Virtual Balise and Digital Map: RFI’s perspective

European Commission

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UE23 PRESIDENCIA ESPAÑOLA CONSEJO DE LA UNIÓN EUROPEA

Rail Session

M. Ciaffi – Head of ERTMS on-board subsystems - RFI

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.

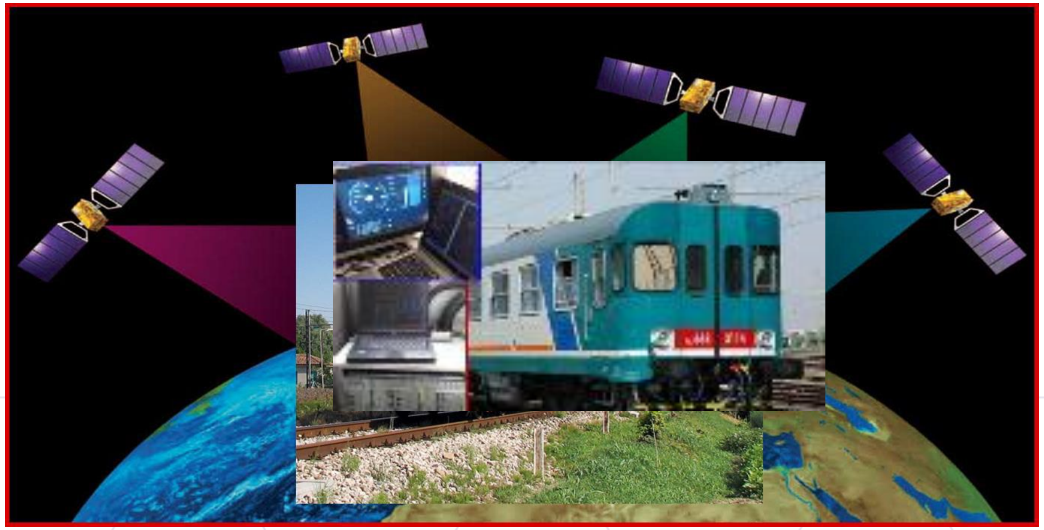
The **GNSS navigation** technology has been successfully tested on tracks in Sardinia on the **Cagliari-S. Gavino** line.

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.

IN FOCUS Italy

ERSAT moves into the roll-out phase

Having amassed nearly 10 years of cumulative experience of satellite technologies for use with ERTMS, including virtual balises and radio frequency interference, RFI has gained sufficient confidence to start work on its first operational application.

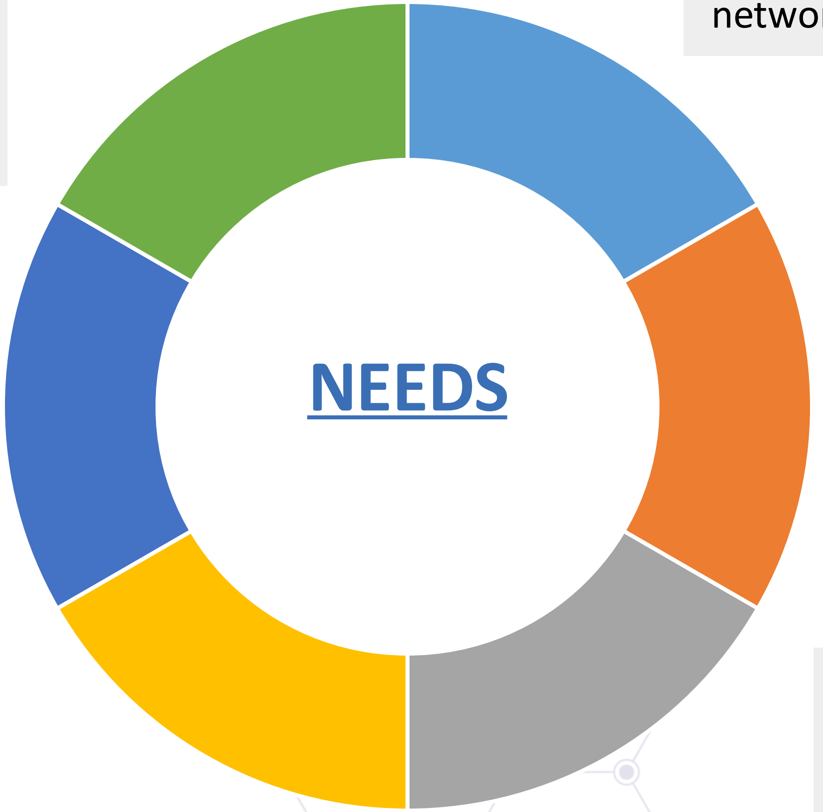


Why introducing GNSS Navigation in ERTMS?

GNSS Navigation technology can meet the evolving railway needs

Improve **safety** and **capacity** of transport networks (moving blocks)

Reduce investment costs (CAPEX) and maintenance costs (OPEX) for the **simplification** of the technological infrastructure



Minimum Impact on **Operational Rules**

Guarantee the safety integrity level **SIL-4** requirements

Modernise the signalling system at lower costs to ensure **sustainability**

Ensure **interoperability** of the fleet and backward compatibility on existing lines

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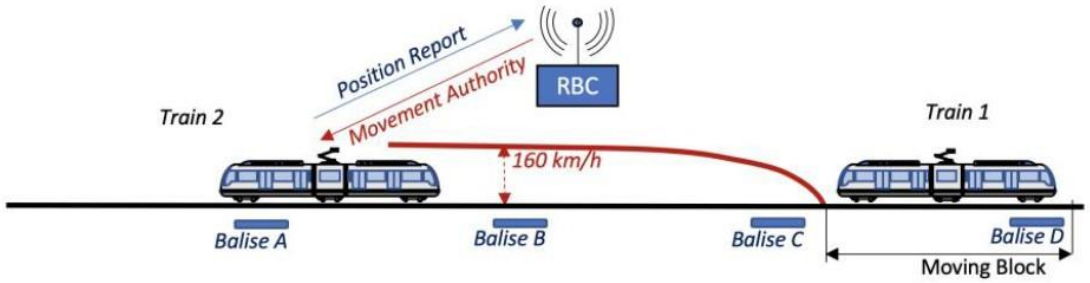
Advantages of using GNSS in ETCS

