STARS

SATELLITE TECHNOLOGY FOR ADVANCED RAILWAY SIGNALLING

D6.4 Implementation plan

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1 INTRODUCTION

1.1 EXECUTIVE SUMMARY

This deliverable outlines a proposal for an implementation plan for the introduction of the GNSS technologies in ETCS. It considers two different time frames, taking into account the state of the art, as well as the evolution of GNSS/EGNSS technologies. The implementation plan for the short - medium time frame will consider the use of the current EGNSS technology, eventually with the addition of adequate local augmentation subsystem (when required) or of some mitigation strategies. The long-term time frame, instead, will consider the use of the possible evolution of the GNSS/EGNSS technologies.

This deliverable is the result of Task 6.4.

The Task 6.4 (Implementation plan) deals with the definition of a possible implementation plan by identifying the major milestones and investment cost items that are relevant to the EGNSS service for ERTMS. With the aim to outline strategic guidelines for the implementation of the system, the main positive and negative factors are defined. Addressing threats such as the current delay in the implementation of the ERTMS program at the European level (e.g. by introducing innovative financing solutions and business models which include mechanism for balancing risk- and benefit-sharing between operators), should be the main sample of the roadmap of the project.

The task 6.4 also includes the expansion of the Cost Benefit Analysis and Impact Analysis results, as from D6.2 and D6.3, to the European level in order to assess the general impact at this level of the introduction of the EGNSS innovative technologies in the railway domain.

1.2 DEFINITIONS AND ACRONYMS

Acronym	Meaning
ATO	Automatic Train Operation
EFTA	European Free Trade Area
EGNOS	European Geostationary Navigation Overlay Services
EGNSS	European Global Navigation Satellite Services
GNSS	Global Navigation Satellite Services
IMU	Inertial Measurement Unit
m€	Millions of Euros
PVT	Position Velocity Time
RAIM	Receiver Autonomous Integrity Monitoring
TTA	Time to Alarm

2 CURRENT PROGRESS OF THE DEVELOPMENT OF THE SATELLITE BASED RAILWAYS SIGNALLING SOLUTION

2.1 STATE OF GNSS/EGNSS TECHNOLOGY

The state of currently available GNSS/EGNSS technology can be summarised as follows:

- There are currently four GNSS navigation constellations in operation:
  - NAVSTAR-GPS (fully operational)
  - Galileo (currently operational with full operational capability 2020)
  - GLONASS (fully operational)
  - BEIDOU (limited coverage, full global coverage planned for 2020)
- The differences between these systems lie mostly in the frequencies used and the signal modulation
- Only Galileo is under full civilian control, the other system are at least partially controlled by military agencies.
- Of these only GPS and Galileo currently provide an open, unrestricted multi frequency service
- An integrity monitoring overlay system is currently only available for GPS (WAAS. EGNOS etc.), with currently no global coverage

EGNOS is the Space Based Augmentation System for the NAVSTAR-GPS. EGNOS and GPS are the GNSS system that provides Safety Of Life services for the Europe. Future developments of GNSS/EGNSS can be summarised as follows:

- For Galileo integrity monitoring will be available with EGNOS V3 in 2025
- EGNOS will be extended to make Galileo usable in safety critical applications
- EGNOS V3 will also support multiple frequencies in 2025
- Multi frequency support in WAAS

2.2 GENERAL ISSUES OF USING GNSS IN SAFETY CRITICAL RAILWAY SIGNALLING

Integrating GNSS in safety critical railway signalling applications requires that the scope is defined, and that a number of basic assumptions are made. The following list contains the general definition and limitation of the scope, as well as assumptions, which have been agreed as part of the STARS project, or are derived from results of the project:

- In the framework of the STARS project, safety critical application is equivalent to ETCS, as this is the signalling system mandated in Europe for the next decades. This implementation plan for the development of satellite based railway signalling solutions is therefore closely tied to the implementation plan of ETCS in Europe.
- The application of GNSS with ETCS is limited to ETCS Level 2/3. An application with ETCS Level 1 is not considered, as Level 1 requires physical balises for data transmission, which reduces the benefits of GNSS to a minimum.
- For ETCS applications, safety integrity level 4 (SIL 4) is currently required. While this does not necessarily mean that the GNSS/EGNSS system itself needs to be compliant with SIL 4, the overall application shall still maintain that safety level when using GNSS.
- Safety critical, non-ETCS applications of proprietary nature are not being considered.
- ETCS is an open standard, based on the requirement to ensure interoperability between equipment from different suppliers (similar to the application of GNSS in aviation). This key feature of ETCS shall be maintained also when using GNSS with ETCS. All related

technologies, designs and specifications shall therefore also be specified in an open standard, which will be put in the public domain.

The proposed implementation plans are also based on a number of technical assumptions, which have a significant impact. If these assumptions are changed, then the implementation plans, including economical evaluation have to be adjusted. In detail the following technical assumptions have been made:

- GPS and/or Galileo cannot be used as standalone systems for safety critical applications, as they do not include any diversities and integrity monitoring. Augmentation systems are then required (e.g. EGNOS) and the use of the Signal in Space (SIS) in the context of ERTMS must also be analyzed with respect to the CENELEC EN50519 standard that addresses both the safety and security issues. The potential security issues associated with the SIS as an open network must be addressed at the ERTMS System Level to assess the potential effects on the position domain, if any, and identify the required mitigations.
- GPS and/or Galileo also don't contain functions which detect safety critical feared events caused by local sources. An exclusion of such events, as done in aviation, is not possible as these events have a significant impact on performance and safety.
- Railway RAIM for coping with specific railway local feared events are necessary.
- The cost-benefit has assumed the use of EGNOS free of charge (as it is in the aviation domain).
- If EGNOS shall be used, then the integrity monitoring data must be sent by other means than geostationary satellites to trains for two reasons:
  - EGNOS coverage on most railway lines is so poor that it becomes essentially useless.
  - The EGNOS data is transmitted without any protection through an open airgap, which will probably make it impossible to produce a safety case considering the requirements in the applicable railway safety standards.
- If an adequate replacement shall be used instead of EGNOS then:
  - The system shall be usable across Europe and preferably also outside Europe without limitations.
  - The required ground infrastructure shall provided by an organization outside individual applications, that must be standard and guarantee interoperability. As with EGNOS this organization also has to guarantee the availability and safety of the augmentation system.
  - The system has to be standardized as an open standard in the public domain, to a point where any supplier can produce the required components free of patent rights or royalties, and that components from different suppliers can be mixed freely and used in an interoperable way.
  - The augmentation system shall use a standardized communication system already in place to send data to the on-board GNSS equipment..

