REPORT ON ROAD USER NEEDS AND REQUIREMENTS

OUTCOME OF THE EUSPA USER CONSULTATION PLATFORM

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01 INTRODUCTION AND CONTEXT OF THE REPORT

Even if the first prototypes of automobile navigation systems were available in the first half of the Twentieth century (see "Iter Avto", the world's first automobile navigator, created in 1930 on Figure 1 here after), millions of drivers discovered the benefits of in car navigation systems in the 90s when GNSS road navigation systems appeared on dashboards. Road traffic information and guidance services took off at the same time.

Figure 1: Iter Avto – The world's first automobile navigation system (1930)

Nowadays GNSS service is an option selected by a significant number of car buyers. Nevertheless, due to the cost of this option, which is very often associated with other devices (like radio or mobile phones) many customers prefer to use a personal navigation device or their familiar smartphones. Consequently, GNSS is present in almost all cars and service providers have developed a long list of services dedicated to comfort, entertainment and safety.

Public authorities also embarked on the new possibilities brought by GNSS. Regulations in Europe for interoperability of Road User Charges, the deployment of eCall on all new types of vehicles from 2018 and the control of digital tachograph on trucks and passenger vehicles with more 9 seats are the most outstanding examples.

The next step will be the intensive use of GNSS in vehicle-to-vehicle and vehicle-to-infrastructure communications that will pave the way to Automated vehicles. Advanced Driver Assistance Systems (ADAS) currently used to improve the safety or mobility of the driver, are being further developed as precursor to automated vehicles. Industry players such as Tesla, Baidu, Honda, Toyota, Uber and more are already rushing to bring the first commercial vehicle to market. Since R&D technical details may reveal the underlining strategy, industry players are not willing to share information about their requirements. Nonetheless, the identification of a set of commonly accepted technical user requirements could provide a number of benefits to the entire industry. In this sense, this document includes a first set of technical User Requirements related to the in-vehicle positioning system with special regards to the performance of the GNSS receiver. Some of the requirements of the in- vehicles Positioning, Velocity and Timing (PVT) system directly apply to GNSS receivers, while others are the result of a data fusion process, which depends on all connected sensors, communication technologies, and PVT processing algorithms. It should be intended as a first step towards the definition of commonly accepted technical user requirements, which should be validated periodically by GNSS technical experts from both the scientific community and the industry. It should also be updated on a regular basis to guarantee adherence to the technology evolution, the evolving normative frameworks and/or the certification/type approval procedures.

NOWADAYS GNSS SERVICE IS AN OPTION SELECTED BY A SIGNIFICANT NUMBER OF CAR BUYERS

The User Consultation Platform (UCP) is a periodic forum organised by the European Commission and the EUSPA involving end users, user associations and representatives of the value chain, such as receiver and chipset manufacturers, application developers and the organisations and institutions dealing, directly and indirectly, with Galileo and EGNOS. The event is a part of the process developed at the EUSPA to collect user needs and requirements and take them as inputs for provision of user driven Galileo and EGNOS services. In this context, the objective of this document is to provide a reference for the European GNSS Programmes and for the automotive community reporting periodically the most up-to-date GNSS user needs and requirements in the Road market segment. This report is considered a "living document" in the sense that it will serve as a key input to the next UCP event where it will be reviewed and subsequently updated. The UCP will be held periodically (e.g. once per year) and this report will be also periodically updated, to reflect the evolution in the user needs, market and technology captured during the UCP.

The report aims to provide the 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 services provided by the European GNSS systems and their evolutions.

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

It must be noted that the listed user needs and requirements cannot usually be addressed by a single technological solution but rather by combination of several signals and sensors. Therefore the report does not represent any commitment of the European GNSS Programmes to address or satisfy the listed user needs and requirements in the current or future versions of the EGNSS services.

1.1 METHODOLOGY

The following figure details the methodology adopted for the analysis of the Road user requirements.

The analysis is split into two main steps including a "desk research", to gather main insights, and a "stakeholders consultation", to validate main outcomes.

More in details, *"desk research"* was based on a secondary research and aimed at providing a preliminary structured analysis:

- leveraging on the Road applications' segmentation as included in the EUSPA GNSS market report, additional relevant applications have been identified and included; and
- for each application identified, the function and level of performance required has been determined.

As a result of this activity, a first draft of the Road User Requirements document has been produced.

In the second step, the "stakeholder consultation" one, main outcomes included in the document have been validated and updated. In this regard, preliminary validation interviews with selected stakeholders have produced the current document to be used as a input for the UPC review and finalisation.

Figure 2: Road User Requirements Methodology

OVERALL METHODOLOGY

1

Desk Research

Identification of all existing Road applications along with the function that they perform

- All Road applications covered in MR5
- Surveying applications found in other sources

User level dimension and characterisation

- Identification of the key GNSS user level dimensions to describe Road user requirements
- Identification and definition of GNSS performance criteria relevant to road

Segmentation of Road Applications

- Definition and classification of applications
- Focused on GNSS usage (not device-based)

Definition of the functions and level of performance required for each application

- Road user requirements analysis based on open secondary research information
- GNSS limitations, market/techno trends and drivers
- Table matching the main applications with the performance criteria

User requirement analysis – *draft 1*

SECONDARY RESEARCH INFORMATION

GNSS magazines - Coordinates, GPS World, Inside GNSS; ESA website; Articles on Google Scholar; Thesis and dissertations on specific database; European regulation or standard; Google

2

Stakeholders Consultation

Validation interviews

- Interview guide
- Selection of the consulted stakeholders
- Primary research: Interviews and reporting

User requirement analysis – *final version*

User Consultation Platform

- User requirements submitted to the first UCP forum for review and finalisation
- Update, validation and expansion of the User Requirements analysis at each UCP

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1.2 SCOPE

This document is part of the User Requirements documents issued by the European GNSS Agency for the Market Segments where Position Navigation and Time (PNT) play a key role. Its scope is to cover user requirements on PNT solutions from the strict user perspective and the market conditions, regulations, and standards that drive them. Therefore, the document includes an analysis of the market trends on this particular segment, then performs a detailed analysis including the prospective uses of GNSS in this market finalising with a specification of user requirements in a format that can be used for System Engineering activities.

In more detail, the document is laid out as follows. It starts with a summarised market overview for road (section 4), where market evolution and key trends, the main market players and user groups are presented.

Then it moves on to the analysis of GNSS user requirements for road (section5). Section 5 is organised as follows:

- Section 5.1 identifies and defines the GNSS use in road, road applications, existing EU regulations, performance parameters and application categories.
- Prospective use of GNSS in road is addressed in section 5.2.
- GNSS limitations for road are described in section 5.2.4.
- Section 5.4 identifies the drivers for user requirements in Road.

Section 6 focuses on the main GNSS user specifications for Road (section 6.1), in addition to summarising the performance requirements by applications.

The document is intended to serve as an input to more technical discussions on Systems Engineering and evolution of the European GNSS systems, so that space infrastructures are effectively linked to user needs.

02 EXECUTIVE SUMMARY

KEY TRENDS AND MARKET EVOLUTION

It is obvious that the motto of map makers *"you can never be lost again driving your car"* has become a reality. Satellite positioning already provides accurate maps and advanced navigation advice. The success of in vehicle systems, portable navigation devices, has been completed by user friendly navigation apps on smartphones, in the last five years.

The dominant place of GNSS road applications in the whole GNSS market is going to be confirmed by public authorities' decisions and the advent of connected cars. Later on, autonomous vehicles will bring a new set of requirements although it is not yet very clear what will be the final role of GNSS in the complex guiding system installed in such cars.

E-call and the Smart Tachograph are already good examples of use of GNSS in European policy. The directive on interoperability of road toll systems in the European Union is another one. But we are moving from specific devices, supporting specific applications, to the vehicle becoming a platform of connected services requiring more stringent performances for positioning, timing and navigation.

Advanced Driver Assistance Systems (ADAS), one of the fastest growing segments in automotive electronics today, are paving the way to a large series of applications based on real-time communications between roads users themselves and infrastructures.

Tier 1 suppliers and vehicles manufacturers will continue to be the main market players. Nevertheless, the deployment of in-vehicle connected platforms will attract the attention of telematics services providers. For the majority of them, accurate geolocalisation and time stamp of collected data is a guarantee for the quality of services they provide.

Pushed by regulators, E-call and tachograph have a strong impact on the market development. Same involvement of public authorities will be welcome to incorporate the GNSS positioning and timing in legal metrology. This action will facilitate the deployment of road tolling, taximeters and various payment applications. The authentication of signals provided by Galileo could benefit from adequate standardization.

PERSPECTIVE USE OF GNSS IN ROAD

Despite some limitations in urban environment and tunnels, the GNSS service will stay the cornerstone of many road applications. It is worth mentioning that with multi-constellations and multi-frequencies the positioning provided by GNSS signals will be significantly improved. Thanks to its great interoperability with GPS, and some wide band signals, Galileo has a major role to play in this evolution. High accuracy and authentication could be another valuable asset. Nevertheless, for the most demanding applications like automatic braking, lane keeping and autonomous cars, the coupling with other on-board sensors and 3D mapping will be inevitable. Like in civil aviation, the in-vehicle positioning system will have a complex architecture to go through the standardization process of safety critical applications.

THE CAR INDUSTRY IS MOVING TOWARDS CONNECTED CARS AND AUTOMATED DRIVING

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The below classification of these applications into four groups can provide an easy bird view on the magnitude of GNSS in the coming car industry evolution:

- Safety critical applications
- Payment critical applications
- Regulatory critical applications
- Smart mobility

Twelve performance parameters have been carefully selected to specify GNSS positioning and timing for road applications. Availability, accuracy, integrity and authentication are the most important ones in particular for safety critical and payment critical applications. A synopsis of the user requirements is provided below for the key performance parameters.

There is a significant potential in perspective for the use of GNSS on the road transport as the whole car industry is moving, worldwide, towards connected cars and automated driving. Certainly, the connected car based on a permanent

Table 1: Performance parameters

	Availability	Positioning accuracy	Timing accuracy	Integrity message	Robustness vs. spoofing	Detection of GNSS interferences
Safety critical - traffic and safety warning	> 99.5%	< 3 metres (horizontal, Day 1 applications) < 1 metre (horizontal, advanced applications)	< 1 second	Required	Robustness vs. spoofing threats required	Required
Safety critical - automated driving	> 99.9%	< 20 cm (horizontal) < 2 metres (vertical)	< 1 micro second	Required	Robustness vs. spoofing threats and notification to the driver required	Required
Payment critical	> 99.5%	< 3 metres (horizontal)	< 1 second	Required	Authentication message required	Required
Regulatory critical	> 99.5%	< 5 metres (horizontal)	< 1 second	Required	Authentication message required	Required
Smart mobility	> 99.5%	< 5 metres (horizontal) < 3 metres (horizontal) if payment functions are included	< 1 second	Not required	Authentication message required	Required

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short-range communication between vehicles, other road users and infrastructure (V2X) offers an almost unlimited series of applications. Among them, the applications dedicated to improving road safety and traffic efficiency have received warm support from public authorities who are ready to regulate as soon as the specific requirements will be settled. These applications, such as collision avoidance, automatic lane keeping, red light violation warning, are putting high requirement on positioning and timing. It is obvious that the deployment of V2X will pave the way to autonomous cars.

Autonomous driving is already a reality in mining industry and numerous pilot projects on different continents are striving to open the door on public roads. Some car manufacturers are already proposing automated driving on motorways and at slow speed, in traffic jams. Transport companies are looking at automated driving for trucks between interchanges and during platooning. We may expect that, very soon, we will see small shuttle buses operating on dedicated urban itineraries and peri-urban itinerary without any person on board able to quickly resume the control. Obviously the in-vehicle guiding system will have a very complex architecture with demanding performance requirements in terms of positioning accuracy, availability and robustness. With its new signals and commercial services Galileo has a great role to play in this architecture.

In autonomous driving, localization is an important part of the overall perception platform of the vehicle, and on the importance to distinguish among absolute positioning

Absolute positioning	Relative positioning
GNSS	LIDAR
WiFi/VANET	SLAM
RADAR	Map matching/ correlation
INS, accel.	Artificial Intelligence
Map matching/ correlation	Optical cameras
SLAM	IoT
HAD maps	Machine learning

versus relative positioning. The former can be fulfilled by GNSS, while other technologies, like cameras, LIDAR, etc. can assist in relative positioning.

Thus, there is a need to fine-tune the performance requirements at the PNT level in a "sensor fusion" perspective which seems to be the way forward for the near future for conditional autonomous driving and other demanding applications. Indeed, future evolution is not expected to take place at the level of stringency of the requirements, but at the level of effectiveness of sensor fusion techniques. The vision is not to have one technology as the 'primary' in the medium term. The PNT solutions will be a combination of all the technologies above. Better coherence between positioning systems needs to be achieved.

DRIVERS FOR USERS' REQUIREMENT AND E-GNSS PROPOSITION

To face up the challenges of positioning and timing in the upcoming V2X and autonomous driving Galileo has key assets. Galileo will benefit of its great interoperability with GPS. A GNSS receiver capable of tracking multi-constellation, multi-frequencies with wide band signals, MBOC in E1 and AltBoc in E5, will provide for better availability, accuracy and robustness in urban environment. In addition, Galileo can take stock of its differentiators. Authentication of open service and high accuracy based on PPP corrections transmitted in the E6 CS signal will be key advantages. For safety and payment critical applications an integrity message adapted to the needs of the road sector will be needed. It could at the same time support legal metrology.

For all the V2X applications including automated driving the exact performances of the in-vehicle navigation systems must be carefully standardized by relevant bodies in order to group a bunch of applications into viable market packages.

Ultimately, the localization system of a vehicle should be assessed against common performance requirements following a type approval process. It should be evaluated the support to design harmonized architectures and certification procedures within industrial organizations, and standardization bodies.

CONCLUSION

If the interactions with stakeholders have confirmed a consensual vision of the advent of connected car and autonomous vehicle, there seems to be a limited confidence in GNSS and, very often, a low awareness of the new possibilities that will be offered by EGNSS. They request more detailed information from EGNSS promoters. All along the road value chain, research and pilot projects are needed to convince all the decisions makers to incorporate latest GNSS signals in their system architecture. Regulations will stay at the corner stone of this market development.