RFI expectations

Overcome some of the weak points of current ETCS odometry having an undesirable impact on operation (e.g., dealing with slip/slide phenomena)	Allow TRK asset reduction by using virtual reference points (provided a standard Digital Map is available) instead of only physical balises	Facilitate the reduction of TTDs above all for high-capacity applications (in combination with additional functions such as Train Integrity and Safe Train Length)	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	Provide possible solutions to additional functions such as Train integrity and Cold Movement Detector


Slip/slide phenomena


Physical balise can be drastically reduced

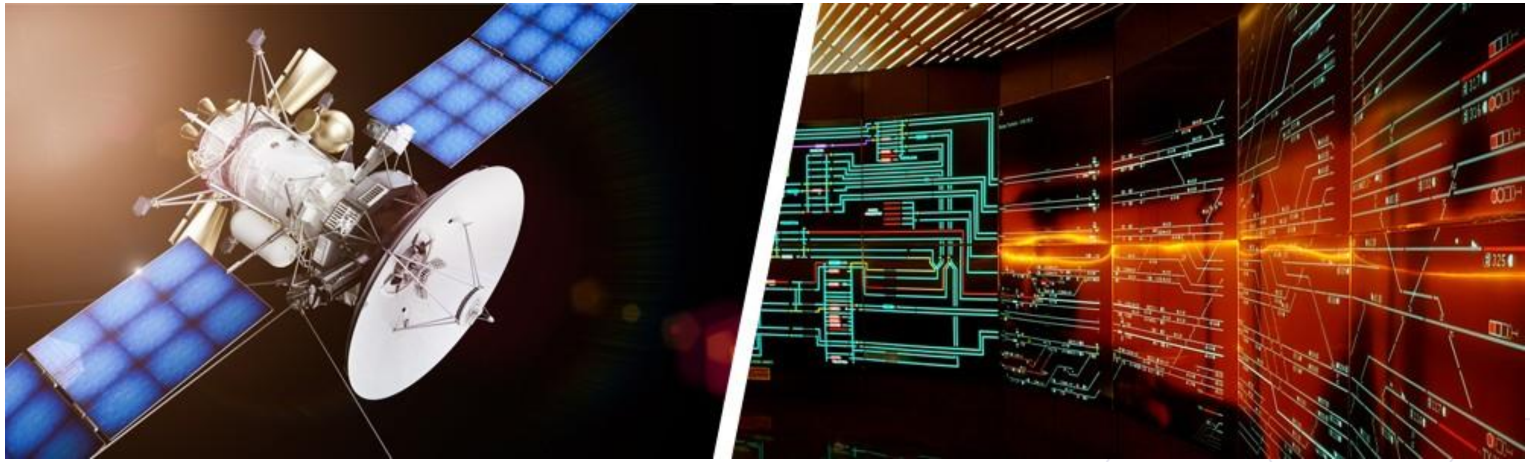


Moving blocks

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

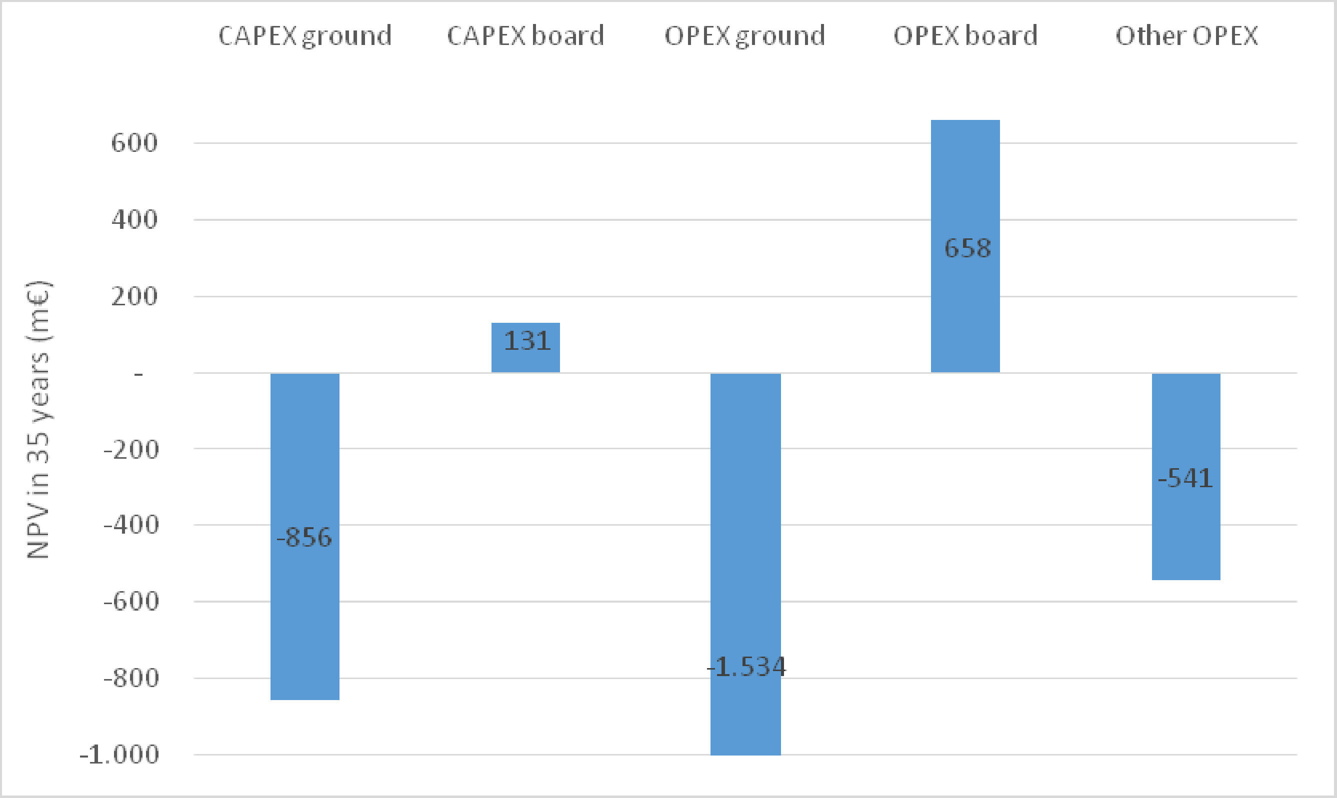
CAPEX and OPEX reduction

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

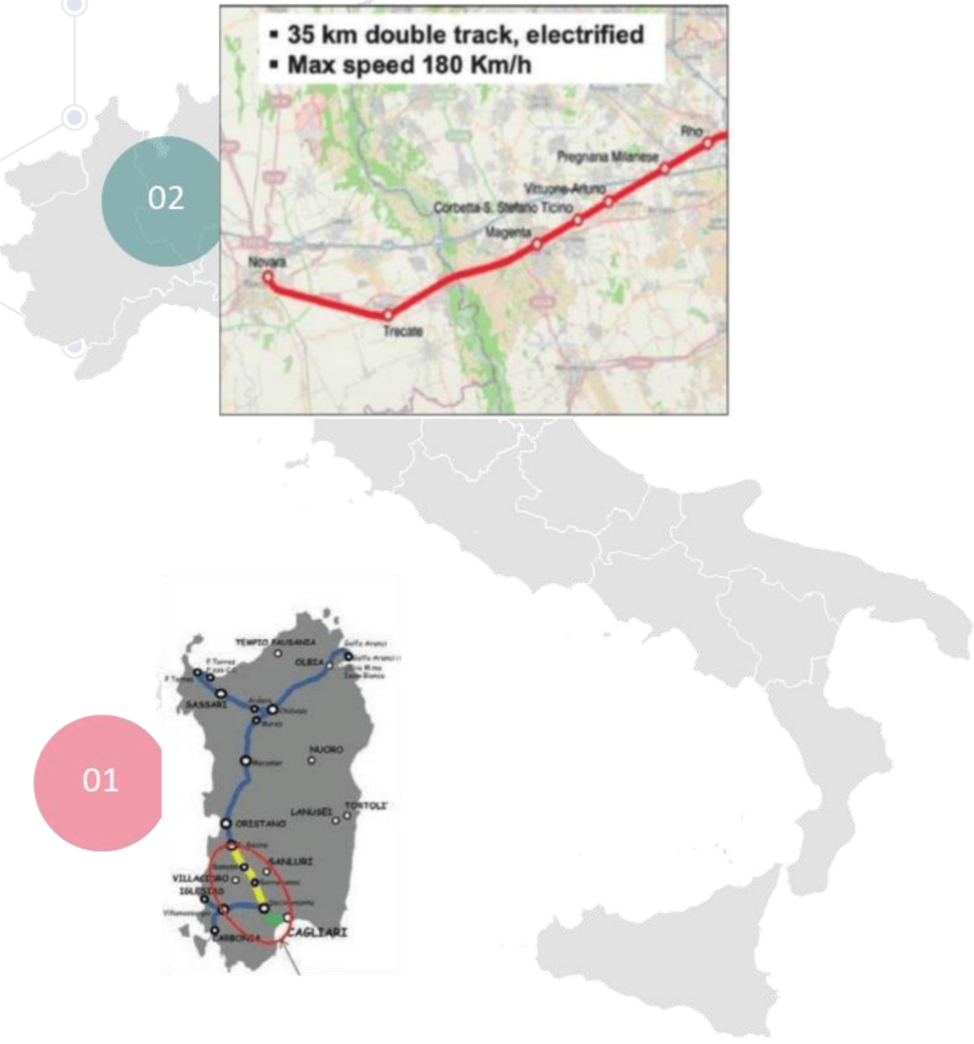
(Source: Bocconi University)

