Satellite Technology for Railways: STARS and ERSAT GGC projects

Jose Bertolin
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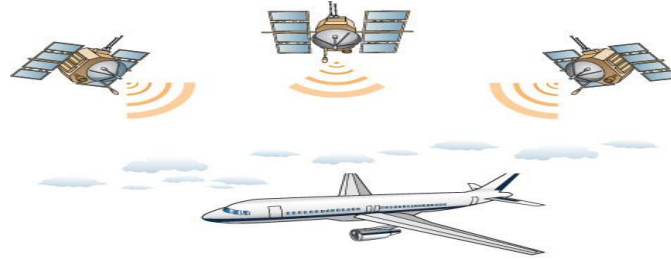
19th September InnoTrans

WWW.UNIFE.ORG

Satellite Application for Railways

More Frequent Use GNSS Technology

Aviation Use Case of Success

Surveying Tracks

Passengers Information System

Railway APP no directly safety critical

Time Arrival Destination
Next Stop

ertms

Application of GNSS in railways into the safety domain

Why use GNSS in Safety Critical Railway Applications

01

ETCS (EUROPEAN TRAIN CONTROL SYSTEM)

System rolled out around Europe to replace more than 20 national legacy systems. Also extended all around the world (ETCS standard).

02

REDUCE TRACKSIDE INFRASTRUCTURE

Eliminate the Eurobalises used as position reference markers replacing them by the Virtual Balise concept

03

BENEFITS

- Reduce cost of Signaling
- Increase availability
- Reduce Maintenance requirements
- Exposure to thefts
- Vandalism

04

APPLICABILITY BASED ETCS

- Low Density secondary lines in Europe
- All lines around the world (ETCS standard)

UNIFE/UNISIG role

2011 — UNISIG started investigating the application of GNSS/EGNOS for ETCS

2012 — MoU first mentioned GNSS / EGNOS as a potential add-on

2015 — ERTMS consider the application of GNSS as Longer Term Perspective

2016 — New MoU signed by the sector on 20th September 2016 including the satellite assets as one of the new breakthrough innovation of the ERTMS evolution plan

Consultation & Event

1st GALILEO USER ASSEMBLY
28-29 NOVEMBER 2017 MADRID

save the date
Warsaw
The EGNOS Service Provision workshop

R&I Activities

(((NGTC)))

STARS

ERSAT GGC

http://www.stars-rail.eu/

Objectives

1 To develop a universal approach to predict the achievable GNSS performance in a railway environment

2 To determine the necessary evolution of ETCS to include GNSS services

3 To quantify the economic benefits through reduction of cost, which will increase market appeal of ERTMS

Objectives

http://www.ersat-ggc.eu/

1 Definition and Delivery of a
Certified Enhanced Functional ERTMS Architecture

2 Definition and Delivery of the
Functional and Not Functional Test Specification

3 Definition of Certified Std Process, methodology and toolset for
Classifying Track Areas for locating Virtual Balises

4 Preliminary integration of the Toolset into ERTMS
Labs

5 Identification of high level Migration Strategy
for upgrading existing ERTMS lines

1 - RFI
2 - ASTS
  2a - ASTS-F (LINKED THIRD PARTIES)
  2b - ASTS-S (LINKED THIRD PARTIES)
3 - RINAC
  3a - RINA (LINKED THIRD PARTIES)
4 - IFSTTAR
5 - CEDEX
6 - INECO
7 - ITALCERTIFER
8 - ADIF
9 - DLR
10 - TRENITALIA
11 - RADIOLABS
12 - UNIFE
13 - SNCF
  13a - SNCF-R (LINKED THIRD PARTIES)
14 - BVI

GNSS in Rail Signalling
from space to railways through open collaboration

European
Global Navigation
Satellite Systems
Agency

GALILEO EGNOS
NAVIGATION SOLUTIONS
POWERED BY EUROPE

Daniel Lopour

19 September 2018

GSA in a nutshell

Mission:

Gateway to Services

- Galileo & EGNOS Operations and Service Provision

- Market Development of the applications and the receivers

Gatekeeper of security

- Security Accreditation

- Operation of Galileo Security Monitoring Centre, governmental service (PRS) activities

Services:

GALILEO

- Worldwide navigation system "made in EU"

- Fully compatible with GPS

- Open service free of charge, delivering dual frequencies

- Signal authentication will provide trustability

EGNOS

- Satellite Based Augmentation System (SBAS)

- Improves GNSS performance

- European coverage (under extension in other regions, e.g. North Africa)

- Available NOW, free of charge and widely adopted in off-the-shelf receivers

GSA objectives in rail

Include E-GNSS within ERTMS:

- contribute to reduction of ERTMS infrastructure CAPEX/OPEX

- improve flexibility and attractiveness of ERTMS for users in Europe and abroad

GSA actions:

- drive GNSS adoption to deliver benefits for IM`s and RU´s

- coordinate the R&D and market related initiatives with key rail and GNSS stakeholders

- provide expertise gained in other market segments and contribute to the safety and certification aspects

- facilitate collaboration between GNSS and railway industry

GSA funded H2020 projects:

GNSS performance analysis

- Rail environment characterised and possibilities of European GNSS contribution to ERTMS evolution identified
- First set of requirements agreed by industry

System Architecture Definition

- Common agreed architecture of the GNSS based train positioning subsystem for ERTMS evolution delivered
- Independent cost benefit analysis performed

System Deployment Definition

- Certification aspects of GNSS solution for low density lines analysed
- Demonstrator of the agreed architecture in preparation

2018

2019

2020

THE EUROPEAN GNSS AGENCY IS WORKING TOGETHER WITH RAIL AND SPACE INDUSTRY STAKEHOLDERS TO ENABLE THE USE OF SATELLITE-BASED POSITIONING FOR RAILWAY SIGNALLING

At the heart of this multi-stakeholder initiative lies the European Train Control System (ETCS), which is now being adopted both in Europe and beyond, as one of the components of the European Rail Traffic Management System (ERTMS). At present, in ETCS the positioning of the train is based on "balise", a physical element mounted at specific intervals along the railway track. The goal is to ensure that wherever possible, the physical balises can be replaced by virtual ones, based on precise, GNSS-based positioning without any operational or safety implications on the ETCS. The roadmap below summarises the main projects currently running and planned, as well as the involvement of the various stakeholders interested to achieve the objective of E-GNSS enabled ETCS together with the GSA.

European Global Navigation Satellite Systems Agency

GSA

unife — THE EUROPEAN RAIL INDUSTRY

UNISIG

CER

ERTMS USERS GROUP

Shift2Rail

EUROPEAN UNION AGENCY FOR RAILWAYS

esa

Linking space to user needs

How to get in touch: **www.GSA.europa.eu**

EGNOS-portal.eu   GSC-europa.eu   UseGalileo.eu

The European GNSS Agency is hiring!

Apply today and help shape the future of satellite navigation!

19th September 2018

# STARS: Satellite Technology for Advanced Railway Signalling

Bernhard Stamm (Siemens)

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No. 687414
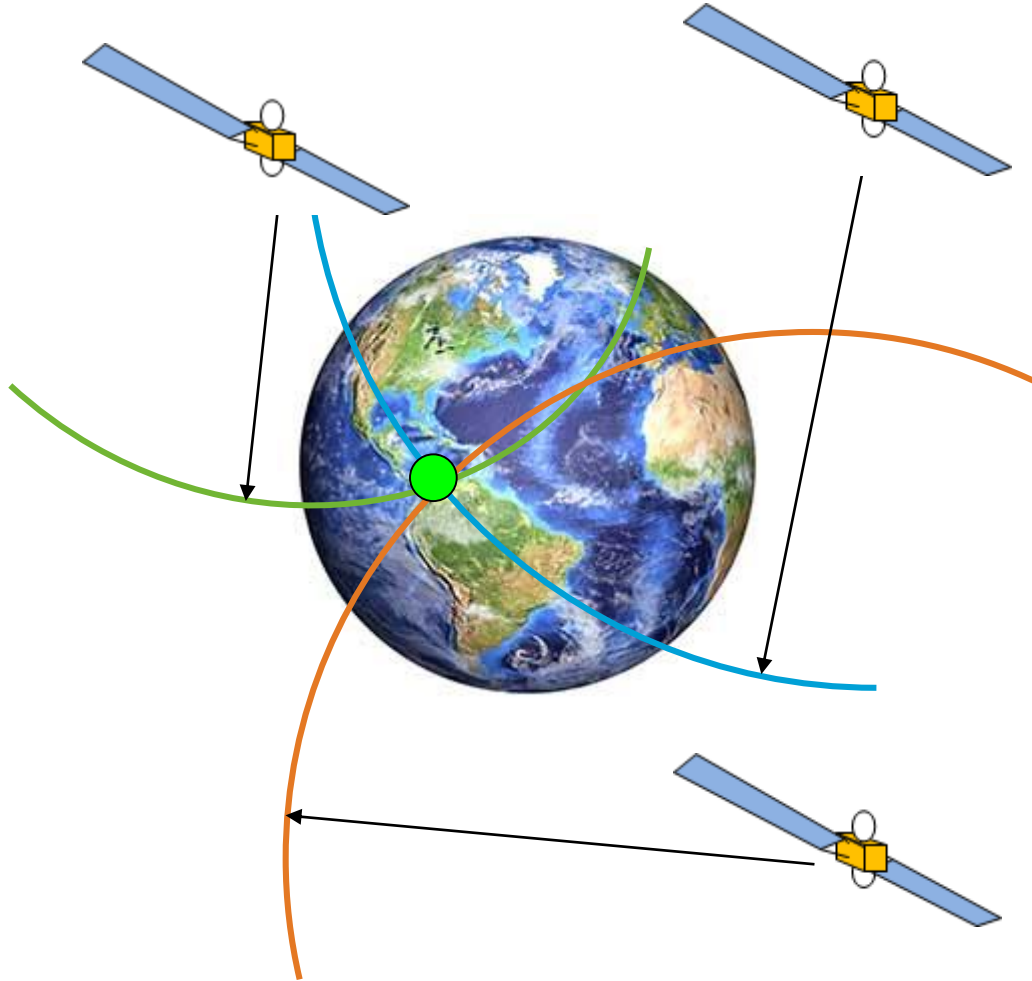
STARS Project

