EXECUTIVE SUMMARY

RAILSAFE

Prepared by:	Javier Fidalgo Prieto Marta López Caamaño
	21/02/2018 X Javier Fidalgo Prieto Firmado por: Javier Fidalgo Prieto
Approved by:	Miguel Azaola Sáenz
Authorized by:	Miguel Azaola Sáenz
	21/02/2018 X Miguel Azaola Sáenz Firmado por: Miguel Azaola Sáenz

Code:	GMV-RAILSAFE-D303
Version:	1.0
Date:	26/12/2017
Internal code:	GMV 24708/17 V1/17

DOCUMENT STATUS SHEET

Version	Date	Pages	Changes
1.0	26/12/2017	12	First version of the document

TABLE OF CONTENTS

LIST OF TABLES AND FIGURES

1. INTRODUCTION

1.1. PURPOSE

This document is the RAILSAFE Executive Summary that summarises the main outcomes of the activities carried out under the project.

1.2. SCOPE

The objective of the Executive Summary is to summarise in a synthetic way the main outcomes, conclusions and recommendations of Railsafe project.

1.3. DEFINITIONS AND ACRONYMS

1.3.1. DEFINITIONS

N/A

1.3.2. ACRONYMS

Acronyms used in this document and needing a definition are included in the following table:

Table 1-1 Acronyms

Acronym	Definition
ARAIM	Advanced RAIM
ATPL	Along Track Protection Level
CTPL	Cross Track Protection Level
DFMC	Dual Frequency and Multi-Constellation
EGNSS	European GNSS
ERTMS	European Rail Traffic Management System
ETCS	European Train Control System
GBAS	Ground Based Augmentation System
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
HPL	Horizontal Protection Level
LFE	Local Feared Events
PNT	Position Navigation and Timing
PPP	Precise Point Positioning
RAIM	Receiver Autonomous Integrity Monitoring
RRAIM	Relative RAIM
SBAS	Space Based Augmentation System
SFSC	Single Frequency and Single Constellation
TTA	Time To Alert
UERE	User Equivalent Range Error

2. REFERENCES

2.1. APPLICABLE DOCUMENTS

The following documents, of the exact issue shown, form part of this document to the extent specified herein. Applicable documents are those referenced in the Contract or approved by the Approval Authority. They are referenced in this document in the form [AD.x]:

Table 2-1 Applicable Documents

Ref.	Title	Code	Version	Date
[AD.1]	Request for Proposal: Innovative Satellite-based Position, Navigation & Timing (PNT) Concepts for New Railway Safety of Life Applications	ESA-IPL-PLH-MOS-RFP-269-2016	-	22/03/2016
[AD.2]	GMV Proposal in Response to RFP ESA-IPL-PLH-MOS-RFP-269-2016	GMV 10924/16	V1/16	19/04/2016
[AD.3]	ESA Contract with GMV (ES): Innovative Satellite-based Position, Navigation & Timing (PNT) Concepts for New Railway Safety of Life Applications	4000117354/16/F/MOS	-	June 2016

2.2. REFERENCE DOCUMENTS

The following documents, although not part of this document, amplify or clarify its contents. Reference documents are those not applicable and referenced within this document. They are referenced in this document in the form [RD.x]:

Table 2-2 Reference Documents

Ref.	Title	Code	Version	Date
[RD.1]	Review of PNT Requirements for railway	RAILSAFE-D101	1.1	17/01/2017
[RD.2]	Technical Report on GNSS System Performance for ETCS	RAILSAFE-D201	1.2	31/10/2017
[RD.3]	Roadmap	RAILSAFE-D301	1.1	24/01/2018
[RD.4]	ETCS Application Level 2 – Virtual Balise Detection Using GNSS. Principles, Procedures and Positioning System Performance Requirements	ESA-TN-ETCS-VBD-00C_Principles	1.8	12/10/2016

3. EXECUTIVE SUMMARY

Implementation of the European Train Control System (ETCS) Level 2 requires that a huge amount of physical balises (known as Eurobalises), used to determine each train's position and direction of motion, be deployed in order to support safe operation of high-speed / high-frequency train services all along the European railway infrastructure. The associated costs are substantial, which motivates the investigation of cheaper technologies. One important candidate technology is GNSS positioning, which in principle would considerably reduce the number of required Eurobalises, many of them being replaced in favor of so-called Virtual Balises. A virtual balise implies the installation of no physical devices on the trackside. Hence, the more physical balises can be replaced by virtual ones, the larger the cost reduction.