From these points two scenarios for the short-medium term (based on current GNSS technology), and a longer term (based on possible evolutions of GNSS technology) can be derived; they are presented in the next sections.

2.3 Development of a GNSS based Solution for ETCS

2.3.1 General

As stated above, ETCS is considered as the basis for integrating GNSS into safety critical railway signaling applications.

ETCS Level 2 currently uses balises and odometry information as the basis for the on-board train positioning function, and track circuits or axle counters for the trackside train detection function. In ETCS Level 2 the position calculated by the on-board unit based on balises and odometry sensors is used by the onboard system to ensure that the train is not exceeding the distance it is allowed to run, and to observe track limitations such as speed limits or to perform special functions.

In ETCS Level 2 the on-board calculated position is made available to the trackside systems by means of the position reports, which however only use it mostly for automation functions. Most of the safety critical signaling functions performed trackside functions, which require train position, such as route release and moving of points, still rely on the train position derived from track circuits or axle counters.

In ETCS Level 3 also the trackside functions will have to rely on the train position reported by the on-board system, which will likely increase safety requirements on the on-board positioning function.

The same is valid for ATO, as e.g. manual driving to stopping points is significantly less prone to be impacted by train positioning errors than in automatic driving. ATO will also likely increase safety requirements on the on-board positioning function and will employ additional sensors or information to improve the position accuracy.

2.3.2 Issues of integrating of GNSS into ETCS

Various concepts could be envisaged on how to integrate GNSS/EGNSS technologies into ETCS. To select an appropriate one, a number of issues have to be considered:

- **Trade-off between the technical complexity and impact on the current ETCS**
  - One of requirements for the introduction of GNSS into ETCS is to minimize the impact on the current ETCS specifications. To follow this requirement the Virtual Balise concept was selected. However, the detection of Virtual Balise will be based on a totally different technology compared with Eurobalise and thus the achievable performance, depending on the employed technology (IMU with different grade/quality, GNSS, odometry, Digital map, etc), is expected to differ more or less significantly.
  - It is known that current GNSS technology certified for aviation has certain usage restrictions when applied to the railway domain; some of them can be minimized by technical solution (e.g. poor availability can be improved by integration with additional sensors), some of them however cannot be solved with reasonable technical means and have to be reflected in ETCS specifications (e.g. lateral accuracy based only on code measurement does not guarantee the expected performance needed for track selectivity; however it remains for further evaluation whether the accuracy achievable with multi constellation/multi frequency receivers will be better and/or whether the use of additional signalling based mitigations will help).
- **Interoperability**
  - Interoperability is a key element of ETCS, which has to be preserved also when integrating GNSS/EGNSS. Also ETCS with GNSS/EGNSS will have to achieve a specified minimal level of performance over entire European Railway Network where GNSS/EGNSS shall be implemented, regardless of trackside or on-board suppliers. To be this feasible, algorithms, processes and procedures for integrating GNSS/EGNSS into ETCS have to be agreed and specified at appropriate level and have to be incorporated into specifications (ETCS subsets, railway MOPS). This concerns both on-board constituent and track side constituent. The specification of the on-board constituent will have to cover e.g.:
    - the characteristics of the GNSS signal receiver, possibly starting from the properties specified in the RTCA standards and also considering their known

evolution; this will contribute to the definition of the minimum performance requirements for a railway GNSS receiver;

    - the algorithms to be performed for PVT calculation, Protection Level computation, calculation of the train confidence interval;
    - in addition, fault detection and exclusion techniques will have to be selected to identify and react properly to local events, whose effects are not considered in the error budget definition.

  - The specifications of track side constituent will have to concern the quality and mode of distribution of integrity and augmentation data.
  - If the final solution requires an onboard track database, and possibly the provision of signalling information to the on-board system, such as point position for map matching, then these aspects will have to be standardized too.

- **Availability**
  - GNSS only works intermittently in the railway environment, as there are locations where coverage cannot be ensured. Obvious examples are tunnels or platform roofs, but other locations exist too where GNSS is not available, such as in urban areas with high rise building etc.
  - It has to be noted that trains can spend long durations under the above described conditions, such as in long tunnels, but also in underground stations. These times are also unpredictable.
  - It is therefore assumed that the capability to continue to use physical balises (when strictly required) and odometry information for the on-board train positioning function will have to be maintained.

- **Proper specification of the minimal level of performance**
  This issue covers two aspects of the specification of the minimal level of performance:
  - The first aspect is how the minimal level of performance is specified in the standard. The two extreme possibilities are either to fully define all algorithms and thus not leave any implementation flexibility, or the opposite, to have specified performance characteristics together with the test procedures only and thus leave freedom to suppliers for implementation. Probably, the good balance has to be found between these two extremes.
  - The second aspect is related to the level of performance. The specified minimal level of performance should be high enough to make the solution attractive for customers. On the other hand, the higher the level of minimal performance the greater the complexity which then results into a more expensive solution. Also high performance requirements e.g. on location accuracy might result in low availability.

    The formalization process of the performance requirements for using GNSS/EGNSS in the railway environment will have to be deeply investigated. This process has started in projects like NGTC and STARS and a complete performance analysis could be derived in the context of the S2R TD 2.4 Fail-Safe Train Positioning.

- **Certification process**

    To reduce the complexity of the certification/authorization for EGNOS using in ERTMS, the pragmatic solution based on the current EGNOS V2 as is has been considered. To cope with the peculiarity of the railway environment, where local phenomena can have a big impact on safety and performance, the proposed approach assumes an EGNOS service provision for railways with commitments on pseudo-range domain performance only, leaving the safe management of any possible effects from the local environment to the railway stakeholders.

The revision and updating of the relative ERTMS subsets will be a direct result of the technical specifications deriving from the service.

