CLUG project overview

VALENTIN BARREAU, SNCF
CLUG PROJECT COORDINATOR

CLUG WEBINAR 09/06/2022

CONTEXT AND AMBITIONS

- **Context**
  - ERA report from 2015: the train-borne localisation function based on satellite positioning is a game changer
  - EU parliament report from July 2021: call for a joint effort towards the introduction of GNSS in the ERTMS deployment
  - European Green Deal

- **Our ambitions**
  - Driven by the European context for interoperability, sustainability and digitalization that rail is currently moving to.
  - To decrease the cost of the ERTMS signaling system

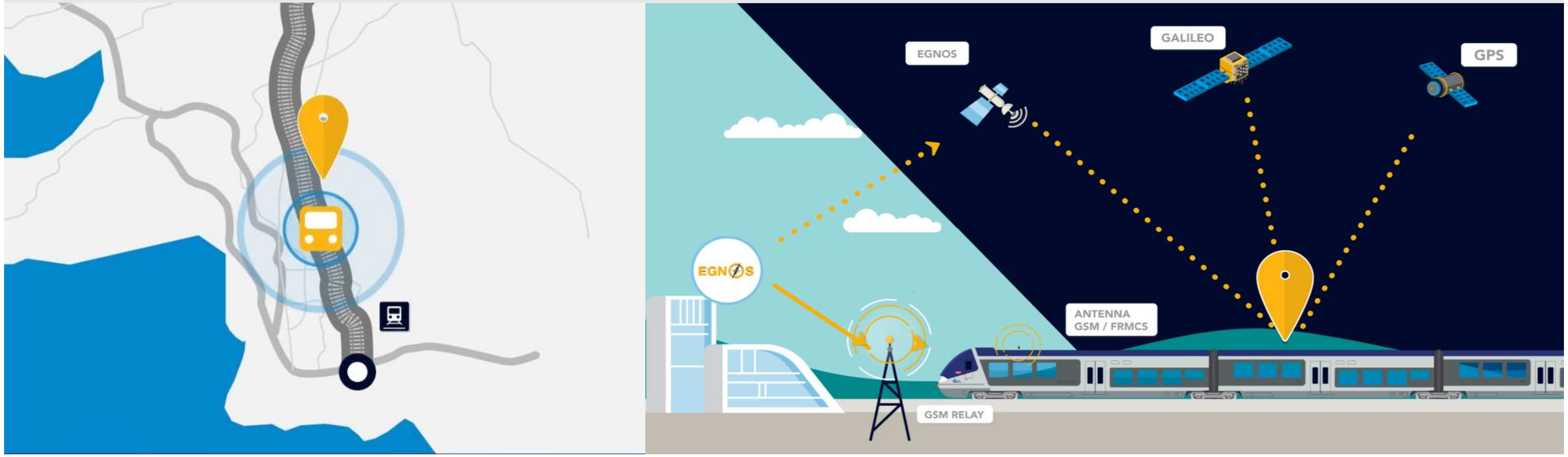
A NEW APPROACH FOR TRAIN LOCALISATION

- **Our goals**

To move ERTMS away from trackside-based train detection systems to onboard safe navigation systems using multi sensor fusion with European Global Satellite Navigation System EGNSS

- **Challenges:**

Delivering a solution with the performance and safety levels required in railway
→ SIL4 safety level: much higher safety level than in aviation or automotive