• Satellite Positioning in Railway Applications

- GNSS in Safety Critical Applications
- Aviation vs. Railway Environments
- STARS Project
  - Project goals
  - Project execution
  - First Results
  - Issues found
  - Cost Benefit Analysis
- Next Steps / Conclusions
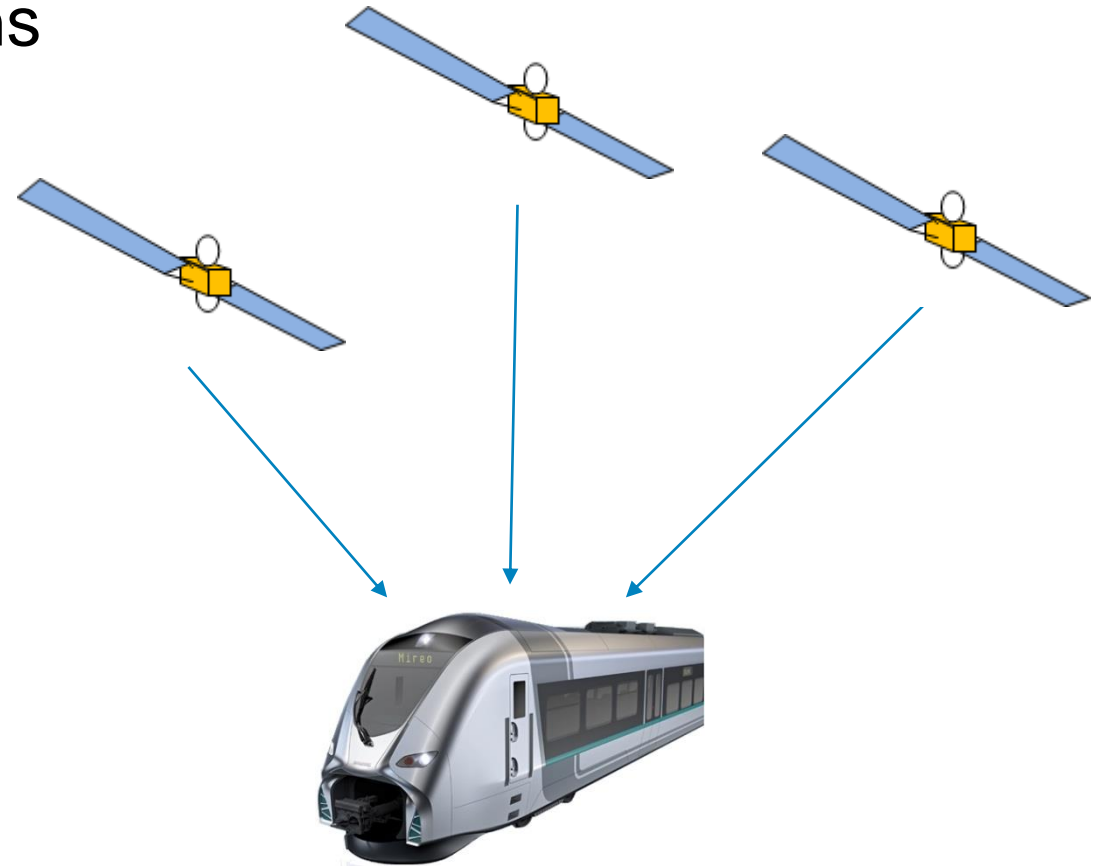
• GALILEO / GPS / GLONASS / BEIDOU

- All GNSS systems determine the position of the receiver by measuring the distance to a number of satellites.

- The distances are derived from the time the signals are received, compared to the time they have been sent.

- Signal travel time from satellite to receiver is in the range of 70 ms (GPS).

- Required clock accuracy is in the range of 100 ps.

- Receivers generate the accurate time from the signals received from multiple satellites.

• How GNSS works

Space Effects

In true world applications a number of effects impact the accuracy of GNSS:

- Inaccuracies in timing signals
- Errors in satellite orbits
- Signal propagation is disturbed by Ionosphere and Troposphere

- Number and relative position of satellites used
- Multipath (reflections of signals)
- Electromagnetic interferences
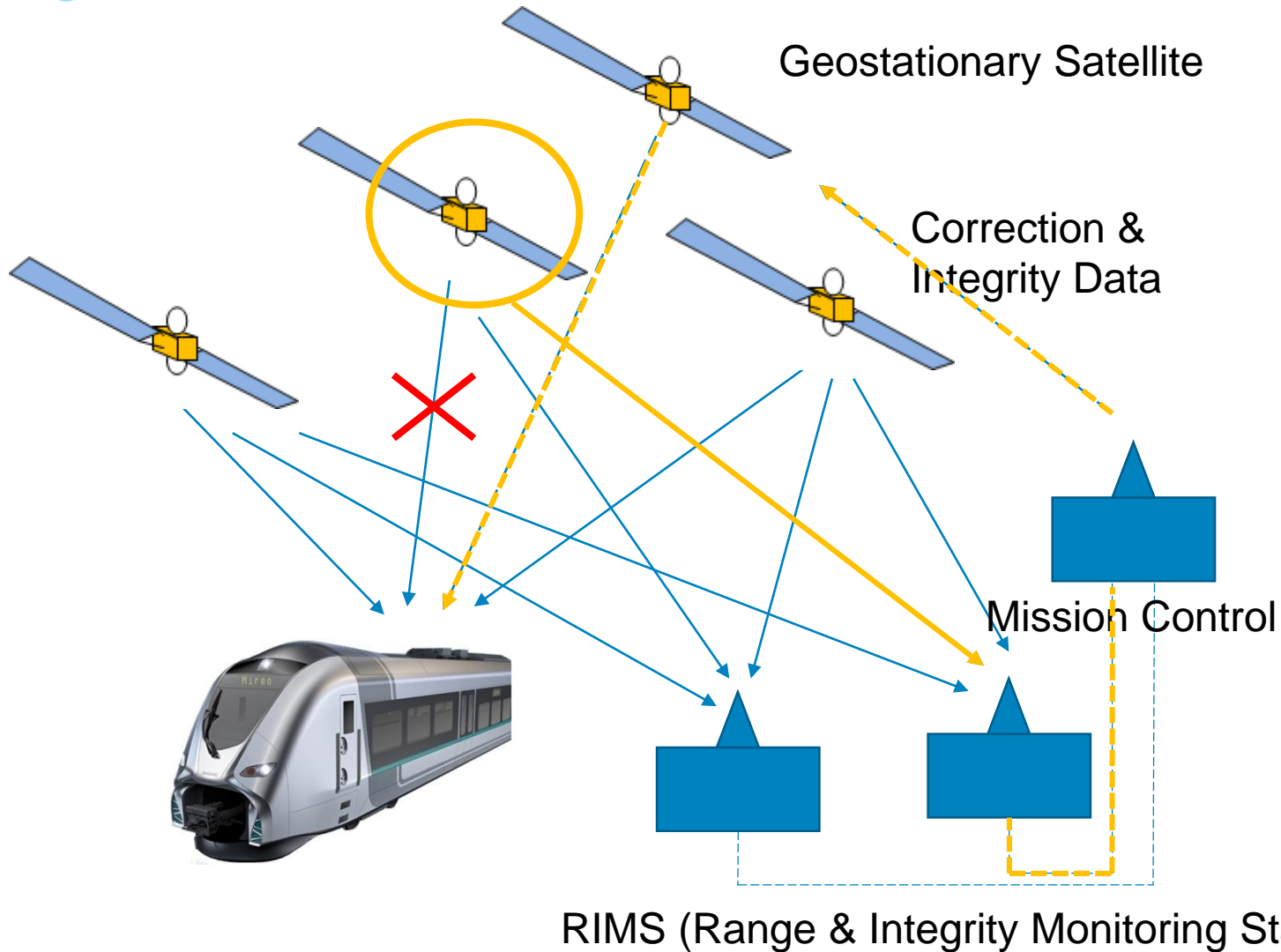- Receiver induced errors

Ground Effects

Receivers estimate the inaccuracy of the calculated position, which is called Dilution of Precision (DOP).

GNSS Satellites

Ionosphere

Obstructed

Troposphere

Direct

Refracted

Reflected
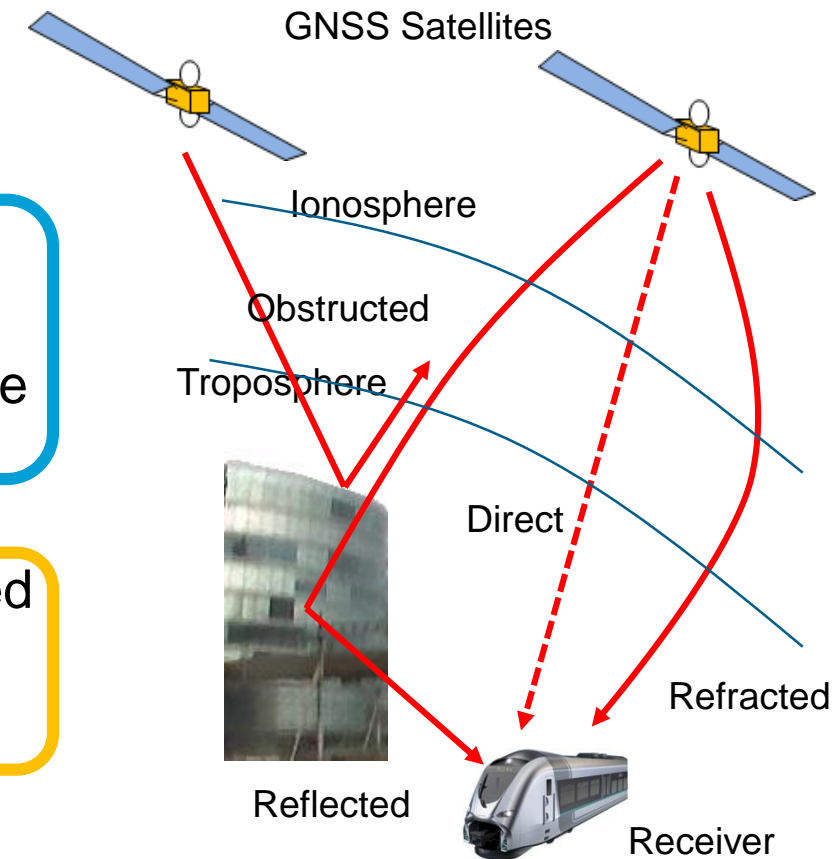
Receiver

• How Augmentation works (SBAS and GBAS)

Geostationary Satellite

Correction & Integrity Data

Mission Control

RIMS (Range & Integrity Monitoring Stations)

- Common mode errors can to a large extend be corrected by using reference stations, which lie in the vicinity of the receiver, and which generate correction data.

- Reference stations can also monitor the integrity of satellite signals, and issue warnings if a satellite malfunctions.

- Correction & integrity data is sent to receivers via geostationary satellites (e.g. EGNOS) or via terrestrial radio links (non standardised).

• EGNOS as an example of an SBAS

Figure 3-4 EGNOS RIMS sites

- • EGNOS is the European Space Based Augmentation System specifically developed for aviation applications.

- • EGNOS operates 39 monitoring stations spread across Europe and North Africa.

- • EGNOS is approved for safety critical applications in aviation (GNSS approaches).

- • EGNOS currently supports GPS L1.

- • With version 3 of EGNOS, planned for 2025, augmentation and integrity monitoring will be extended to Galileo, as well as to the L2 frequency.

• Using GNSS in Railway Applications

Covered by EGNOS

In true world applications a number of effects impact the accuracy of GNSS:

- Inaccuracies in timing signals
- Errors in satellite orbits
- Signal propagation is disturbed by Ionosphere and Troposphere

- Number and relative position of satellites used
- Multipath (reflections of signals)
- Electromagnetic interferences
- Receiver induced errors

Require other means to detect/correct

Receivers estimate the inaccuracy of the calculated position, which is called Dilution of Precision (DOP).

