# EGNSS MATE: Towards accurate and reliable GNSS- and map-supported train localisation

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## EGNSS MATE project facts

EGNSS MATE (*European Global Navigation Satellite System based Map Assisted Train localisation for ERTMS*) contributes towards climate-friendly, cost-efficient, digital, interoperable, and safe European railways by researching and analysing advanced onboard train localisation with GNSS and other sensors.

The project partners comprise the Swiss Federal Railways (SBB) as railway operator, Industrieanlagen-Betriebsgesellschaft mbH (IABG) as GNSS and testing expert company, and the German Aerospace Center (DLR) as research institute with a transportation focus.

Figure 1: EGNSS MATE contributes to the safe and accurate localisation of trains using onboard data.

The project has started in 01/2023 and will conclude in 01/2025.

The focus of EGNSS MATE is onboard train localisation within the European Train Control System (ETCS) of the European Rail Traffic Management System (ERTMS). GNSS technology and map-supported multi-sensor fusion algorithms on all vehicles will facilitate moving block operation and thereby increase line capacities. Track-side infrastructure for localisation can be reduced, which translates to lower costs and more flexibility for operators. A prerequisite is the safe and accurate localisation of trains. Improved accuracy can be achieved by exploiting the track-constrained vehicle motion. Suitable map data need to be provided and tightly integrated into localisation algorithms. GNSS signals are transmitted over the air and received by onboard antennas. Although GNSS provides advantages for flexibility and ETCS interoperability, there are potential risks of signal interference. The thorough understanding of railway-targeted GNSS jamming and spoofing is needed to find safe and secure localisation solutions. Furthermore, advanced GNSS services (Galileo HAS, Galileo OSNMA) have good potential in aiding onboard localisation.

The above aspects are researched on actual measurement data from an SBB vehicle that traverses the entire SBB rail network.

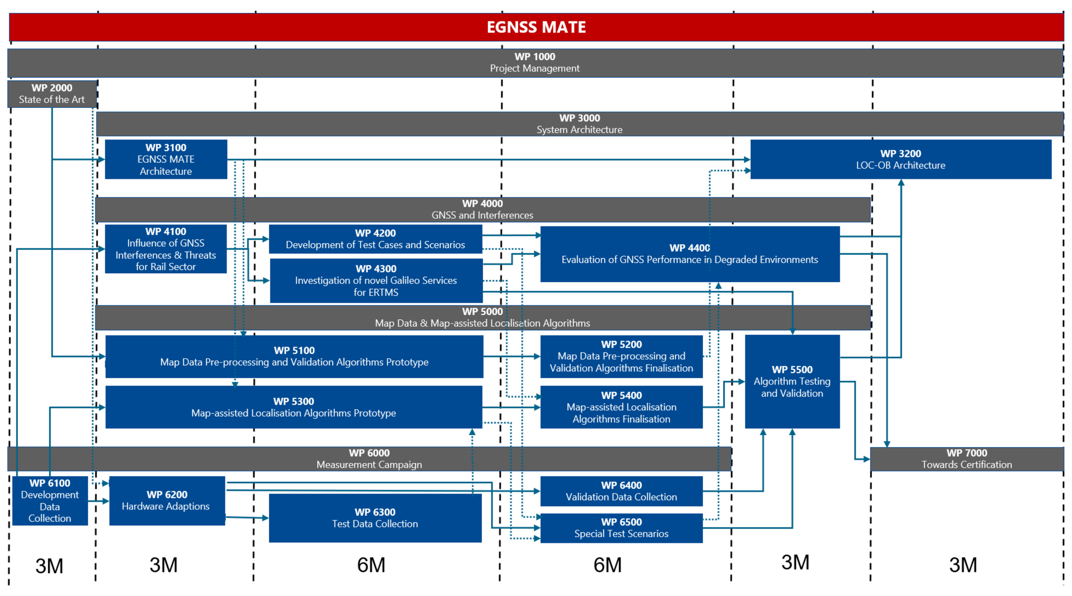


Figure 2: The EGNSS MATE work package structure

## State of the art and requirements

A state of the art work package has been included to understand the complex stakeholder landscape, to survey existing literature and project results, and to derive requirements.