03 REFERENCE DOCUMENTS

Ref.	Reference	Title	Date
[RD1]	Market Report 4	GSA GNSS Market Report Issue 4	March 2015
[RD2]	New GNSS paradigms in Road	Technical analysis of new paradigms increasing EGNSS accuracy and robustness in vehicles	May 2015
[RD3]	C-ITS Platform	C-ITS Platform Final Report https://ec.europa.eu/transport/themes/its/c-its_en	January 2016
[RD4]	Tu Automotive	Graham Jarvis / Auto Jarvis	April 2016
[RD5]	ESCAPE Project	European Safety Critical Applications Positioning Engine, http://www.gnss-escape.eu/	June 2017
[RD6]	SaPPART COST Action TU1302	SaPPART Handbook, "Assessment of positioning performance in ITS applications", available at http://www.sappart.net/wp-content/uploads/2017/06/	June 2017
[RD7]	US DOT /Iteris	List of V2V and V2I applications http://www.iteris.com/cvria/html/applications/applications-groupsort.html	2016
[RD8]	Car-2-car consortium	https://www.car-2-car.org/index.php?id=5	2015
[RD9]	Cloud LSVA	http://cloud-lsva.eu	2016
[RD10]	UNECE	United Nations Economic Commission for Europe, UNECE, approved on March 23 autonomous driving systems on the roads	March-2016
[RD11]	ETSI TS 103 246-5	ETSI TS 103 246-5, Satellite Earth Stations and Systems (SES), GNSS based location systems - Part 5: Performance Test Specification	2015
[RD12]	ETSI TS 103 246-3	ETSI TS 103 246-3, Satellite Earth Stations and Systems (SES), GNSS based location systems - Part 3: Performance requirements	2015
[RD13]	ETSI TS 103 246-2	ETSI TS 103 246-2, Satellite Earth Stations and Systems (SES), GNSS based location systems - Part 2: Reference Architecture	2015
[RD14]	EN 16803-1:2016	EN 16803-1:2016 Space - Use of GNSS-based positioning for road Intelligent Transport Systems (ITS): Part 1: Definitions and system engineering procedures for the establishment and assessment of performances.	2016
[RD15]	GNSS Technology report	https://www.gsa.europa.eu/newsroom/news/gnss-user-technology-rapidly-evolving-landscape	2016
[RD16]	Open Auto Drive Forum - OADF	http://www.openautodrive.org/index.html	2016
[RD17]	Car2car consortium	www.car-2-car.org	2014

Ref.	Reference	Title	Date
[RD18]	Alpine interview	Director Alpine Electronics R&D Europe	2017
[RD19]	Denso interview	Senior Technical Manager, Industry Relations & Business Development	2017
[RD20]	Navinfo interview	Business Development & Strategy Advisor	2017
[RD21]	uBlox interview	Principal Corporate Strategy	2017
[RD22]	Continental interview	Head of Security, SW Group Leader for Positioning	2017
[RD23]	Techno. Report	GNSS Technology Report issue 1	2016
[RD24]	GSA-MKD-RD-MOM-246194-UCP2018-Transport-Road	User Consultation Platform 2018 – Minutes of Meeting of the Road Panel	03.12.2018
[RD25]	Euractiv Forum	Declaration on horizontal accuracy of automated driving in urban environment	26.12.2018

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04 GNSS MARKET OVERVIEW AND TRENDS FOR ROAD

4.1 MARKET EVOLUTION AND KEY TRENDS

First quantified in the GNSS Market Report for the year 2012 with approximately 1.6 mln unit, the shipments of insurance telematics have witnessed a significant growth surpassing 6 mln units in 2015.

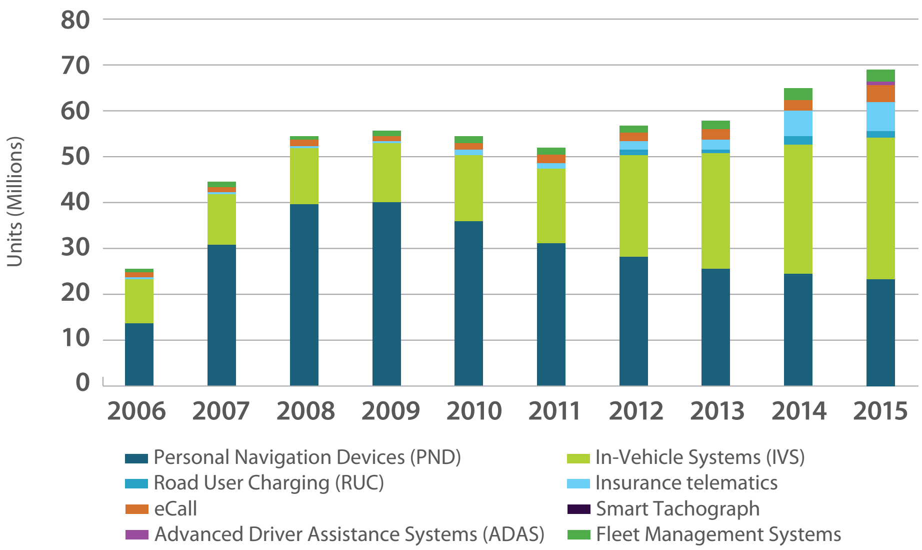
Although the annual shipments of road GNSS devices is largely dominated by Personal Navigation Devices (PNDs) and In-Vehicle Systems (IVS), accounting for 23 mln and 30 mln units respectively in 2015, their share on the total amount of shipments has been gradually decreasing due to the growing uptake of regulated and mandatory applications such as On-Board Units (OBUs) for Road User Charging (RUC) and commercial eCall systems. Whereas IVS and PND shipments accounted for 95% of total GNSS shipments in 2008, the share dropped to 79% in 2015 and is expected to witness a further decrease. [RD1]

Talking about regulated applications, alarm unit shipments (including also commercial versions) grew by a CAGR of 16.4% between 2010 and 2015 reaching global shipments of 3.4 mln units in 2015. OBUs dedicated for RUC of heavy commercial vehicles realized shipments of 1.6 mln units in 2015 and an estimated 4.4 mln units are in use.

Since 2012, Asia-Pacific has become the largest market (share of 37%) for road GNSS devices. Historical market information on GNSS shipments is provided on the following figure.

In terms of market perspectives, shipments of IVS are expected to reach 63 mln by 2025, effectively doubling the shipments realised in 2015. In some regions such as Europe and North America, the penetration rate of IVS in new vehicle shipments is expected to reach 80% over the

Figure 3: Historical GNSS Road market data – shipments



ASIA-PACIFIC HAS BECOME THE LARGEST MARKET FOR ROAD GNSS DEVICES

period 2020-2030. Through the IVS, OEMs are able to provide Connected Vehicle platforms and services to the customer adding additional revenue models to their portfolio.

Boosted by the EU legislation requiring all new types of car sold in the EU from 2018 onwards to be equipped with an eCall system, eCall shipments (which include also commercial solutions) are expected to grow by a CAGR of 17% till 2025 reaching 38 mln units. From 2018 onwards, the Russian eCall equivalent, ERA-GLONASS, is also expected to be introduced in other members of the Eurasian Economic Union, bringing GNSS-supported emergency call to countries such as Kazakhstan and Belarus.

Shipments of commercial vehicle related applications such as RUC OBUs, Smart Tachographs and commercial Fleet Management Systems are growing from 4.3 mln units in 2015 to 15.4 mln units by 2025 with Fleet Management Systems making up for almost 50% of the annual shipments. Several commercial vehicle OEMs already pre-fit their new models with the hardware and basic software to support Fleet Managements System services.

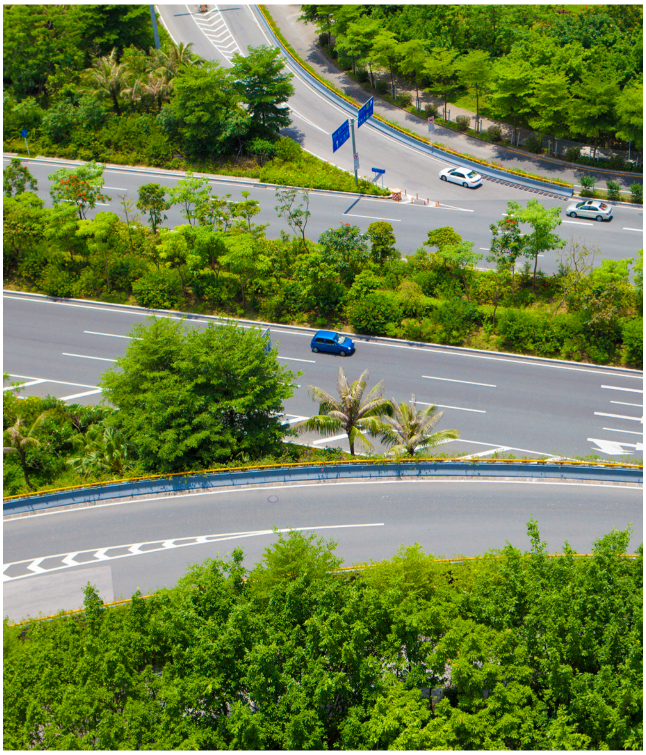
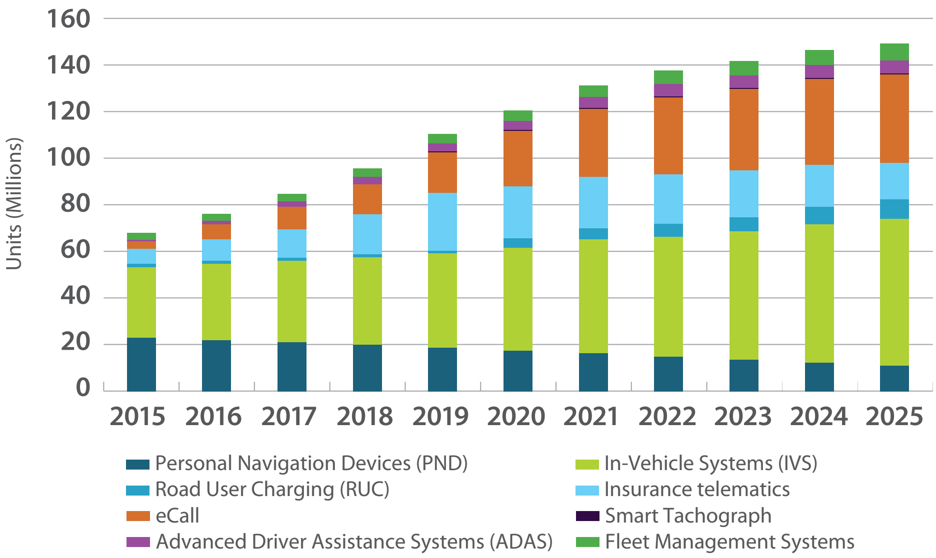


Figure 4: Forecast GNSS Road market data – shipments



4.2 MAIN MARKET PLAYERS

Main market players in the Road segment can be identified in the following value chain. For logistics, transport professionals play a major role. Road users like transport professionals are under the control of public authorities who have the possibility to regulate when it is needed.

Figure 5: GNSS Road Value Chain

> IN THE WORLD MARKET INNOVATION IS THE KEY REQUEST TO SURVIVE

In addition, new players such as Tech giant and mobility providers show a greater interest in the Road segment. Google develops its own autonomous car, Apple prefers to sit on its role of software providers and Microsoft signed with Renault Nissan an agreement to support the connected car. It is worth mentioning new manufacturers like Tesla which bring a very disruptive approach in the electric car industry.

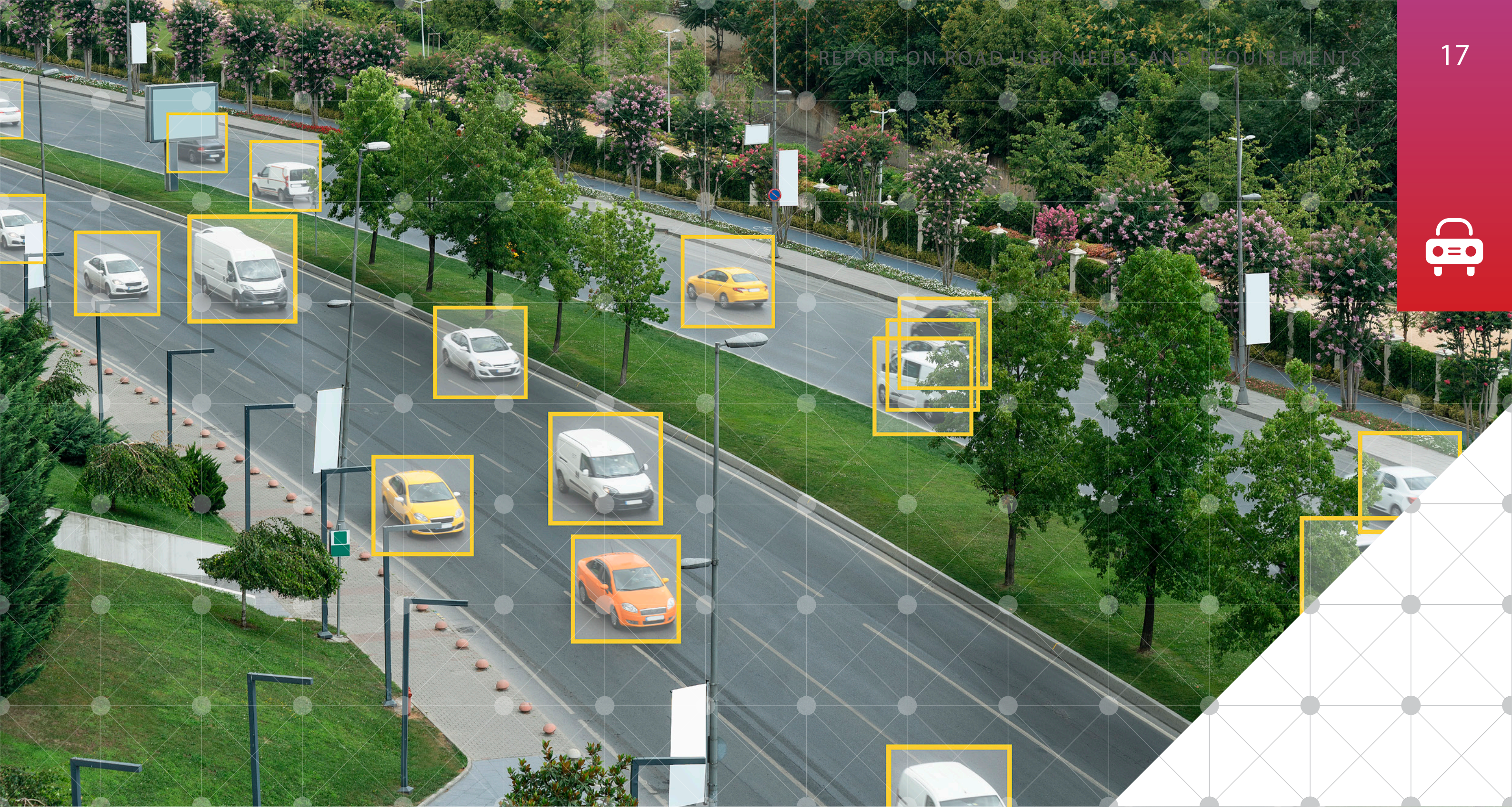
At first sight the value chain in the road GNSS sector seems very straightforward. It goes from chipset manufacturers to car owners via tier 1 suppliers and vehicle manufacturers. These actors are multinational corporations which operate mainly at international scale. Car manufacturers and on-board equipment manufacturers are engaged in a fiercely competition on a world market where innovation is the key request to survive. Car manufacturers and their suppliers have to change how they think to stay ahead in the fast moving areas of connected car, autonomous driving and personal mobility.