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



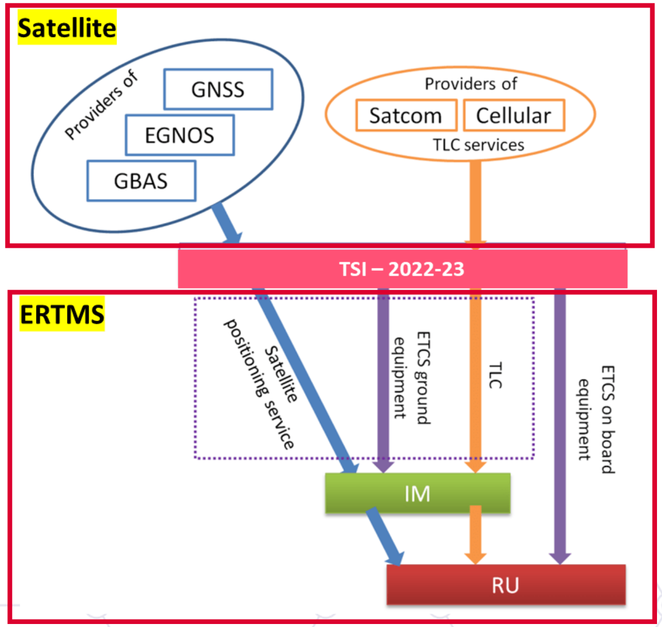
Experimenting GNSS on tracks

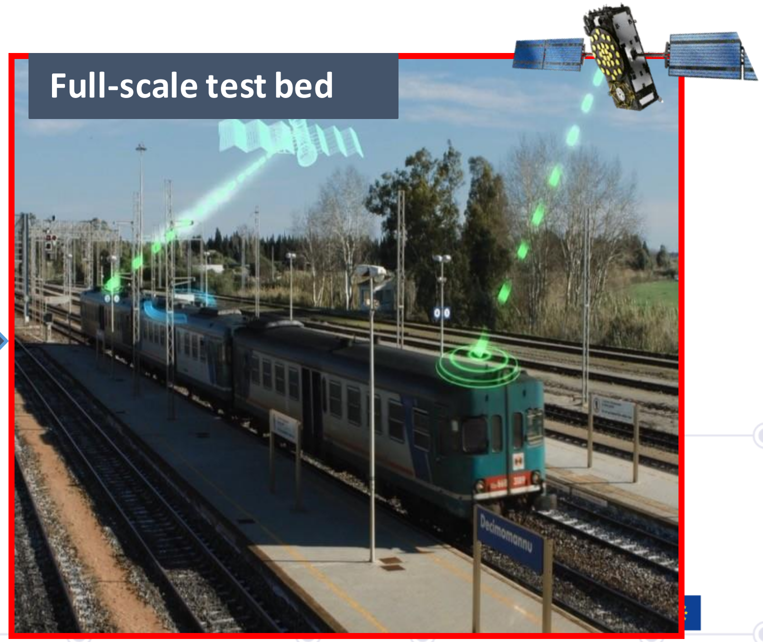
The Italian sites



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

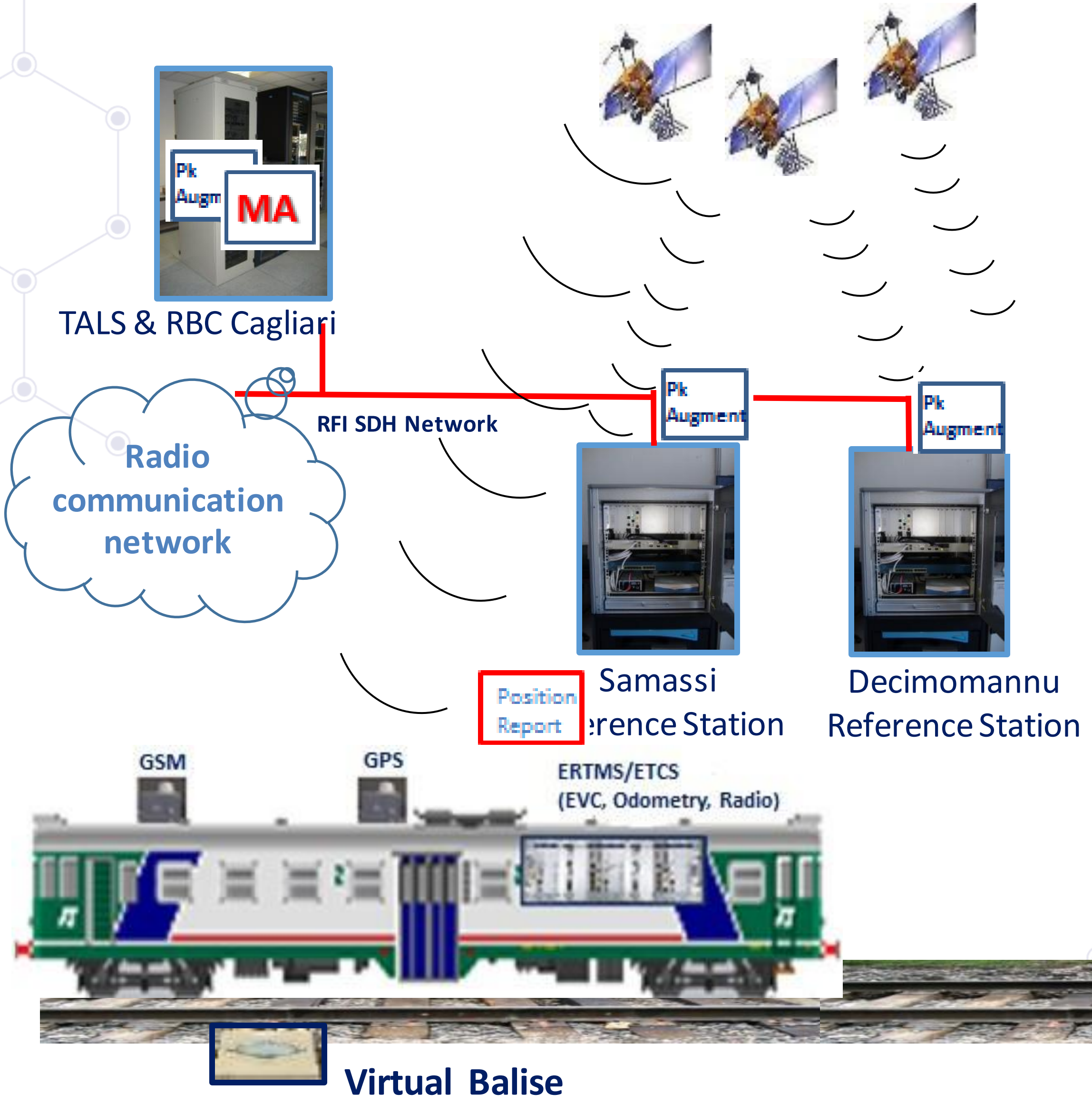
02 Pilot line **Novara - Rho** with ERTMS L2 and GPS + GALILEO satellite navigation systems.





ERSAT Trial Site Architecture

GNSS Constellation (GPS + Galileo)



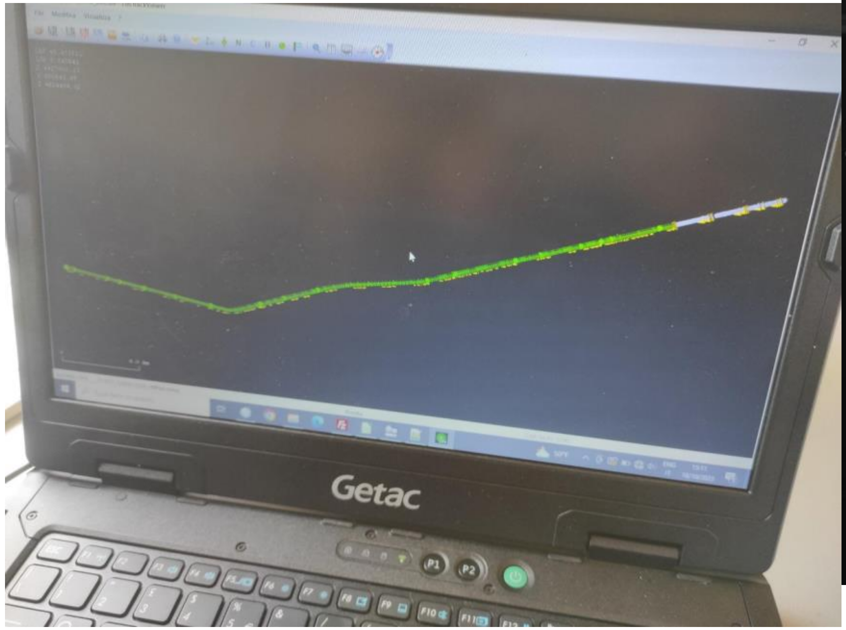
The concept of VB is useful to translate the satellite-based location determination into the legacy balise language.
The detection of the VB is accomplished by mapping the augmented GNSS-based PVT to the Digital Map and comparing the current position on the map with the VB locations referenced in the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