GNSS Satellites

Ionosphere

Obstructed

Troposphere

Direct

Refracted

Reflected

Receiver
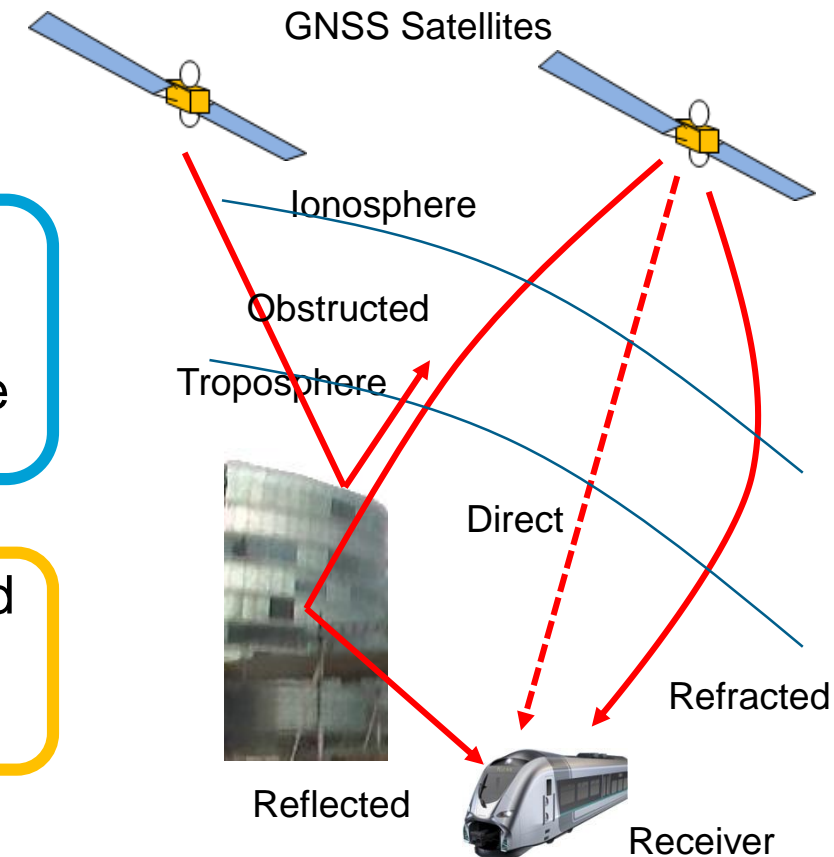
• Using GNSS in Safety Critical Applications

GNSS can either be not available, or produce erroneous positions.

Many applications however use GNSS "as it is", tolerating interruptions as well as position errors. In the best case they indicate this to the user, but often they don't.

Safety critical applications however have to consider and manage both issues.

Which level of unavailability and/or position error can be tolerated is application dependant. In aviation this has been defined in a so called MOPS (minimum operational performance standard).

For railway applications there is currently no MOPS, as operation is much more complex and the impact of unavailability and/or position errors application dependant.
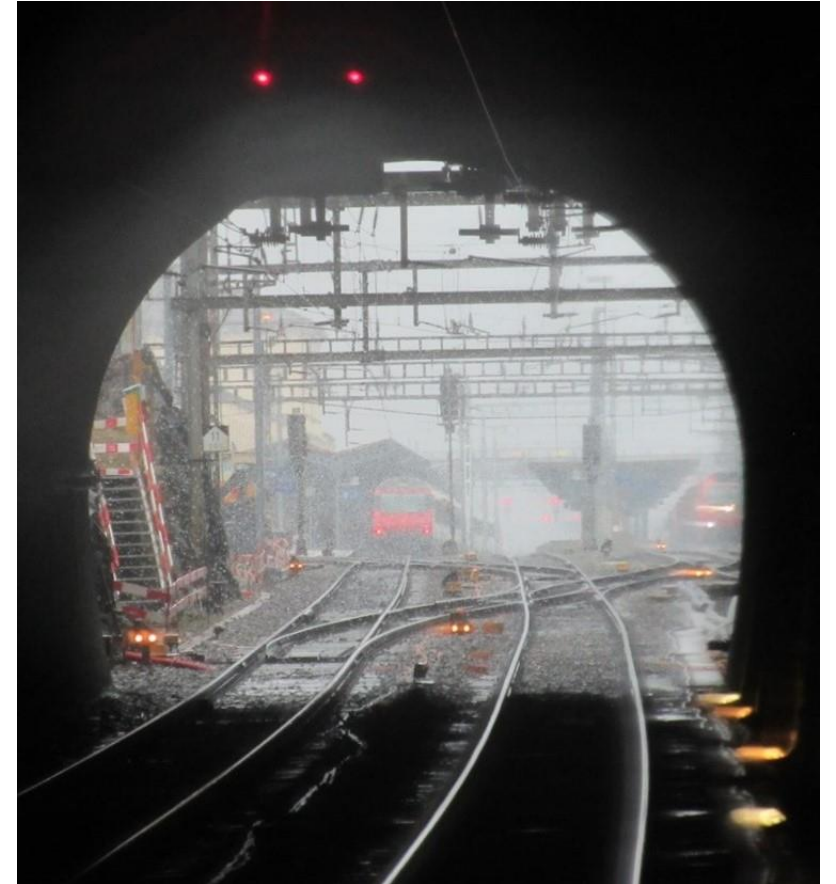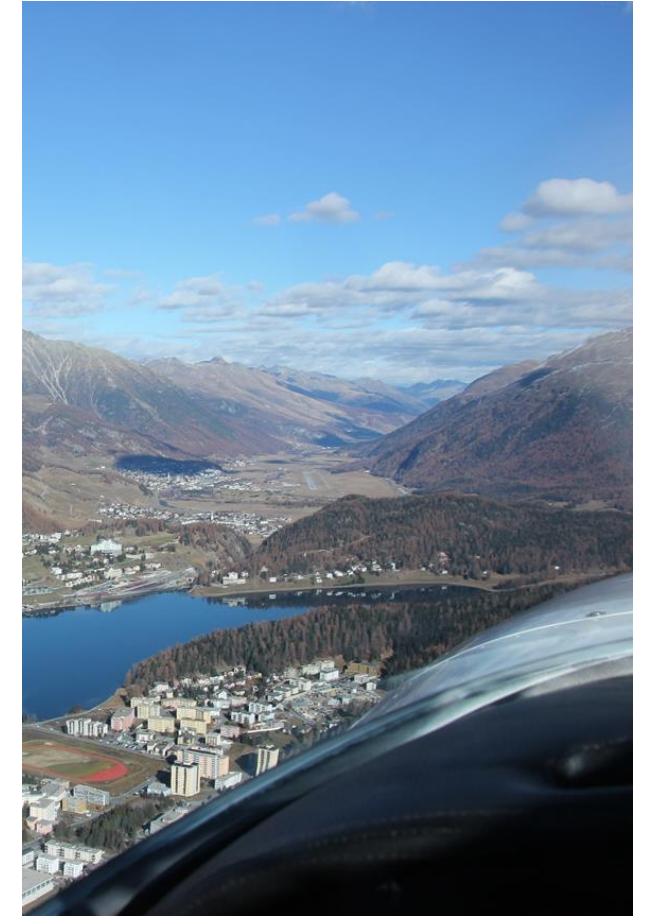
• Using GNSS in Safety Critical Applications

For aviation applications it has been demonstrated that the standardised algorithm used to calculate the Protection Level (estimated error) is always more conservative than the Position Error (true error), which ensures safe operation.

It has also been demonstrated that the Alarm Limit is only exceeded with such a low probability that a reliable operation is achieved.

These demonstrations only apply under well defined conditions:

• A sufficient number of GPS Satellites, as well as one EGNOS Satellite need to be visible continuously.

• Obstacle free zones around runways have to be ensured.

• Antennas have to be placed far from electromagnetic interferes.

• Jamming and spoofing are not considered.

• Using GNSS in Safety Critical Applications

Railway applications are much more challenging for GNSS due to the environment.

- There is no continuity in the visibility of Satellites.

- Obstacle free zones near railway tracks don't exist.

- Locomotives themselves are source of significant electromagnetic interferences, with the antennas placed directly underneath the catenary.

- Railway Safety Standards explicitly state that jamming and spoofing have to be assumed, and protective measures implemented.

As a result, GNSS only works intermittently in the Railway environment.
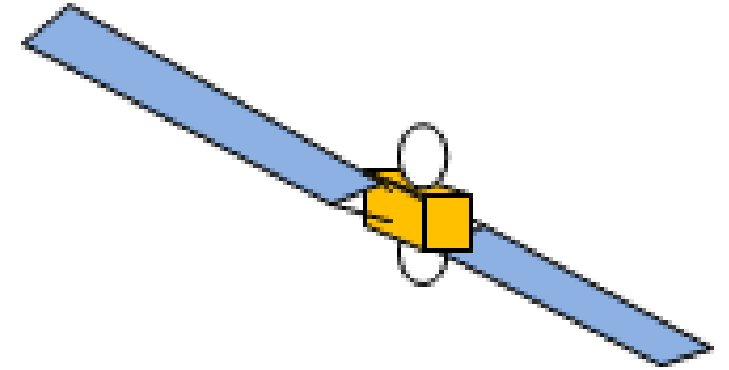
In addition, EGNOS is often lost long enough that Ephemerides and Almanac data expire, so re-establishment of a safe GNSS position can take minutes once EGNOS reception is re-gained.
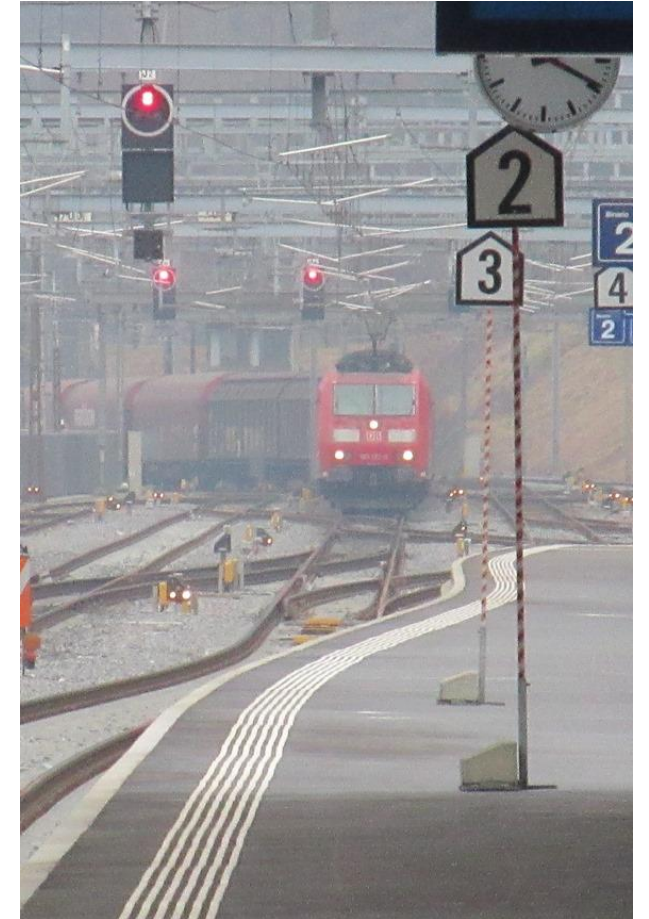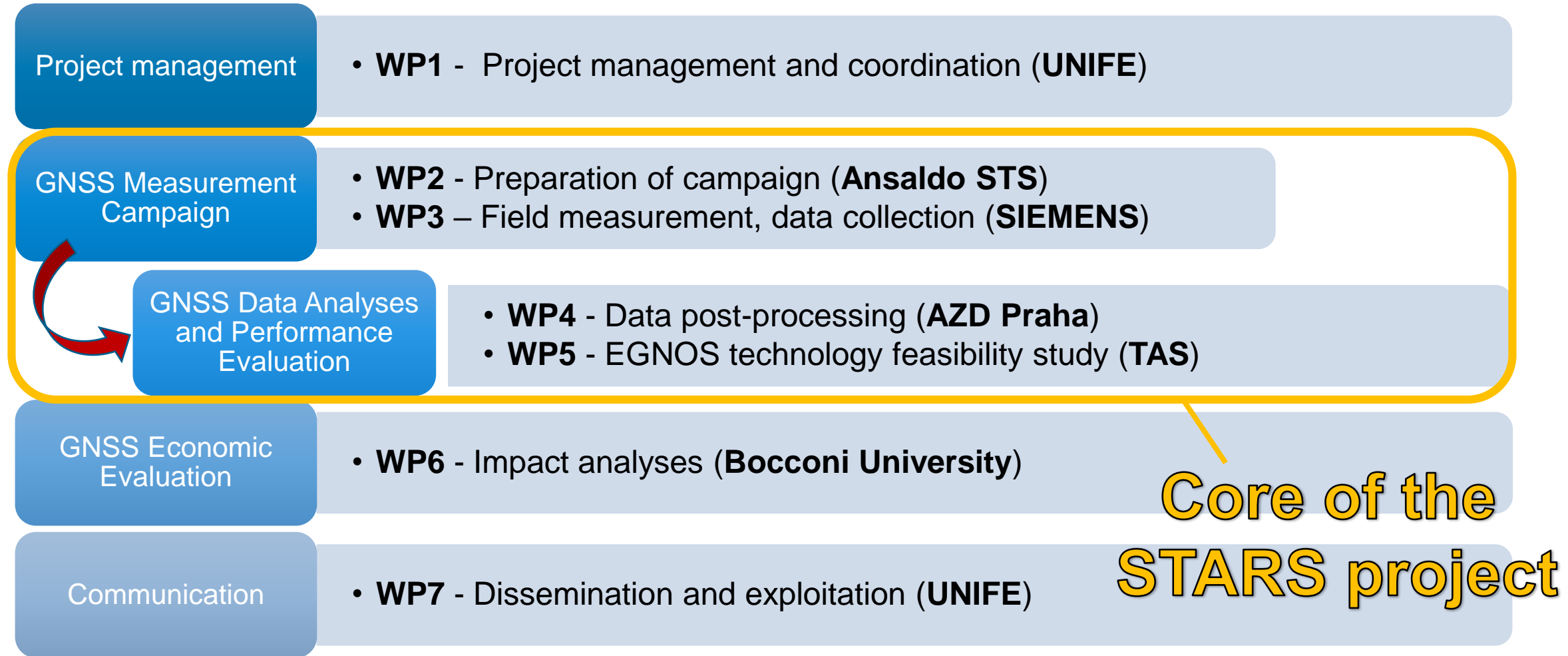
• Origins of the STARS Project