When going more downstream and exploring the service dimension, the eco system is more complex. Professionals do not have the same needs as average drivers. Digital map providers are establishing strategic agreements with car manufacturers or OEM providers to embark surely on connected and automated driving trend while in the meantime car manufactures are opening their on-board platform to start-ups to build their own on-board apps platform.

Finally, setting the framework for the adoption of high tech solutions falls under the responsibility of policy bodies at national, regional and international level.

In summary, as far as GNSS requirements and technical specifications are concerned, four distinct groups set the stage:

- **Vehicle manufacturers** and **Tier-1 suppliers** appear to be the key decision makers. They are not fully aware of the new possibilities offered by Galileo and GPS III signal plan and they prefer to stick to proven solutions
- **Service providers** which encompass traditional traffic information providers, toll operator, fleet and freight managers but more and more mobile network operators, cloud services, telematics services providers, specialised application developers, aftermarket solutions providers, etc.
- **Public authorities and Road operators** to provide high level dynamic maps, which require precise localization of road objects (fixed and mobile) and develop services to automatically detect hazards (potholes …)
- **Component manufacturers** for chipset, screen, antennas, map makers and device vendors integrating different technologies in one solution



- **Legislation and policy bodies** that put forward measures and regulation towards sustainable, competitive and environmentally-friendly mobility solutions in liaison with local authorities

4.3 MAIN USER GROUPS

Target groups of GNSS users that can effectively contribute to smooth some blocking points and facilitate the development of road GNSS markets are:

- Group 1: Research institutes and universities working in the field of navigation and positioning for automotive industry with a particular focus on signal processing, in order to demonstrate the benefits of multi-frequencies wide band in urban environment to mitigate multipath effects. Some institutes involved in legal metrology can also participate.
- Group 2: Public authorities at National and European level aware of the GNSS possibilities in safety, payment and regulatory critical applications. Metrology, type approval are covered by public bodies, whereas certification is offered by private organizations.
- Group 3: Standardization bodies like ETSI, CEN/CENELEC informed of GNSS performance criteria to better specify the positioning and timing in the standards.
- Group 4: Industry, of course, is the main group to be informed and convinced. Tier 1 suppliers and aftermarket device vendors will play a major role between vehicle manufacturers and component suppliers to enrich the final services; industry has set up multiple working groups to proceed jointly on specifications and requirements ([RD17], [RD16]).
- Group 5: The users' community can express very different needs. Insurance companies, fleet operators, road network operators, shippers, logistics companies, public transport companies may have some specific needs which are not included in the car owner's package.

05 GNSS MARKET OVERVIEW AND TRENDS FOR ROAD

5.1 GNSS USE IN ROAD

5.1.1 MAIN GNSS TECHNIQUES USED IN ROAD APPLICATIONS

GNSS techniques have obviously played a major role in the Road segment. Initially GNSS was used with basic road navigation associated with road traffic information broadcasted in a European standard i.e. RDS-TMC. It was then intensively employed by surveyors to build and maintain the road infrastructures. At these early stages, coverage, availability and accuracy were the main performance requests. **GNSS built the foundation of what experts have called the intelligent highway and the Intelligent Transport System (ITS).**

In the next phase, road users charging, stolen vehicle recovery, insurance telematics and fleet management became increasingly popular.

IT IS EXPECTED THAT MORE AND MORE RECEIVERS WILL BE ABLE TO ACCEPT DIFFERENTIAL CORRECTIONS BROADCAST BY SBAS

Nowadays with ADAS services, cooperative ITS, autonomous driving and more globally Mobility as a Service solutions, the positioning and timing information are entering in a new era: high accuracy, reliability, authenticity, integrity will have to reach higher level of performance.

Due to natural constraints in tunnels, in towns or under dense canopy where GNSS signals are obstructed or strongly distorted manufacturers use various hybridization technics. Hybridization is normally performed in an on-board navigation unit, although personal navigation devices (PND), totally independent of the vehicle, are very often slicked on the dashboard by drivers. PNDs are cheap, up to date, and easy to move from one vehicle to another. As an alternative, road navigation is very often used as a simple additional application on smartphones. In that case they can be considered as a LBS (Location Based Service)_service. No specific regulation has been adopted so far for the use of such devices during driving, however it is clear that the driver uses them at its own risk and that the ergonomics of such solution is often questionable.

On the contrary, the on-board navigation receivers are qualified by car manufacturers. As they increasingly feed not only navigation but also safety critical applications, they can provide positioning and timing services in line with the stringent requirements they pose.

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Receivers for Road already largely have multi-constellation capabilities. In 2018 several new chipsets supporting multi-frequency were launched. The forerunners to ASIL/ISO26262 certified chipsets, for automated vehicles, already support multiple frequencies (L1 and a choice of L2 or L5 for the second frequency). Receivers are coupled with other on-board sensors like accelerometer, odometer and gyroscope. The trend for this type of receivers is to include other constellations on the same band.

With the application of the eCall regulation 2017/78, applicable from 31st March 2018, it is expected that more and more receivers will be able to accept differential corrections broadcast by Satellite Based Augmentation System (SBAS). Nevertheless, this technique will have some limitations in urban canyons and it is not sure that the vehicle will have the possibility to download regularly the EGNOS messages provided by the EGNOS Data Access Service or the data provided by Assisted GNSS servers. So the receiver will have to rely on hybridization with external sources to achieve high availability and continuity.

According to several technical analyses of new paradigms increasing EGNSS accuracy and robustness in vehicles [RD2] a loosely or tightly coupled GNSS receiver with an inertial measurement unit or other on board sensors seems to be the main trend in the automotive industry to reach high performances at a reasonable price.

Map-matching is currently used in navigation systems and traffic control center. It integrates position data with a road network data to determine a position of a vehicle on a specific link. Mountain areas and complex interchanges or cross roads in urban environment are the source of many errors. The 3D mapping will allow improving the position computation (see [RD2] p 73) by eliminating the Non-Line Of Sight signals (NLOS) and, at the same time, prepare the coming up of autonomous car. In the future, it is expected that maps will be updated or corrected in real time based on techniques inspired by SLAM (simultaneous location and mapping).

Autonomous vehicle promoters show a lot of interest in visual information and 3D mapping, very often linked to machine learning. Although the LIDAR technique used on autonomous car in demonstration projects will stay out of reach for mass market, the link with an image data base stored in the cloud brings great expectations and has pushed cloud providers like Microsoft, Amazon web service to sign agreements with car manufacturers (see [RD9] Cloud LSVA project).

The position accuracy is very likely to be significantly improved through the fusion of GNSS, other in-vehicle sensors and Computer Vision technology. Also crowdsourcing data is obviously a required source of information to contribute with the sensor fusion to maintain for instance the dynamic data in the Local Dynamic Map. The Local Dynamic Map is an essential data base virtualizing the driving environment and allowing the use of ADAS, autonomous driving, building up as well on the deep learning technologies.

Although these techniques seem very promising, this is still to be considered as research work. A precise satellite positioning will bring a major help to select the right images that the system will have to use and will remain the key mode to drive the autonomous car on country roads where the landmarks are rare. Nevertheless, autonomous driving experts consulted in the scope of the study believe that, in the long term around 2027, the navigation and autonomous driving will rely primary on camera based technology (see [RD22]).

5.1.2 OVERVIEW OF ROAD APPLICATIONS

The following classification will be used to carry out the user requirements analysis.

A. **Safety critical applications:** forward collision warning (V2X), 360° all around view pedestrians, cyclists and motorcyclists protection(V2X), speed limitation, lane departure warning (if based on GNSS) ...

B. **Payment critical applications:** Road user charging, Pay as you drive insurance, pay per use insurance, on street parking billing,

C. **Regulatory critical applications:** e-call, digital tachograph, hazardous material tracking, livestock tracing,

D. **Smart mobility:** Smart mobility is a broad concept that encompasses applications used by professional like road network operators and fleet managers and applications used by drivers. Subsequently the smart mobility can be split into:

a. *Smart mobility traffic and productivity management:* Freight and fleet tracking help transport companies to better manage their assets as floating car data provide valuable information to the traffic control center to better manage the traffic. Ultimately these information like traffic jams, travel time, accidents can be validated and broadcast to the drivers as a safety and comfort service.

b. *Smart mobility for user's safety and comfort:* Thanks to positioning and timing provided by GNSS, OEM and PND manufacturers are very active to develop services that offer more safety and comfort to the drivers. The basic route guidance service has been enriched by road traffic information, speed limit warning and travel time. More sophisticated services like lane level positioning, electronic horizon and green light optimum speed advisory are coming soon. It is worth mentioning also the specific need of electric cars which, due to limited capacity of the batteries, have to go often to refilling.

GNSS BUILT THE FOUNDATION OF THE INTELLIGENT HIGHWAY AND THE INTELLIGENT TRANSPORT SYSTEM

c. *Smart mobility for the Digital infrastructure:* Autonomous driving will require more details maps, not only HD maps with more accurate position and an up-to-date status of the components of the road infrastructure but also dynamic data relating to the other road users and hazards

d. *Smart mobility for electrical vehicles (EV):* provides optimization of routes and vehicle usage, based on the availability of charging spots or itineraries of the vehicle user

e. *Smart mobility services, where the user is not the driver but the client of a mobility service* (e.g. public transport, UBER …)

Note: Section 5.1 will focus on the applications currently using GNSS. Perspective applications (V2X, Autonomous vehicles) have been identified in this segmentation but will be tackled in Section 5.2.

5.1.3 EXISTING AND COMING EU REGULATIONS

Several existing EU regulations are driving the use of GNSS in the Road segment:

- Directive 2004/52/EC on the interoperability of road toll system in the community
- Directive 2008/68 on the inland transport of dangerous goods
- Delegated regulation 886/2013 for the provision of road safety related minimum universal traffic information follow up of directive 2010/40/EU
- Delegated regulation 962/2015 supplementing Directive 2010/40/EU with regard to the provision of EU wide real time traffic information services
- 2019 update: Regulation 165/2014 and implementing Regulation EU 2016/799 on tachographs in road transport
- 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
- 20130418 Commission implementing decision on the protection of animals during transport
- Council regulation N°1/2005 on the protection of animals during transport

Dangerous good tracking is under scrutiny at European and International level to prepare new regulations. The GPS based positioning data are linked with other sensors data describing the nature and status of the cargo. This information can be send to a central point of control with a geo fencing application. For example, this geo-fencing application can prevent hazardous material to drive through a densely populated area.

The impacts of these regulations on the User Requirements are considered in the following analysis.

5.1.4 PERFORMANCE PARAMETERS

The following performances parameters are listed and described in [RD2]. A short description of each parameter is provided in Annex 4:

1) Horizontal position accuracy
2) Vertical position accuracy
3) GNSS time accuracy
4) Time to first fix
5) Position authenticity
6) Robustness to interference
7) Position integrity
8) GNSS sensitivity
9) Availability
10) Continuity

The performance features reported above describe the behavior of the positioning terminal when it operates in relationship and interaction with the external world. However, in addition to the performance features reported above, there are other two important parameters of the positioning terminal that are determined by the design of the terminal and can influence the overall service performance:

11) Position fix rate

12) Latency

The GNSS receiver remains the fundamental source of absolute positioning among the other sensors. In addition, most of the positioning performance features have been derived from a context in which positioning was essentially GNSS-based only. For applications such as safety critical ones, some of the requirements put on the positioning terminal directly pass to the GNSS receiver, while others must be appropriately shared with the other sensors. Those performances are relating to the GNSS device providing PVT. However, it has been advised in the Inlane project to develop performance requirements for the systems resulting from the sensor fusion, where the position is computed with the GNSS in combination with other sensors (IMU, Video ….

5.1.5 APPLICATIONS CATEGORIES

A general description of each application category is provided in the following sub sections. For each category a summary table of each application is provided focusing on their GNSS usage.

5.1.5.1 SAFETY CRITICAL

Safety critical applications are applications in which drivers, passengers and other road users can be severely injured if the performance of the GNSS-based in-vehicle positioning system does not work properly. Availability, integrity, accuracy, GNSS sensitivity and robustness to interferences are the key performances indicators in this category.

Current applications provide safety related support based on contextual information such as queue warning, obstacles on the road, work zone warning etc. In these applications GNSS is already used as a complement to RDS TMC location tables or TPEG used in cell phones. The current requirements are not very stringent. But, when these safety applications will be supported by V2X communications, requirements figures will drastically increase and will become more stringent. For example, the red-light violation warning and the 360° all around view will require meter accuracy in horizontal positioning.