Relevant stakeholders comprise railway and infrastructure operators, railway technology providers, political institutions and funding agencies, and research institutes. The relevant literature is spread over different communities (GNSS, railway, sensor fusion).

Requirements for the project work and beyond have been defined based on available results. Environmental conditions for the project localisation have been considered, including modes of vehicle operation (low and high density lines). Functional requirements on the data sources (map data, GNSS and multi-sensor data) and the localisation output (continuous at 10 Hz, restricted to track hypotheses, with confidence intervals) have been formulated.

## Architecture

EGNSS MATE contributes to a wider solution for onboard localisation for future implementations within ERTMS. Architecture aspects from the Open CCS On-board Reference Architecture (OCORA) are considered. Specifically, contributions to an onboard localisation unit (LOC-OB) are developed.

The EGNSS MATE architecture comprises onboard and back-office components. The onboard data acquisition is conducted with a number of sensors and systems that record time-stamped data. The onboard hardware utilised for localisation comprises GNSS, IMU and velocity sensors (wheel odometer, optical speed sensor). An independent set-up with high-quality GNSS, IMU, wheel odometry, and a Eurobalise reader is employed as data source for ground truth computation.

The onboard data are stored for offline access in a relational database. For the algorithm development and testing, a simulation environment is set up in the back-office. Simulation is understood as replay of onboard data streams so that localisation and integrity monitoring algorithms can be executed as if they were on an actual vehicle. Robot Operating System (ROS) is used.

## Advanced GNSS and interference

EGNSS MATE investigates radio-frequency interferences (RFI) affecting the GNSS signals and the potential added value of the Galileo High Accuracy Service (HAS) and the Galileo Open Service Navigation Message Authentication (OSNMA).

Earlier, RFI had mainly concerned armed forces. Nowadays, intentional jamming and spoofing of GNSS receivers are potential threats to the operation of a dense railway system. Jamming describes a threat case or single event in which an entity intentionally tries to prevent a GNSS processing device from receiving satellite signals by transmitting an interfering higher power signal in the respective radio frequency bands. Spoofing is a method that intentionally emits an imitated satellite signal towards the receiver forcing it to calculate erroneous position, velocity, or time (PVT) solutions. Jamming activities target degrading the GNSS availability, spoofing targets degrading the GNSS integrity.

An analysis of a one-year long data set of GNSS receiver recordings collected on an SBB wagon traveling across Switzerland has been performed. It has revealed multiple RFI occurrences and allowed to infer correlations between RFI events and anomalies in the GNSS data. Dedicated jamming and spoofing experiments are in preparation at the moment.

## Map data and map-supported sensor fusion

Localisation in the rail domain is challenging for many regulatory and technical reasons. There is no standalone onboard system (only GNSS or only odometry) that can provide safe and accurate estimates at the required availability. A combination of onboard sources must be used.

Onboard sensors and systems have individual error characteristics. GNSS requires signal reception, which is often compromised (tunnels, urban areas). Inertial measurement units (IMU) measure accelerations and turn rates. IMU exhibit typical bias errors that slowly drift over time. Calibration is required. Velocity sensors based on wheel rotation are affected by slip and slide phenomena. Optical or radar velocity sensors can exhibit errors that depend on weather conditions.

Rail vehicle motion is constrained to paths in the railway network. Transitions from track to track can occur only at switches. There is much potential in utilising this information. Therefore, SBB map data is pre-processed for tight integration into the localisation algorithms.

The combination of onboard sensor and system data is achieved with tools from the field of statistical sensor fusion. Specifically, Kalman filter approaches (KF) are investigated. KF advantages include modularity with respect to available sensors, separate modeling of the state evolution and the measurements, and the capability to embrace uncertainties (measurement/noise/result covariance matrices). Vehicle motion along discrete paths in the network cannot be achieved with one KF alone. However, KF banks can be employed. Here, a KF bank maintains a list of current path hypotheses. Each hypothesis has an on-path KF in which the position represented as a scalar distance.