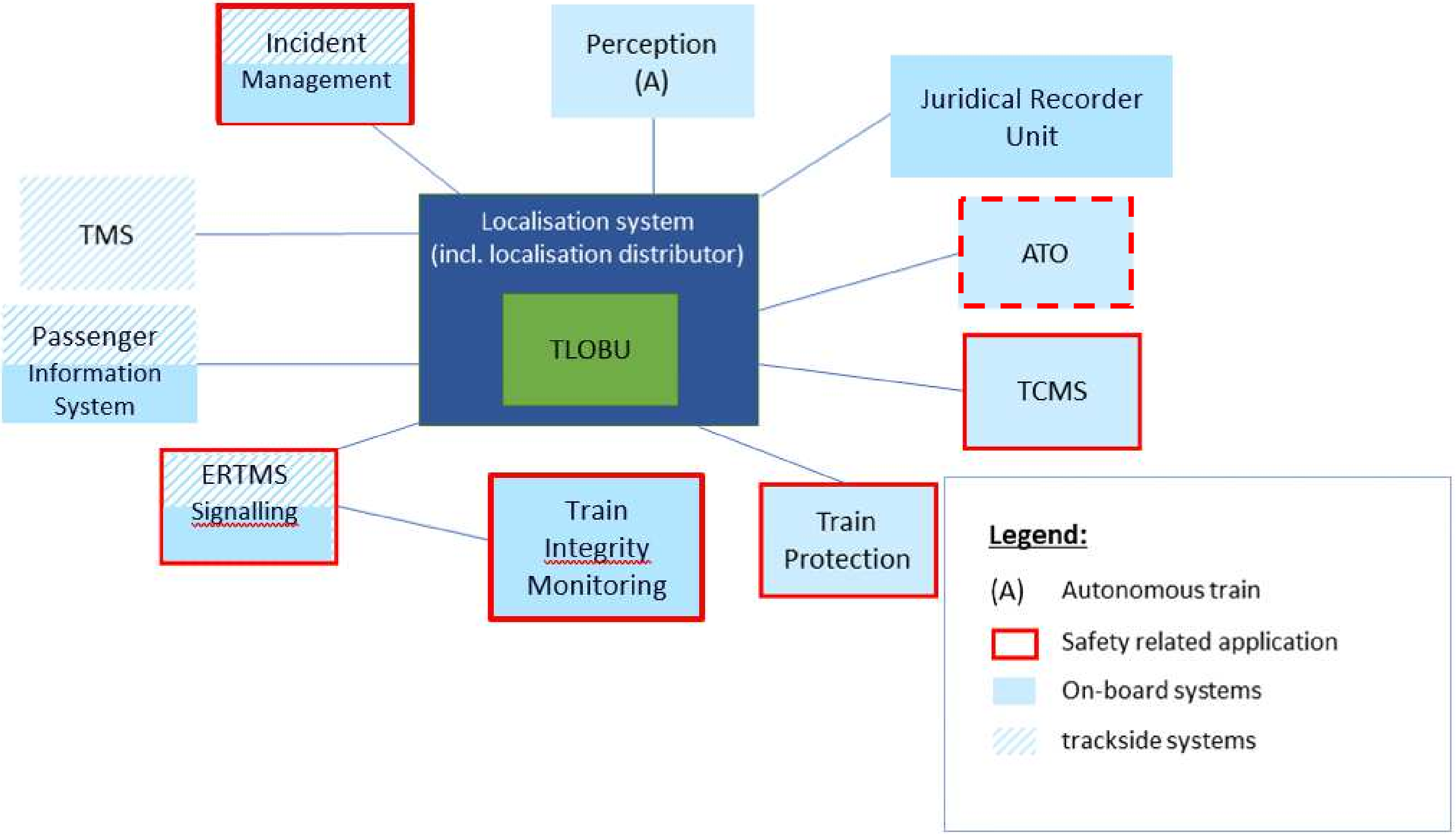


A NEW APPROACH FOR TRAIN LOCALISATION

- **Safe onboard localization unit**
  - **What for?**
    - To have a solution oriented towards the needs of the future railway system
  - **What needs?**
    - Optimise the line capacity by reducing headways between trains.
      - Facilitator of ERTMS L3 Moving Block
    - Need for a cheaper signalling system,
      - Less Eurobalises and other track equipment to improve the economic balance
    - Need for advanced traffic management and controls
    - Need for better customer satisfaction
      - by enabling comfort functions such as real time train tracking

A NEW APPROACH FOR TRAIN LOCALISATION

- **A solution for which applications?**



A NEW APPROACH FOR TRAIN LOCALISATION

- **The economic model:**
  - Balance to be found between the costs of the infrastructure managers (IM) and the costs of the railway undertakings (RU)
    - Reducing the trackside equipment decrease the CAPEX and OPEX costs for the IM
    - Changing the onboard system may increase the costs for RU
  - To achieve this transformation, the onboard localization system must remain affordable
  - Economic analyses are on going on operator side

THE CLUG PROJECT OBJECTIVES

Goal: to perform a mission analysis and a preliminary feasibility study of a failsafe on-board multi-sensor localisation unit

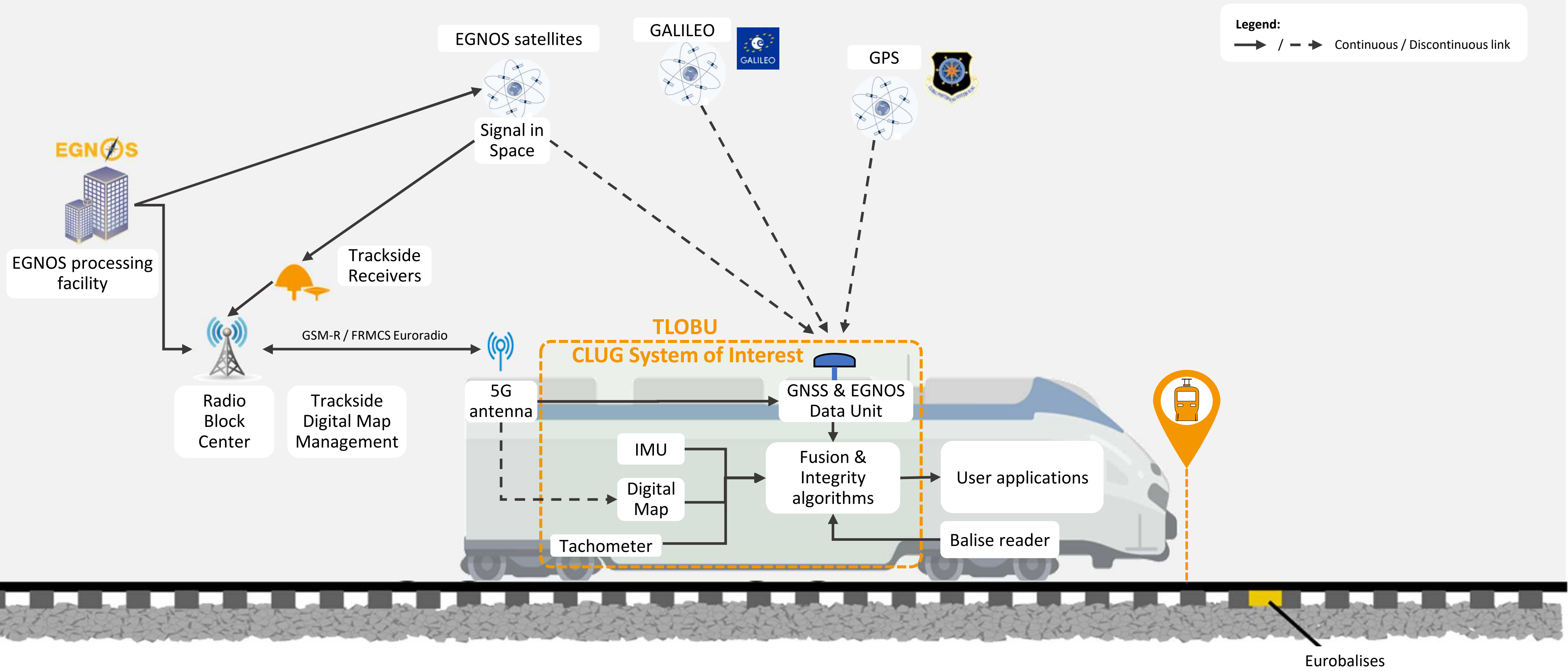
Mission requirements definition.