If the vehicle is able to activate the brakes automatically to avoid a collision, the system will have to be certified with a specific integrity message adapted to V2X safety applications. This function is clearly on the road map of automated driving and autonomous car.

Availability is the main requirement for all GNSS road applications, as the multi-constellation will improve the reception in urban environment; multipath will stay a major obstacle to reach high precision demanded by V2X safety applications. Data fusion with other sensors and map matching are unavoidable. Tunnel and indoor parking will stay out of reach of GNSS signals unless a repeater or a pseudolite is used. In addition, cybersecurity threats will require authenticating the signals in many safety critical applications.

Finally, Cooperative Intelligent Transport System is seen today by many governments as the only mean to decrease the number of road fatalities. This application is covered in section 5.2.

In accordance with [RD4], the applications of interest might be classified in 4 categories as follows:

- **Traffic Warnings:** General warnings/advices with respect to speed limits, congestion ahead, etc.;
- **Safety Warnings:** Safety related warnings that require immediate human intervention;
- **Automated Interventions:** Safety-related automated intervention such as emergency braking;
- **Driving Automation:** Advanced level of driving automation, such as ADAS.

An extensive list of application is described below:

AVAILABILITY, INTEGRITY, ACCURACY, GNSS SENSITIVITY AND ROBUSTNESS TO INTERFERENCES ARE THE KEY PERFORMANCES INDICATORS IN SAFETY CRITICAL APPLICATIONS

Table 2: Safety Critical Applications

Applications	Application description
Red light violation warning	An in-vehicle device determines according to its position and speed if the vehicle is in danger of violating a red light or a stop and sends a message to others
Curve speed warning	An in-vehicle device determines according to its position on the map and speed if the vehicle is in danger of losing its trajectory
360° all around view, blind spot lane change warning, oversize vehicle warning	The vehicles exchange in real time their position with other road users to mitigate blind spot effect
Obstacles on the road, work zone warning, weather based hazards, Queue warning, pedestrians in crossroads, cooperative intersection, collision avoidance including railways	An in-vehicle device displays the position of the danger to the driver with a certain accuracy and in real time
Emergency brake assist, collision avoidance	The vehicles exchange in real time the position, speed and direction to set up an emergency braking
Wrong way driving	The in-vehicle device must be able to determine according to its position on the digital map that the vehicle is driving on the wrong way of the motorway
Emergency electronic break light	In case of severe braking or blockage of the road the vehicle sends an alert message with its location to coming vehicles
Automatic speed limitation,	An in-vehicle device limits automatically the speed of the vehicle matching the position with a speed limit data base
Automated driving	Accurate positioning linked to other sensors will assist the driver to secure the automatic driving
Autonomous car	Only a deep integration of sensors will be able to secure the movements of autonomous car in various environments.
Synchronisation	Precise time synchronization will always be a strong requirement in all safety related applications

5.1.5.2 PAYMENT CRITICAL

In payment critical applications, billing is mainly based on the position and timing provided by an in vehicle GNSS device. The accuracy requested by these applications depends of the nature of the service. For example, Road User Charging (RUC) will request a higher accuracy than Pay Per Use Insurance.

All the applications in this category are commonly used by private entities but as soon as a public entity is involved like for RUC the GNSS positioning is not considered as a legal mean of measuring distance. The promoters of RUC have found a substitute. The itinerary is split into variable sections of a few kilometers each, basically from junctions to junctions, controlled by a pricing point that functions like a virtual gantry. The distance taken into account for the calculation of the fee is the sum of sections where the vehicle has passed a pricing point.

For future applications like dynamic ride sharing with exchange of small sums of money the legal status of GNSS metering will have to be elevated as a legal mean of metrology. This type of service could be used also by taxis and will be cheaper than a mechanical mean of distance measuring.

Accuracy, availability in towns and authenticity are the main performance indicators in this case. Indeed, cybersecurity threats will also affect the reliability of many payment applications.

Finally, it is worth mentioning that the GNSS positioning and timing has not yet an adequate status in the legal metrology to allow financial transactions. This shortfall will hamper the deployment of taxi meters and dynamic ride sharing for short distances.

Table 3: Payment Critical Applications

Applications	Application description
Road user charging	Position and timing provided by GNSS is recognized in the EU directive on interoperability of tolling systems and already commonly used in Europe
Pay as you drive insurance	Positioning, speed and timing can be linked to how, where and when a vehicle is driven, and provide valuable information for the insurance company
Pay per use insurance	Coverage of the assurance can be based on mileage aggregated from GNSS data
Taxi meter	A taxi meter is a device installed in car that calculates passenger fares based on combination of distance travelled and waiting time. Use of GNSS will simplify the device.
Parking fee calculation	Where satellite signal is available, positioning and timing provided by satellite can be used to calculate the parking fee. In addition, the vehicle can inform the parking manager that the place is free when it starts.

5.1.5.3 REGULATORY CRITICAL

Applications where the presence of an on board GNSS based positioning and timing equipment is imposed by national or international legislations are not numerous but new legislations are coming up.

Digital Tachograph and pan European eCall are tremendous boosters for the deployment of GNSS in the road segment.

Hazardous material tracking linked with appropriate virtual fencing to prevent dangerous material to drive through the inner city when it is not necessary should contribute to another deployment.

Moreover, Geo-fencing can also be used for developing a progressive urban pricing or prevent polluting cars to enter a low emission zone area.

As shown in the Appendix to Annex 2 on Performance Parameters, availability, accuracy, authentication and robustness will be the main performances criteria.

Table 4: Regulatory Critical Applications

Applications	Application description
Digital tachograph	In order to facilitate the verification of compliance with the regulation the position of the vehicle shall be recorded at specific points where the satellite signal is available
eCall	In case of crash or after manual activation, the vehicle must send a minimum set of data to public safety answering points, in which time stamp and location are provided by satellite positioning.
Hazmat tracking	A fleet management concept adapted to hazardous material tracking is under review in the UNECE group.
Livestock tracing	See Commission implementing decision on the protection of animals during transport
Geo fencing (low emission area, forbidden area, alert, …)	The in board GNSS based device triggers an alert when the vehicle enters or exit boundaries defined by geographical coordinates. It can be used as an access control to specific zones where only authorized vehicles are accepted. No regulations so far have been adopted but the geo fencing can play a major role in many applications like access control protected areas or tolling in urban centres

5.1.5.4 SMART MOBILITY

At first sight, a category of applications with no safety, payment, and regulatory requirements should not be of main relevance. Nevertheless, these applications play a great role in the deployment of smart mobility. In this category the availability, continuity and time to first fix are the most important criteria (see [RD2] table 4.3 Annex 1).

As described above, in paragraph 5.1.2 overview of road applications, this category has been split into two market segments: traffic manager and transport companies on one hand and drivers on the other hand. These applications are mainly driven by the market demand and subject to the dynamism of startup companies.

Table 5: Smart mobility for traffic managers and transport companies

Applications	Application description
Freight, Fleet, cargo asset management	Timely position of trucks, trailers, wagons, drivers, cargo, forklift and load units, remote vehicle diagnostics are key data for the optimum management of the supply chain.
Vehicle access/ clearance control	An authenticated position can facilitate the clearance control of vehicles travelling in and out an area
Floating car data	Localization, speed and time information produced by on board devices are intensively used by service providers an road network operator to produce traffic information
Origin destination survey	Precise geo coded of origin and end of trips provides a detailed picture of patterns and travels choice that help urban planners
Dynamic speed harmonisations	At specific location and timing vehicles are invited to slow down to adapt an appropriate speed to increase the capacity. This measure is also developed as an A-CCS
Emergency vehicle priority	An appropriate GNSS on board device can locate the priority vehicle relative to the traffic lights, send a message to adapt the signal phase timing and get a green light
Bus and tram priority at traffic lights	Same as above but I that case the tram or the heavy bus can't stop if it has no green light

Table 6: Smart mobility for safety and comfort of drivers

Applications	Application description
Road navigation with lane level positioning	The accuracy of the GNSS based device and map shall be able to provide a lane level positioning.
Speed limitation information	The speed limitation is displayed to the driver according to a speed data base and the location of the vehicle.
In vehicle signage	A static or dynamic sign information is displayed to the driver without roadside units just taken into account the localization and direction of the vehicle on the road
Electronic horizon	Thanks to an accurate digital map the driver can be informed of potential dangers located ahead of his current vision like sharp curve, pedestrian crossings or round about
Reduce speed warning	A warning is automatically issued to the driver if his speed doesn't match the lay out of the road taken into account the characteristics of the vehicle
Do not pass warning	During an overtaking knowing the exact position of vehicles coming in the opposite direction is strong request
Green light optimal speed advisory	Taken account the relative position of the vehicle and the traffic lights an optimum speed advice is given to the driver to pass the next traffic lights during a green phase
Automated parking	A very accurate positioning is needed to guide the vehicle during the parking process
Tailgating advisory	Exchange of relative positions between heavy vehicles to warn the driver that he is too close to another vehicle in front of it, creating an unsafe driving condition
Lane departure warning	An accurate position and a precise map can warn the driver that he is drifting off the lane
Traffic jam ahead and snowplough in operation	Knowing how far away is the next traffic jam helps the driver to adapt his speed, same for a plough in operation
Connected eco driving	Eco driving uses a map and the location of the vehicle to advice timely the driver so he can adjust his driving to save fuel and reduce emission. The service can be connected for real time data
Dynamic ride sharing	In dynamic ride sharing GNSS helps to precise the location of meeting points and facilitate the fee calculation
Stolen vehicle recovery	This application provides the position of the stolen vehicle
Electro mobility	Applications allowing the optimising usage of EV (Electric Vehicle) while providing the best route, including charging spots as necessary
Mobility services	Application where the user is not the drivers but use vehicle from a service provider (taxi, public transport …) needing the position of the clients and the vehicles

5.2 PROSPECTIVE USE OF GNSS IN ROAD

In the global automotive industry, today there are three major areas that will make an intensive use of GNSS positioning and timing: Advanced Driver Assistance Systems (ADAS), Vehicle to Vehicle/Infrastructure communication (V2X) and autonomous vehicle. As underlined by several interviewees (see [RD22] and [RD21]) there is not a clear separation between the groups, a smooth glide is expected from the most advanced ADAS applications like automatic cruise control, lane keeping to autonomous vehicle.

These categories gather a set of applications that will be progressively incorporated in vehicles and ultimately lead to the full autonomous car. For example, the automatic breaking from ADAS will be incorporated in the autonomous car. But it is useful to distinguish the various stages of the development of these applications. Each stage has its own market size and its own requirement as positioning and timing are needed.

THE EUROPEAN COMMISSION HAS SET A PLATFORM FOR COOPERATIVE INTELLIGENT TRANSPORT SYSTEM

5.2.1 ADAS

What do we call ADAS?

Advanced Driver Assistance Systems (ADAS) are developed to automate/adapt/enhance vehicle systems for safety and eco driving. Safety features are designed to avoid collisions and accidents by offering technologies that alert the driver to potential problems, or to avoid collisions by implementing safeguards and taking over control of the vehicle. In that case we may talk of Machine to Machine communication. Adaptive features may automate lighting, provide adaptive cruise control, automate braking, incorporate GNSS/ traffic warnings, connect to smartphones, alert driver to other cars or dangers, keep the driver in the correct lane, or show what is in blind spots.

5.2.2 V2X

What do we call Cooperative Intelligent transport system or in short V2X?

Cooperative Intelligent Transport Systems (C-ITS) use technologies that allow road vehicles to communicate with other vehicles, with traffic signals and roadside infrastructure as well as with other road users. The systems are also known as vehicle-to-vehicle communications, or vehicle-to-infrastructure communications (V2X). V2X communications also cover communications with other road users like motorcycles, bicycles and pedestrians. These communications are based on standardised messages CAM (Cooperative Awareness Message) and DENM (Decentralized Environmental Notification Message) and can support a lengthy list of applications. Positioning and timing are important data in CAM and DENM messages.

The 5.850-5.925 GHz band (ETSI ITS G5 802.11p) has been allocated in the USA and Europe for a variety of Dedicated Short-Range Communications (DSRC) uses to exchange automatically formatted messages between vehicles and vehicles infrastructure. Some applications such as traffic monitoring, traffic congestion detection or road works warning need only 10 metre accuracy but others like emergency vehicle signal pre-emption of traffic lights, red light violation warning or green light optimal speed advisor will require higher performances for the GNSS position. In addition, the CAM message (Cooperative Awareness Message) will be broadcast permanently by all vehicles to provide each driver with a 360° vision around his vehicle.

If for the first generation of C-ITS applications the car driver will be involved, in the second generation, automatic braking, collision avoidance, automatic lane keeping, speed adaptation to pass a green light (GLOSA message) the quality of positioning will have to be enhanced. High availability, accuracy, continuity, integrity, robustness against multipath, jamming and spoofing, time to first fix when the car leaves the underground parking should be considered.