- **Integrity**
  - The current integrity concept of GNSS/EGNSS was specifically developed to suit the conditions of aviation applications. It has to be adapted to suit the the quite different conditions of railway applications. A pure PVT solution does for example not make sense in a railway environment, as the absolute position of a train is defined as distance along the track, as well as the discrimination of the track in locations with multiple parallel tracks. Therefore, a definition of e.g. a protection level must take into account the different scenarios in the computation of the position. The protection level should be modified to differentiate the uncertainty along track from the uncertainty on parallel tracks (if feasible by using GNSS in the future).
  - The integrity figures must be analysed in terms of the integrity tree to check if the risk allocation is suited also for rail environment.
  - The transition to EGNOS V3, even if it improves the overall performance of the GNSS-based solution, cannot solve the basic problem of local feared events such as multipath or electromagnetic interference.
  - In order to overcome the above problems, GNSS/EGNSS might have to be complemented by other sensors, or by map matching; this complementation must be however be defined, demonstrated to be effective, and subsequently standardized.

2.3.3 Solution for integrating GNSS into ETCS

Based on these issues, the concept of virtual balises has been developed. In this concept a GNSS based on-board function detects when the train passes waypoints, which are called virtual balises. The ETCS on-board system can then reset the confidence interval of the train position, using a mechanism very similar to the one used for physical balises. More detailed investigations of the concept have however revealed a number of technical challenges, which will have to be solved.

- The positioning accuracy of virtual balises is lower than the one of physical balises, both longitudinally along the track as well as regarding track selectivity.
- An increased longitudinal error might result in operational limitations, such as a reduced stopping accuracy which might e.g. require longer tracks in stations. Therefore, the solution must include mechanisms or algorithms for avoiding not tolerable impacts on signaling operational scenario.
- Certain balise based functions, such as e.g. “Stop if in Shunting” require balises to be placed at specific locations, regardless whether the environment is suited for virtual balises. This might either result in the unavailability of these functions, or the need to use physical balises to implement them. Therefore, the design and the implementation of the virtual balise must be done to also allow its use for sending these commands and/or other signaling mitigations have to be identified for leading to an acceptable limitation from the signaling operational point of view.
- Ensuring track selectivity is extremely safety critical, and might require other means, such as map matching and provision of point information to the on-board system.
- VB detection algorithm has to work in railway environment which is prone to GNSS signal outage, signal distortion due to multipath and RF interference (intentional or unintentional). The predictability of these effects is a key issue for the definition of appropriate measures to cope with them, and to include them in a protection level computation tailored to the railway environment. In STARS, significant work has been performed to identify and characterise local phenomena in measured data (such as MP, NLOS, and RF). Significant effort will however still have to be performed to readjust/formalize the local error budget (static and or dynamic, or a combination of them), basing on the experimental data results.

- Rules will have to be developed for defining possible locations for virtual balises, meaning locations will have to fulfil certain requirements.
- Countermeasures for the detection and eventually for the exclusion of feared events will have to be developed and standardised.
- Train positioning using virtual balises will have to maintain SIL4. A significant contributor to the safety concept is EGNOS. However, if EGNOS data is sent to the train via geostationary satellites it is sent unprotected, and coverage is very poor. Consequently, other means of delivering of EGNOS messages to the on-board constituent will be required, such as sending it via the secure radio link between RBC and train. This will likely require an EDAS type of service suitable for railways applications (i.e. compliant with CENELEC 50159 and with guaranteed safety level and availability); or other similar solutions to be defined.
- A feature inherent from EGNOS for aviation applications is a Time to Alarm (TTA) parameter in the order of several seconds. The consequence is that the GNSS position can be potentially out of the tolerance during this time period. A suitable technical solution will be required to manage this EGNOS feature, unless it can be demonstrated that the TTA delay has no unmitigated impact on the resulting train position.

Most of these issues will be solved in subsequent projects (e.g. S2R TD2.4).

3 IMPLEMENTATION PLAN

3.1 SCOPE DEFINITION AND RELEVANT ISSUES CONCERNING THE IMPLEMENTATION

The elaboration of an Implementation Plan for the integration of GNSS in safety critical railway requires a definition of the solution's scope, as well as of the selection of technologies on which the implementation is based. The state of GNSS/EGNSS technology, as well as of the solution how to integrate it into safety critical railway signalling applications are described in chapter 2 of this document. From that separate possible implementation plans have been developed for a short-medium term and a long-term implementation, using current, respectively future GNSS/EGNSS technologies.

3.2 OVERVIEW

As described in chapter 2, the use of an ERTMS system also based on the GNSS/EGNSS solution which provides the required services to be used for the safety critical application with ETCS in compliance with railway constraints and safety standards is based on the completion of the following steps:

- Definition of the expected EGNSS services performances in relation with well-defined railway mission scenarios.
- Development of a technical solution for the Virtual Balise concept, including:
    - performing a safety analysis to determine whether and/or how SIL 4 can be maintained when using GNSS/EGNSS
    - determining what additional sensors and/or inputs are required by the virtual balise reader function to ensure both availability as well as track selectivity
    - developing a PVT algorithm which considers the railway environment
    - developing a Protection Level algorithm which considers the railway environment
    - specifying and developing GNSS receiver and Positioning functions which can detect and bound the effects of local feared events in the position domain
    - specifying minimum receiver and positioning performances
    - specifying an on-board database, including mechanisms to maintain and update the database
    - an EGNOS ground service or a solution to allow the delivery of Augmentation Data to the onboard ETCS platform via the signaling trackside constituent
    - an alternative augmentation system, if considered to be advantageous over EGNOS
    - definition of engineering rules to determine where virtual balises can be placed
    - specify operational scenarios to determin which operational limitations result, if any, for the ETCS application from the reduced performance of an EGNSS based solution compared using physical balises, and determining whether these operational limitations are acceptable, and how they impact the cost-benefit analysis
    - develop test specifications for the vitual balise reader function
    - clarify issues with the safety certification

  The development of this solution is in the scope of the S2R TD 2.4 Project.
- Definition of a certification and qualification plan that will allow demonstrating that the overall system will satisfy the expected operational performances for the identified missions scenarios.
- Validation that the overall system (ERTMS with the satellite localization based on the EGNSS services) fulfils the applicable safety, security and accuracy performances.
- Definition and agreement at European level of the necessary contract for the provision of the EGNOS railway service.
- Specification of the evolution of ERTMS/ETCS standards integrating the EGNSS contribution, including test specifications etc.

- Publication of the changes to ERTMS/ETCS in a future release of the TSI, in order to allow infrastructure managers to implement the concept and to require railway operators to equip their vehicles accordingly, and the supply industry to develop and certify the new products.

The Implementation Plan also needs to consider an incremental deployment approach that allows to maintain the backward interoperability with previous existing signaling systems and the service continuity during operations in case of heterogeneous systems.