PILOT LINE NOVARA-RHO

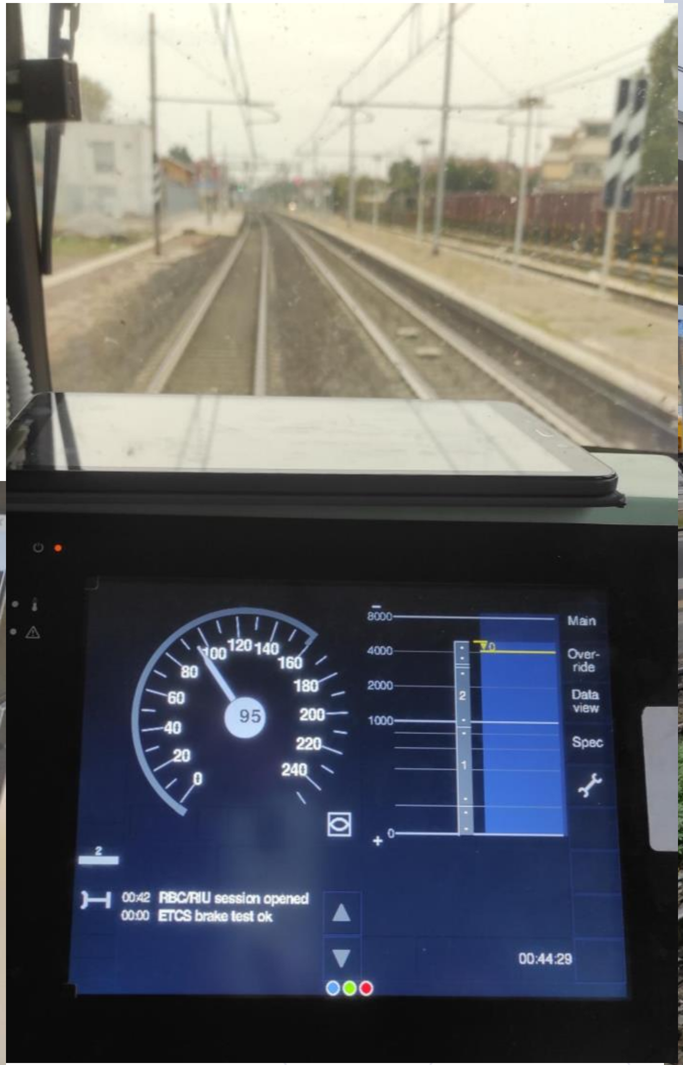
Virtual balise + ERTMS L2

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



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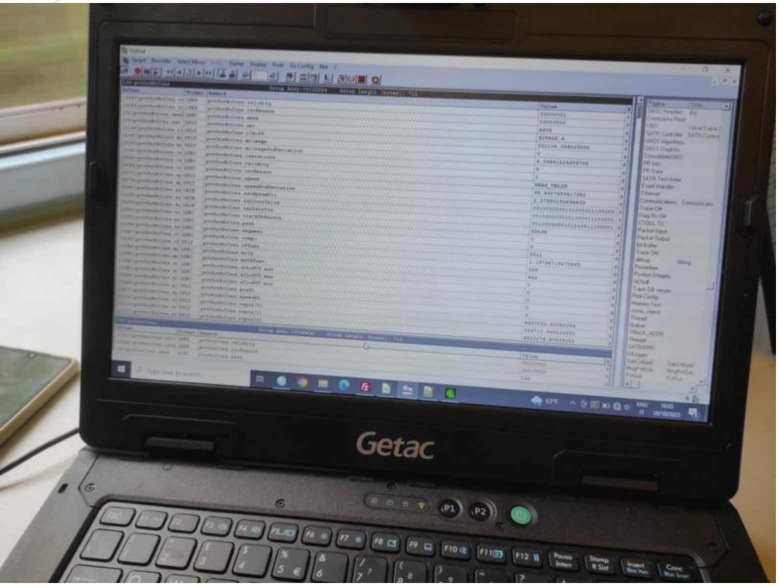
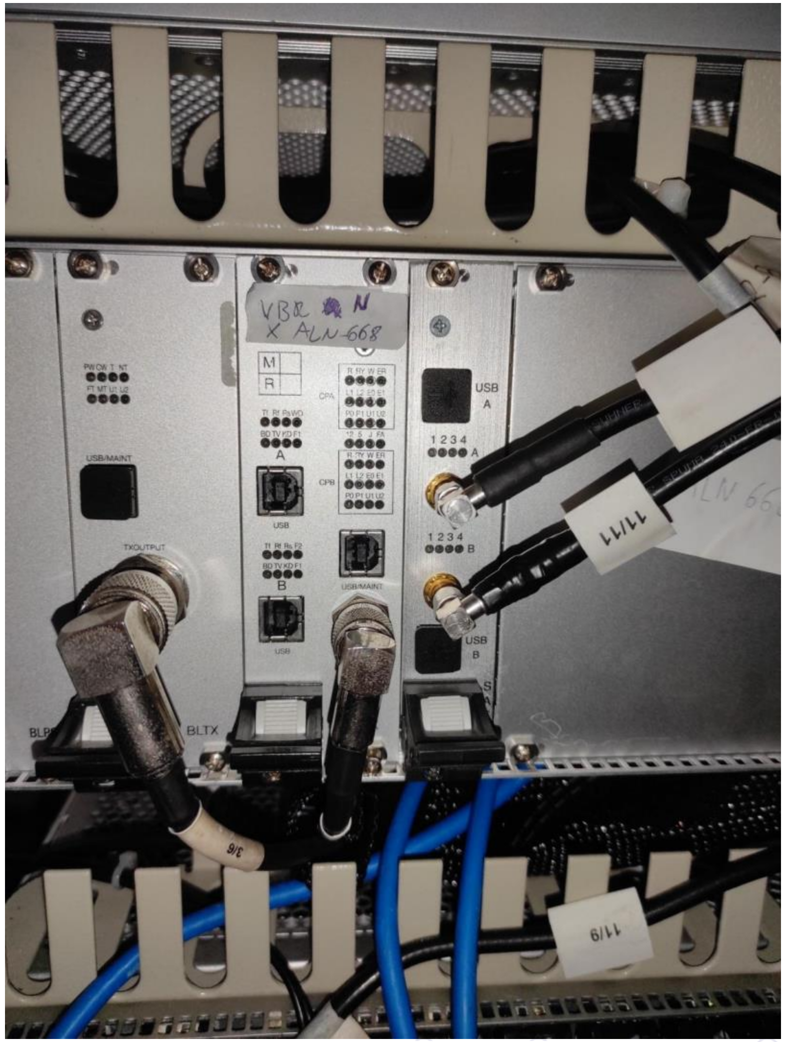
PILOT LINE NOVARA-RHO