Due to the high stakes of the connected vehicle in terms of economics and road safety, the European Commission has set a platform for cooperative ITS. Here under is the list of early services selected by the group of experts [RD3]:

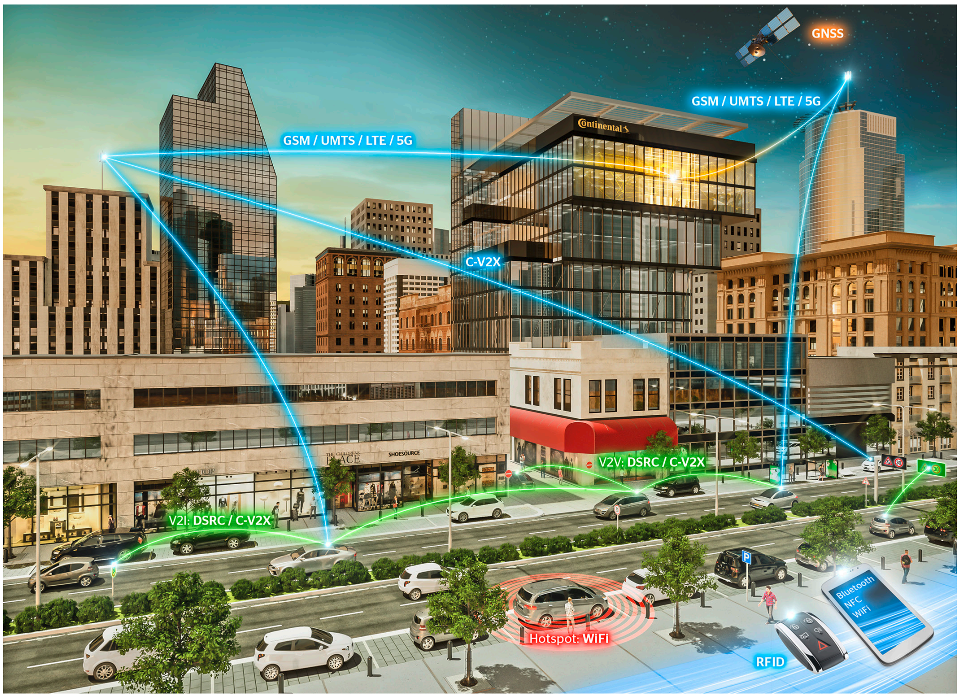
List of Day 1 services

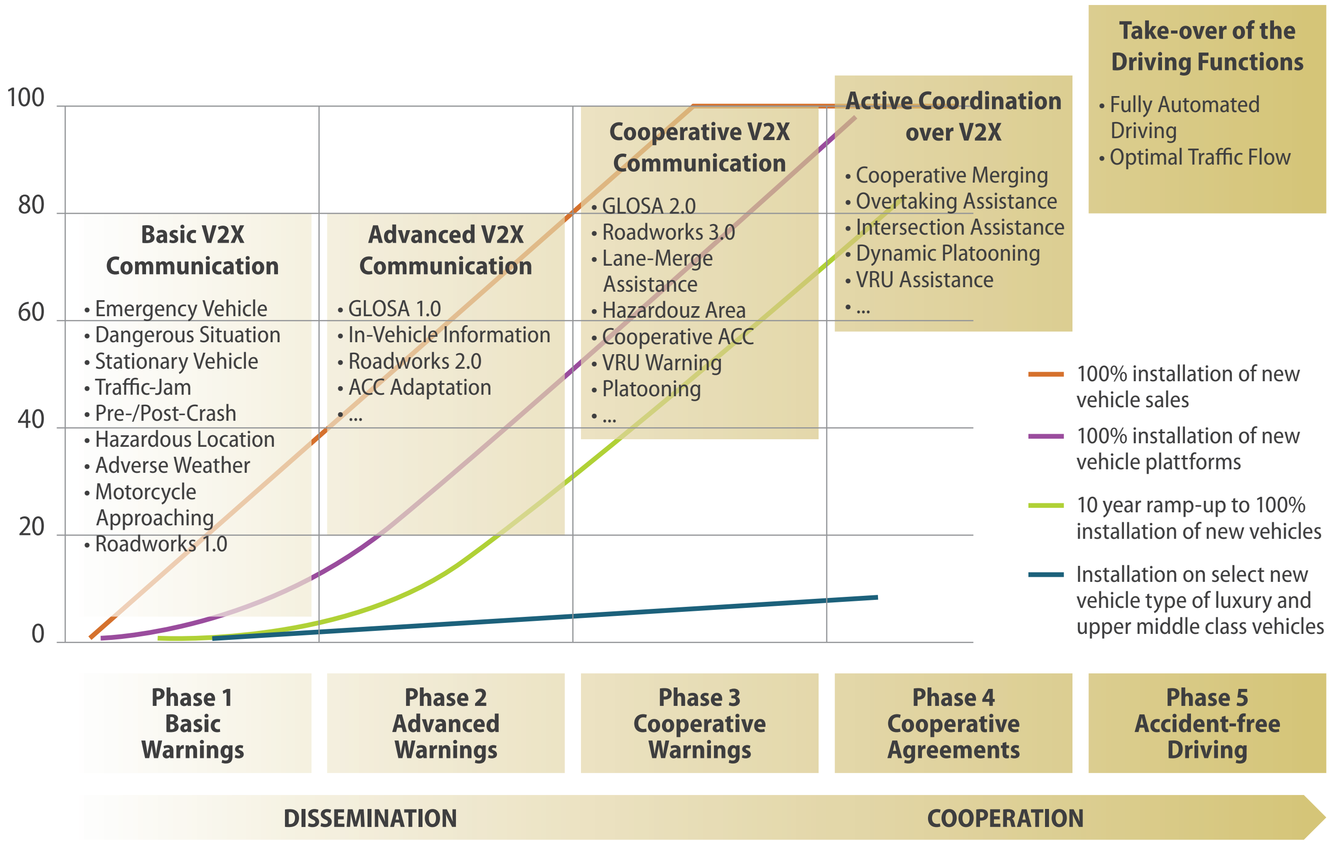
The C-ITS Platform agreed on a list of 'Day 1 services' which, because of their expected societal benefits and the maturity of technology, are expected to and should be available in the short term (personal benefits, users' willingness to pay, business cases and market driven deployment strategies were not considered at this stage):

List of Day1 services includes:

- **Hazardous location notifications:** Slow or stationary vehicle(s) & Traffic ahead warning, Road works warning, Weather conditions Emergency brake light, Emergency vehicle approaching, Other hazardous notifications
- **Signage applications:** In-vehicle signage, In-vehicle speed limits, Signal violation / Intersection Safety, Traffic signal priority request by designated vehicles, Green Light Optimal Speed Advisory (GLOSA), Probe vehicle data, Shockwave Damping (falls under ETSI Category "local hazard warning")

Figure 6: Car2Car V2X applications roadmap





Source: Car 2 Car

Furthermore, the C-ITS Platform also agreed on a list of *'Day 1.5 services',* considered as mature and highly desired by the market, though, for which specifications or standards might not be completely ready.

List of Day 1.5 services includes:

- **Parking:** off street parking, on street parking and management, par and ride information,
- **Smart routing:** information on alternative fuel charging stations, zone access control for urban area, loading zone management,
- **Road safety:** cooperative collision risk warning, vulnerable road user protection, motorcycle approaching indication, wrong way driving.

Some projects and institutions have provided a long list of applications enabled by V2X technologies. For example, the lists provided by cooperative ITS platform [RD3], US DOT [RD7], Car to Car consortium [RD8].

AUTONOMOUS VEHICLES CREATE HUGE INTEREST FROM CAR MANUFACTURERS AND PUBLIC AUTHORITIES

Connected Vehicle Applications of Interest to Public Agencies

For this analysis, it is important to understand the applications that have the greatest applicability to state and local transportation agencies. To identify which applications may best serve the interests of the state and local transportation agencies and their constituents, it is useful to examine the objectives behind any Connected Vehicle deployments by the public sector. Five objectives can be considered in the selection of applications by state and local agencies, in the frame of improving transportation safety, which has become the keystone opportunity for Connected Vehicle deployment. A recent National Highway Traffic Safety Administration (NHTSA) analysis concluded that up to 79 percent of all crashes by unimpaired drivers could potentially be addressed by V2V and V2I technology combined. In terms of more specific objectives, applications contributing to improved safety would, for example, create results that include the following:

- Reduce the likelihood of collisions at intersections
- Reduce the likelihood of forward and lateral (lane change and merge) collisions
- Reduce the likelihood of secondary crashes
- Reduce the likelihood of road departure crashes
- Provide more accurate and timely road condition alerts

As mentioned earlier C-ITS applications have a great potential to improve road safety. Consequently, as shown in in Appendix to Annex 2 on Performance Parameters, the performance criteria will have to reach the highest values in terms of availability, horizontal accuracy, integrity, authentication sensitivity and robustness. These values will be reachable only with receivers capable of exploiting all the added values brought by multi constellations, multi frequencies wide band offered by Galileo in addition to other constellations 'see paragraph 5.5.1 Galileo frequency plan and GNSS technology report [RD14].

Smartphones are now widely used in mobility services for Road users (e.g. car sharing) needing increased navigation performance requirements, but also possibly to broadcast vulnerable road user presence to vehicles in V2X, requiring thus to investigate whether the GNSS performances should be similar to safety relevant applications.

5.2.3 AUTONOMOUS VEHICLES

A complex and challenging ecosystem

Autonomous vehicles currently create huge interest from car manufacturers and public authorities worldwide. The first ones as they strive to keep their core business and the second ones as they will have to adapt rigid regulations. A lot of startups are aiming to develop specific bricks, while the big techplayers like Google, Apple and innovative OEMs such as Tesla have their own agenda.

Figure 7: Komatsu began trials of its Autonomous Haulage Systems (AHS) in a partnership with mining company Rio Tinto in 2008.

Figure 8: In 2015, the EZ10 model was one of the first autonomous pod under operation using RTK-GNSS.

As far as positioning and timing are concerned it is worth distinguishing some key segments.

- Automatic driving is already on the road. Tesla, Ford, Mercedes, BMW and others already have this option in their catalogue. They are mainly dedicated to motorways and the driver must stay in control. In the US Automatic driving for trucks on motorway between two main interchanges is already tested. These services are already available in the mining industry and have a great potential to increase safety. These services will require high performances in positioning and timing.

- Small shuttles buses like Navya and EasyMile are already able to operate at low speed on public fixed routes. The UNECE [RD10] and specific national regulation support the development of pilot projects. The use of RTK to improve the GNSS positioning is well-known.

- Finally, the driverless cars which will be mainly operated in urban environment have the most stringent requirements. If Uber and Lyft in USA are trying to familiarize the public with the driverless cars, a majority of car specialists do not expect a real uptake before 2030. Nevertheless, the driverless car is a key element of the future smart city. Cities, originally designed around private owned cars, will suddenly be able to reclaim much of the space otherwise occupied by things like garages, parking lots and gas stations. Urban environment is a real challenge to mitigate GNSS limitations.

Autonomous vehicle is the final step of a long evolution process. Consequently, some V2X applications will be used in the autonomous car like automatic braking, collision avoidance system, 360° surround view, and the performances of the GNSS receivers will have to reach the same standards. As explained in paragraph 5.1.2 a data fusion with other sensors is inevitable. In the main constrained environment, it is expected that the GNSS receiver will only have a backup role.

5.2.4 MOBILITY SERVICES

Application enabling the provision of mobility services using a combination wide range of mean of transport: public transport, car sharing, and ride sharing …

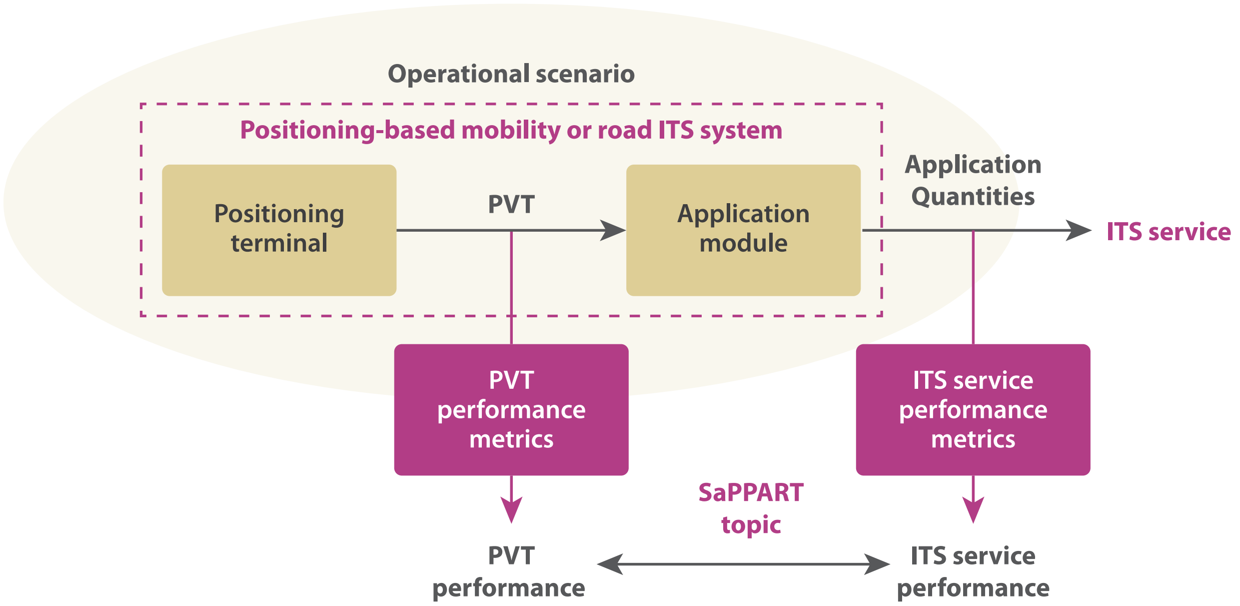
It has been highlighted in some presentations that the provision of mobility service is expected to provide > 30% of margin compare to a margin below 5% for car selling.

5.3 GNSS LIMITATIONS FOR ROAD

5.3.1 RECEIVER VS. IN-VEHICLE SYSTEM USER REQUIREMENTS

It is important to recognize that the relationship between the performance requirements of the End to End (E2E) application and the performance requirements of the vehicle positioning system is not straightforward. This is well documented in the "SaPPART handbook" [RD6], even with some examples. In fact, [RD6] investigates the relationship between the performance of the GBPT at the PVT level and the performance of the entire system at the service level, with the reference architecture depicted in Figure 9.

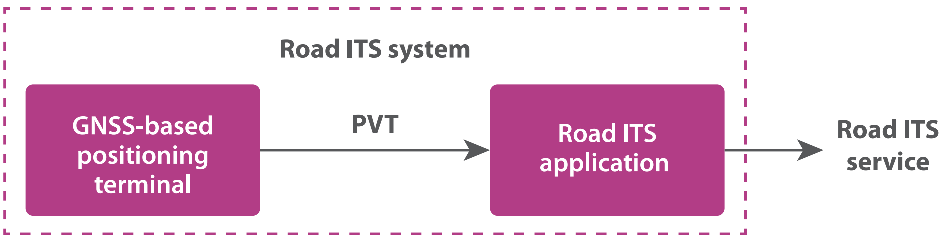
Figure 9: Block diagram from [RD6], showing the relationship between performance at PVT and application levels.



