis of Requirements Relevant to EO

EO applications in this segment fall under Type C. Therefore, they won't be discussed in this section. These applications include:

- Bus: transportation network planning and optimisation.
- Tram: transportation network planning and optimisation.

6.3 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. Most of the inputs came from the persons listed below while the community participated as well via the UCP.
Additional details may be provided (organizations, contacts, etc) depending upon the segment.

7 ANNEXES

A.1 Definition of key GNSS performance parameters

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) refers 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

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 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 List of Acronyms

Acronym	Definition
EC	European Commission
EGNOS	European Geostationary Navigation Overlay Service
EGNSS	European Global Navigation Satellite System
EO	Earth Observation
ESA	European Space Agency
EU	European Union
EUSPA	European Agency for the Space Programme
GNSS	Global Navigation Satellite System
HAS	High Accuracy Service
IRIS	Infrastructure for Resilience, Interconnectivity and Security by Satellite
ITxPT	Information Technology for Public Transport
MR	Market Report
EUSPA	European Union Agency for the Space Programme
OSNMA	Open Service Navigation Message Authentication
PNT	Positioning, Navigation and Timing
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
SoL	Safety of Life Service
SST	Space Surveillance and Tracking
UCP	User Consultation Platform
UCR	User Community Representatives

A.5 Reference Documents

Id.	Reference	Title	Date
[RD 1]	EUSPA Market Report	EUSPA EO and GNSS Market Report (*Issue 1*)	Jan. 2022
[RD 2]	GNSS Technology Report	GSA GNSS Technology Report (*Issue 3*)	Sept. 2020
[RD 3]	GSA-MKD-RL-UREQ-A11400	Public Transport user needs and requirements	April 2021

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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