Architecture definition and algorithm proof of concept development

Definition of a process for prototypical certification of the localisation unit

Demonstration of the feasibility of a multi-sensor approach

THE CLUG CONCEPT



CLUG PROJECT IDENTITY

Funded by the European Union Agency
for the Space Programme (EUSPA)
Grant agreement number 870276

30 months
December 2019 – May 2022

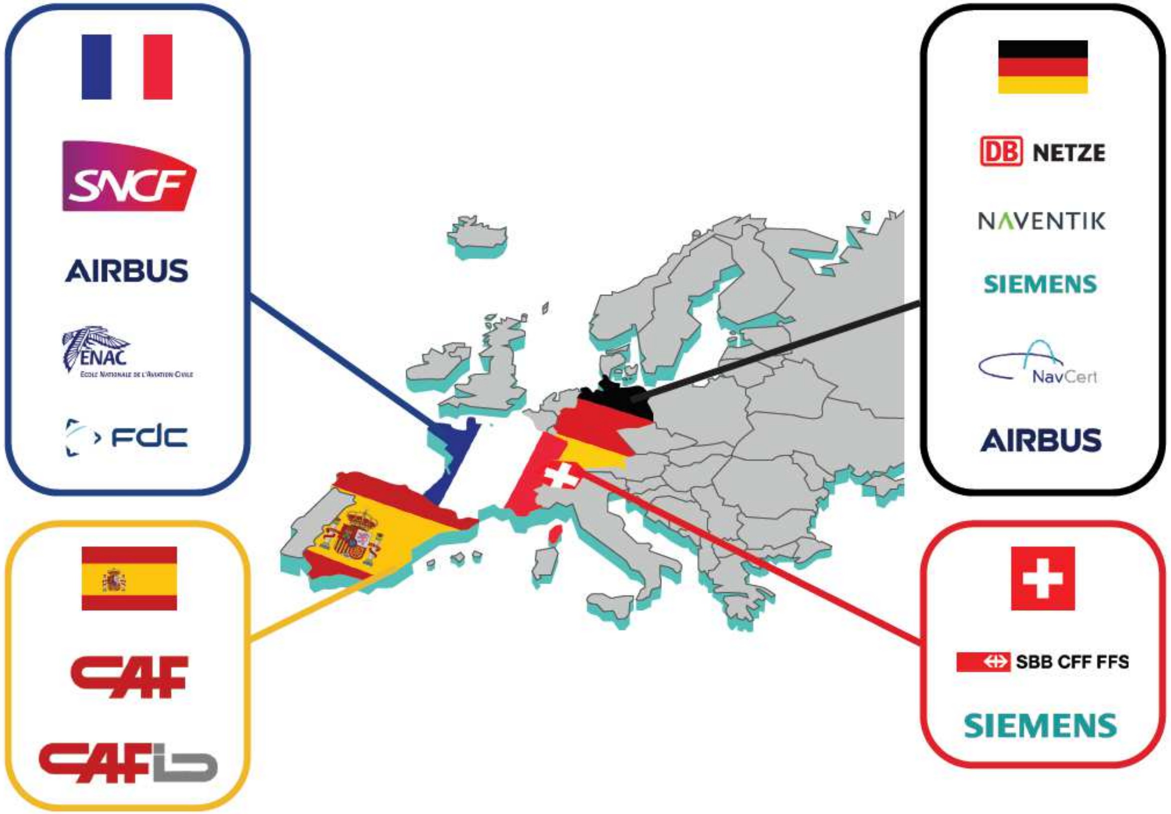
Project cost

3 804 327€
30% companies investment,
70% EC subvention

http://clugproject.eu/
https://www.linkedin.com/company/the-clug-project

CLUG CONSORTIUM

- **4 countries**
- **10 companies with expertise in**
    - Railway systems & operation
    - Aeronautics & Railway safety
    - Navigation expertise
    - Certification



CLUG WP ORGANISATION

CLUG PROJECT

- **WP1**
  Project Management and coordination
- **WP2**
  Mission definition and System requirements
- **WP3**
  Localization System Design
- **WP4**
  Testing and evaluation
- **WP5**
  Application to the Train Localisation System

ANY QUESTIONS

Valentin BARREAU - CLUG Project Coordinator

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CLUG TIMELINE

12.2019
- Project kick off

07.2020
- Data collection plateforme validation

09.2020
- Start of the measurement campaign

11.2020
- Mission and system requirements definition
- Preliminary Architecture design

09.2021
- Certification methodology
- Archi design definition
- Analysis tool validation