The possible Implementation Plans defined in the following sections therefore includes:

1) a short-medium term timeframe, based on EGNOS V2 as is or EGNOS V3 if available;
2) a long-term timeframe, in which possible evolutions of the EGNSS technologies shall be used.

3.3 IMPLEMENTATION PLAN FOR SHORT – MEDIUM TIME FRAME BY USING THE CURRENT EGNSS TECHNOLOGY

If only currently available GNSS/EGNSS technology shall be considered in the frame of the short-medium term implementation plan, then this would limit the choice to the combination of GPS plus EGNOS, as this is the only technology currently available which includes any form of measures to ensure integrity and safety.

However, as Galileo will achieve full operational capability in 2020, and the EGNOS V3 has been contracted and will be operation in 2025, they can be considered to be included in the short-medium timeframe. From a technical point of view both can be considered proven technologies with low risk; provided that the integrity is guaranteed or the used EGNOS V3 properties are guaranteed by the EGNOS service, EGNOS V3 can be included in the short-medium term plan. Considering the many tasks still to be done this will not result in any delays to the short-medium term implementation.

Starting from this, the following conclusions can be made:

- Based on the assumptions made in the introduction an EGNOS ground service or equivalent solution is required, as EGNOS coverage on most railway lines is so poor that it becomes essentially useless, unless the implementation would be restricted to only the most open lines. In this case the assumed percentage of the network where GNSS can be used would have to be assumed to only a few percent of the European.
- Considering the openness of the GNSS airgap and the lack of any safety measures against interferences, EGNOS data will have to be sent to the train via a protected connection.
- The only currently available, standardized possibility to do this is via the standard ERTMS radio connection between the radio block center and the train, which is safe and secure.
- EGNOS data will therefore have to be made available to the radio block center by the EGNOS ground segment through a protected ground link or equivalent solution.
- The provision of EGNOS data must be guaranteed in regards to safety and availability, so a contract between the EGNOS provider and the Infrastructure Managers will have to be established, similar to the one in aviation.
- Regarding local augmentation subsystem there is currently nothing available which is intended for safety critical applications, available as an open standard, and does not have the same issues as EGNOS.

If current GNSS/EGNSS technology shall be used in safety critical railway applications then this is limited to GPS plus EGNOS, as this is the only combination currently available which includes any form of measures to ensure safety. As EGNOS coverage on most railway lines is so poor that it becomes essentially useless, EGNOS data will have to be transmitted to the on-board platform by other means, the data also needs to be protected against interferences, unintentional or intentional.

The only, currently available, standardized possibility to do this is via the GSM-R radio connection between the radio block center and the train, which is encrypted. And again to protect the EGNOS data, it shall be made available to the radio block center by the EGNOS ground segment through a protected ground link or similar solutions to be defined. This could largely be based on the EGNOS Open Service, A contractual arrangement will be required between the EGNOS provider and the end users similar to the one in aviation. Regarding local augmentation subsystem there is currently nothing available which is intended for safety critical applications, and does not have the same issues as EGNOS.

The following table summarizes the Implementation Plan via its main milestones and the envisaged year of fulfilment. Each milestone is then illustrated in more detail and its main players and risks identified.

#	Milestone	Year of fulfilment
M1	Definition of System Requirement Specifications and system architecture	*2020*
M2	Development and laboratory demonstration of fail-safe train positioning subsystem	*2021*
M3	On-site demonstrations	*2022*
M4	Development of laboratory toolchain and GNSS receiver	*2022*
M5	Implementation of a terrestrial communication link standard or equivalent solution	*It is expected by 2024*
M6	System integration	*It is expected by 2025*
M7	Certification and operational readiness review	*It is expected by 2027*

Figure 1: Implementation plan overview

Milestone 1 – Definition of System Requirement Specifications and System Architecture

Description	System definition versus mission needs, overall design, development and deployment planning and feasibility assessment. • Definition of the expected EGNSS services performances in relation with well-defined railway mission scenarios. • Specification of the evolution of ERTMS/ETCS standards integrating the EGNSS contribution. • Technical Feasibility assessment on key components of the architecture • Validation that the overall system (ERTMS+EGNSS services) fulfils the applicable safety, security and accuracy performances. • Definition of a certification and qualification plan that will allow to demonstrate that the overall system will satisfy the expected operational performances for the identified missions scenarios. • Estimation of overall development, deployment and operations costs • Assessement of operational gains resulting from the updated architecture • Trade-off analysis between technical solutions and benefits • Consolidation of the overall architecture and development plan based on all the inputs collected during this phase to allow the start of the development phase.

Expected year of fulfilment	2020
Main players driving its fulfilment	• ERTMS and EGNSS industries • Railway stakeholders and experts
Risks	• Lack of assessment of critical design performances in real condition (to be mitigated by means of system prototyping, real tests and simulations) • Weak consideration of critical planning constraints (to be mitigated by means of risks analysis on event that could impact the overall architecture)
Cost	Activities planned in the context of the S2R TD2.4 project.

Milestone 2 – Development and laboratory demonstration of fail-safe train positioning subsystem

Description	Various possible solutions for Fail-Safe Train Positioning subsystem will be identified and their possible use will be demonstrated. The new processes will be used for performing the verification & validation and the Certification of new ERTMS systems based on the new Fail-Safe Train Positioning subsystem will be identified and described. Verification in the Laboratories of the developed components for new Fail-Safe Train Positioning and development of the complete Fail-Safe Train Positioning prototypes and their verification in the laboratories. The complete Fail-Safe Train Position subsystem and related demonstrators will be available and operational in the Laboratories. This milestone corresponds to the completion of Shift2Rail TD2.4 Phases 2 and 3.
Expected year of fulfilment	2021
Main players driving its fulfilment	• Shift2Rail JU Members, including main European Rail Industry companies • Rail infrastructure Managers • Rail Operators
Risks	• Underperformance of proposed solutions • New technology development risks.
Cost	Activities planned in the context of the S2R TD2.4 project.

Milestone 3 – On-site demonstrations

Description	Demonstration of the benefits coming from the use of the new Fail-Safe Train Positioning subsystem in the new generation of ERTMS systems will be qualitatively and quantitatively demonstrated: three Trial Sites will be operational with this new solution. This milestone corresponds to the completion of Shift2Rail TD2.4 Phase 4.
Expected year of fulfilment	2022
Main players driving its fulfilment	• Shift2Rail JU Members, including main European Rail Industry companies • Rail infrastructure Managers • Rail Operators
Risks	• Underperformance of demonstrated solutions as compared to the expectations of potential partners
Cost	Activities planned in the context of the S2R TD2.4 project.