A Virtual Balise (VB) is similar to a physical fixed balise in terms of functionality, but it differs from it in that no physical device needs to be installed on the track, thus reducing costs. ETCS train positioning is relative. Absolute reference points are required to reset the confidence interval; Eurobalise provides an absolute position as can GNSS. They are intended to replace as many physical balises as possible as part of an evolution of ERTMS/ETCS Level 2 which incorporates GNSS technologies.

Virtual balises are to be used much in the same way as physical ones, i.e. mainly to determine the train's position and direction of train position, direction of train orientation and running direction being subject to the same requirements, interfaces and operational procedures as physical balises as far as possible. For instance, virtual balises have also telegrams associated to them, although for obvious reasons they cannot be physically transmitted from the VB to the train. Instead, virtual balise positions and telegrams are pre-known to the on-board (whether via an on-board database or extended virtual balise information provided with a movement authority). The list of virtual balises to be expected along the route (together with their positions) and the distances between them is passed to the train within the Linking Information (which in this case is called Extended Linking Information and includes both physical and virtual balises).

RAILSAFE project has studied the introduction of GNSS technologies in ERTMS context for balise virtualization.

In [RD.1] it has been studied the Virtual Balise operational envelope, in which a number of parameters have been identified such as the speed or acceleration ranges, ambient temperature, humidity etc. The RF environment has been identified as a delicate subject for GNSS introduction in ERTMS due to aspects such as:

- Sky visibility
- Multipath
- Interference

The operational modes relevant for the virtual balise concept are the modes with a Movement Authority and Linking Information and the modes without Mission Authority (such as Staff Responsible) during the Start of Mission. As a consequence, the following Use Cases have been identified:

- UC-001: detection of VB with a MA
- UC-002: detection of VB in SR mode (e.g. during SoM with an UNKNOWN position)
- UC-003: approx. train positioning during SoM with an INVALID or UNKNOWN position

The PNT requirements identified in [RD.4] and analysed in the context of Railsafe are shown in the following table:

Table 3-1: Summary of PNT requirements

Use cases	UC-001	UC-002	UC-003
Integrity target (GNSS-MI)	7.5E-06 / hour	7.5E-06 / hour	1.0E-04 / hour
Time to Alert (TTA)	10 seconds	10 seconds	10 seconds

Use cases	UC-001	UC-002	UC-003
Along-track Protection Level (ATPL) upper bound	20 meters	20 meters	N/A
Cross-track Protection Level (CTPL) upper bound	N/A	N/A	N/A
Horizontal Protection Level upper bound	N/A	N/A	10 meters
Continuity	TBD	TBD	TBD
Availability	TBD	TBD	TBD

Some important topics related with the virtual balise detection process have been analysed during the project execution such as the projection of 3D position into the track, the 1D-constrined solutions with different degrees of track information detail, the ATPL computation based on the virtual balise detection strategies or the TTA management, in which two options appear: coasting versus a posteriori validation of ATPL.