02.2022
- RAMS analysis and performances

04.2022
- Test campaign performance evaluation
- Certification principle analysis

05.2022
- Project public result publication
- Final Event

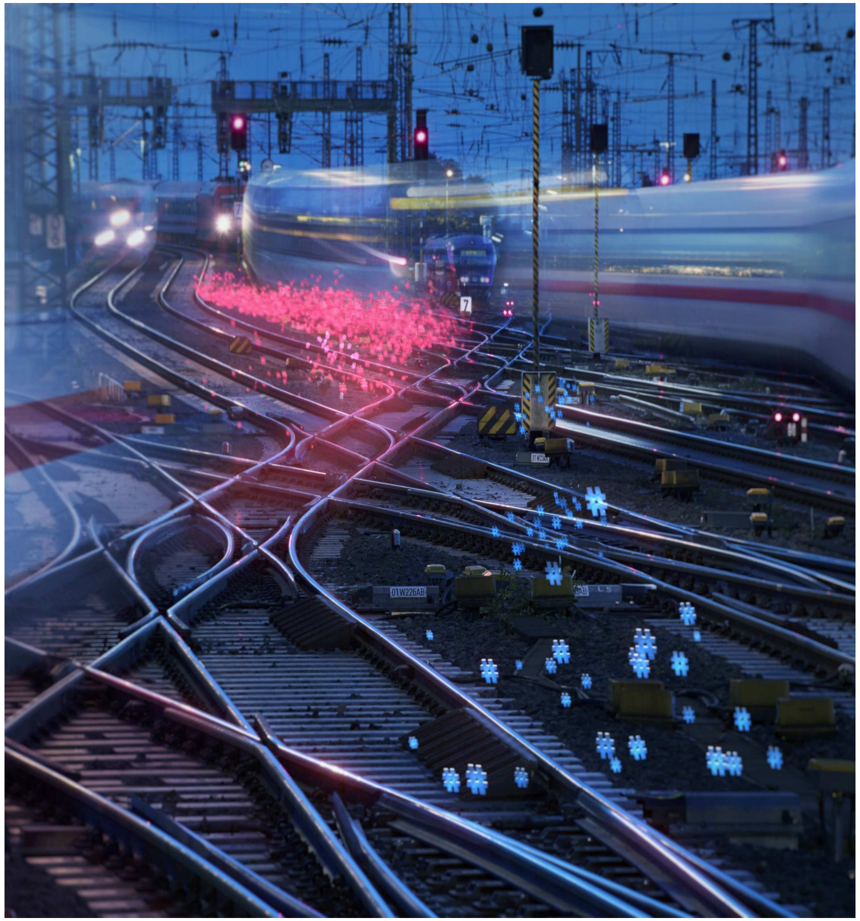
Localisation needs of the railways and System requirements

Muthukumar kumar, CLUG technical manager,

DB Netz AG

AN INNOVATIVE APPROACH FOR TRAIN LOCALISATION

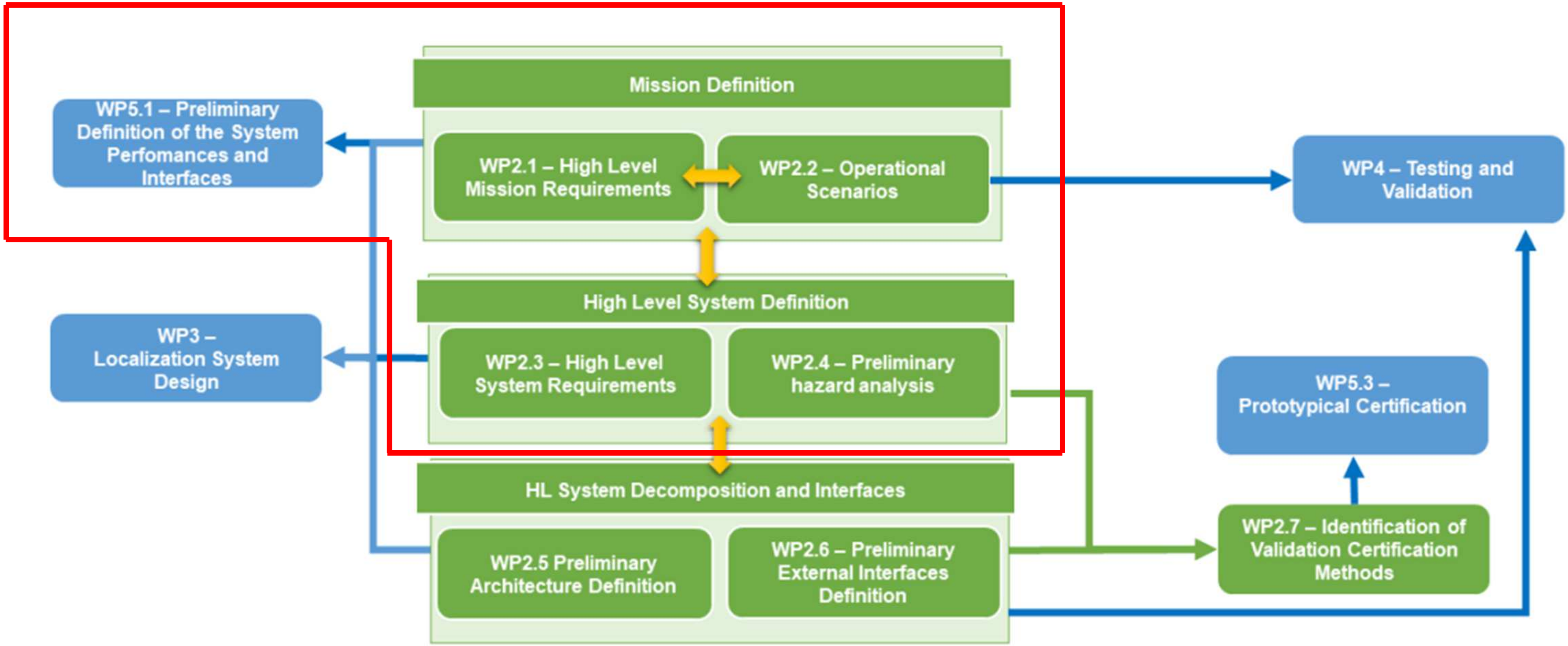
Our vision:
Bring the ERTMS/ETCS train localisation system to a new era with an innovative multi-sensor approach using digital maps and European satellite navigation system (GNSS)