Note that there is also a (non trivial) relationship between the performance of the GBPT at PVT level and the performance of the embedded GNSS receiver, that in road is typically augmented with data from other sensors, such as inertial sensors and odometers. Indeed, a very similar logical architecture is addressed in the CEN standard EN 16803- 1:2016 [RD14], as reported for completeness in Figure 10.

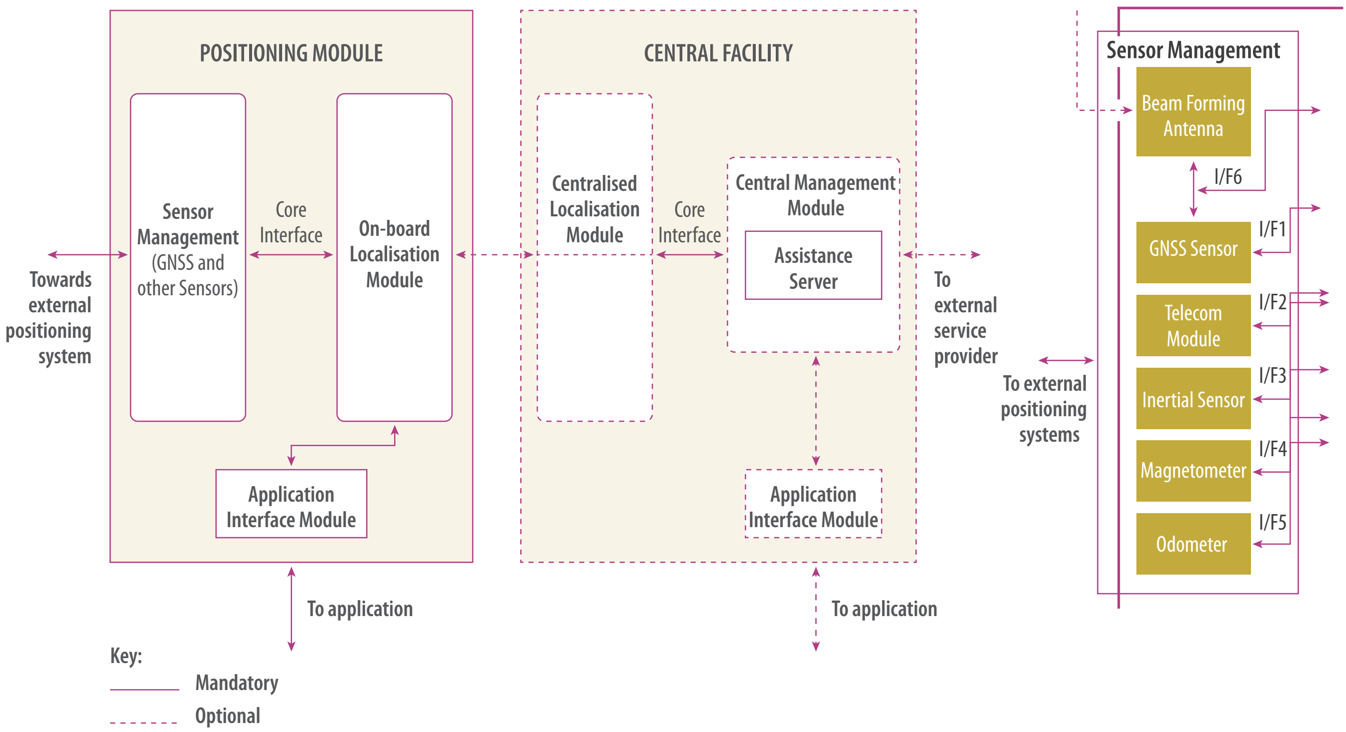
Also, the ETSI standard ETSI TS 103 246 "Satellite Earth Stations and Systems (SES), GNSS based location systems"

Figure 10. The logical breakdown and PVT interface between GNSS-based positioning terminal and road-domain application, as adopted in [RD14].



[RD13] adopts a similar logical breakdown for the so- called GNSS-Based Location Systems (GBLS). As shown in Figure 11(a), the Positioning Module (that can be considered the equivalent of the positioning terminal in Figure 9) includes the Sensor Management functionality, which manages data from the GNSS receiver and other sensors. These sensors are further detailed in the block diagram of the GBLS architecture, as reported for sake of completeness in Figure 11(b).

Figure 11: Block diagram of the GBLS (level 2) [RD13], showing details of the Positioning Module (a). Block diagram of the GBLS (level 3) [RD13], showing possible sensors of the Positioning Module (b).



In the rest of this document we acknowledge the substantial agreement of the functional architectures addressed in [RD6], [RD13] and [RD14], as well as in [RD5], and we adopt the following terminology:

- **Positioning terminal**, to indicate the logical and physical entity responsible for i) executing the measurements needed to determine its position, velocity and time (PVT), ii) implementing the PVT determination function, and iii) providing its own PVT-related data to the Application module. It is composed of a GNSS receiver and possibly additional sensors;
- **PVT determination function**, to indicate the logical entity inside the Positioning terminal responsible for collecting the PVT-related measurements from the set of available sensors and, on their basis, computing the information of position, velocity and time of the target;
- **GNSS receiver**, to indicate the logical and physical entity inside the positioning module responsible for receiving and processing the GNSS signals in space, and timely providing its PVT-related measurements at the appropriate rate to the PVT determination function;
- **Application module**, to indicate the logical entity in charge of retrieving the PVT-related data from the positioning terminal and processing it in order to deliver to the application user the service it has been designed for;
- **User requirement**, to indicate the needs posed by the service user to the application that provides the service. For the purpose and scope of this document only, we assume that the user requirements coincide with the application requirements.

5.3.2 KEY CONSIDERATIONS ON REFERENCE TEST SCENARIOS

The behaviour of positioning systems, especially those based on GNSS, is highly dependent on the operational scenario. For this reason, it is well understood that any evaluation of performance of a GNSS-based positioning terminal must be clearly associated to the definition of a scenario in which the performance is measured [RD6][RD12][RD11].

For testing purposes, the reference scenarios must be completely and unambiguously defined so that they are thoroughly repeatable by any test laboratory.

There are two different approaches that allow this complete and unambiguous definition of the test reference scenarios, necessary preamble to any certification process:

- The pure simulation approach that uses constellation simulators to define the synthetic signals that will be injected into the receiver under test.
- The "Record and Replay" approach that uses data re-players to inject the real signals that have been captured during a field test into the receiver under test.

The main advantages of the first approach are:

- The capacity to assess the performances of the receiver while it is experiencing interferences or jamming/spoofing attacks, thanks to dedicated functions
- The fact that the "true" trajectory is perfectly and accurately defined.

The main advantages of the second one include:

- The capacity to include in the scenarios the impacts of all the real physical phenomena affecting the quality of the positioning, like multi-path of Non-Line-Of-Sight, that are quite impossible to simulate correctly with mathematical models,
- The simplicity and the cost-effectiveness of the replaying process that does not need a high level of expertise on GNSS technology.

Below is proposed an example of reference scenarios definition for simulation tests. The typical classification of reference scenarios for GNSS considers at least three environmental conditions and two receiver dynamics, leading to at least six test cases as represented in Table 7:

Table 7: Example of identification of reference scenarios for testing purposes

User dynamic / ***Environmental condition***	**Static user** The receiver is still in a given position for the whole duartion of the test.	**Dynamic user** The receiver moves along a pre-defined trajectory, with a pre-defined velocity profile.
Open area - Nominal received power from all the satellites with azimuth between 0° and 360° and elevation > 5° with respect the receiver location; - No multipath; - No interference.	***Test case 1***	***Test case 4***
Intermediate/Light Urban area - Blocked received power from all the satellites with azimuth in a certain Interval (X_1° to X_2°) and elevation < Y° with respect the receiver location (e.g.: $X_1 = 30$, $X_2 = 150$, $Y = 60$); - Nominal received power from all the satellites with azimuth in a certain Interval (X_3° to X_4°) and elevation > 5° (e.g.: $X_3 = 230$, $X_2 = 310$); - Slightly attenuated received power from all the satellites with other elevations and azimuths (e.g.: attenuation 10 to 15 dB with respect to nominal); - Mullipath effect; - Non-zero level of wideband interference (e.g.: wideband interference level @ -195 dBW/Hz).	***Test case 2***	***Test case 5***
Urban area - Nominal received power from all the satellites with azimuth hosted within X° in a given direction (e.g.: X = 120) to describe a urban canyon situation and elevation > 5°; - Nominal received power from all the satellites with elevation > Y° with respect the receiver location (e.g.: Y = 60); - Attenuated/Blocked received power from all the satellites with other elevations and azimuths; - Multipath effect; - Non-zero level of wideband interference (e.g.: wideband interference level @ -195 dBW/Hz).	***Test case 3***	***Test case 6***

These scenarios assume that only the GNSS signal reaches the receiving antenna, plus thermal noise. On the other hand, when structured interference effects are addressed in the test, the receiver can be assumed in 'open area' with respect to the satellite visibility, so that the interference impact is not masked by other environmental effects. This is the approach chosen in [RD12]. The same rationale can be applied when other possible impairments are under test, for example spoofing attacks or scintillation events.

Other specific test conditions that should be explicitly defined include the usable GNSS constellations, the maximum usable dilution of precision, the duration of the test, the pre-defined receiver trajectory [RD12].

It is important to remark that the above classification is purely indicative, since different standardization/certification bodies or performance assessment projects may define their specific testing conditions. The only mandatory aspect is the completeness, non-ambiguity and repeatability of the conditions.

5.4 DRIVERS FOR USER REQUIREMENTS IN ROAD

As mentioned above, the applications that will soon appear on cooperative systems can be classified into two groups. The first group can be put on the market very quickly and just requires an accuracy of around 10 metres. These are the applications proposed by the Amsterdam Group[1] and Scoop@F[2] in France: road works warning, road hazards warning, unexpected end of traffic queue etc. Most of these applications are already available on mobile devices and based on crowdsourcing. Generally speaking all the early services mentioned in the ITS directive under the wording *"data and procedures for the provision, where possible, of road safety related minimum universal traffic information free of charge to users"* can be launched with the current GNSS receivers. Nevertheless, a double constellation will dramatically improve the DOP factor (Dilution of Precision).

A significant amount of progress has already been achieved and C-ITS is now moving, from research and pilot projects to the stages of early real-life deployment. Such new activities have been recognised as an important driver to be taken into account when revisiting aspects and priorities for future international cooperation and new challenges.

1 The Amsterdam Group is a strategic alliance of committed key stakeholders to deploy first Cooperative ITS on the corridor Rotterdam – Frankfurt/M. – Vienna corridor.

2 Scoop@FScoopaF is a project by the French Ministry in charge of transport. 3000 cars fitted with OBUs will travel on 1 000 km of motorways equipped with Road Side Units

But the next generation of applications currently under field operational tests or pilot projects, such as Red-Light Violation Warning (RLVW) or Green Light Optimal Speed Advisor (GLOSA) request more stringent performances in terms of continuity, availability and precision. RLVW allows for a driver approaching a green light who nevertheless has to stop because on the adjacent road a driver is arriving too quickly to stop at the red light. GLOSA aims at saving gas and pollution by a close liaison between the traffic light control centre and the movement of cars. A reference speed or the duration of the remaining red phase will be broadcast into the car to avoid a stop at red lights. In addition, for cars equipped with start and go, the engine will be kept running if there are only a few seconds left before the green light (SPAT: Signal Phase and Timing).

NEARLY 70% OF ALL CHIPSETS AND MODULES ON THE MARKET SUPPORT MULTIPLE CONSTELLATIONS

To improve the accuracy of car positioning for cooperative systems, the work plan can be described in a three-step approach. The first step is to make the best possible use of SIS (Signal In Space) which is free and available worldwide. The second step is to develop hybridization with on board equipment like accelerometers and gyroscopes. The car can still drive autonomously on all roads. On the other hand, for the final step, that is to say for the most demanding applications, real-time correlation between images and maps will be required. In this case the construction and maintenance of a precise digital map is necessary and this cannot be developed for all roads overnight.

Car navigation devices and smartphones already use all 3 stages but the emphasis must be put on the first one to leverage on the differentiators of the Galileo signals. The calculation of relative positioning between vehicles and obstacles could be facilitated.

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The large majority of chipsets and modules currently on the market support multiple constellations. With the increasing demand for better resilience across all applications, the need for higher accuracy and integrity that automation demands, adoption of dual frequency solutions (E1/L1 + E5/L5) is also growing.

In summary, the following drivers for user requirements have been identified:

- **Driver 1:** Authentication and robustness are becoming key parameters to mitigate the risks in all critical applications.
- **Driver 2:** As it has been done so far for tolling and emergency call, the benefit of using GNSS should be emphasized among regulators and stakeholders who are not always fully aware of all the possibilities offered by new GNSS signals. Dedicated outreach groups will be welcome.

- **Driver 3:** V2X applications could widen GNSS use in Road and prepare the introduction of autonomous vehicles. V2X are not only related to cars but also to the "other" road users: motorcycles, cyclists, road workers etc., which could use GNSS to be localized as road user, rather than for navigation.
- **Driver 4:** The V2X applications are based on the tretment of two key messages broadcast by cooperative ITS actors: the CAM message and the DENM message. In ETSI Standards elaborated in the framework of European mandate 453, the positioning performances are loosely described.
- **Driver 5:** For lane keeping and collision avoidance application decimeter accuracy will be welcome in all the landscape and urban environment.
- **Driver 6:** Legal metrology is another point to tackle. A legal status for payments based on GNSS timing has to be developed at European level. Key payment critical applications like taxi meter and GNSS tolling are at stake.

5.5 CONCLUSIONS

In the early 90's, GPS gave access to the World Geodetic System (WGS) 1984 to all military and civil users anywhere anytime on the planet. It was a real disruptive technology. For the road users, the possibility to get an accurate, real time all weather position, velocity and time information set up the foundation of the intelligent highway that became later on the intelligent transport system.

Reserved at the beginning to expensive cars, due to the huge investments needed to build up the unavoidable digital maps, the prices of personal navigation devices plummeted very quickly to become a mass market product. The success of GPS navigation on the road has never stopped since that time and it appears now as a free service available on many smartphones.

The permanent enrichment of this basic guiding service by telematics service providers has opened the door to many add-on applications, such as point of interest, tracking of fleets, information on speed limitation, curves warning, eco driving.