On-board equipments



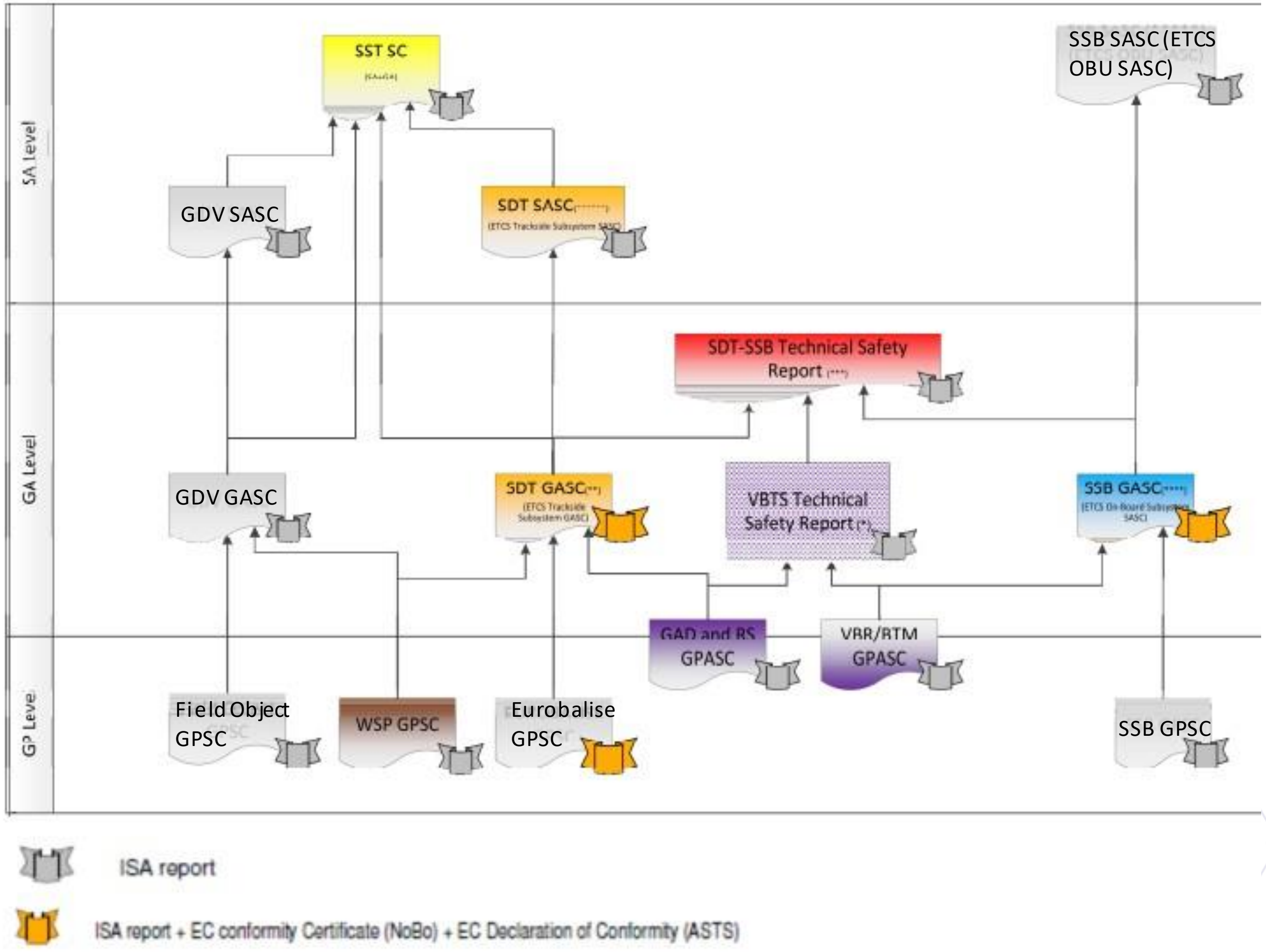
On-board Diagnostic Tools



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

2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023

3inSAT	Assessment della tecnologia satellitare	2012-2016
ERSAT EAV+GCC	ERTMS + GNSS First use of GALILEO with EGNOS + Local Augmentation Network	2015-2019
DB4RAIL	Mitigation solutions GNSS interfence for ERTMS L2	2017-2021
SAT4Train	Multi Link Communication Platform (MLCP) Terrestrial and Satellite Public Communication Services	2017-2021
Gate4RAIL	Virtual GNSS Test Bed Development Zero-On Field Test	2018-2021
SBSphase2	ERTMS + GNSS demonstrator and IP-based public communication services (including SATCOM)	2018-ongoing
PILOT LINE	ERTMS + GNSS virtual balise validation and certification	2021-ongoing
VOLIERA	GNSS + IMU + Lidar + Video camera multi-sensor positioning	2020-2022
RAILGAP	Ground Truth & Digital Map	2021-ongoing

NEW

2023-2025 National Aug. network

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7 - 9 November - Sevilla, Spain