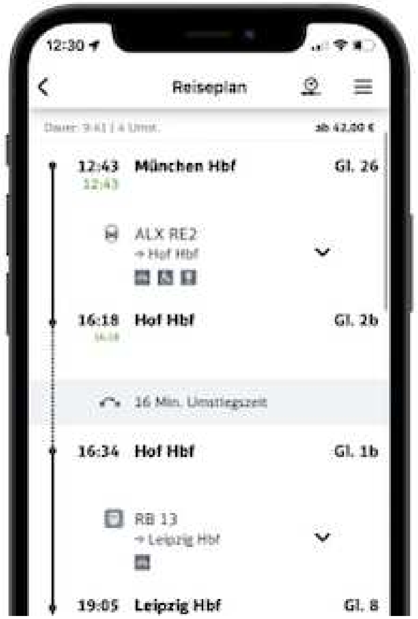
Localisation as a key enabler:

- Foster concepts such as intelligent traffic management, automated train operation (GoA2 to GoA4), ERTMS/ETCS Level 3
- Improve operational quality through localisation performance
- Decrease capital expenditure (CAPEX) and operational expenditure (OPEX) of field elements needed for localisation, e.g. less Eurobalises
- Standardised interfaces to enable modularisation of ETCS On-Board

WORK PACKAGE LOGIC AND SCOPE



LOCALISATION INFORMATION FOR PASSENGERS



DRIVERS FOR THE FUTURE DIGITIZED RAILWAYS

Capacity

Reliability

Efficiency

Innovation

LOCALISATION IS A CORE FUNCTION IN THE RAILWAY ARCHITECTURE

Localisation

Moving block operations
- Train protection
- Train control

Highly automated train operations
- Automatic Train Operations (ATO)
- Traffic Management

Fully automated train operations
- Obstacle detection
- Incident management and Perception