EGNSS MATE follows a timely and collaborative approach in the algorithm research by developing open-source software. A DLR localisation toolbox for expert users will be published within the project.

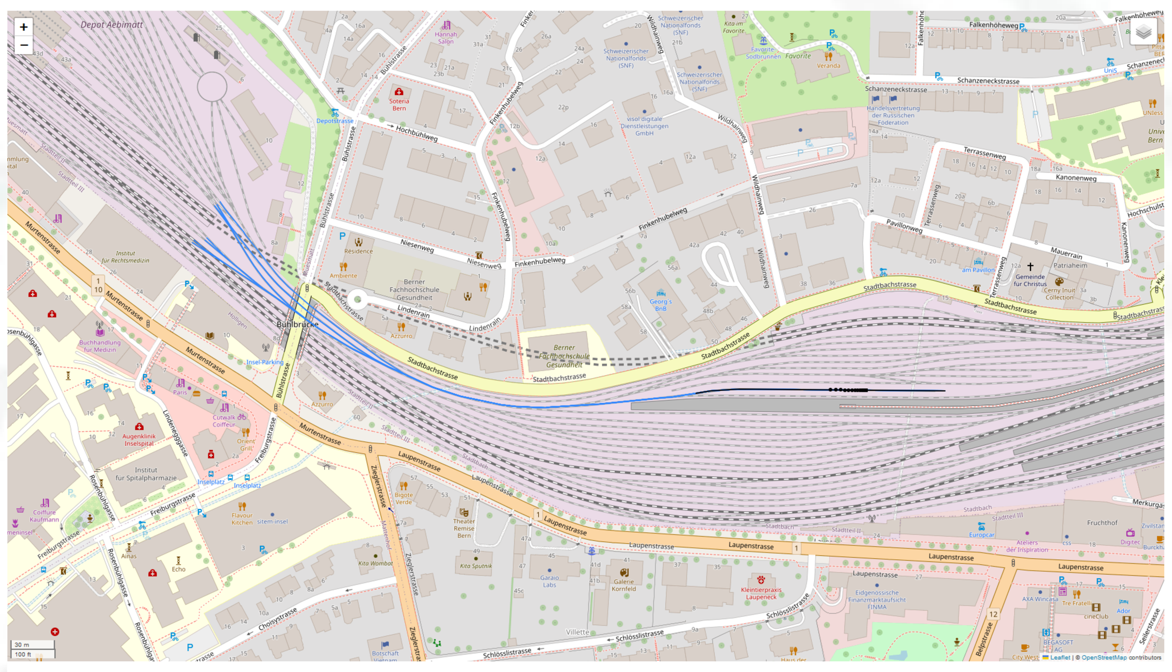

Figure 3: Examples of possible path hypotheses (blue) that can be reached by extending an initial track (black).

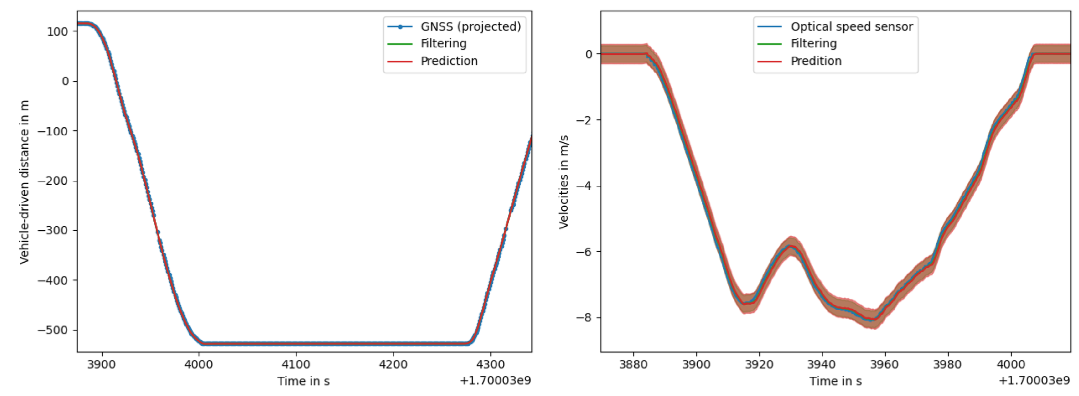


Figure 4: Example localisation results (distances, velocities) from an on-path Kalman filter.

