Virtual Balise and Digital Map: RFI’s perspective

Rail Session

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ERSAT (ERtms + SATellite)  

GNSS as Game-Changer innovation for ERTMS

- RFI have been believing in the opportunities of the introduction of GNSS navigation technologies into ERTMS since 2012 (more than **10 years**), date of the launch of the ERSAT programme.

- The primary objective was to test and validate the integration of **GNSS navigation technology** in railway, by leveraging "**virtualization**" of **balises** without altering the ERTMS architecture.

The **GNSS navigation** technology has been successfully tested on tracks in Sardinia on the **Cagliari-S. Gavino** line.

The validation and certification phase of the "**virtual balise**" **functionality** using GNSS on the **Novara-Rho** pilot line (where ERTMS is already activated with physical balises) has been recently commissioned.
Why introducing GNSS Navigation in ERTMS?

GNSS Navigation technology can meet the evolving railway needs

- Reduce investment costs (CAPEX) and maintenance costs (OPEX) for the **simplification** of the technological infrastructure
- **Guarantee the safety integrity level** SIL-4 requirements
- **Modernise** the signalling system at lower costs to ensure **sustainability**
- Improve **safety** and **capacity** of transport networks (moving blocks)
- Minimum Impact on **Operational Rules**
- Ensure **interoperability** of the fleet and backward compatibility on existing lines
<table>
<thead>
<tr>
<th>Advantages of using GNSS in ETCS</th>
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<tr>
<td><strong>RFI expectations</strong></td>
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<tr>
<td>Overcome some of the weak points of current ETCS odometry having an undesirable impact on operation (e.g., dealing with slip/slide phenomena)</td>
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<tr>
<td>Allow TRK asset reduction by using virtual reference points (provided a standard Digital Map is available) instead of only physical balises</td>
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<td>Facilitate the reduction of TTDs above all for high-capacity applications (in combination with additional functions such as Train Integrity and Safe Train Length)</td>
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<td>Minimise the distance travelled in SR to SoM or after recovery from a fault, being able to always estimate the position of the train along the track</td>
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<td>Provide possible solutions to additional functions such as Train integrity and Cold Movement Detector</td>
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*Image: Slip/slide phenomena and Physical balise can be drastically reduced*
Virtual Balise

Satellite-based localization translated into the legacy balise language

- A Virtual Balise is a **virtual point** on the track that can be detected by a train equipped with a GNSS receiver and an antenna.

- The **Virtual Balise Reader** (VBR) processes GNSS signals to evaluate a condition of “matching” between the estimated train position and the known VB Location; if a VB detection event occurs, the related Balise Information is sent to ETCS Kernel as a Real BTM function would.

- The virtual balise functionality in ETCS can **reduce** the installation and maintenance costs (by replacing or complements the physical balise), **increase** the flexibility and scalability of the railway system, and improve the performance and safety of train control.
Virtual Balise

CAPEX and OPEX reduction

The 'virtual balise' solution is able to improve the sustainability of the ERTMS signalling system over its entire lifetime (reduction of CAPEX and OPEX approx. 40 K€/Km), the regularity of the rail service (-30% failures) and increase capacity by 15% to 30%.

Application of a cost-benefit analysis to compare the cost-effectiveness of GNSS-based ERTMS versus traditional ERTMS at European level

(Source: Bocconi University)

Additional benefits with the Hybrid ERTMS L3 for which up to 16 balise/km are necessary
Experimenting GNSS on tracks

The Italian sites

01 Trail site of the ERSAT EAV project operating in Sardinia on the Cagliari - San Gavino line since February 2015

02 Pilot line Novara - Rho with ERTMS L2 and GPS + GALILEO satellite navigation systems.

Satellite

Box: EGNOS

Box: GBAS

Box: Providers of Satcom and Cellular

Box: TLC services

Box: IM

Box: TSI – 2022-23

Box: ERTMS

Box: RU

Full-scale test bed

Experimenting GNSS on tracks
ERSAT Trial Site Architecture

The concept of VB is useful to translate the satellite-based location determination into the legacy balise language. The detection of the VB is accomplished by mapping the augmented GNSS-based PVT to the Digital Map and comparing the current position on the map with the VB locations referenced in the map as well.
PILOT LINE NOVARA-RHO

Virtual balise + ERTMS L2

Experimenting the integration of the ERTMS L2 system with a satellite solution derived from the ERSAT project.