Passenger / Customer-oriented applications

LOCALISATION & FUTURE RAILWAY ARCHITECTURE

Reliability issues of odometry

Dependency on trackside infrastructure elements

Continuous and fail-safe localisation

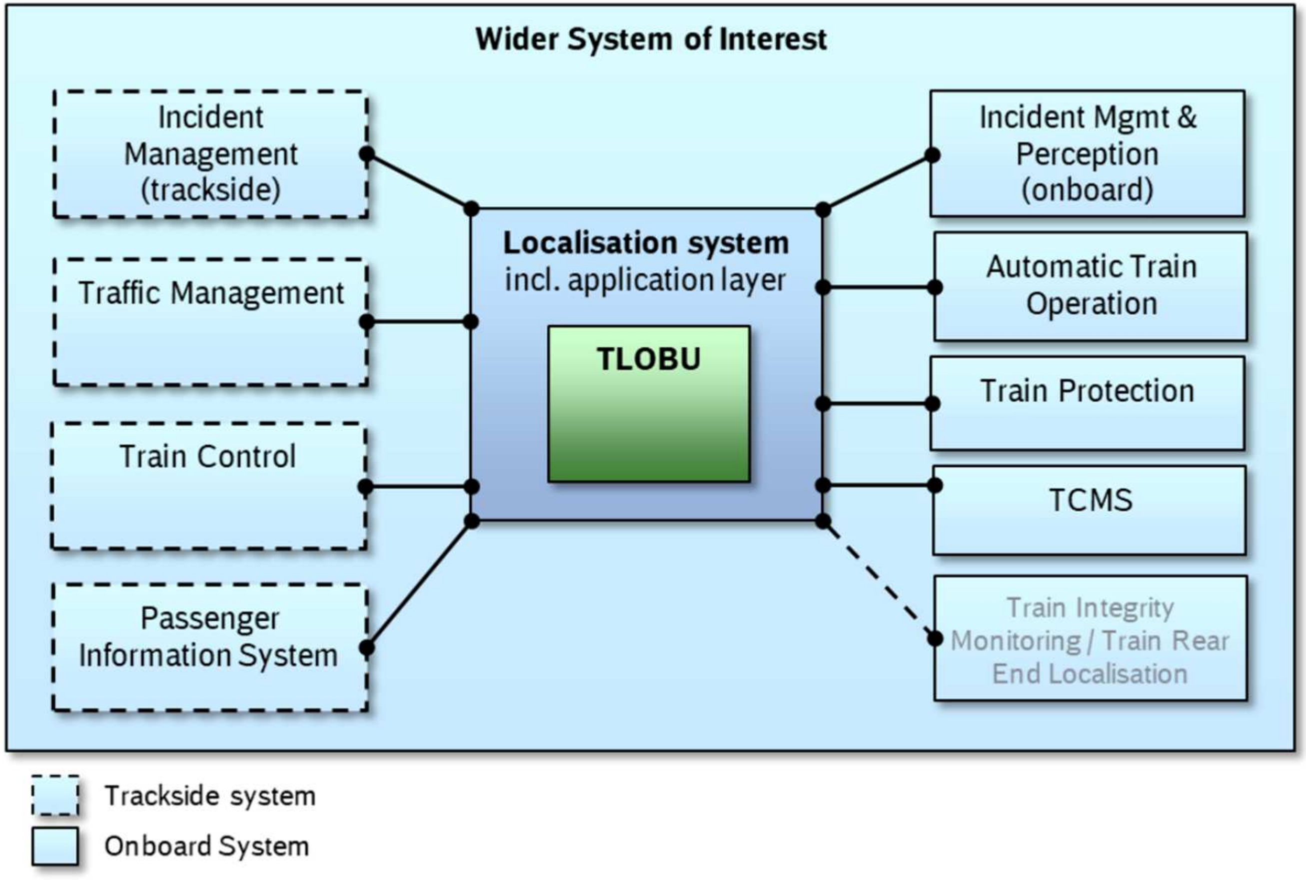
Intelligent traffic management systems

Train Localisation in Global Coordinate System

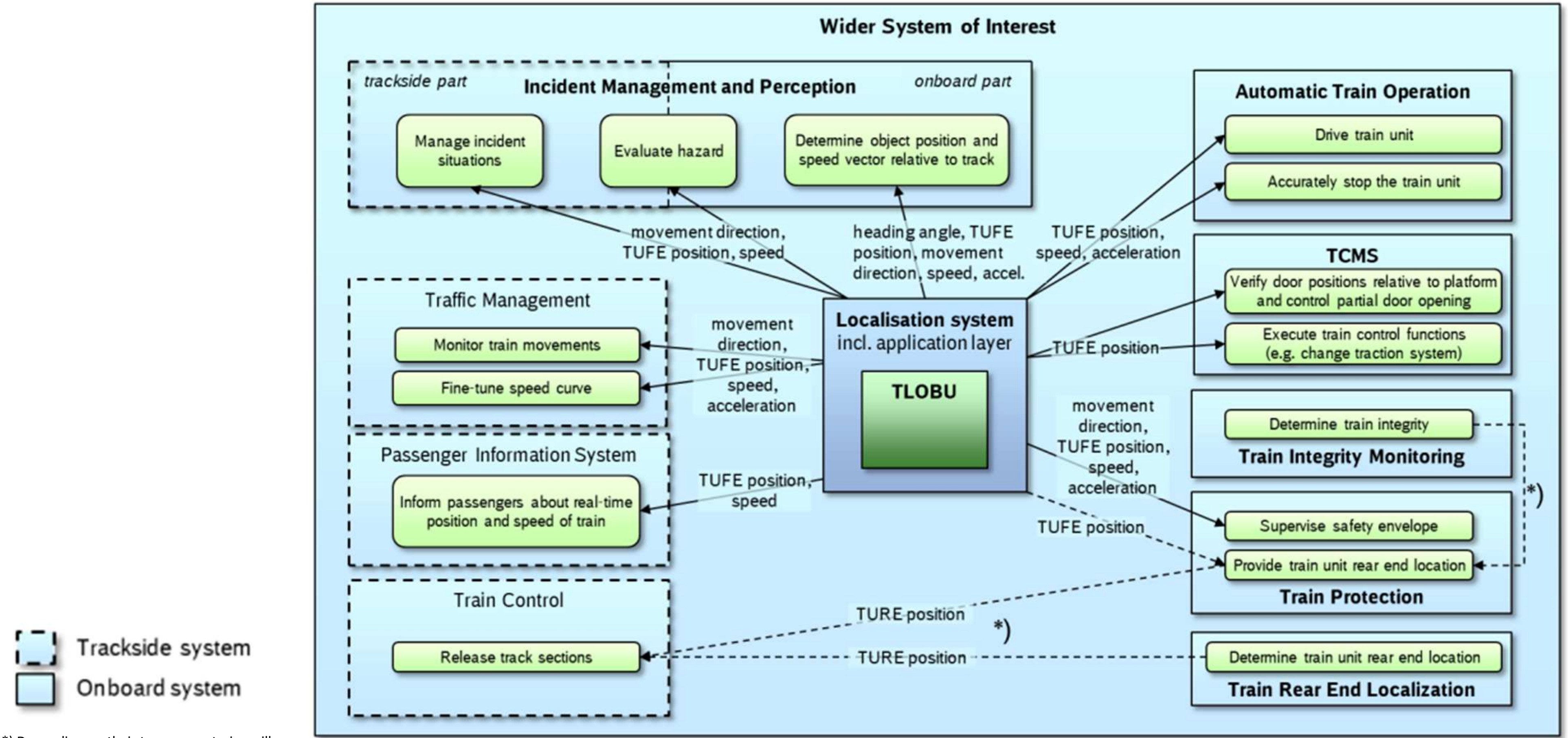
Today

Digitalised Railways of the future