- The European **G**lobal Navigation **S**atellite Systems **A**gency (GSA) has over the years finance a number of research projects to investigate how GNSS usage can be extended into safety critical applications other than aviation, such as railway signalling, and specifically into ETCS, the European Train Control System.

- None of these project did however thoroughly investigate the true impact of the various environmental impacts on GNSS performance.

- In discussions with GSA industry has proposed an extensive field measurement and data analysis campaign, with which the realistically achievable performance of GNSS in the railway environment shall be investigated.

- This project is called STARS, an acronym for **S**atellite **T**echnology for **A**dvanced **R**ailway **S**ignalling

• Overall structure of the STARS work-plan

Project management	• **WP1** - Project management and coordination (**UNIFE**)

GNSS Measurement Campaign	• **WP2** - Preparation of campaign (**Ansaldo STS**) • **WP3** – Field measurement, data collection (**SIEMENS**)

GNSS Data Analyses and Performance Evaluation	• **WP4** - Data post-processing (**AZD Praha**) • **WP5** - EGNOS technology feasibility study (**TAS**)

GNSS Economic Evaluation	• **WP6** - Impact analyses (**Bocconi University**)

Communication	• **WP7** - Dissemination and exploitation (**UNIFE**)

Core of the STARS project

• Data Collection and Analysis

Key element of all data analysis performed is the generation of a true position of the train, called Ground Truth. This is the reference, against which a position generated by GNSS is evaluated.

 Analysis being are being performed with two parallel methods:

- Automated analysis of large volumes of data is being performed, mostly with tools and methods developed by the project partners (mostly MATLAB based).

- Manual inspection of data is being performed, and disturbances are then analysed against both GNSS data as well as pictures of the environment. For that tools supplied by the receiver manufacturers are used, as well as SPRING, a tool provided to the project by CNES, the French National Centre for Space Studies.

• External support for the STARS Project

- It was foreseen from the beginning to perform measurements in at least three different countries / environments.

- Measurements had to be performed on trains in regular service, as renting trains would have been prohibitively expensive.

- This required support from train operators, permitting the installation of the measurement equipment onboard suitable rolling stock.

- Depending on the site, support was also required from the infrastructure manager as accurate GNSS referenced track data was required and/or tags had to be installed to provide absolute position references.

- We have succeeded in securing support from Czech Railway, RFI / FS in Italy and Swiss Federal Railway.

• Data Collection, Example Switzerland

Swiss Federal Railway SBB is supporting the project by having allowed us to install the necessary equipment in the baggage compartment and on the roof of a regional train.

This installation had to be safety approved, as:

• sensor data from the active safety systems is used to generate the ground truth

• the installation has to be crash-worthy to 5 g and

• antennas have to be tested to withstand 15 kV / 16.7 Hz

SBB CFF FFS

• Test Train, Example Switzerland

The equipment installed in the train consists of:

- A high end GNSS receiver to record raw data (pseudo ranges of each satellite)
- A spectrum analyser to identify the presence of interferers
- An HF recorder, recording raw signals to identify interferers (producing 10 GB of data per minute)
- A number of reference receivers, including one low cost receiver common to all three installations and one certified aviation receiver supplied by Thales Avionics
- Various odometry related sensors (radars, tachos, accelerometers etc.)

Most measurements can be done remotely, some have however to be performed manually. This is possible during commercial services as the equipment is located in the baggage compartment.
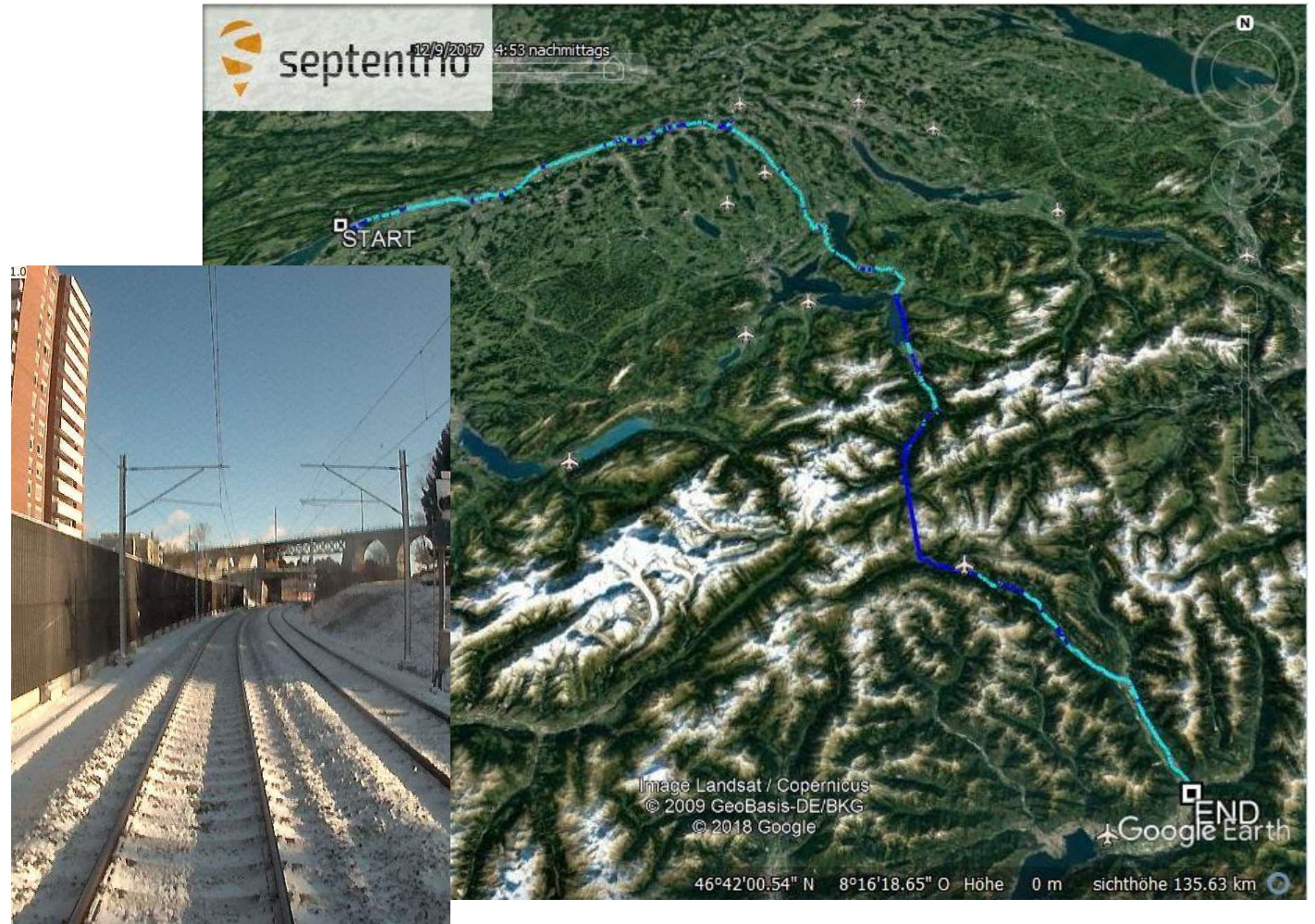
• Test Tracks, Example Switzerland

As a major difference to the test installations in the Czech Republic and in Italy, the Swiss test train belongs to a pool of identical vehicles which operates on many different lines.