Funded by RFI to validate and certify the GNSS in the frame of the ERTMS

PVT solution on the entire track
PILOT LINE NOVARA-RHO

On-board equipments

On-board Diagnostic Tools

Virtual Balise Reader
PILOT LINE NOVARA-RHO

• ASSESSMENT AND CERTIFICATION PLAN

Acronyms:
• SST: Trackside subsystem
• SDT: RBC + Eurobalises
• GDV: Interlocking
• SSB: On Board subsystem
• VBR: Virtual Balise Reader
• WSP: Wayside Standard Platform
• GNSS: Global Navigation Satellite System
• GAD: GNSS Augmentation Dissemination
• VBTS: Virtual Balise Transmission System
• RS: Reference Station
• EVC: European Vital Computer
• BTM: Balise Transmission Module
PILOT LINE NOVARA-RHO

• ASSESSMENT AND CERTIFICATION PLAN

Aim of the assessment and certification activities is:

• As.Bo. Assessment. Goal of this item, both at RBC and ETCS on board level, is the demonstration of:

  • Safety Integrity level (SIL4) of the satellite hardware and software components with reference to the safety requirements identified during the risk analysis;

  • Safety Integrity level (SIL4) of the RBC and ETCS on board including the satellite technology parts;

  • Demonstration of the no intrusiveness of the satellite technology on the ERTMS hardware and software already in service on the Novara-Rho line;

• No.Bo. Certification: Demonstration of the certifiability of the interoperable components (RBC and ETCS on board) after the introduction of the satellite hardware and software technology
Projects supporting the ERSAT program

- **3inSAT**
  - Assessment della tecnologia satellitare
  - ERTMS + GNSS
    - First use of GALILEO with EGNOS + Local Augmentation Network
  - 2012-2016

- **ERSAT EAV+GCC**
  - Mitigation solutions
    - GNSS interference for ERTMS L2
  - 2015-2019

- **DB4RAIL**
  - Multi Link Communication Platform (MLCP)
    - Terrestrial and Satellite Public Communication Services
  - 2017-2021

- **SAT4Train**
  - Virtual GNSS Test Bed Development
    - Zero-On Field Test
  - 2018-2021

- **Gate4RAIL**
  - ERTMS + GNSS demonstrator and IP-based public communication services (including SATCOM)
  - 2018-ongoing

- **SBSphase2**
  - ERTMS + GNSS virtual balise validation and certification
  - 2020-2022

- **PILOT LINE**
  - GNSS + IMU + Lidar + Video camera multi-sensor positioning

- **VOLIERA**
  - Ground Truth & Digital Map

- **RAILGAP**
  - 2023-2025 National Aug. network

**NEW**
RAILGAP Project: Focusing on Digital Map

G. Emmanuele – RAILGAP Project Coordinator - RFI
RAILGAP

Railway Ground Truth and Digital Map

The project is funded by the H2020 EUSPA with GA N. 101004129.
The project aims to address two gaps still hindering the adoption of satellite-based solutions in railway applications:

- the lack of high-quality and fidelity *Ground Truth* data, to be used for characterizing, evaluating and assessing any solutions with impact on the train position that will be chosen for safe applications

- the need for a modernized process for *mapping existing railway tracks cost-effectively*

*Ground Truth and Digital Maps will be essential elements of EGNSS train positioning systems and V&V environment.*
RAILGAP
The innovative concepts

Leveraging **commercial train rides** to measure and store a big amount of data

SoA **Artificial Intelligence** techniques to process and analyze the big amount of acquired data

Defining methodologies and developing tools for building high accuracy and precision **Ground Truth** and **Digital Map** for the railway environment

**COTS sensors** to build the on-board measurement system:
- GNSS receivers
- INS-D
- LIDAR
- stereo-camera

No needs to install or modify any equipment on the trackside infrastructure
Digital Map

How has it been defined in RAILGAP?

- The Trackside Digital Map (TDM) tool has been designed for the needs of railway companies, operators and maintenance personnel, with the aim of providing an **up-to-date** and **detailed** georeferenced information of the track layouts, infrastructure, and signalling items, as selected in RAILGAP.

- The TDM could help to improve overall operational efficiency and reduce downtime. It can also be used to support maintenance activities, ensuring the efficient and reliable operation of the rail network.