RAILGAP Project: Focusing on Digital Map

Rail Session

G. Emmanuele – RAILGAP Project Coordinator - RFI

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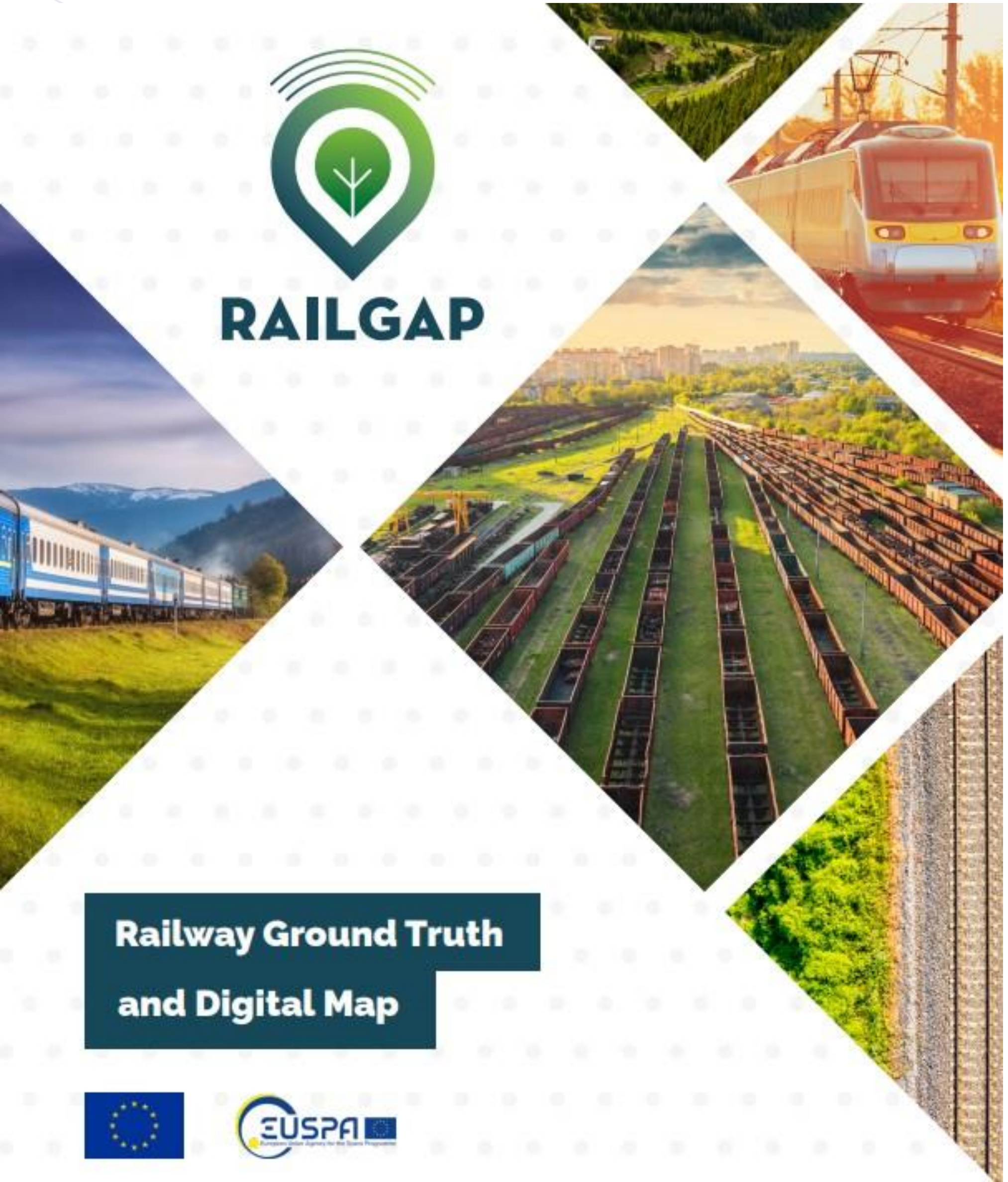
RAILGAP

Railway Ground Truth and Digital Map



RFI RETE FERROVIARIA ITALIANA
GRUPPO FERROVIE DELLO STATO ITALIANE

Project coordinator

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DLR
TRENITALIA
Université Gustave Eiffel
HITACHI Inspire the Next
ineco
unife

3.13M€	TOTAL PROJECT VALUE	36	MONTHS DURATION
2.72M€	EUROPEAN UNION CONTRIBUTION	12	PARTNERS

The project is funded by the H2020 EUSPA with GA N. 101004129.

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RAILGAP

Main objectives

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RAILGAP

RAILway Ground truth and digital mAP

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

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

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

RAILGAP

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

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

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:

Topology	The track network is described as a topological node-edge model.
Coordinates	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.
Geometry	The track geometry described in terms of radius and gradients.
Railway infrastructure elements	The railway assets selected in RAILGAP that can be found on, under, over or next to the railway track, e.g., balises