This has the advantage that data can be collected in many different environments, but also makes generation of ground truth data significantly more complex as track data is required for all lines to be analysed.
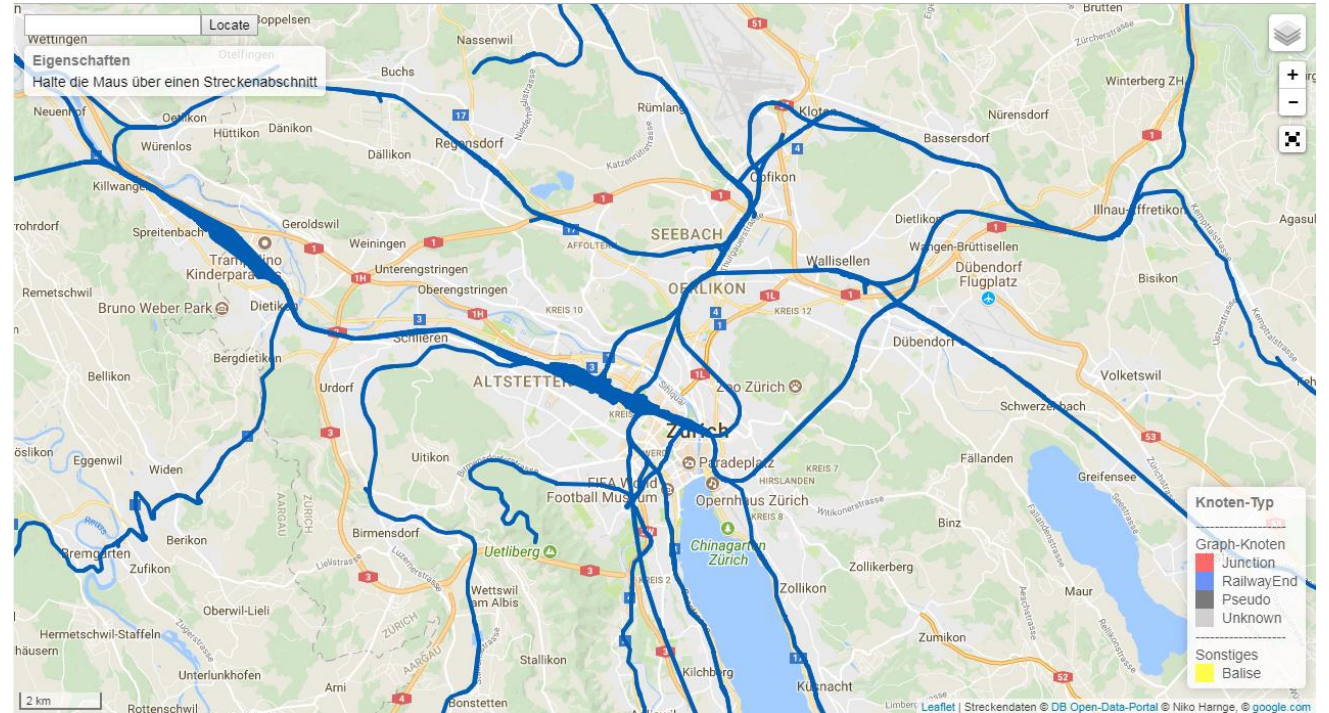
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• Ground Truth, Example Switzerland

Producing Ground Truth data requires:

- GNSS referenced track data

- Absolute reference positions (e.g. tags)

- Accurate odometry

This been especially complex in the Swiss case, as data collection has not only taken place on a dedicated test track, but anywhere on the network.

This excluded special measures, such as e.g. the placement of STARS related reference markers.

• Ground Truth, Example Switzerland

Luckily Swiss Federal Railway SBB supplied us with very accurate track data, which includes the position of all ETCS balises which have been installed for ETCS Level 1 or Level 2.

The data covers approx. 3'000 km of lines with 5'000 km of track and 50'000 balises.

The data is referenced to the Swiss Terrestrial Reference System, it therefore had to be converted to WGS84 format before use.
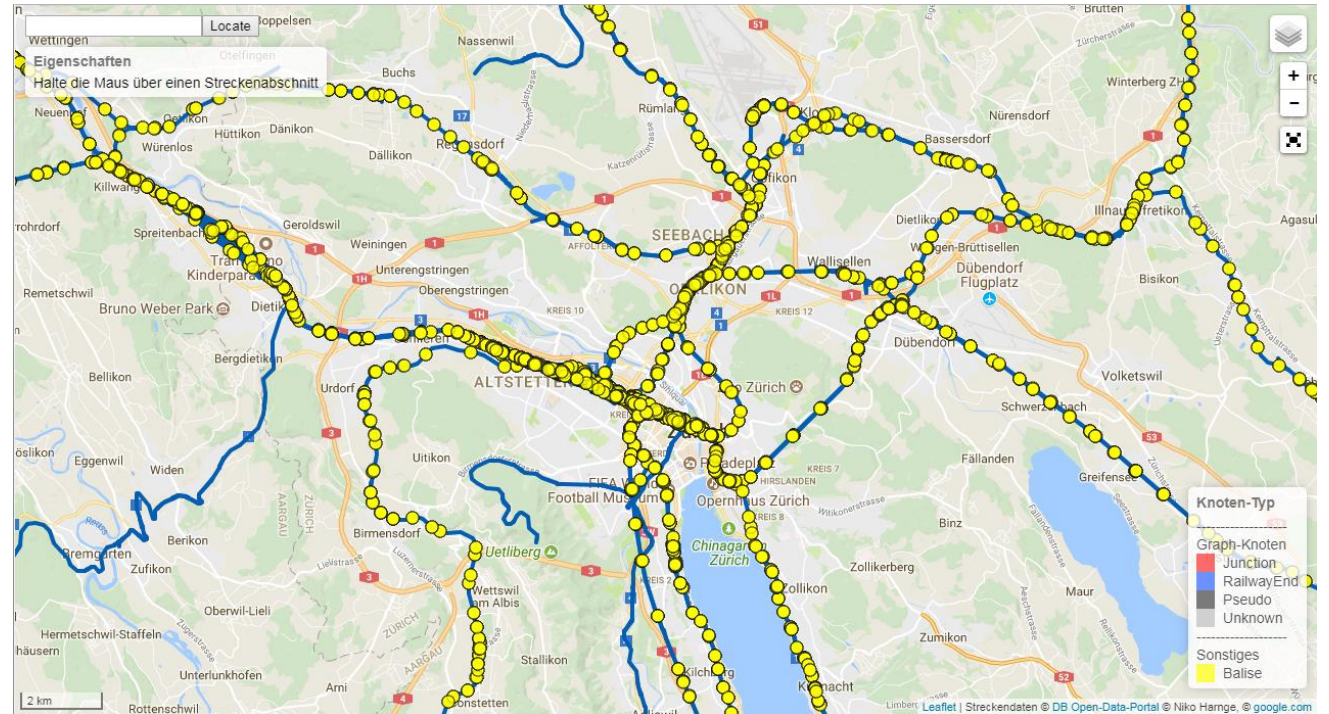
• Ground Truth, Example Switzerland

During each trip the measurement system records not only GNSS data, but also the balises passed as well as odometry data.

From this the true position of the train can be produced for any given time (typically in 100 ms intervals) by deriving the path taken between recorded balises (absolute positions) and by using odometry, mapping intermediate locations onto the GNSS referenced track.
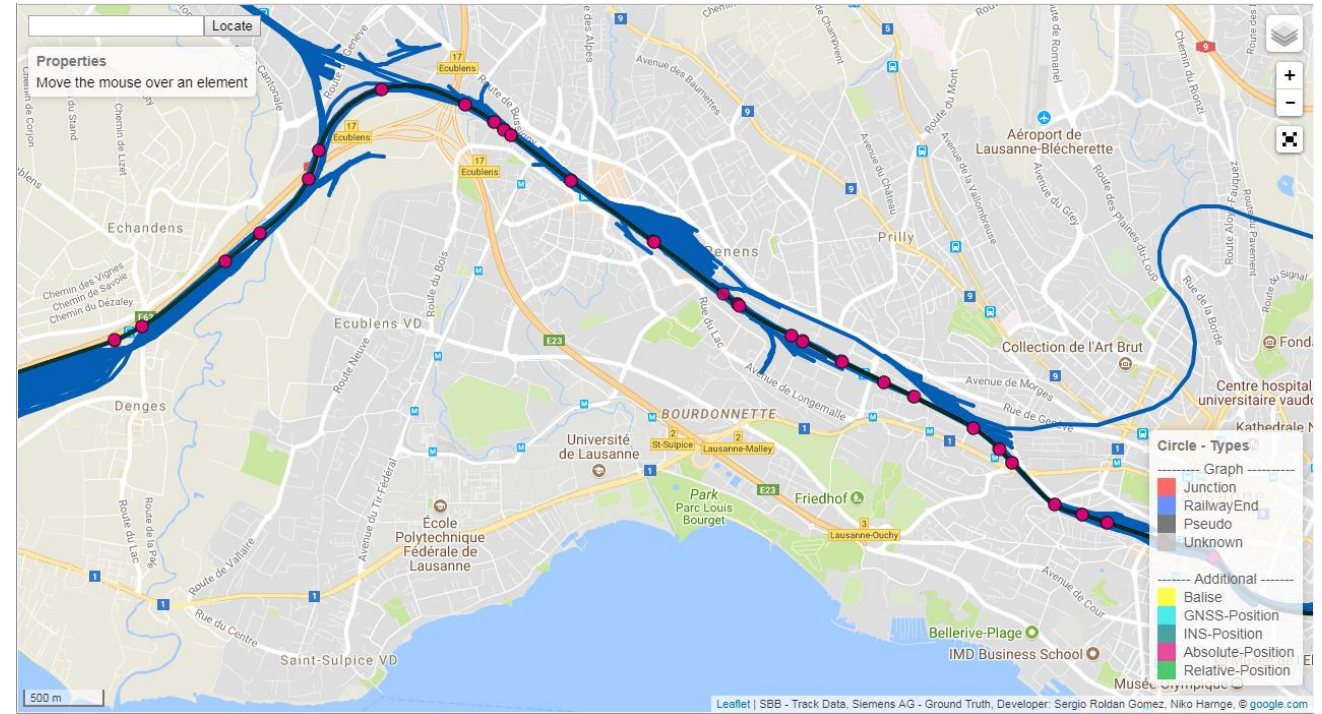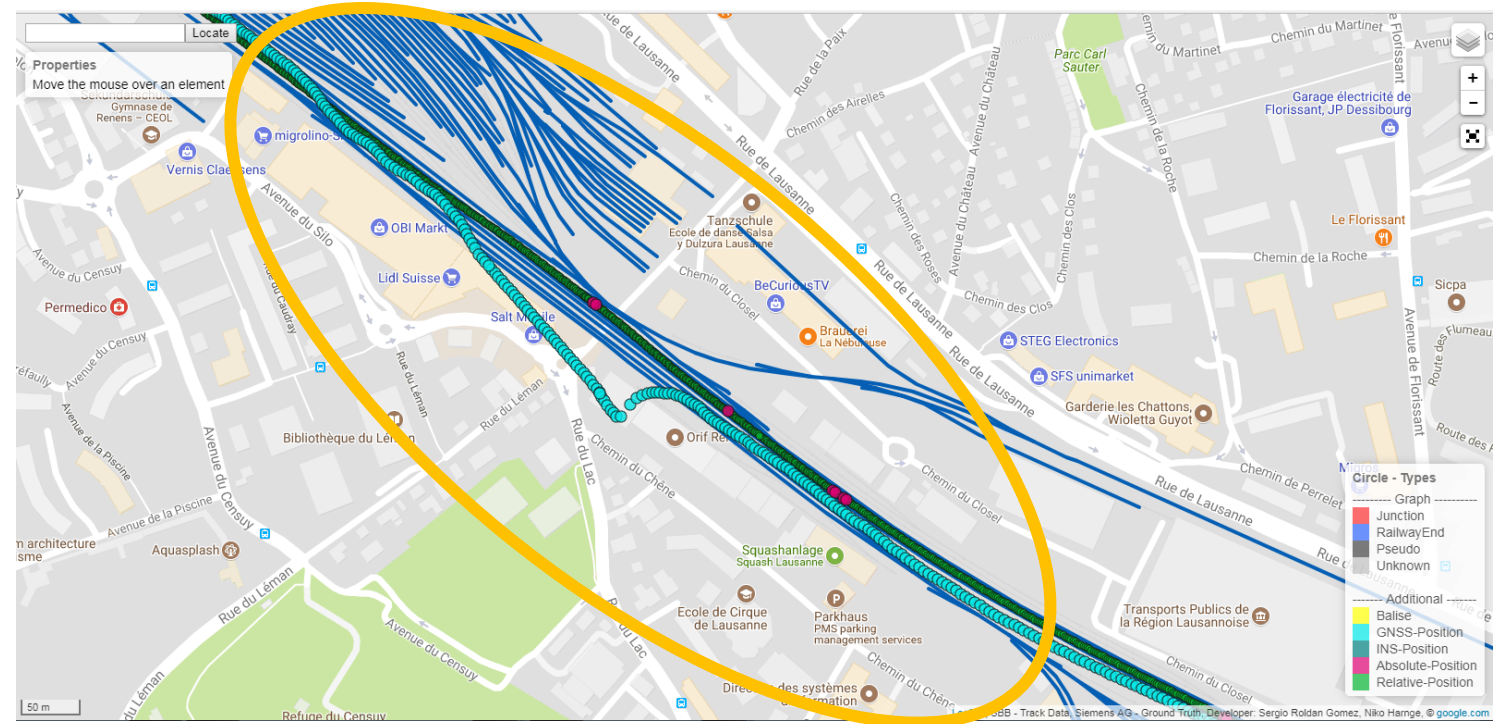
• Data Analysis, Example Renens

Once the true position has been generated it can be compared with the position generated by one of the reference receivers.