Milestone 4 – Development of laboratory toolchain and GNSS receiver

Description	Development of laboratory tools such as a GNSS simulation testbed and comprehensive multipath, EMI and intentional interference (spoofing and jamming) models to support testing of equipment in railway environments under nominal conditions and fault injection. GNSS receiver technology development, focusing on advanced integrity algorithms and techniques, and resilience against intentional and unintentional interference.
Expected year of fulfilment	2022
Main players driving its fulfilment	• European Space Agency • GNSS industry • Rail industry
Risks	• Developed laboratory tools are not fully coherent with Shift2Rail technical approach towards fail safe satellite based positioning. • Lack of enough information about the integrity risk apportionment and mitigation of the operational EGNOS system (to be mitigated with the support of ESA for a deeper analysis of the EGNOS integrity tree). • The railway specific GNSS receiver may significantly increase the overall cost of the complete fail safe satellite based system.
Cost	GSA and ESA initiatives are expected to be set up

Milestone 5 – Implementation of a terrestrial communication link standard for EGNOS correction broadcast

Description	Implementation of a terrestrial communication link standard for EGNOS correction broadcast or equivalent solution.
Expected year of fulfilment	*It is expected by* 2024
Main players driving its fulfilment	• Space industry (to analyse the impacts on the augmentation system) • Signalling industry (to provide the knowhow on the rail standard) • TLC operators and service providers (to consider the use of a private or public network) • Rail Standardization Authority
Risks	Difficulties in the choice of a common standard (interoperability issue) (it can be mitigated via the possible use of 4G, 5G standards – at least in Europe)
Cost	GSA and ESA initiatives are expected to be set up

Milestone 6 – System Integration

Description	Following the development of each subsystem, qualification of subsystems independently, and system integration and qualification. Implementation of the first prototype and start of the certification process.
Expected year of fulfilment	*It is expected by* 2025
Main players driving its fulfilment	• Space industry (receiver manufacturer) • TLC industry (TLC link dedicated receiver) • Signalling industry (for the integration in the signalling product) • TLC operators and service providers (TLC connectivity provider if needed) • Certification Authorities
Risks	• Development delays due to weakness of specifications and complexity • Development extra costs due to delays or technical issues
Cost	GSA, ESA, EU and S2R initiatives are expected to be set up

Milestone 7 – Certification and Operational Readiness Review

Description	This phase includes the system certification and start of operations.
Expected year of fulfilment	*It is expected by* 2027
Main players driving its fulfilment	• ERTMS and EGNSS industries • Certification authorities
Risks	• Weak certification files could endanger the start of operations (to be mitigated with an increased cooperation with certification authorities) • Lack of contractual agreement could delay the start of operations (to be mitigated via an anticipation of contractual schemes and agreement leading to the operational activities)
Cost	GSA and ESA initiatives are expected to be set up

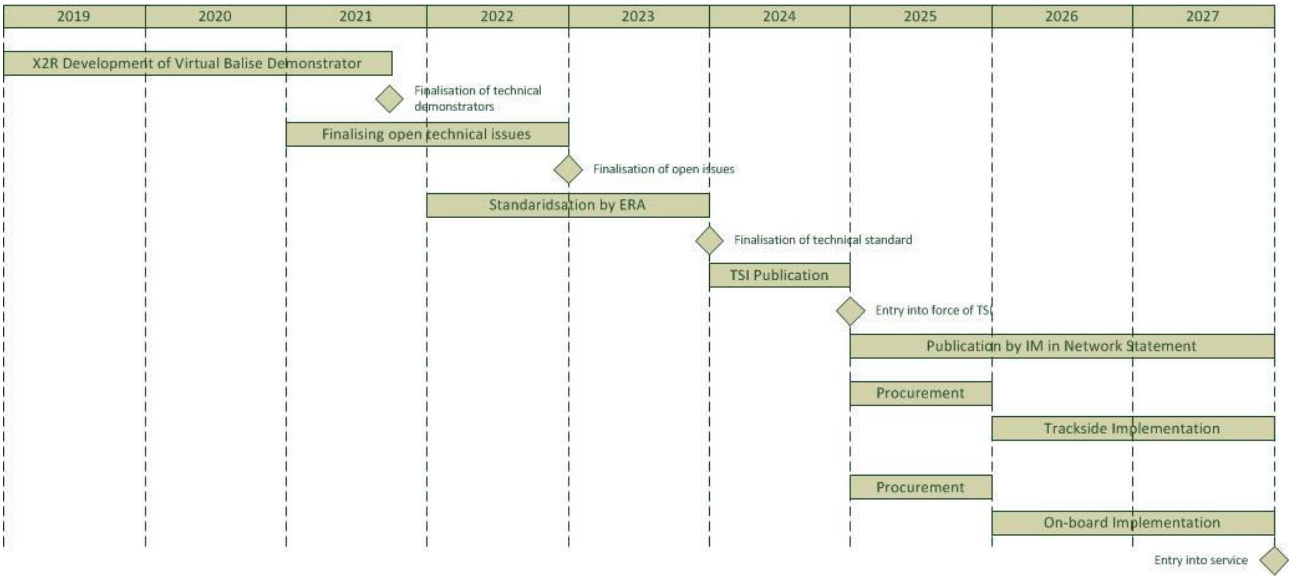
3.3.1 Deployment plan for short – medium time frame

The most relevant pre-requisite for targeting the deployment of a GNSS-based train positioning solution with ETCS is the definition of an adaptation of the legal framework regulating the European Railway sector.

For this purpose, a number of issues are to be addressed; the main ones include:

- A modification of the Technical Specifications for Interoperability (TSI), that needs to be justified with a EU Directive, and that specify which systems can be mandated by IMs.
- The elaboration of Reference Standards for the specification of the technical details of the systems that can be mandated.
- The update of Network Statements by IMs for the identification of systems that are considered mandatory for specific lines.

The modification of the TSI to include the possibility of satellite-based ERTMS is the main driver impacting the timeframe for the deployment. Since the publication date of such modified TSI depends on exogenous factors, the following time frame is a possible reasonable one. Some dates can anticipated based on the needs and the commitment of the interested stakeholders.