From the preliminary assessment of suitability of the different technologies performed in WP200 [RD.2], the following conclusions can be extracted:

- SBAS/GBAS are candidate technologies as far as system-level threats are concerned
- RAIM/ARAIM are also candidates, with some a priori pros and cons wrt SBAS/GBAS
- RAIM with hybridisation (GNSS + Inertials/Odometers): this technology has similar capabilities as RAIM/ARAIM and needs enhanced outlier detection (hence better mitigation of local and system-level FEs)
- Relative RAIM (RRAIM) is to be considered also in connection with SBAS/GBAS for improved management (coasting)

Concerning the safety assessment, two approaches were considered: first, a bottom-up approach FMEA-like was considered in order to analyse the impact of the Feared Events and another with a top-down approach with a fault-tree Analysis. The following figure shows the generic fault-tree developed:

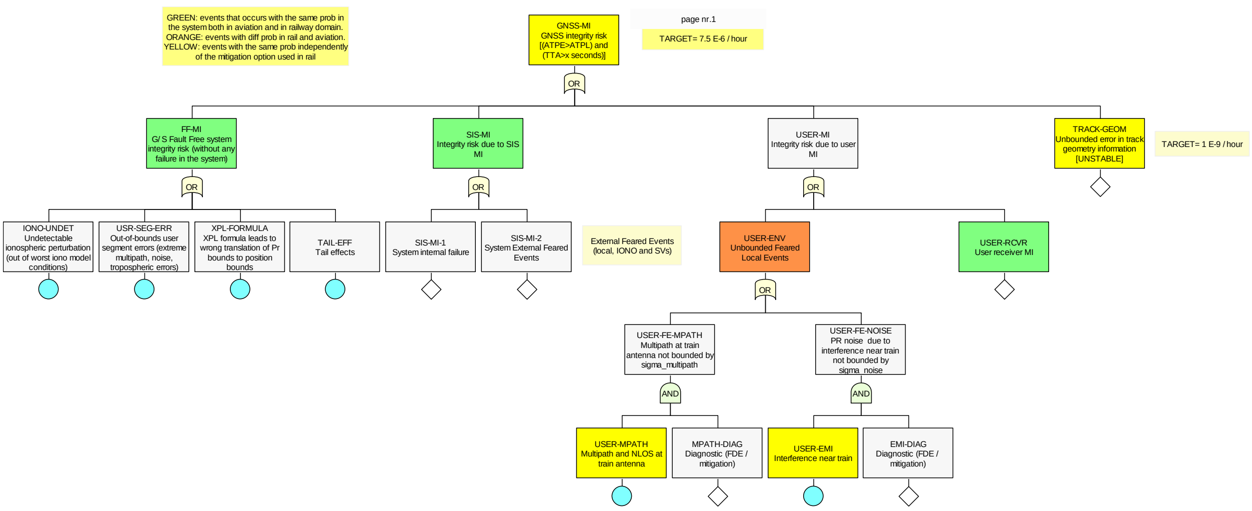

Figure 3-1: GNSS MI apportionment

The following main conclusions can be extracted:

- System-level FEs are mitigated satisfactorily by all technologies considered:
  - SBAS/GBAS by system design
  - RAIM/ARAIM and Hybridised RAIM thanks to the prior failure probabilities

  - RAIM requires that LFE be removed in a prior stage so that single fault assumptions are satisfied
- Local FEs have not been considered, and they could have a severe impact on safety
- The analysed technologies are to be complemented with effective local FE mitigation means (critical)
- Probabilities allocated to the different elements in the fault trees need consolidation
- Hybridised solutions should be further investigated as they may substantially improve detectability of local FEs. A recommendation is issued to launch specific activities on the subject.

A theoretical performance assessment has been developed based on service volume simulations for the different GNSS technologies. Concerning the configuration of the simulations the following is to be mentioned:

- Scenarios with GPS-only and dual constellation (GPS and Galileo) have been run in the simulations
- It has been assumed a specific UERE budget including local and system-level contributions
- Single frequency and dual-frequency have scenarios have been run, based on the UERE budget (Iono vs dual-frequency noise amplification effect)
- Scenarios with harsh environments have been simulated based on local contribution to UERE and elevation mask

The following simulation cases have been run:

- SIM-A: DC + DF + SBAS + Odometer Coasting + Low Noise + 5deg (Baseline scenario).
- SIM-B: DC + SF + SBAS + Odometer Coasting + Low Noise + 5deg
- SIM-C:
  - SIM-C-1: DC + DF + SBAS + Odometer Coasting + Low Noise + 10deg
  - SIM-C-2: DC + DF + SBAS + Odometer Coasting + Low Noise + 15deg
  - SIM-C-3: DC + DF + SBAS + Odometer Coasting + Low Noise + 20deg
- SIM-D: GPS + DF + SBAS + Odometer Coasting + Low Noise + 5deg
- SIM-E: DC + DF + SBAS_low (GBAS) + Odometer Coasting + Low Noise + 5deg
- SIM-F: DC + DF + SBAS_low (GBAS) + Odometer Coasting + High Noise + 5deg
- SIM-G: DC + DF + SBAS + RRAIM Coasting + Low Noise + 5deg
- SIM-H: SC + SF + SBAS + RRAIM Coasting + Low Noise + 5 deg

The following simulation results on percentile 90% and 99% of the HPL have been obtained for the different scenarios:

Table 3-2: Percentiles 90% and 99% of the HPL for the different scenarios

		1-D		3-D	
	Velocity	**Percentile 90%**	**Percentile 99%**	**Percentile 90%**	**Percentile 99%**
SIM-A	50	9.16	9.74	14.97	16.25
	80	13.39	13.96	19.2	20.50
	120	19.06	19.63	24.86	26.17
	250	37.47	38.04	43.30	44.58
	350	51.64	52.21	57.47	58.75
SIM-B	120	19.62	20.17	25.42	26.64
SIM-C-1	120	19.55	20.27	26.02	27.89

		1-D		3-D	
SIM-C-2	120	20.21	21.31	27.68	29.89
SIM-C-3	120	21.13	22.29	29.73	33.14
SIM-D	120	21.25	22.28	29.14	32.63
SIM-E	120	19.06	19.63	24.79	26.09
SIM-F	120	20.16	21.07	26.29	27.87
SIM-G	120	2.39	2.96	8.19	9.43

The performance assessment has shown that:

- RRAIM coasting performs far better than odometer coasting (especially at high speed)
- Harsh environments (with worse carrier phase continuity) usually correspond to low speed use cases (e.g. near stations) where odometer coasting performance improves
- A speed-based combination of coasting techniques could therefore be a good option

In [RD.3] roadmaps for the introduction of different GNSS technologies in ERTMS for balise virtualization have been developed and a trade-off between the different GNSS technologies has been conducted evaluating a set of technical, programmatic and strategic criteria. The main conclusions that can be extracted from this activity are:

- The target timeframe (2022) of introducing GNSS in ERTMS for balise virtualization is feasible for some of the GNSS technologies taken into account
  - The technologies that could be compliant with the expected timeframe of GNSS introduction in ERTMS by the end of 2021 are:
    - SFSC SBAS
    - RAIM with or without hybridization
  - Other GNSS technologies would not be compliant with the expected timeframe but could be introduced later such as:
    - DFMC SBAS by 2024
    - SFSC GBAS by 2023
    - DFMC GBAS by 2024
  - In a longer term, also the following GNSS technologies could be introduced in ERTMS:
    - PPP with integrity by 2025
    - H-ARAIM by 2025

The timeframe for the introduction of the different GNSS technologies in ERTMS is depicted in the following figure:

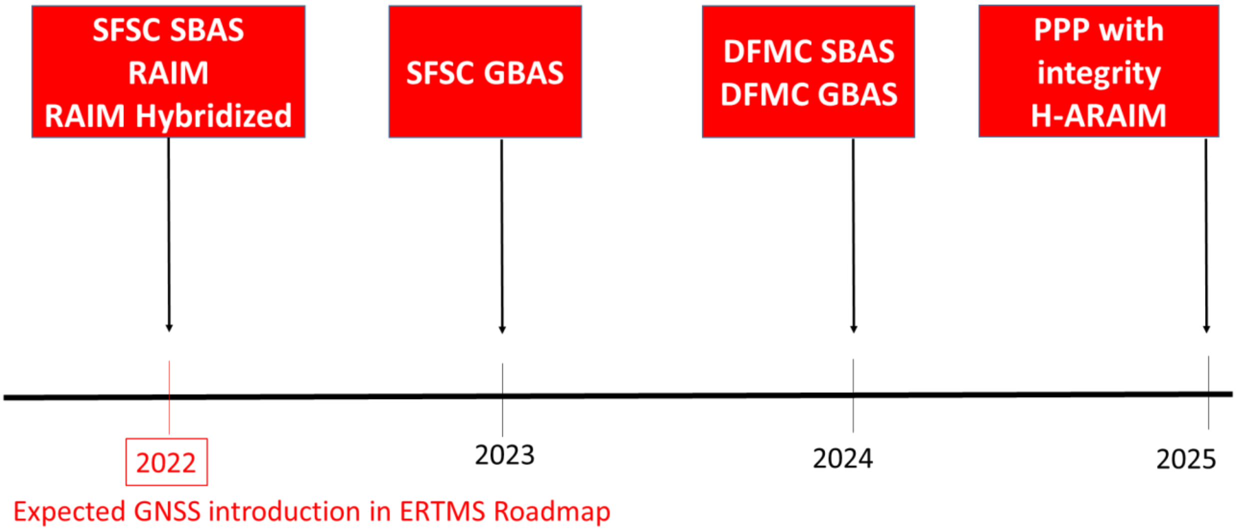

Figure 3-2: Timeframe

- For the trade-off the following criteria have been evaluated for the different GNSS technologies:
  - Cost
  - Expected performance
  - Operational benefit
  - Timeframe
  - Usage of EGNSS
- Both SBAS and RAIM-like technologies have a very similar score in the trade-off considering the benchmark weights of the different criteria, with certain pros and cons for each option. The results are shown in the following table:

GNSS Technology	Global score
DFMC SBAS	2.9
SFSC SBAS	2.9
RAIM	2.7
RAIM hybridized	2.7
SBAS L1 Legacy on GPS L1 + ARAIM for Galileo	2.6
H-ARAIM	2.5
H-ARAIM hybridized	2.5
DFMC GBAS	2.15
PPP with integrity	1.8
SFSC GBAS	1.75

- The results do not allow a clear recommendation on the most suitable GNSS technology for ERTMS balise virtualization but allow to identify the pros and cons for each option.
- SBAS technology seems suitable for ERTMS according to the trade-off developed
  - SFSC SBAS can be introduced by the expected timeframe (2022)

  - DFMC SBAS can be introduced later as a second step
- RAIM-like technologies are also found suitable for ERTMS
- GBAS technology seems less adequate for ERTMS due to the fact of being local systems with a high cost associated to the deployment along the railway
- PPP with integrity could be considered for Start of Mission, having less operational benefits than the other technologies
- The weights defined for the different trade-off criteria do have an important impact on the results. A sensitivity analysis has been performed in order to analyse how the weights of the different criteria do affect the global scores of the different GNSS technologies. With the sensitivity analysis it has been shown that the technologies most disfavored by the increase of the weight of a certain criterion are the ones with a poorer score in the associated criterion. In addition, it has also been concluded that varying the weight of a certain criterion, the most suitable GNSS technologies for introduction in ERTMS could change.
- When considering only technical and programmatic criteria, without considering the strategic criterion of the usage of European GNSS technologies, the trade-off results seem more conclusive, favoring RAIM-like technologies and SFSC SBAS.

The main recommendations that can be provided are:

- In order to comply with the expected GNSS introduction timeframe for ERTMS it is recommended to select the most suitable GNSS technology and to launch as soon as possible technical activities to confirm the feasibility and to solve potential open points.
- The development of a demonstrator is recommended in order to conduct an experimentation campaign. Trials are also recommended