Any deviations from the true position become easily visible, the respective location can then be analysed further.
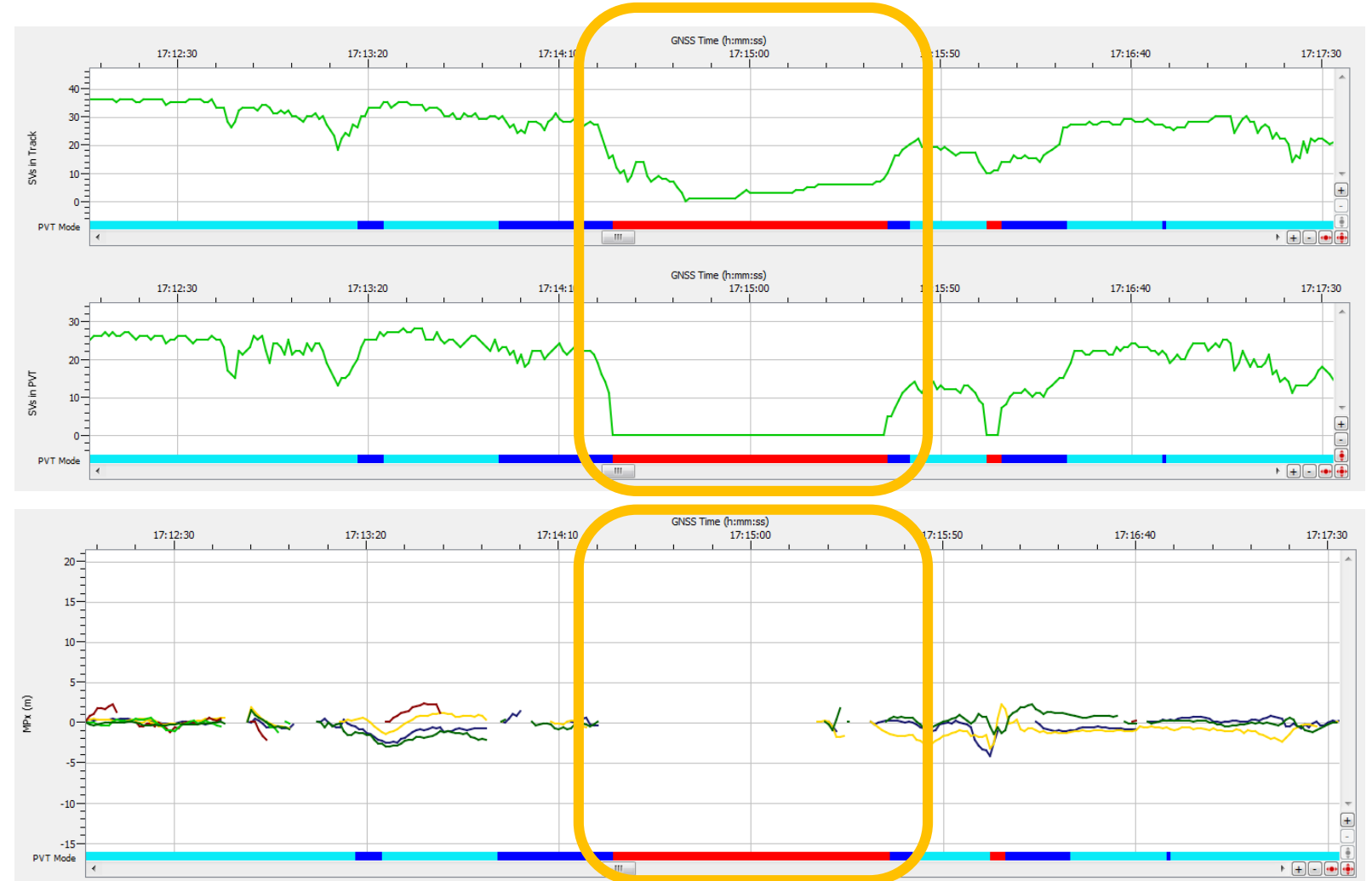
• Data Analysis, Example Renens

Raw data reveals that in that specific location the number of visible satellites drops drastically.

The multipath plot on the other hand shows no significant multipath.

• Data Analysis, Example Renens

Looking at the planimetric plot one can see that the algorithms of the high send Septentrio receiver stops producing position data, which results in a gap of more than one kilometre in length.
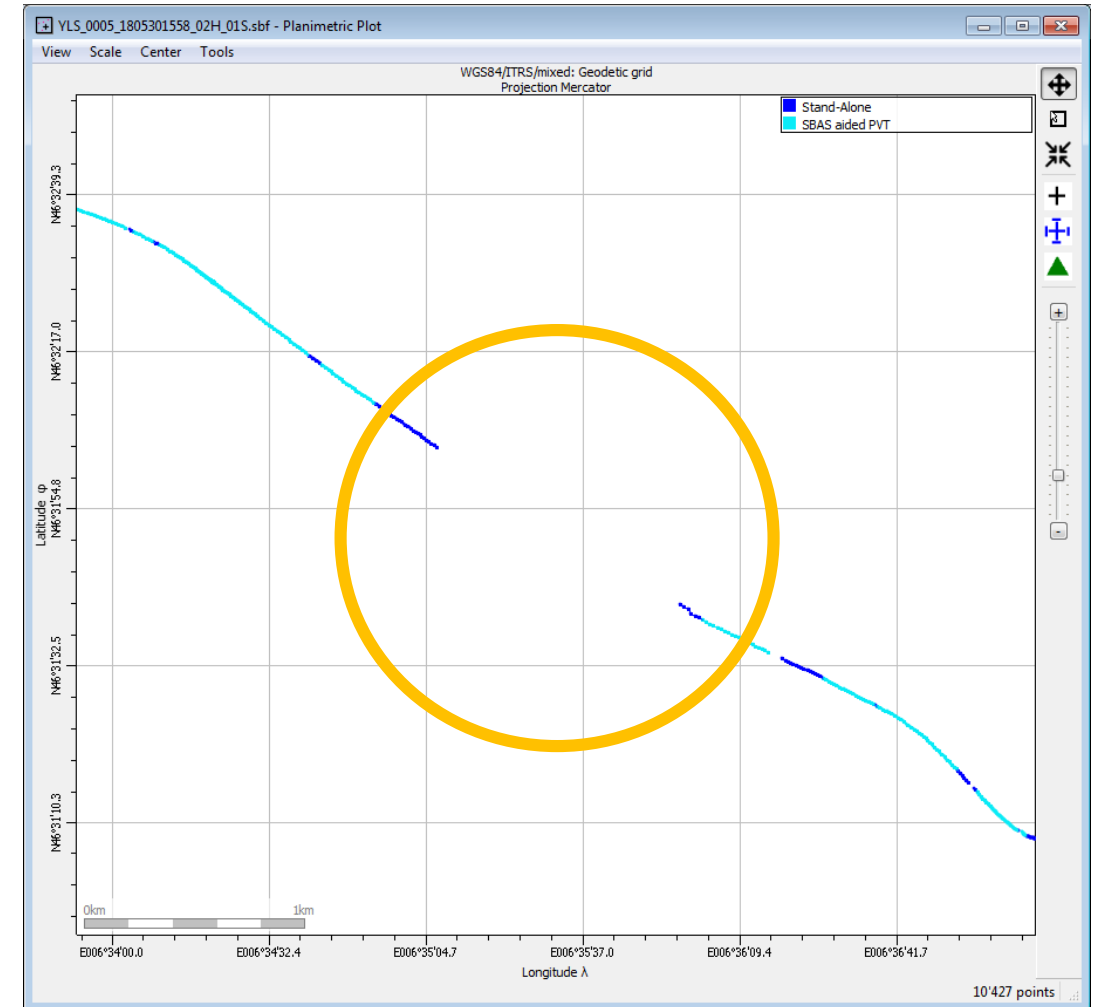
• Data Analysis, Example Renens

What causes such deviations can then be derived from the detailed analysis of the raw data, which should reveal the presence of e.g. multi path, masking of satellites or electro-magnetic interferers.

The true root cause might then be identified by looking at either the pictures taken by the camera installed in the cab, or by looking at aerial pictures (note that they might be outdated). They should then reveal the presence of either e.g. reflective buildings, transmitters or platform roofs.
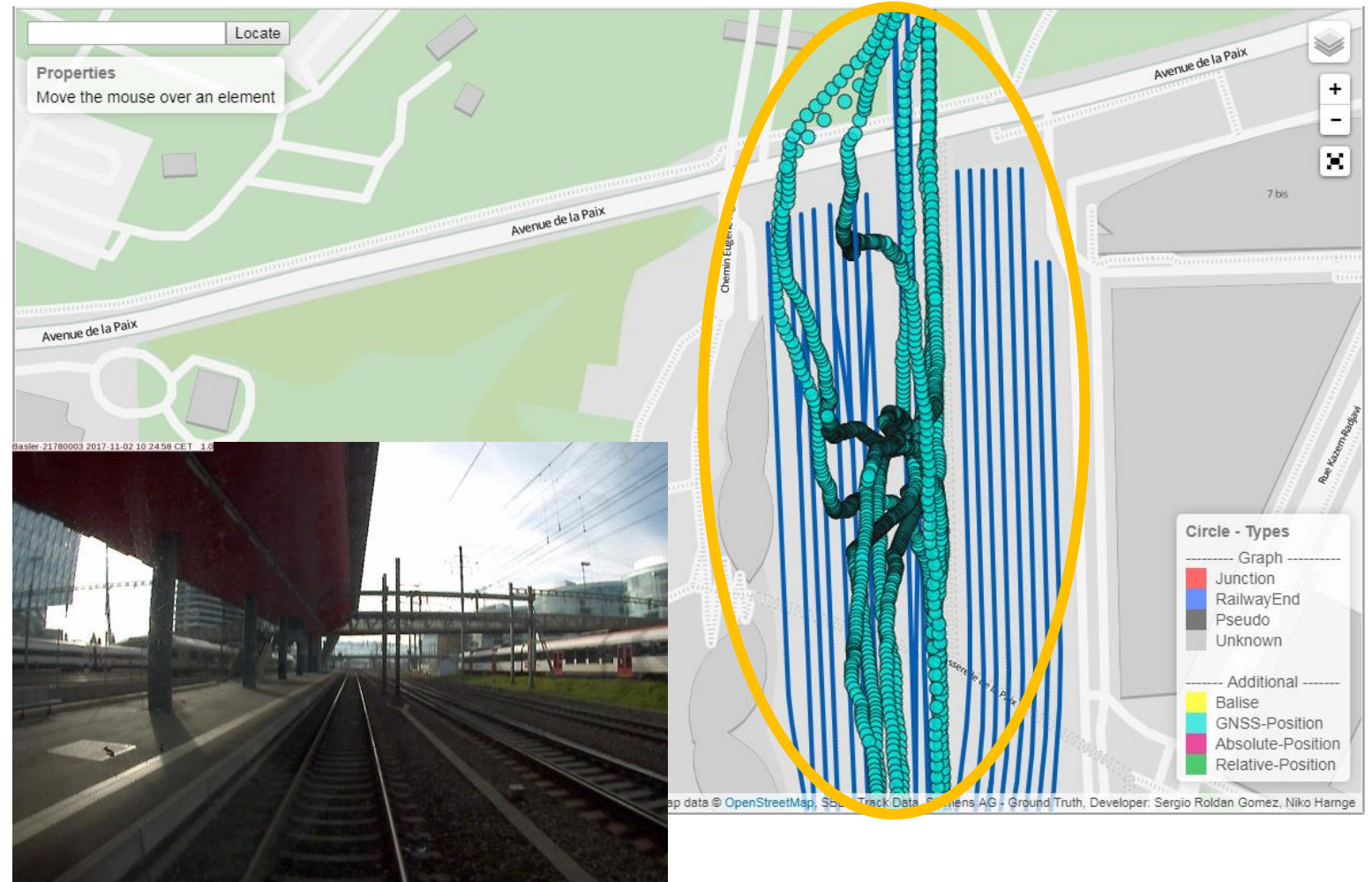