The previous success of radio navigation on the road is still going on, but with the connected cars and autonomous driving we are entering in a new era in which the performance parameters will become more stringent. As our cities' roads become increasingly crowded, congested and polluted, public authorities see the connected car and autonomous driving as a possible solution to improve our mobility, while at the same time increasing road safety. In addition, the convergence of the automotive and high-tech sectors will rewrite the rules of competition and acts as a booster.

Facing these disruptive trends that will transform the automotive industry, Galileo offers real advantages and has a major role to play. If multi-constellation, multi-frequencies receivers will be able to improve the positioning in urban environment, the most demanding applications like collision avoidance, lane keeping, and automatic breaking will need authentication, integrity and robustness.

The in-vehicle navigation system for autonomous cars will become a highly integrated system of high-end sensors similar to a flight management system in an aircraft. European GNSS has a major role to play in the architecture that will come out of a complex standardization process. Pilot projects are already demonstrating to the main decisions makers in the value chain how to reap the benefits brought by latest GNSS signals.

Beyond the vehicle centric opportunities, the actual users of a wide range of mobility solutions will also profit of the Global localization services provided by Galileo, like for instance improving the detection of vulnerable road users or geolocating mobility services clients.

06 USER REQUIREMENTS SPECIFICATION

6.1 SYNTHESIS OF USER ANALYSIS

The requirements have been gathered according to the groups described in paragraph 5.4 and are consistent with the table provided in Annex 2. When a requirement is common to one or two groups the same nomenclature, reference is used.

As confirmed by some interviewees ([RD22], [RD21], [RD20]), in most ITS applications the standardization process is not yet fully advanced. Requirements that could not be identified in the literature were validated during the User Consultation Platform Forum.

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6.1.1 REQUIREMENTS FOR SAFETY CRITICAL APPLICATIONS

Among this group we must make a distinction between applications which just give a warning to the driver and applications which take control of the vehicle. The latest ones are related to V2X applications and autonomous driving.

For Traffic and Safety Warning applications:

Table 8: Requirements for Traffic and Safety Warning applications

id	Description	Type	Source
GSA-MKD-USR-REQ-ROA-0012	The positioning system shall provide an availability better than 99,5 %	Performance (availability)	[RD24]
~~GSA-MKD-USR-REQ-ROA-0020~~	~~The positioning system shall provide an accuracy better than 3 meters~~	~~Performance (accuracy)~~	
GSA-MKD-USR-REQ-ROA-0021	The positioning system shall provide an accuracy better than 3 meters for day 1 applications, better than 1 meter for advanced (lane-level) applications	Performance (accuracy)	[RD24]
GSA-MKD-USR-REQ-ROA-0032	The timing system shall provide an accuracy better than 1 second	Performance (accuracy)	[RD24]
GSA-MKD-USR-REQ-ROA-0043	The positioning system shall provide an integrity message	Function (integrity)	[RD22]
GSA-MKD-USR-REQ-ROA-0053	The positioning system shall provide robustness against GNSS spoofing threats	Function (authentication)	[RD18], [RD19, [RD20], [RD21], [RD22]
GSA-MKD-USR-REQ-ROA-0063	The positioning system shall be able to detect GNSS interferences and inform the driver	Function (interference detection)	[RD22]

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Note: the requirements apply to the overall positioning system, not to the GNSS receiver only

For automated interventions and autonomous driving, more stringent performances are required:

Table 9: Requirements for automated interventions and autonomous driving

id	Description	Type	Source
~~GSA-MKD-USR-REQ-ROA-0070~~	~~The positioning system shall provide an availability better than 99,9 %~~	~~Performance (availability)~~	
GSA-MKD-USR-REQ-ROA-0071	The positioning system shall provide an availability better than 99,9 %[1]	Performance (availability)	[RD24]
~~GSA-MKD-USR-REQ-ROA-0080~~	~~The positioning system shall provide a horizontal accuracy better than 1 metre~~	~~Performance (accuracy)~~	~~[RD18], [RD19], [RD20], [RD22]~~
GSA-MKD-USR-REQ-ROA-130	The positioning system shall provide a horizontal accuracy better than 20 centimetres	Performance (accuracy)	[RD18], [RD19], [RD20], [RD22]
GSA-MKD-USR-REQ-ROA-0040	The positioning system shall provide an integrity message. Levels of confidence should target 10-15 metres of protection level at Integrity Risk 10^{-7}	Function (integrity)	[RD22] [RD24]
GSA-MKD-USR-REQ-ROA-0050	The positioning system shall provide robustness against GNSS spoofing threats and inform the driver	Function (authentication)	[RD18], [RD19], [RD20], [RD21], [RD22], [RD24]

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Note: the requirements apply to the overall positioning system, not to the GNSS receiver only 2019 update

6.1.2 REQUIREMENTS FOR PAYMENT CRITICAL APPLICATIONS

Table 10: Requirements for payment critical applications

id	Description	Type	Source
GSA-MKD-USR-REQ-ROA-0010	The positioning system shall provide an availability better than 99,5 %	Performance (availability)	[RD24]
GSA-MKD-USR-REQ-ROA-0020	The positioning system shall provide an accuracy better than 3 meters	Performance (accuracy)	[RD24]
GSA-MKD-USR-REQ-ROA-0030	The timing system shall provide an accuracy better than 1 second	Performance (accuracy)	[RD24]
GSA-MKD-USR-REQ-ROA-0041	The positioning system shall provide an integrity message	Function (integrity)	[RD22]
GSA-MKD-USR-REQ-ROA-0051	The positioning system shall provide an authentication message	Function (authentication)	[RD18], [RD19], [RD20], [RD21], [RD22]
GSA-MKD-USR-REQ-ROA-0061	The positioning system shall be able to detect GNSS interferences and inform the driver	Function (interference detection)	[RD22]

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Note: the requirements apply to the overall positioning system, not to the GNSS receiver only 2019 update

1. To be understood as the highest possible availability

6.1.3 REQUIREMENTS FOR REGULATORY CRITICAL APPLICATIONS

Table 11: Requirements for regulatory critical applications

id	Description	Type	Source
GSA-MKD-USR-REQ-ROA-0011	The positioning system shall provide an availability better than 99,5 %	Performance (availability)	[RD24]
GSA-MKD-USR-REQ-ROA-0120	The positioning system shall provide an accuracy better than 5 meters	Performance (accuracy)	[RD24]
GSA-MKD-USR-REQ-ROA-0031	The timing system shall provide an accuracy better than 1 second	Performance (accuracy)	[RD24]
GSA-MKD-USR-REQ-ROA-042	The positioning system shall provide an integrity message	Function (integrity)	[RD24]
GSA-MKD-USR-REQ-ROA-0052	The positioning system shall provide an authentication message	Function (authentication)	[RD18], [RD19], [RD20], [RD21], [RD22]
GSA-MKD-USR-REQ-ROA-0062	The positioning system shall be able to detect GNSS interferences and inform the driver	Function (interference detection)	[RD22]

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Note: the requirements apply to the overall positioning system, not to the GNSS receiver only

6.1.4 REQUIREMENTS FOR SMART MOBILITY APPLICATIONS

Table 12: Requirements for smart mobility applications

id	Description	Type	Source
GSA-MKD-USR-REQ-ROA-0013	The positioning system shall provide an availability better than 99,5 %	Performance (availability)	[RD24]
~~GSA-MKD-USR-REQ-ROA-0120~~	~~The positioning system shall provide an accuracy better than 5 meters~~	~~Performance (accuracy)~~	
GSA-MKD-USR-REQ-ROA-0121	The positioning system shall provide an accuracy better than 5 meters. The positioning system shall provide an accuracy better than 3 meters if smart mobility applications include payment functions.	Performance (accuracy)	[RD24]
GSA-MKD-USR-REQ-ROA-0033	The timing system shall provide an accuracy better than 1 second	Performance (accuracy)	[RD24]
~~GSA-MKD-USR-REQ-ROA-0040~~	~~The positioning system shall provide an integrity message~~	~~Function (integrity)~~	~~[RD24]~~
GSA-MKD-USR-REQ-ROA-0054	The positioning system shall provide an authentication message	Function (authentication)	[RD18], [RD19], [RD20], [RD21], [RD22]
GSA-MKD-USR-REQ-ROA-0064	The positioning system shall be able to detect GNSS interferences and inform the driver	Function (interference detection)	[RD22]

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Note: the requirements apply to the overall positioning system, not to the GNSS receiver only

07 ANNEXES

ANNEX 1: MAJOR PROJECTS V2X UNDERWAY IN THE WORLD

Major projects underway in the world today testify the great interest of public authorities in V2X technology. They see V2X as the only mean to improve road safety before the coming up of the autonomous car.

It's worth recalling the magnitude of pilot projects underway in the US: Ann Arbor Michigan with 2.800 cars equipped, 10.000 cars in New York City, in France 3.000 cars and 2.000 km of motorway equipped with WiFi G5 hot spots, the Dutch German, Austria Corridor (aka the Amsterdam Group).

In the USA, the latest NHTSA declaration states that the next big step to improve road safety in the country will be based on communications between vehicles and on the first results of the Safety pilot project of Ann Arbour where2.800 cars driven by ordinary citizens are evaluating the benefits of VtoX communications.

In Japan 1.600 WiFi hot spots and 16.000 cars are already equipped with road side and OBUs. The last ITS world congress presented a pilot project on Assisted Automatic Control; in this project the equipped car received messages from a WiFi Hot spot to adopt a specific speed and inter-distance. This service is expected to increase the capacity of a motorway by 20%.

ANNEX 2: SYNTHESIS OF ROAD USER REQUIREMENTS

To get a comprehensive view of the GNSS road market it is proposed to use a table matching the main applications with the performance criteria, which is included as Appendix to this report. A list of main applications is provided in the second column. For each line, the performance parameters are weighted according to their expected needs. A tentative weighting is indicated at the bottom of the table based on a preliminary expert judgment. The score in the last column allows an easy detection of the most demanding applications.

ANNEX 3: KEY STANDARDIZATION BODIES AND ORGANIZATIONS

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, in particular for safety-critical applications:

ETSI TC SES/SCN

- Standards about GNSS performance, relevant for Location Based Services (land applications); focus on lab tests with simulators.
- Activities concluded, suite of 5 documents published related to "GNSS based location systems" (i.e. from TS 103 246-1 to TS 103 246-5)

CEN/CENELEC

- Standards about GNSS performance, relevant for road applications; focus on field tests, record & replay tests.
- Suite of 3 standard documents: EN 16803-1 (basic metrics), EN 16803-2 (field and "Record and Replay" testing procedures), EN 16803-3 (focus on spoofing and interferences)
- EN 16803-1 published in October 2016. On-going work (just started) for EN 16803-2 and EN 16803-3
- Review of preliminary results preliminary results from the GP-START project (GNSS Performance Standardization for Road Transport)

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.ERTRAC (European Road Transport Research Advisory Council): 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): it is an 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.
- ETSC (European Transport Safety Council): 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 LSVA (Large Scale Video Analysis) 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
- Society of Automotive Engineers (SAE) International: On-Road Automated Driving (ORAD) committee. Documents released:
  - J3016 Taxonomy and Definitions for Terms Related to On- Road Motor Vehicle Automated Driving Systems": Definition of well-known levels of automation
  - J3018 Guidelines for Safe On-Road Testing of SAE Level 3, 4, and 5 Prototype Automated Driving Systems (ADS)
  - J3092 Dynamic Test Procedures for Verification & Validation of Automated Driving Systems (ADS) - *Work in progress*
  - J3131 Automated Driving Reference Architecture - *Work in progress*

ANNEX 4: DEFINITION OF KEY GNSS PERFORMANCE PARAMETERS

This Annex provides a definition of the most commonly used GNSS performance parameters, coming from [RD23] and including additional details which are relevant for the Road community.

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

- System: the percentage of time the system allows the user to compute a position – this is what GNSS Interface Control Documents (ICDs) refer to
- Overall: takes into account the receiver performance and the user's environment (for example if they are subject to shadowing).

Availability is one of the most important performance features in supporting any safety-critical application, e.g. emergency services.

AVAILABILITY IS ONE OF THE MOST IMPORTANT PERFORMANCE FEATURES IN SUPPORTING ANY SAFETY-CRITICAL APPLICATION

Accuracy: the difference between true and computed position (absolute positioning). This is expressed as the value within which a specified proportion of samples would fall if measured. Typical values for accuracy range from tens of meters to centimeters for 95% of samples. Accuracy is typically stated as 2D (horizontal), 3D (horizontal and height) or time. More in details:

- **Horizontal position accuracy** is the statistical measure of the horizontal position (or velocity) error (e.g. 95th percentiles of the cumulative error distribution), being this error the difference between the true horizontal position and the position (or velocity) estimated by a positioning system at a given time. The requirements for this feature can range from relaxed constraints for personal navigation applications, to more stringent ones for LCA such as road user charging and tracking of dangerous goods.
- **Vertical position accuracy** is the statistical measure of the vertical position error (e.g. 95th percentiles of the cumulative error distribution), being this error the difference between the true vertical position and the position estimated by a positioning system at a given time. This feature applies when vertical guidance is required, for instance to allow proper positioning in case of parkade (multi-levels parking) or overlapping road segments, especially in urban environments.
- **GNSS time accuracy** is the statistical measure of the GNSS time error (e.g. 95th percentiles of the cumulative error distribution), being this error the difference between the true GNSS time (as implemented in the GNSS system timing facility) and the time returned by the positioning system based on the PVT solution. Generally, this feature is of interest for applications requiring synchronisation of assets distributed across wide geographical areas, where GNSS time is used as a reference. Focusing on the road segment, GNSS time accuracy applies for example in case on VANET applications (involving a very large number of distributed nodes) that in future might require the use of synchronous Medium Access Control (MAC) in order to overcome the known scalability issue of the decentralized and asynchronous Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) method.

Continuity: ability to provide the required performance during an operation without interruption once the operation has started. Continuity is usually expressed as the risk of a discontinuity and depends entirely on the timeframe of the application (e.g. an application that requires 10 minutes of uninterrupted service has a different continuity figure than one requiring two hours of uninterrupted service, even if using the same receiver and services). A typical value is 1x10-4 over the course of the procedure where the system is in use.