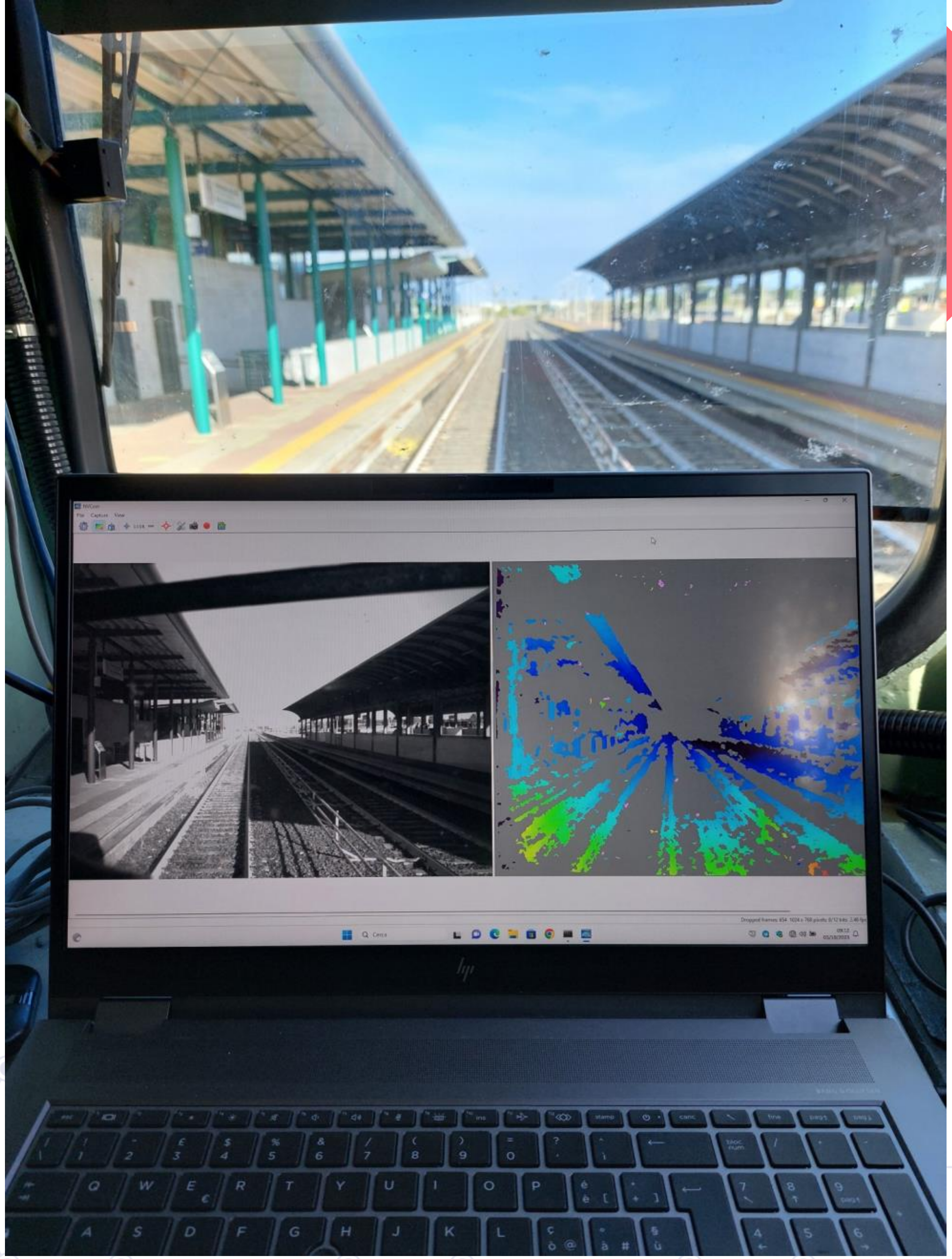
Digital Map

Track elements to be identified in the context of RAILGAP

Elements on the railway track
Switch indicator
Eurobalises

Other track elements
Tunnel
Bridge / Road overpass
Track

Elements in the track proximity
Light signals / ETCS marker
Track sign
Level crossing light signal
Pole of overhead power line



Stereo-camera data acquired during the RAILGAP field test campaign in Sardinia

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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

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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.

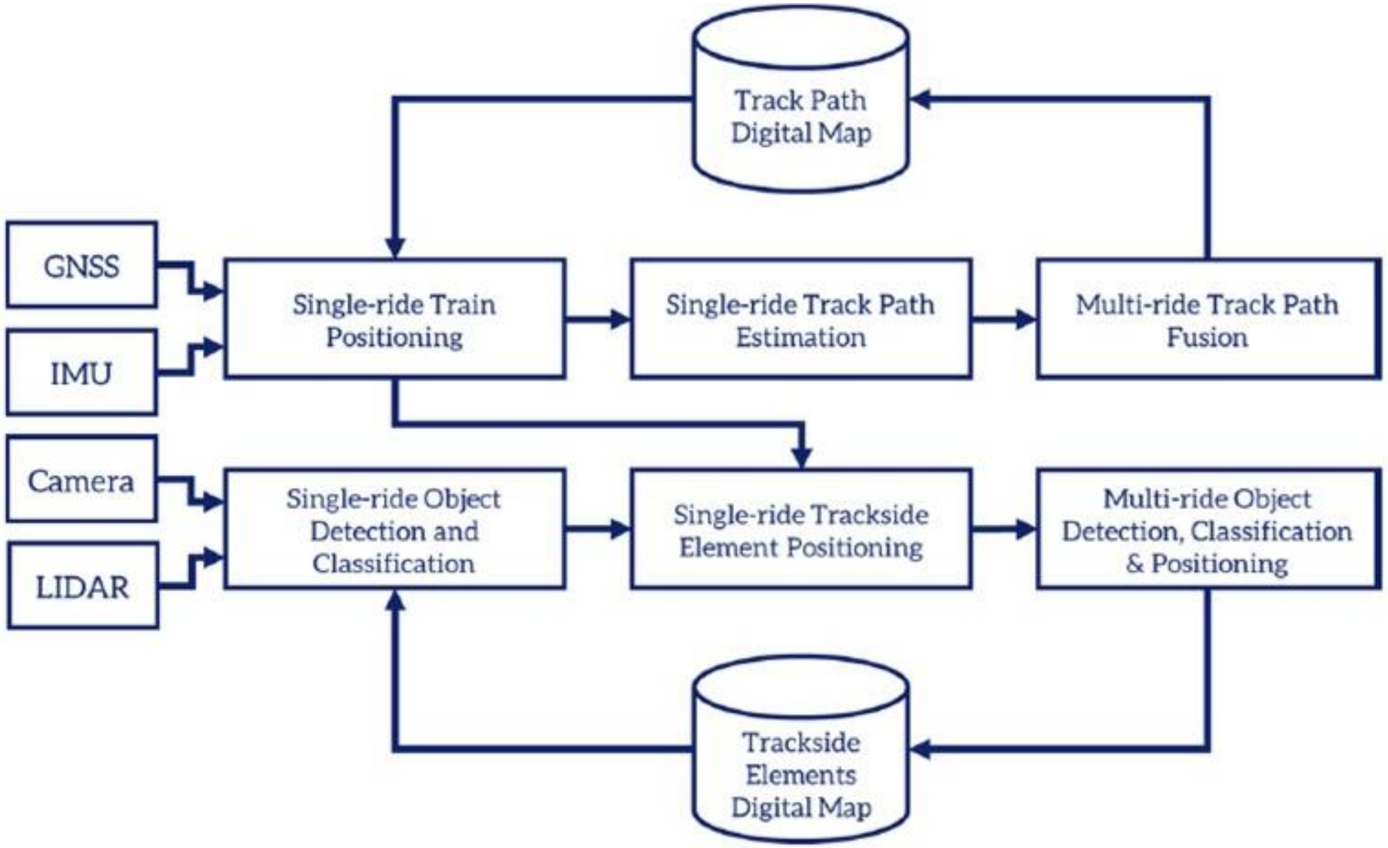
RAILGAP DM construction scheme

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

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