3.4 LONG-TERM IMPLEMENTATION PLAN BY USING THE POSSIBLE EVOLUTION OF THE EGNSS TECHNOLOGIES

An implementation plan for long-term evolutions of EGNSS cannot be produced with a level detail reaching a time-frame for milestones, like for the short-medium term, because the possible evolutions are not yet specified, and their availability is not ensured. A number of future technologies have been discussed in various working groups, but it is currently not clear whether and when they will become available. For the scope of the present study, it is possible to outline the most prominent ones, namely:

a) Dual frequency receivers could be used to improve accuracy and to provide additional mitigations to local feared events for some operational scenarios, as EGNOS 3 will also cover GPS L5 and Galileo E5 frequencies.

b) A ground-based augmentation system could be used instead of EGNOS, such as GBAS, which has been developed for aviation. This system would however require railways to install their own ground station networks and still leave the data distribution issue to be solved, as with EGNOS. Such a system might improve performance; the cost-effectiveness of its implementation is however to be investigated.

c) Other differential systems could also be used, such as the IALA compliant network provided in Germany by the German Wasserstrassen- und Schifffahrtsverwaltung des Bundes, WSV, or other similar systems available in other countries. In this case the ground station networks are provided by third parties, but currently only with none, or limited performance guarantees. However, in such cases as well, the data distribution issue would need to be solved, as well as the safety issue as these systems have typically not been developed to comply with high safety standards.

4 Conditions of Convenience of the Solution

This section shows the scaling up of the CBAs performed in D6.2 to the European level, highlighting the impact of the introduction of the satellite based technological solution in the European ETCS domain.

4.1 Recap of the Case Studies Results

In D6.2 a CBA has been performed for 9 different case studies, each one characterized for a different type of line (Local; Regional; Main) and a different area in which the line is located (Isolated; Medium; Dense).

In this paragraph the main results of those analyses will be recapped.

The following tables recap the case study definition, as described in D6.1

	LINE		VEHICLES			PRODUCTION		
	LineKm	TrackKm	Vehicles	% non-dedicated vehicles	TrKm/ Vehicle	Train/day	Train/y	Production/y (TrKm)
LOCAL	100	105	6	100%	200.000	28	10.220	1.022.000
REGIONAL	100	190	13	90%	250.000	80	29.200	2.920.000
MAIN	100	200	24	50%	350.000	144	52.560	5.256.000

	LINE		BALISES				
	LineKm	TrackKm	Balise/Km	TOT Balises	% virtualizable balises	Phisical balises	Virtual balises
LOCAL	100	105	2,5	263	100%	-	263
REGIONAL	100	190	3,0	570	90%	57	513
MAIN	100	200	3,0	600	75%	150	450

Figure 2: Case study definition

Only results related to the 3 "medium area" case studies will be considered. This, because the results of the sensitivity analyses performed in D6.2 show that there are few and marginal economic differences in the three different case studies related to isolated, medium and dense area.

The following table recaps the CBA results related to the three main case studies that will be considered in the expansion of the analysis to the European scope.

	ENPV	Cumulated flow	BCR	Project solution convenient under the base assumptions
Cut-off value	***> 0***	***> 0***	***> 1***	
LOCAL LINE	442.105	607.525	2,17	YES
REGIONAL LINE	279.693	311.434	1,18	YES
MAIN LINE	- 385.458	- 639.618	0,86	NO

Figure 3: CBA results for case studies

As shown, the CBA for the **regional line** and the **local line** case studies show a positive impact under the base assumptions, while the one for the **main line** shows a negative impact. The consequence is that, under base assumptions, the satellite based ETCS technological solution is better of the traditional one only in 2 case studies out of three.

4.2 Expansion of the Analysis to the European Level

4.2.1 Methodology, hypothesis and scope

As explained in D6.1, the analysis has been performed for hypothetical case studies lines, theoretically characterized, so that a parametrical expansion of the results to a higher level could be possible. In this case, Local, Regional and Main lines have to be considered as related to the part of the European network that has characteristics, in term of signalling equipment, train productivity, need of balise and coverage of the satellite signal, similar to the ones described for the three case studies analysed.

The methodological approach used for scaling up of the CBA to a European level is then based on the extension of the 3 case studies results. After the elaboration of the CBA in D6.2, parameters for the European level are computed for each cost and benefit item considering a weighted average of the results from the three case studies analysed previously and related to the sub-networks Local, Regional and Main line. With the parameters in hand, assuming they could represent a solid cost figure applicable for the whole European level, the CBA is scaled up to the reference network of this task.

The CBAs results shown in D6.2 and in the previous paragraph outline that only in two out of three case studies the results are positive. In fact, only on lines with characteristics like the ones of the regional and local line case study the satellite based ETCS technological solution is better of the traditional one. Contrary, under the base assumptions, the traditional ETCS solution remain the best on lines with characteristics like the ones of the main line case study. As a consequence, the extension of the results to the European level will be just performed on the part of the network that has characteristics like the ones of the regional and local line case study. If an integrated platform for BTM and VBR functions and a lower estimation of CAPEX related to Track DB and Digitalization campaigns are used, the CBAs may also provide a positive result for main lines.

The extension of the reference European network has been estimated with data from UIC, considering all the railway networks length in the EU28 countries plus the ones in the EFTA countries (Iceland, Liechtenstein, Norway and Switzerland). The total extension of the network is then estimated in **219.233 LineKm**.

The hypothesis, here, is that half of the network has characteristics like the ones of the main line case study, so that it is automatically out of the extension analysis, since this case showed negative results. The other hypotheses are that 20% of the network could be assimilated to the local line case study and the remaining 30% to the regional line case study. The **reference network** of this extension analysis is then just half of the EU + EFTA railway network, that is itself divided in two subnetworks: one associated to the local line case study and accounting for 20%, and the remaining 30% associated to the regional line case study.

It is the case to further outline that all the results shown have to be considered valid under the base assumptions described in the D6.1 and D6.2 and under the cost figures considered in the analysis. D6.2 shows a series of sensitivity analyses aiming at testing the convenience of the project scenario, that is the satellite based ETCS technological solution, under a wide range of different hypotheses.

4.2.2 A CBA at the European level

This section shows the CBA of the investment at the European level, as described in the previous paragraphs.

The following table summarizes the ENPV and the total cumulated cash flow of the investment in the baseline scenario, that is as if the traditional balise based ETCS technological solution is implemented on the reference network of this analysis.