SYSTEMS THAT REQUIRE LOCALISATION INFORMATION

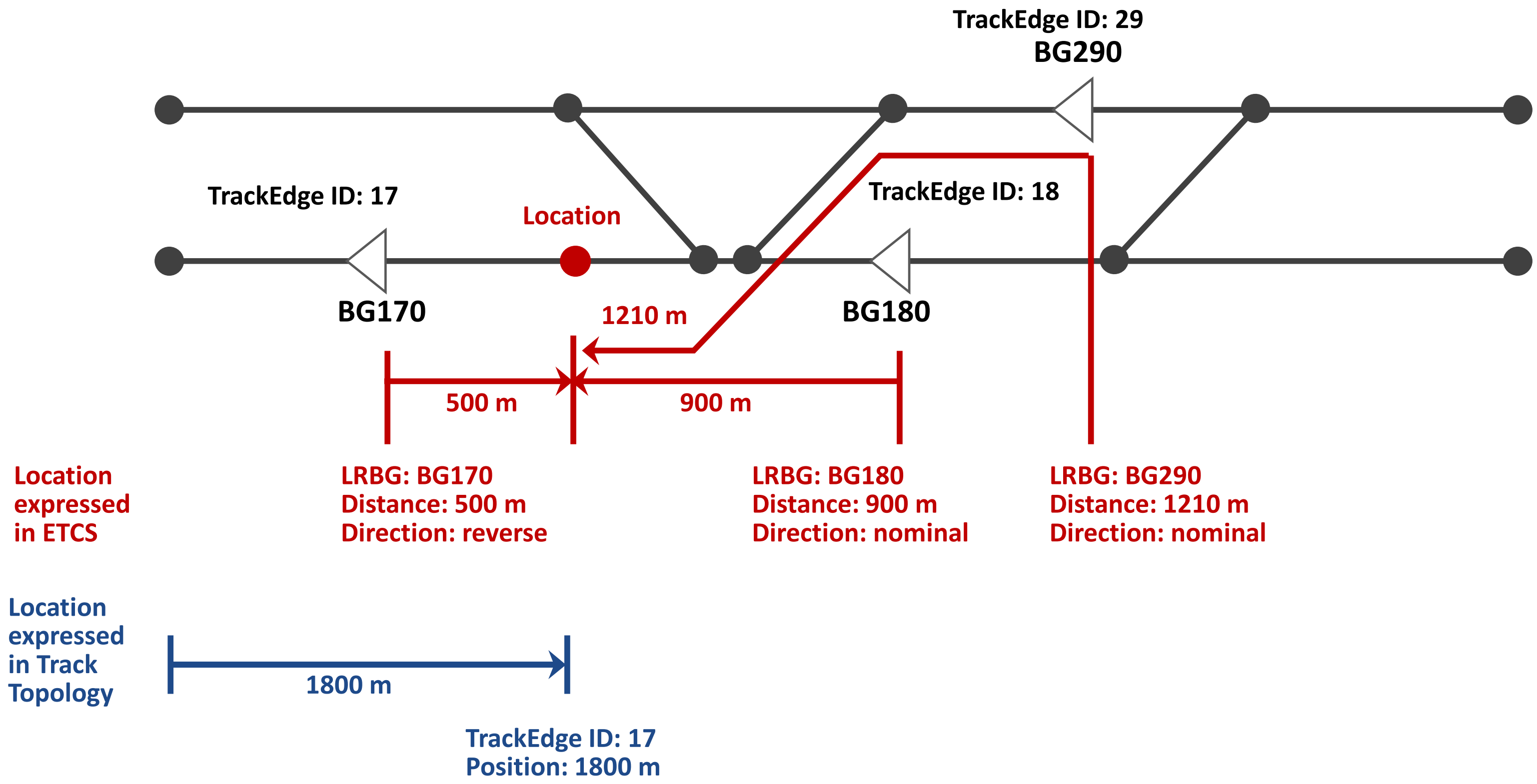


WIDER SYSTEM OF INTEREST

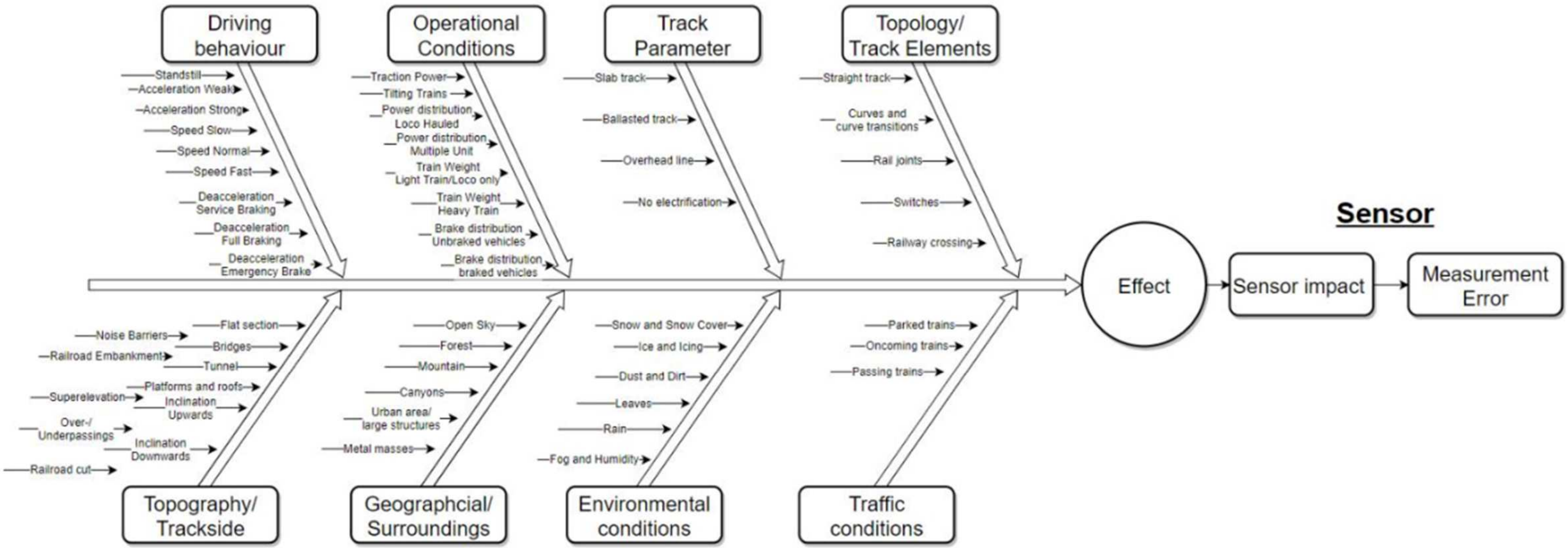


*) Depending on their type, some trains will determine their rear end indirectly with help of train integrity monitoring and others by a dedicated rear end localization system. The exact distribution of functions for this purpose is outside the scope of CLUG. (see 2.1.5)