Basler-21780003 2018-05-30 19:31:52 CEST 1.0

Metal grid

• Data Analysis, Example Geneva

Significant position distortions have also been detected in the station of Genêve-Sécheron.
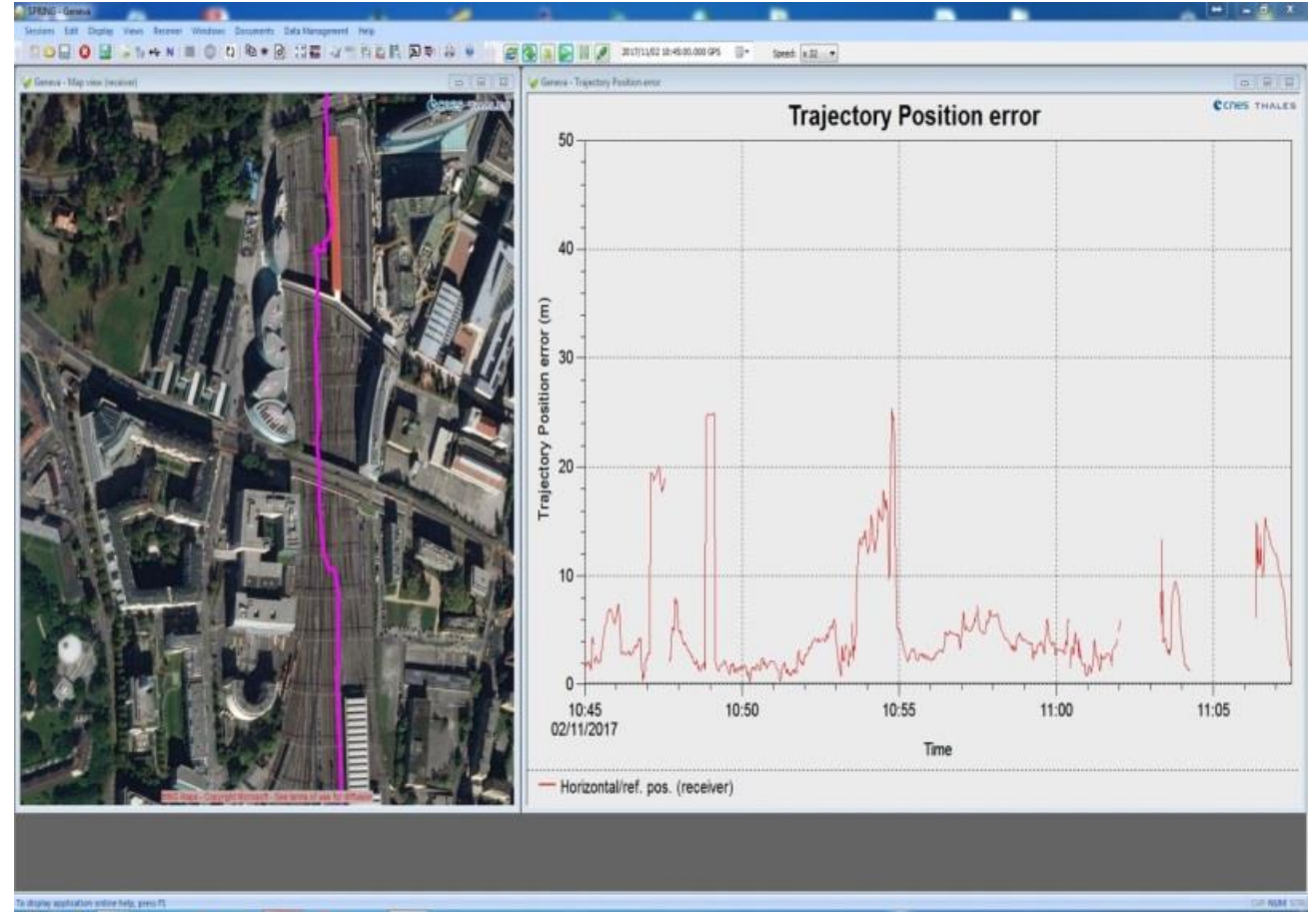
When looking at the pictures taken by the camera installed in the cab one can identify the platform roof which extends over the track and blocks the line of sight to many satellites.

• Data Analysis, Example Geneva

These distortions have been analysed with the SPRING tool provided by CNES, the French Centre National d'Études Spatiales.

• Data Analysis, Example Geneva

Raw data from this example reveals that the number of visible satellites remains sufficiently high.

The multipath plot on the other hand shows the presence of significant multipath.
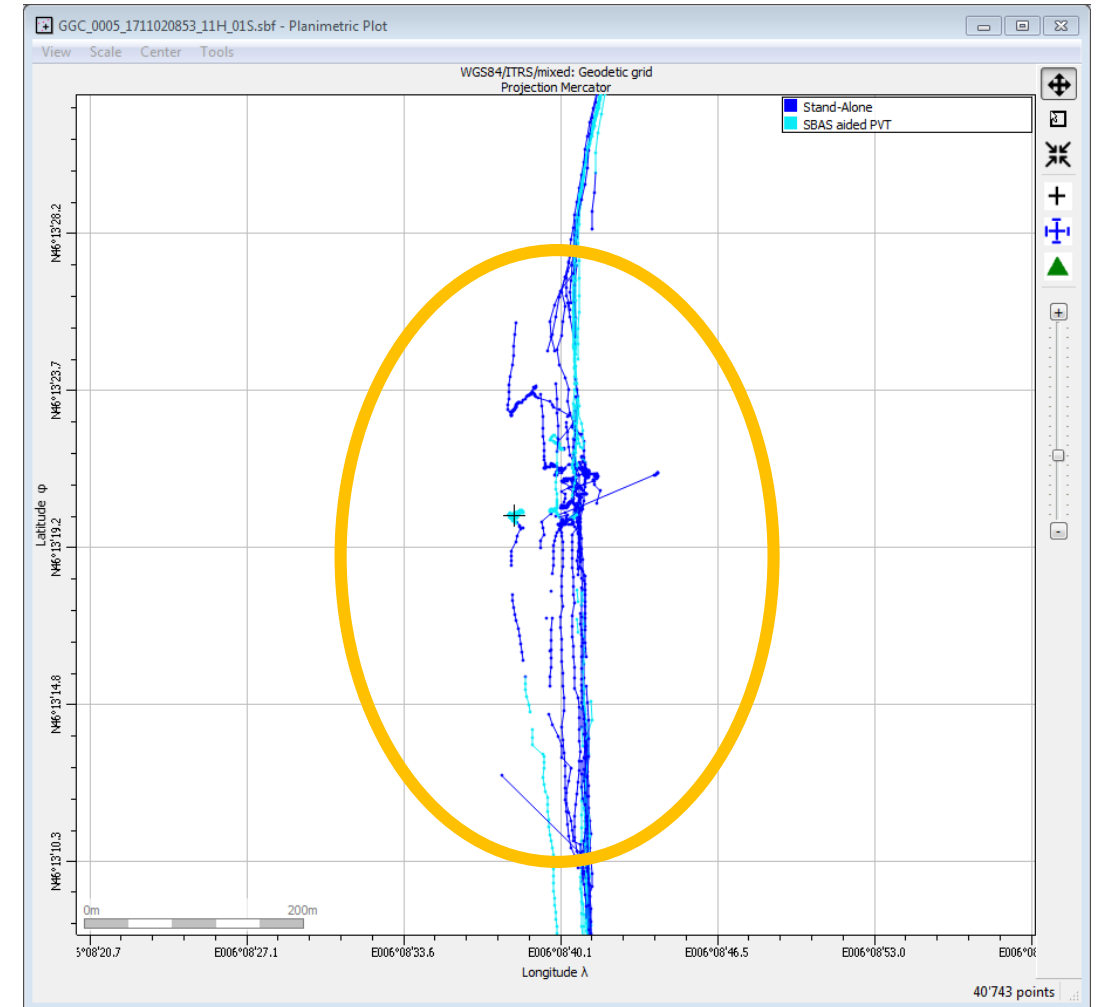
• Data Analysis, Example Geneva

Compared to the case in Renens, the high end Septentrio receiver continues producing position data, some of it with EGNOS corrections, but mostly without.

Lateral position errors in this case reach around 60 m, with offsets dominantly to the west.

• Data Analysis, Example Geneva

With the position errors overlaid onto Google Earth

Raw data analysis shows significant multipath, which is probably caused by a number of modern buildings adjacent to the track with curved, glass covered facades, forming perfect reflectors for GNSS signals.