EUROPEAN NETWORK - BASELINE SCENARIO	ENPV	Cumulated flow
CAPEX GROUND	785.983.665	944.594.538
ETCS planning, installation, interfacing	-	-
RBC	-	-
TAL-Server	-	-
Track Database	-	-
Digitalization campaign	-	-
Physical balises	785.983.665	944.594.538
CAPEX BOARD	293.800.856	311.544.124
ETCS	-	-
BTM	293.800.856	311.544.124
VBR	-	-
OPEX GROUND	187.330.505	351.520.271
RBC	-	-
TAL-Server	-	-
Recalibration of track database	-	-
Physical balises Dense area	-	-
Physical balises Medium area	187.330.505	351.520.271
Physical balises Isolated area	-	-
OPEX BOARD	271.827.877	510.077.144
OBU modules	271.827.877	510.077.144
TOTAL Baseline	**1.538.942.904**	**2.117.736.077**

Figure 4: CBA EU - Baseline scenario

The following table summarizes the ENPV and the total cumulated cash flow of the investment in the project scenario, that is as if the innovative satellite based ETCS technological solution is implemented on the reference network of this analysis.

EUROPEAN NETWORK - PROJECT SCENARIO	ENPV	Cumulated flow
CAPEX GROUND	*143.434.068*	*160.599.967*
ETCS planning, installation, interfacing	-	-
RBC	-	-
TAL-Server	23.724.229	25.156.987
Track Database	23.724.229	25.156.987
Digitalization campaign	35.849.947	38.015.002
Physical balises	60.135.663	72.270.992
CAPEX BOARD	*519.275.932*	*550.636.126*
ETCS	-	-
BTM	225.475.076	239.092.002
VBR	293.800.856	311.544.124
OPEX GROUND	*17.990.990*	*33.759.573*
RBC	-	-
TAL-Server	3.658.321	6.864.733
Recalibration of track database	-	-
Physical balises Dense area	-	-
Physical balises Medium area	14.332.670	26.894.840
Physical balises Isolated area	-	-
OPEX BOARD	*480.439.969*	*901.531.696*
OBU modules	480.439.969	901.531.696
TOTAL Project	**1.161.140.960**	**1.646.527.363**

Figure 5: CBA EU - Project scenario

The following table summarizes the ENPV and the total cumulated cash flow differences between the investments envisaged in the project and in the baseline scenario. The table details the differential results by cost category, then highlights the total ENPV, cash flow and BCR

EUROPEAN NET	TOTAL	
	ENPV	**Cumulated flow**
∂ CAPEX GROUND	642.549.597	783.994.571
∂ CAPEX BOARD	- 225.475.076	- 239.092.002
∂ OPEX GRUND	169.339.515	317.760.698
∂ OPEX BOARD	- 208.612.092	- 391.454.552
TOTAL DIFFERENTIAL RESULT	**377.801.944**	**471.208.715**
BCR	**1,33**	

Figure 6: CBA EU - Differential values

The analysis shows a positive differential impact of the investment envisaged in the project scenario with respect to the one envisaged in the baseline scenario, with a **positive ENPV of 378 m€** and 471 m€ of cumulated flow.

The overall BCR is equal to 1,33, greater than the minimum acceptable value of 1.

As expected, the differential results in the sub categories of cost highlight higher cost in the project scenario with respect to the baseline scenario for which related to the on-board side. Nevertheless, these incremental costs are more than compensated by savings related to the ground side.

The following figure shows that most of the savings are in both CAPEX and OPEX related to the ground side, due to the avoided investment in balises. Higher cost, instead, arise on the board side, due to the additional modules envisaged in the on-board platform.

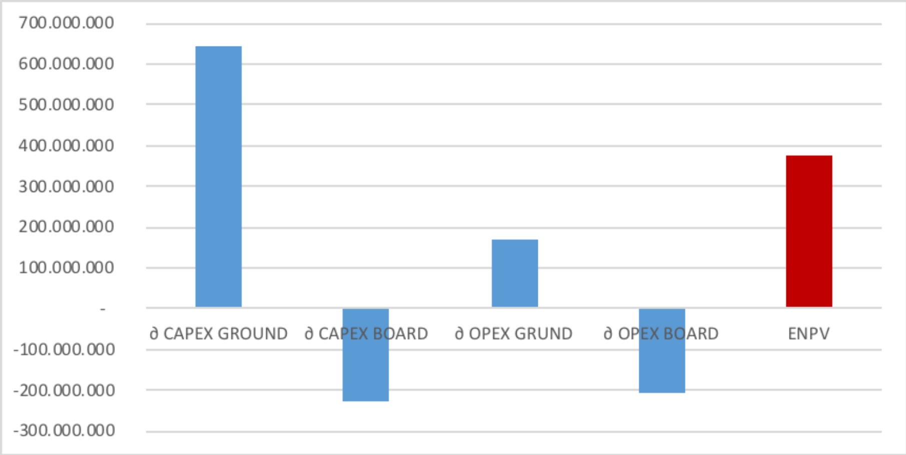


Figure 7: CBA differential results at the European level

4.2.3 Sensitivity analysis

Sensitivity analysis is aimed at investigating the effects of relevant modifications of initial assumptions on certain variables of the analysis onto the final results of the analysis. Depending on the selected variable, the sensitivity analysis can lead to the individuation of a switching value (the threshold value that keeps the analysis positive) or to simply describe the potential of improvement of the economic indicators linked to corresponding item.

The analysed variables are chosen considering the level of validity of the initial assumption. The more the uncertainty on the initial value assumed, the higher the need for a sensitivity analysis.

In this occasion, due to the state of the technology and the possible envisaged dynamics of the market of the signalling equipment, a particular sensitivity analysis is performed on the cost of the on-board unit. The assumption is that the market can grow, and the suppliers can do enough industrial efficiencies allowing a substantial decrease in costs of the on-board equipment.

The sensitivity analysis therefore considers the initial value as prudential, then decreases it by half. The results are shown in the following table and figure. Obviously, the higher the cost reduction (lower the cost of the equipment), the better the BCR and the ENPV of the project.