Integrity: the measure of trust that can be placed in the correctness of the position or time estimate provided by the receiver. This is usually expressed as the probability of a user being exposed to an error larger than alert limits without warning. The way integrity is ensured and assessed, and the means of delivering integrity related information to the user are highly application dependent. For safety-of-life-critical applications such as passenger transportation, the "integrity concept" is generally mature, and integrity can be described by a set of precisely defined and measurable parameters. This is particularly true for civil aviation. For less critical or emerging applications, however, the situation is different, with an acknowledged need of integrity but no unified way of quantifying or satisfying it. Throughout this report, "integrity" 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 by other applications and sectors. In road applications, it is relevant to SCA and LCA (e.g. critical navigation, billing).

Robustness to spoofing and jamming: robustness is a qualitative, rather than quantitative, parameter that depends on the type of attack or interference the receiver is capable of mitigating. It can include authentication information to ensure users that the signal comes from a valid source (enabling sensitive applications).

Note: for some users robustness may have a different meaning, such as the ability of the solution to respond following a severe shadowing event. For the purpose of this document, robustness is defined as the ability of the solution to mitigate interference or spoofing. Within robustness:

- **position authenticity** 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 position data as output of the system itself.
- **Robustness to interference** is the ability of the positioning system to operate under interference conditions and to maintain the applicable positioning service level requirements. Location Systems might be required to operate in constrained RF environments, in particular in the GNSS frequency bands. Note that interference can be either unintentional or deliberate (e.g. jamming).

Indoor penetration: 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 Wi-Fi base stations for Wi-Fi-based positioning).

Time To First Fix (TTFF): a measure of a receiver's performance covering the time between activation and output of a position within the required accuracy bounds. Activation means subtly different things depending on the status of the data the receiver has access to:

- **Cold start:** the receiver has no knowledge of the current situation and thus has to systematically search for and identify signals before processing them – a process that typically takes 15 minutes.
- **Warm start:** the receiver has estimates of the current situation – typically taking 45 seconds.
- **Hot start:** the receiver knows what the current situation is – typically taking 20 seconds.

This feature is of particular interest for the navigation support (route guidance) of emergency vehicles, provided that the positioning system in the emergency vehicle has to be prompt to accurately estimate its position.

Latency: the difference between the time the receiver estimates the position and the presentation of the position solution to the end user (i.e. the time taken to process a solution). Latency is usually not considered in positioning, as many applications operate in, effectively, real time. However, it is an important driver in the development of receivers. This is typically accounted for in a receiver, but is a potential problem for integration (fusion) of multiple positioning solutions or for high dynamics mobiles. In the context addressed in this document, the PVT latency may matter in two families of cases:

- **GNSS latency:** the first case is the integration of GNSS measurements with other higher-rate sensors, in which a latency in the provision of the PVT-related measurements by the GNSS sensor may encompasses several adjacent measurements of the higher-rate sensor, imposing the need for a non-trivial re- synchronization. This case might be significant for autonomous driving applications, in which high-rate sensors readings may be a safety factor.
- **PVT latency (from the positioning terminal):** the second case represents the situation in which the PVT solution provided by positioning terminal to the application interface is delayed by a certain amount of time with respect to the nominal instant of the measurements, due to the amount of processing performed by the PVT determination function. PVT latency may become non-negligible in case of complex integration processing, or latencies in data retrieval from the sensors or from other external sources (e.g., PPP corrections from the internet).

Power consumption: 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, GPS chips will use more power when scanning to identify signals (cold start) than when computing position. Typical values are in the order of tens of mW (for smartphone chipsets).

GNSS sensitivity refers to the minimum GNSS signal strength at the antenna, detectable by the receiver (dBW or dBm). The GNSS sensitivity is a relevant feature in all the applications involving possible urban and light indoor scenarios (especially eCall and emergency services).

Position fix rate It is the rate at which the positioning terminal outputs the PVT data. This is not independent from the PVT update rate of the GNSS receiver, for which the typical rate is 1 Hz. Consequently, the distance between two positions if the vehicle drives at 90Km/h, would be 25 meters. Nonetheless some positioning architectures (e.g.: GNSS receiver coupled with inertial sensors) might require higher output rates from the GNSS receiver. For certain automotive application like collision avoidance or red light violation warning the fix rate should be 10 Hz or more.

ANNEX 5: LIST OF ACRONYMS

ADAS	Advanced Driver Assistance Systems
AHS	Autonomous Haulage Systems
BOC	Binary Offset Carrier
CAGR	Compound Annual Growth Rate
CAM	Cooperative Awareness Message
CDMA	Code Division Multiple Access
CBOC	Composite BOC
CS	Commercial Service
CSMA/CA	Carrier Sense Multiple Access with Collision Avoidance
DENM	Decentralized Environmental Notification Message
DOP	Dilution Of Precision
DSRC	Dedicated Short Range Communications
EGNSS	European GNSS
FDMA	Frequency Division Multiple Access
GGTO	GPS to Galileo Time Offset
GLONASS	Global Orbiting Navigation Service System
GLOSA	Green Light Optimal Speed Advisor
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
IR	Integrity Risk
ITS	Intelligent Transport System
IVS	In-Vehicle Systems
LBS	Location Based Services
LCA	Liability Critical Applications
MAC	Medium Access Control
MBOC	Multiplexed BOC
NHTSA	National Highway Traffic Safety Administration
NLOS	None Line Of Sight
OBU	on-board unit
OEM	Original Equipment Manufacturer
PD	Probability of detection
PFA	Probability of false alarm
PL	Protection level
PND	Personal Navigation Device
PPP	Precise Point Positioning
PVT	Position Velocity Time
RLVW	Red Light Violation Warning
RTK	Real Time Kinematics
RUC	Road User Charging
SBAS	Satellite Based Augmentation System
SCA	Safety Critical Applications
SCE	Spreading Code Encryption
SIS	Signal In Space
SLAM	Simultaneous Location And Mapping
TMBOC	Time Multiplexed Binary Offset Carrier Signals
UCP	User Consultation Platform
V2X	Vehicle to Vehicle/Infrastructure communication

Application categories	Applications	Cell phone (+ RDS-TMC)	VtoX	Regulation	Availibility	Horizontal Accuracy	GNSS Time Accuracy
Safety Critical Applications	Red light violation warning		Yes		3	1	1
	Queue warning	Yes	Yes	Yes	3	2	1
	Obstacles on the road	Yes	Yes	Yes	3	2	1
	Work zone warning	Yes	Yes	Yes	3	2	1
	Weather based hazards	Yes	Yes	Yes	3	2	1
	Curve speed warning				3	2	1
	Emergency electronic brake light		Yes		3	2	2
	Oversize vehicle warning		Yes		3	1	1
	360° all around view		Yes		3	3	2
	Blind spot lane change warning		Yes		3	1	1
	Pedestrians in crossroads		Yes		3	2	1
	Wrongway driving		Yes	Yes	3	3	2
	Cooperative intersection collision avoidance including railways		Yes		3	3	3
	Automatic speed limitation		Yes		3	2	1
	Emergency brake assit syste, forward collision avoidance		yes		3	3	3
	Automatic driving				3	3	3
	Autonomous car		Yes		3	3	3
	Synchronization		Yes		3	0	3
Payment Critical Applications	Road User Charging	Yes		Yes	2	2	2
	Pay as you drive Insurance				2	2	1
	Pay per use Insurance				2	2	1
	Taxi meter				2	2	2
	Parking fee calculation				2	2	1
Regulatory Critical Applications	Digital Tachograph	Yes		Yes	3	1	1
	Hazardous Material Tracking	Yes			3	2	1
	e-call	Yes		Yes	3	1	1
	Geo-fencing (low emission zone area, forbbiden area, alert)				3	2	1
Smart mobility traffic management	Freight and fleet management	Yes			2	2	1
	Cargo/asset management	Yes			2	2	1
	Vehicle access/clearance control				2	2	1
	Floating Car Data	Yes			2	1	1
	Origin-Destination survey	Yes			2	2	1
	Dynamic speed harmonization		Yes		2	2	1
	Emergency vehicle priority				2	2	1
	Bus and tram priority at traffic lights*	Yes	Yes		3	3	3

Position integrity	Position Authentication	Continuity	Position fix rate	Vertical Accuracy	GNSS Sensitvity	Robustness to Interferences	Time to First	Latency	Score
3	2	3	2	1	3	3	2	2	**26**
3	3	1	2	1	3	3	2	2	**26**
3	3	2	2	1	3	3	2	2	**27**
2	2	2	2	1	3	3	2	2	**25**
2	2	2	2	1	3	3	2	2	**25**
3	3	2	2	1	3	3	2	2	**27**
2	2	2	2	1	3	3	2	2	**26**
2	2	1	1	1	3	3	2	1	**21**
3	3	2	2	1	3	3	2	2	**29**
3	3	2	2	1	3	3	2	2	**26**
3	3	2	2	1	3	3	2	2	**27**
3	2	3	2	2	3	3	2	2	**30**
3	3	3	3	2	3	3	2	3	**34**
2	3	2	2	1	3	3	2	2	**26**
3	3	3	3	1	3	3	2	3	**33**
3	3	3	3	3	3	3	2	3	**35**
3	3	3	3	3	3	3	3	3	**36**
3	3	3	3	0	3	3	3	3	**30**
2	3	2	2	1	3	3	2	2	**26**
2	3	2	1	1	2	3	2	1	**22**
2	2	2	1	1	2	3	2	1	**21**
1	2	1	1	1	2	3	2	1	**20**
2	3	2	1	3	2	3	2	1	**24**
2	3	2	1	1	2	3	2	1	**22**
2	3	2	1	1	2	3	2	1	**23**
2	2	2	1	1	2	2	2	1	**20**
2	3	2	1	1	3	3	2	1	**24**
1	2	1	1	1	1	1	2	1	**16**
1	3	1	1	2	2	1	2	1	**19**
1	3	1	1	1	2	2	2	1	**19**
1	1	1	1	2	1	2	2	1	**16**
1	1	1	1	2	2	2	2	1	**18**
1	2	1	1	1	1	2	2	1	**17**
1	2	1	1	1	2	2	2	1	**18**
1	3	1	3	1	3	3	2	3	**29**

Application categories	Applications	Cell phone (+ RDS-TMC)	VtoX	Regulation	Availibility	Horizontal Accuracy	GNSS Time Accuracy
Smart mobility for user's safety and comfort	Road navigation with lane level positioning				2	1	2
	Speed limitation information	Yes	Yes	Yes	2	2	1
	In vehicle signage		Yes		2	2	1
	Electronic horizon				2	2	1
	Reduce speed warning				2	2	1
	Do not pass warning				2	2	2
	Green Light Optimal Speed Advisory		Yes		2	1	2
	Automated parking				2	1	1
	Tailgate advisory				2	2	2
	Lane departure warning system				2	1	2
	Slow or stationary vehicle		Yes	Yes	2	2	1
	Traffic jam ahead warning	Yes	Yes	Yes	2	2	1
	Connected eco driving		Yes		2	2	1
	Snowplough in operation	Yes	Yes	Yes	2	2	1
	Dynamic ride sharing	Yes			2	2	1
	Stolen vehicle recovery	Yes	Yes		2	2	1

Availibility	1 means <95%, 2 means between 95% and 99.9%, 3 means > 99.9%	
Horizontal accuracy (95%)	1 means roughly 10 m	2 means between 1 and 10 m
Time accuracy (95%)	1 means rough 1 second	2 means between 1 micro second and 1 second
Position integrity	1 means low: PL>25m at IR=10exp-4	2 medium reseved to payment critical applications: PL<25m, at IR=10exp-4
Position authentication	1 means low: Pfa<10% and PD>68%	2 means medium: Pfa<1% and PD>75%,
Continuity	low	Medium
Position fix rate	1 means 1 Hz	2 means between 1 and 20 Hz
Vertical accuracy (95%)	1 means roughly 10 m	2 means between 2 and 10 m
GNSS sensitivity	1 means more than -148 dBm	2 means between -148 dBm and -160 dBm
Robustness to interferences	1 means low robustness	2 means medium
TTFF	1 means roughly 30 s	2 means ≤ 30s
Latency	1 means roughly 100 miliseconds	2 means between 20 and 100 miliseconds
Tram priority at trafic lights could be a critical safety application if the traffic management wishes to shorten the duration of green light		

Position integrity	Position Authentication	Continuity	Position fix rate	Vertical Accuracy	GNSS Sensitvity	Robustness to Interferences	Time to First	Latency	Score
2	2	1	2	1	3	3	2	2	**23**
1	1	1	1	1	2	1	2	1	**16**
1	2	1	1	1	2	2	2	1	**18**
1	2	1	1	1	2	2	2	1	**18**
1	2	1	1	1	2	2	2	1	**18**
1	3	2	2	1	2	2	2	2	**23**
2	2	2	2	1	3	3	2	2	**24**
1	1	1	1	1	1	1	2	1	**14**
2	2	1	1	1	1	2	2	1	**19**
1	2	1	2	1	2	3	2	2	**21**
1	1	1	1	1	1	2	2	1	**16**
1	1	1	1	1	1	1	2	1	**15**
1	1	1	1	1	1	1	2	1	**15**
1	1	1	1	1	1	2	2	1	**16**
1	1	1	1	1	1	1	2	1	**15**
1	1	1	1	2	1	1	2	1	**16**

3 means ≤ 1 m	
3 means ≤ 1 micro second	
3 means high applied to safety critical applications: PL<2.5m at IR=10exp-6	PL (protection level); IR (integrity risk)
3 means high: Pfa<0.2% and PD>85%	Pfa (probability of false alarm), Pd (probability of detection)
high	
3 means > 20Hz	
3 means ≤ 2 m	
3 means ≤ -160 dBm	
3 means high robustness to Interf	
3 means ≤ 1.5 s	
3 means ≤ 20 miliseconds	

ANNEX 6: UPDATES FOLLOWING THE USER CONSULTATION PLATFORM 2018

As per EUSPA document reference GSA-MKD-AGR-UREQ-250283 available here.

ANNEX 7: UPDATES FOLLOWING THE USER CONSULTATION PLATFORM 2020

As per EUSPA document reference EUSPA-MKD-AGR-UREQ-250283 available here.

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