DM is described in terms of the following information:

<table>
<thead>
<tr>
<th>Topology</th>
<th>The track network is described as a topological node-edge model.</th>
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<tbody>
<tr>
<td><strong>Coordinates</strong></td>
<td>Railway infrastructure elements can be located in an arbitrary 2- or 3-dimensional coordinate system, e.g. the WGS84 that is widely used by today's navigation software.</td>
</tr>
<tr>
<td><strong>Geometry</strong></td>
<td>The track geometry described in terms of radius and gradients.</td>
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<tr>
<td><strong>Railway infrastructure elements</strong></td>
<td>The railway assets selected in RAILGAP that can be found on, under, over or next to the railway track, e.g., balises</td>
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Digital Map

Track elements to be identified in the context of RAILGAP

<table>
<thead>
<tr>
<th>Elements on the railway track</th>
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<tr>
<td>Switch indicator</td>
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<td>Eurobalises</td>
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<table>
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<tr>
<th>Other track elements</th>
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<tbody>
<tr>
<td>Tunnel</td>
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<tr>
<td>Bridge / Road overpass</td>
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<tr>
<td>Track</td>
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<table>
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<th>Elements in the track proximity</th>
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<tr>
<td>Light signals / ETCS marker</td>
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<td>Track sign</td>
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<tr>
<td>Level crossing light signal</td>
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<td>Pole of overhead power line</td>
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Stereo-camera data acquired during the RAILGAP field test campaign in Sardinia
RAILGAP DM User Requirements

TDM toolset shall be able to **process time-synchronized data** coming from **different sensors** based on positioning (i.e., GNSS and IMU), imaging and ranging sensors (i.e., cameras and LIDAR) acquired through commercial trains equipped with the RAILGAP measurement subsystem.

TDM toolset shall be able to **detect, classify and georeference** signaling object components of the TDM, selected in RAILGAP.

TDM toolset shall be able to build the DM by using **standard format** and **semiautomatic way**.

TDM toolset shall be able to **perform continuous monitoring, control and automatic update** of the RAILGAP TDM when significant changes occur.

TDM toolset shall be able to **scale** the DM structure allowing aggregation of additional information layers and the connection of different sections of the railways network (national or European).

Positioning, imaging and ranging sensors’ records shall contain **timestamps** to enable the offline ordering of the events.

To define the track layout, the process for building the Digital Map should be able to compute parameters such as **gradient, radius** or **CANT** by offline processing the recorded data.
RAILGAP DM User Requirements

DM topology shall be integrated in a format allowing the integration of the different layers of information such as railway standardized format (e.g. RailML), track topology, signaling elements and conditions (e.g. UNISIG Subset-112 or RailML) and/or universal description of railway business objects (e.g. UIC RailTopoModel or RailML).

The toolset for performing the continuous monitoring, control and update of the DM shall detect anomalies (critical deviations) w.r.t. the current version of the RAILGAP Digital Map.

The whole process of creating and updating the digital map could be carried out automatically by the toolset, with the involvement of a human operator only in the case of anomalies or discordant choice factors.

DM toll shall incorporate a monitor for detection of conditions that may impair a reliable map construction, such as poor visibility or LIDAR range degradation. Under such conditions the tool will discard runs or parts of them and will raise alerts.

More details can be found in the public deliverable “D2.1 USER REQUIREMENTS DOCUMENT RELATED TO DIGITAL MAP AND REFERENCE MEASUREMENT VALUES & PROCEDURES” available for download on the RAILGAP official webpage.
RAILGAP DM construction scheme

A recursive approach

- LIDAR and camera data collected during a single ride are used to estimate the location of track signalling elements in the global reference frame with the help of GNSS and IMU measurements.

- Then, a recursive procedure allows to fuse the last single-ride map with the multi-ride map. In this way, the track signalling elements’ location is refined after each ride.

- An anomaly detector is used to monitor the track signalling elements by analysing deviations from stored digital maps.
Conclusions

Looking ahead

• RFI plan is **coherent with the Eu-Parliament Directive** of July 7th 2021 art.34 “Points out the need to ensure synergies between the ERTMS and the European Global Navigation Satellite System (GNSS) as soon as possible, especially since **GNSS signal availability relies on virtual balises**, which would be less costly to deploy and to maintain, since it would speed up the ERTMS roll-out and since it would enhance the competitiveness of the ERTMS outside the EU”.

• **ERSAT** has demonstrated the technical & economical viability of introducing GNSS and Satcom in the ERTMS system.

• **RAILGAP** is providing a contribution on remaining GAPS for the Digital Map.

• **Pilot Line Novara – Rho** will validate and certify the GNSS positioning in the frame of ERTMS.

Next actions

• Adoption of **Satcom** in combination with other bearers as defined in the **FRMCS**

• Standardization of the air-interface to use **EGNSS Augmentation networks**

• Exploiting synergies for technological infrastructures (5G, GNSS...) common to ERTMS and Smart Roads
Thank you for your attention