Cost reduction of the VBR	ENPV	BCR	Notes
Ref. value	377.801.944	1,33	Sat. solution applied just to Local and Regional lines
-10%	434.364.817	1,39	
-20%	490.927.691	1,47	
-30%	547.490.564	1,55	
-40%	707.693.795	1,20	Sat. solution applied also to Main lines
-50%	895.798.235	1,27	

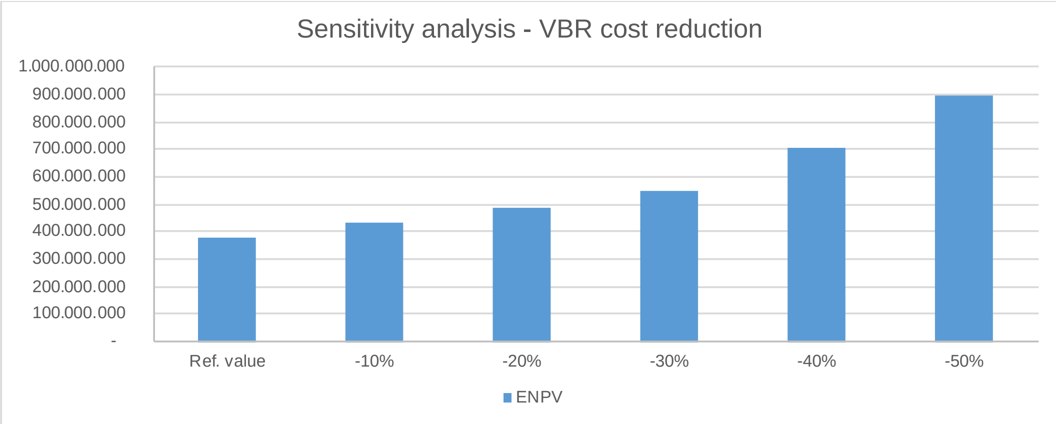


Figure 8: Sensitivity analysis - VBR

This sensitivity analysis shows that if the signalling industry is able to make efficiencies and decrease the cost of the on-board equipment needed for the satellite technological solution, the **ENPV could grow up to 896 m€**.

We observe a faster growing of the ENPV and a drop of the BCR passing from 30% to 40% and more cost reduction of the VBR (e.g. an integrated solution of BTM and VBR function on the same hardware platform). This happens because if the VBR cost decreases under a certain threshold, also the CBA related to the Main line case study becomes positive, then, the expansion analysis has to widen in the reference network to all the European network, also including the main line share.

4.2.4 Main findings

The scaling up of the CBA shows that, under base and prudential assumptions, the introduction of the satellite based ETCS solution can provide **benefits for 378 million €** in term of ENPV in the whole EU28 + EFTA countries. These benefits would be limited to the local and regional network, since, under the base and prudential assumptions, the traditional balise based ETCS solution is still better on those parts of the network comparable to the Main line case study.

The sensitivity analysis also shows that, if the signalling industry is able to develop efficiencies allowing a lower cost of the on-board units needed for the satellite localisation, the solution can be applied to a wider network and can provide **benefits up to 896 million €** in term of ENPV in the whole EU28 + EFTA countries.

5 SUMMARY

The present report has presented the progress of the development of the solution for using GNSS in ETCS, and has outlined an Implementation Plan, with a particular focus on the short-medium timeframe, and a preliminary evaluation of the conditions of economic convenience for the railway system as a whole, based on the scope defined within the STARS project activities in terms of assumptions and limitations concerning the technical issues of safety critical applications of GNSS in the railway signalling domain.

Such assumptions include the following aspects:

- The GNSS application in ETCS is limited to Level 2-3, and SIL4 is required.
- ETCS is an open standard, based on the requirement to ensure interoperability between interoperable constituents from different suppliers, and this must be true for a GNSS application as well.
- GPS and/or Galileo require to be coupled with a subsystem and a module for both the augmentation (e.g. EGNOS) and the detection of local feared events.
- If EGNOS shall be used, it must be free of charge for railway applications (as it is for aviation), and integrity monitoring data must be sent by other means than geostationary satellites.
- If an adequate replacement shall be used instead of EGNOS, requirements must be set, regarding usability, standardisation, interoperability.

The Virtual Balise concept, that the implementation plan focuses on, has been developed considering a number of issues concerning the integration of GNSS into ETCS: (i) trade-off between the technical complexity and the impact on current ETCS; (ii) interoperability; (iii) availability; (iv) proper specification of minimal level of performance; (v) certification process; (vi) integrity.

The issues to be solved in the future in order to reach the operating phase for an ERTMS system based on GNSS are the following:

- Definition of the expected EGNSS services performances in relation with well-defined railway mission scenarios.
- Development of a technical solution for the Virtual Balise concept (which is in the scope of the Shift2Rail TD 2.4 Project).
- Definition of a certification and qualification plan that will allow demonstrating that the overall system (ERTMS plus the GNSS Service) will satisfy the expected operational performances for the identified missions scenarios.
- Validation that the overall system (ERTMS plus the GNSS Service) fulfils the applicable safety, security and accuracy performances.
- Definition and agreement at European level of the necessary contract for the provision of the EGNOS railway service.
- Specification of the evolution of ERTMS/ETCS standards integrating the EGNSS contribution, including test specifications etc.
- Publication of the changes to ERTMS/ETCS in a future release of the TSI, in order to allow infrastructure managers to implement the concept and to require railway operators to equip their vehicles accordingly, and the supply industry to develop and certify the new products.

Based on this, a short-medium term Implementation Plan, which assumes the use of current EGNSS technology (EGNOS V2, or V3 if available), has been defined, identifying major milestones, their expected year of fulfilment, the players driving their fulfilment and the related risks. Such milestones – the first three of which especially rely on the output of Shift2Rail projects – are:

M1 Definition of System Requirement Specifications and system architecture (2020)

M2 Development and laboratory demonstration of fail-safe train positioning subsystem (2021)

M3 On-site demonstrations (2022)

M4 Development of laboratory toolchain and GNSS receiver (2022)

M5 Implementation of a terrestrial communication link standard (by 2024)

M6 System integration (by 2025)

M7 Certification and operational readiness review (by 2027)

The actual deployment plan is mainly dependent on the timeframe for the publication of the modified TSI, which is difficult to foresee; for an entry into service in 2027, it is assumed that such publication can be achieved by 2024.

As concerns the long-term evolutions of EGNSS, a similar implementation plan, with a level of detail reaching a timeframe for milestones, like for the short-medium term, cannot be produced, because the possible evolutions are not yet specified, and their availability is not ensured.