• GNSS Application-Related Issues

Producing Ground Truth data has revealed some issues, which will have to be solved if GNSS shall be used:

- Data needs to be correct

- Data needs to be up to date at any given time

Most concepts to integrate GNSS into ETCS consider it necessary to have a route map on board the trains, this will require standardisation of both the database, and the management processes.
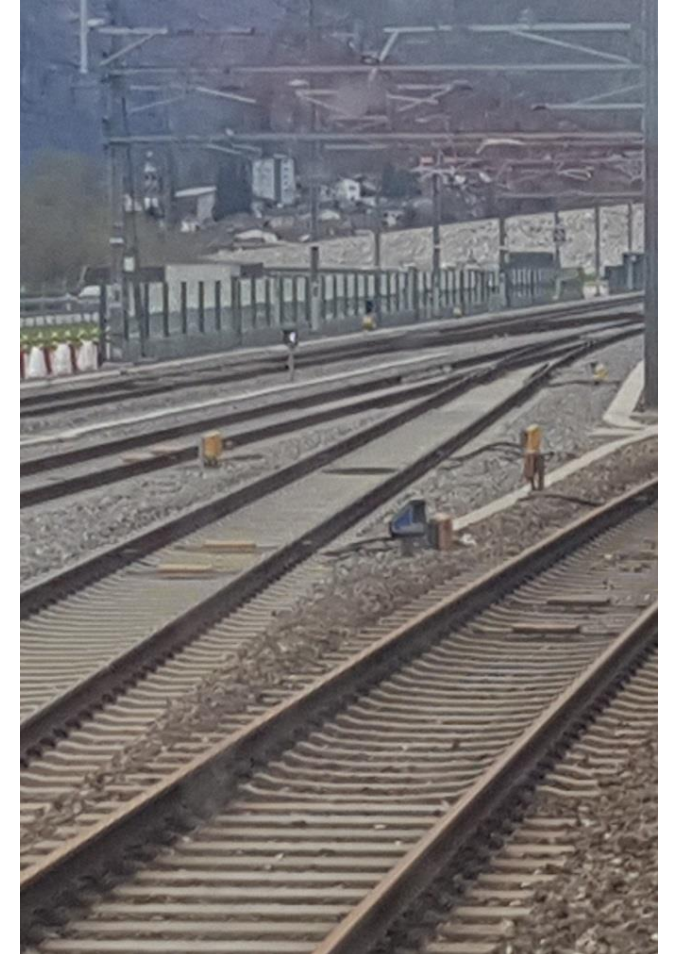
• Economical Analysis

GSA required the project to perform an Economical Analysis to demonstrate the benefits of using GNSS in railway applications.

This is done through a cost - benefit analysis, which obviously requires both cost assumptions and a quantification of benefits.

Unfortunately EU law does not allow participating signalling companies to share cost assumptions, as this might be seen as a form of price fixing.

Also cost and benefits depend significantly on the specific conditions of each application.

As a result the project produced a model to calculate the cost - benefit ratio, into which appropriate figures can be inserted on a project by project basis.

• Economical Analysis

One project partner produced cost - benefit calculations with the model developed, using realistic input parameters which were however not disclosed.

The results show that a positive benefit can be achieved if a majority of balises can be eliminated in ETCS Level 2 applications and only trains operating dominantly on the line have to be equipped with the necessary on-board equipment.

The results however also show that cost and benefit are unequally distributed, with infrastructure manager benefiting from eliminated equipment, while train operators have to bear most cost. A solution might therefore have to be found to share cost and benefits more evenly.
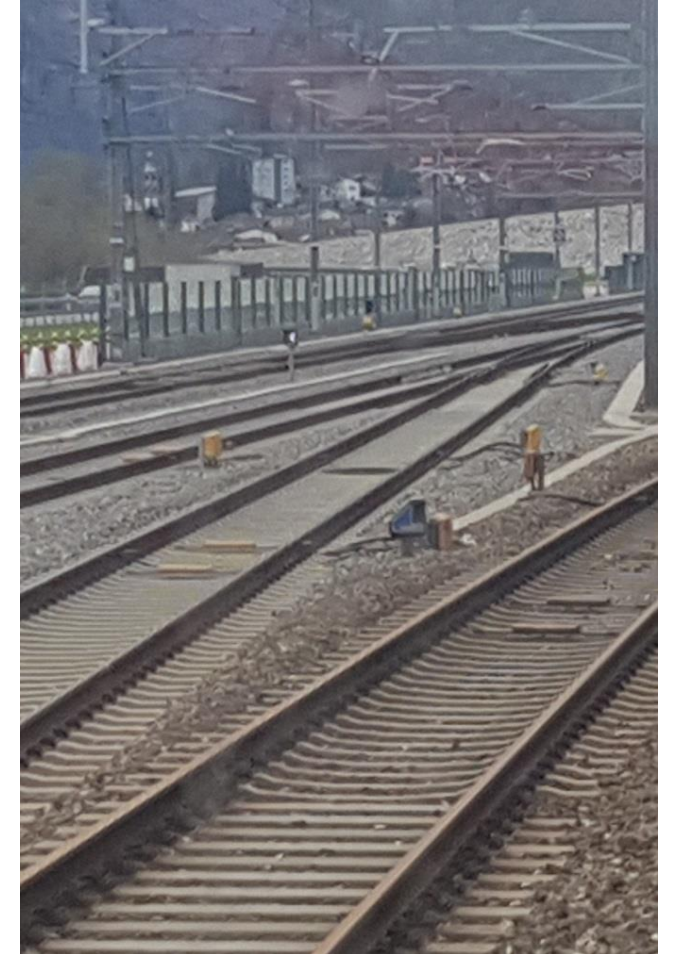
• Summary

There is potential for GNSS in safety critical applications in railway applications.

Compared to aviation, the railway environment is however much more challenging, and changing continuously beyond the control of the railways.

Sensor fusion and possibly map matching will probably be required in all but the most GNSS friendly environments.

Receiver functions will also be required to monitor the environment, and to improve the calculation of the Protection Level.

Finally a better way for distributing EGNOS than via geostationary satellites will have to be found.

• Summary

The final report from the STARS project will be delivered to GSA at the end of 2018.

The report will include detailed data on the achievable performance and on the coverage of GNSS in the railway environment, as well as on the impact of different environmental effects

Measures to improve the achievable performance will be identified, and a proposal made how to better incorporate EGNOS, including additional functions in EGNOS for safety critical railway applications.

Shift^{2}Rail will investigate these issues further, with the goal to deliver demonstrators of a GNSS based train positioning system.
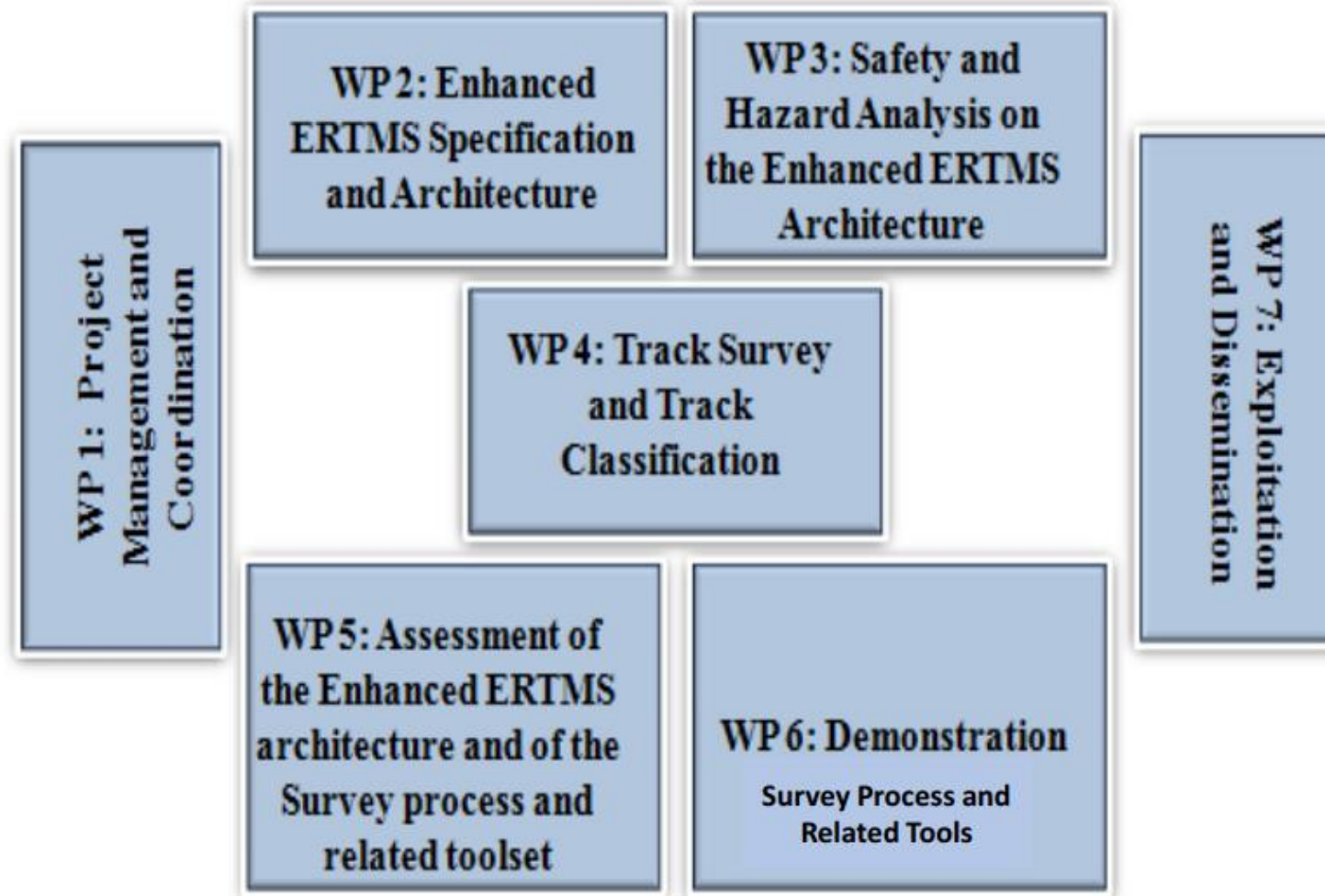
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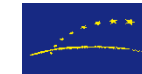
Innotrans 2018

Jose Bertolin Unife

Berlin, 19th September

WP Structure

Technical WPs Objectives

WP2 Enhanced ERTMS Specification and Architecture

- **Review of the Enhanced ERTMS Functional Architecture,** based on GNSS technology and the Virtual Balise concept, defined in other R&D projects;

- **Consolidation of the Enhanced ERTMS Functional Architecture** based on the GNSS localization and on IP based Public Mobile Radio Networks (Land and/or Satellite):

    - ✓ Signalling Functional and Not Functional Requirements;
    - ✓ Signalling Operational Scenarios;
    - ✓ Packets that can be sent via Virtual Balises;
    - ✓ Reference Mission Profile;
    - ✓ Impact Analysis on Current Operational Directive;
    - ✓ Migration Strategy.

- **Definition and development of the Functional and Not Functional Test Specification** to validate future new ERTMS systems based on the Enhanced ERTMS Functional Architecture.

Technical WPs Objectives

WP3 Safety and Hazard Analysis of the Enhanced ERTMS Architecture

Development of a **customized *Failure Mode, Effects, and Criticality Analysis (FMECA)* :**

- ✓ Identification of the hazards affecting Virtual Balise and Mobile Radio Network related functions

- ✓ Identification of Railway System level mitigations

WP4 Track Survey and Track Classification

- Definition of a **Standard Process, Methodology** and the related **Toolset** for Classifying Track Areas as **Suitable** or **Not Suitable for locating Virtual Balises** based on potential GNSS local threats.

- **Testing, Evaluation** and **Integration** of related Toolset in laboratory environment of partners.

Technical WPs Objectives

WP5 Assessment of the Enhanced ERTMS architecture and the survey process and related tools

To perform, according to the CENELEC rules, an independent **assessment** of:

- ✓ the **Enhanced ERTMS architecture** in order to evaluate its full **compliance** with **all applicable standards** and norms;

- ✓ the **process performed** and the **toolset** used for the realizing the survey of the track for their classification as good or not good for VB locations.

WP6 Demostration

According to WP4 and WP5 outcomes, **the measurement system shall be tested** on selected railway lines aiming at demonstrating the fulfilment of the expected results

- **The track survey on the field** according to the methodology and the toolset already defined, developed, and assessed;

- **The acquired field data analysis** in the CEDEX and RFI laboratories.

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