## Measurement campaigns

Data are continuously recorded with the aforementioned GNSS and sensors on an SBB vehicle that traverses the entire SBB network. In addition, dedicated GNSS test campaigns are performed. In November 2023 data for OSNMA availability, RFI threat identification, and specifically challenging localisation environments (alpine, urban, shunting) have been recorded. Jamming and spoofing tests are in preparation for May 2024.

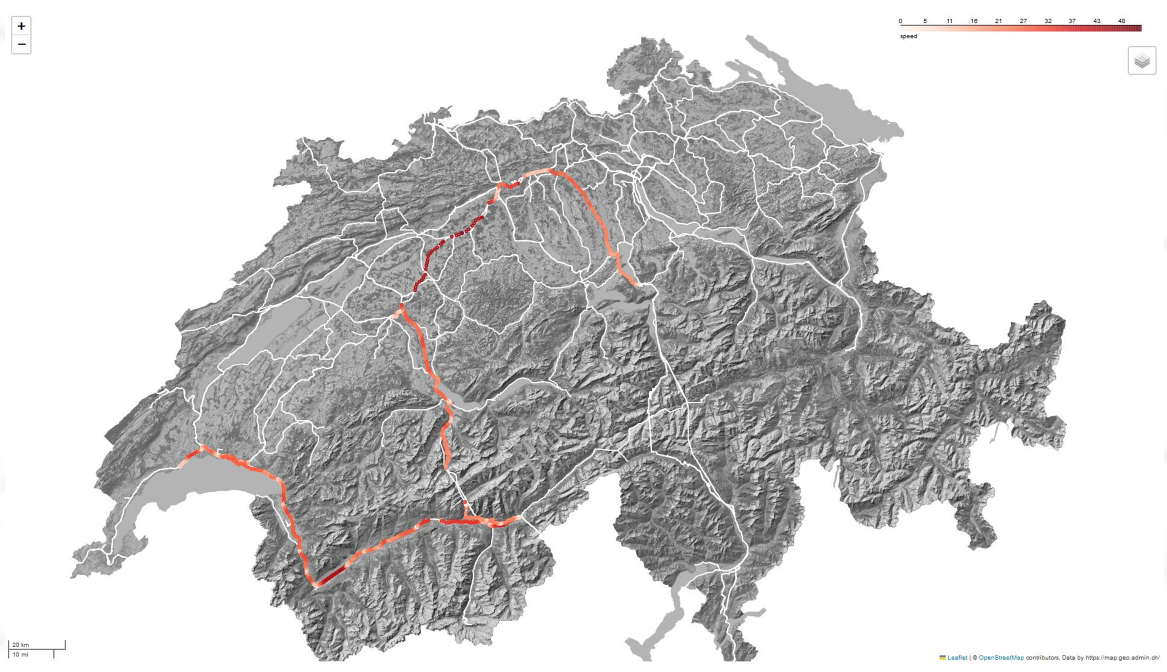

Figure 5: Coverage of the November 2023 measurement campaign.

## Concluding remarks

The activities in EGNSS MATE foster the use of GNSS- and map-supported onboard localisation within ERTMS/ETCS. Our TRA paper provides further information about the project context and the individual work packages.

EGNSS MATE is ongoing at full pace and planned to conclude in January 2025. The insights and results of the project will aid in the implementation, GNSS testing, and certification ambitions in the railway stakeholder landscape. With the complex challenges at hand (from large-scale real-world sensor and map data to localisation filter banks, from jamming and spoofing to Galileo HAS and OSNMA) follow-up activities will soon be initiated.

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