DIGITAL MAPS AS REFERENCE POINT



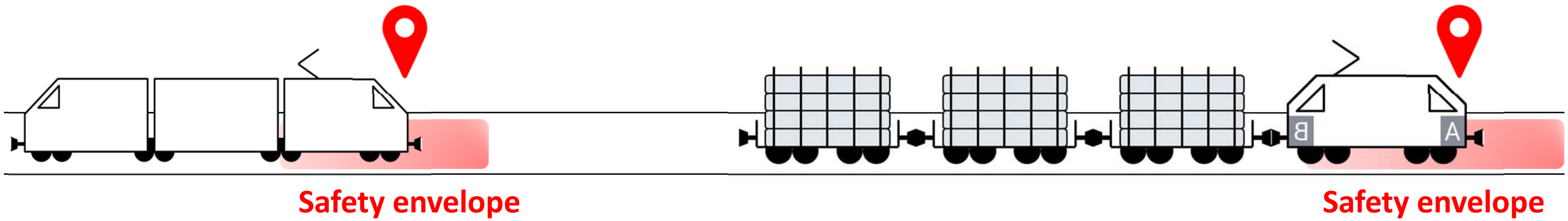
OPERATIONAL SCENARIOS



CAPACITY TARGET TO LOCALISATION ACCURACY

The **safety envelope** in advance of the train must not be enlarged by more than 1s by the under-reading amount of the TUFE.

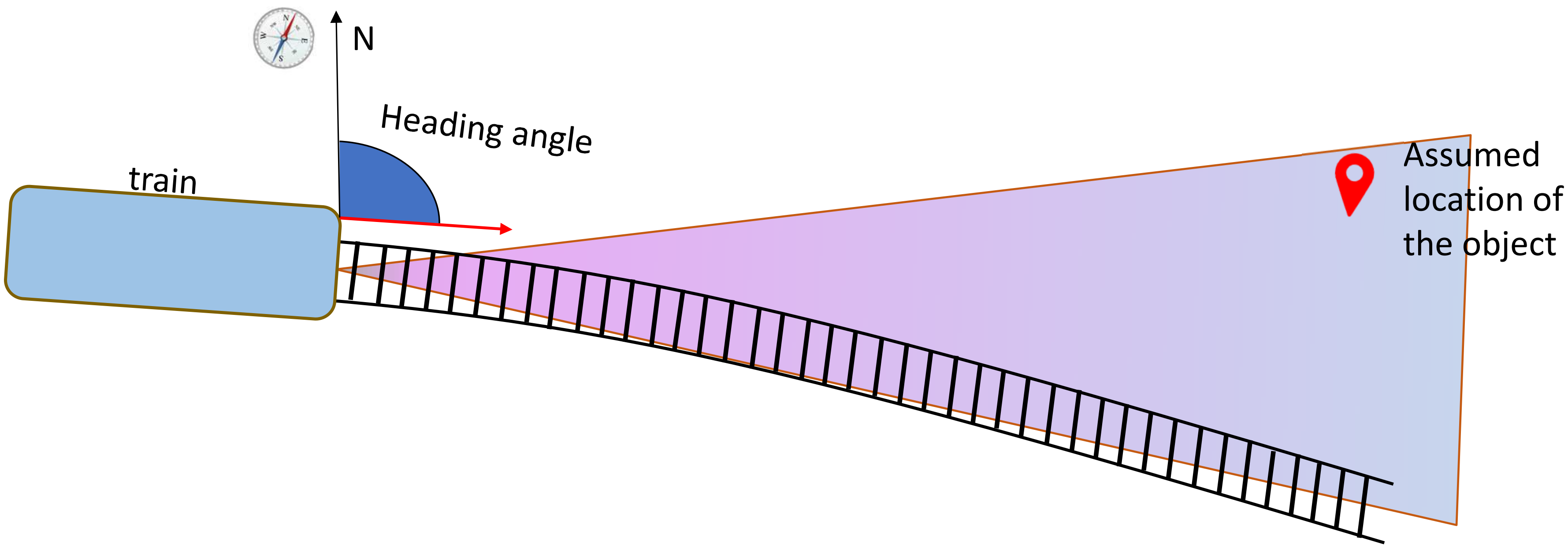
Speed dependent localisation accuracy for meeting capacity target



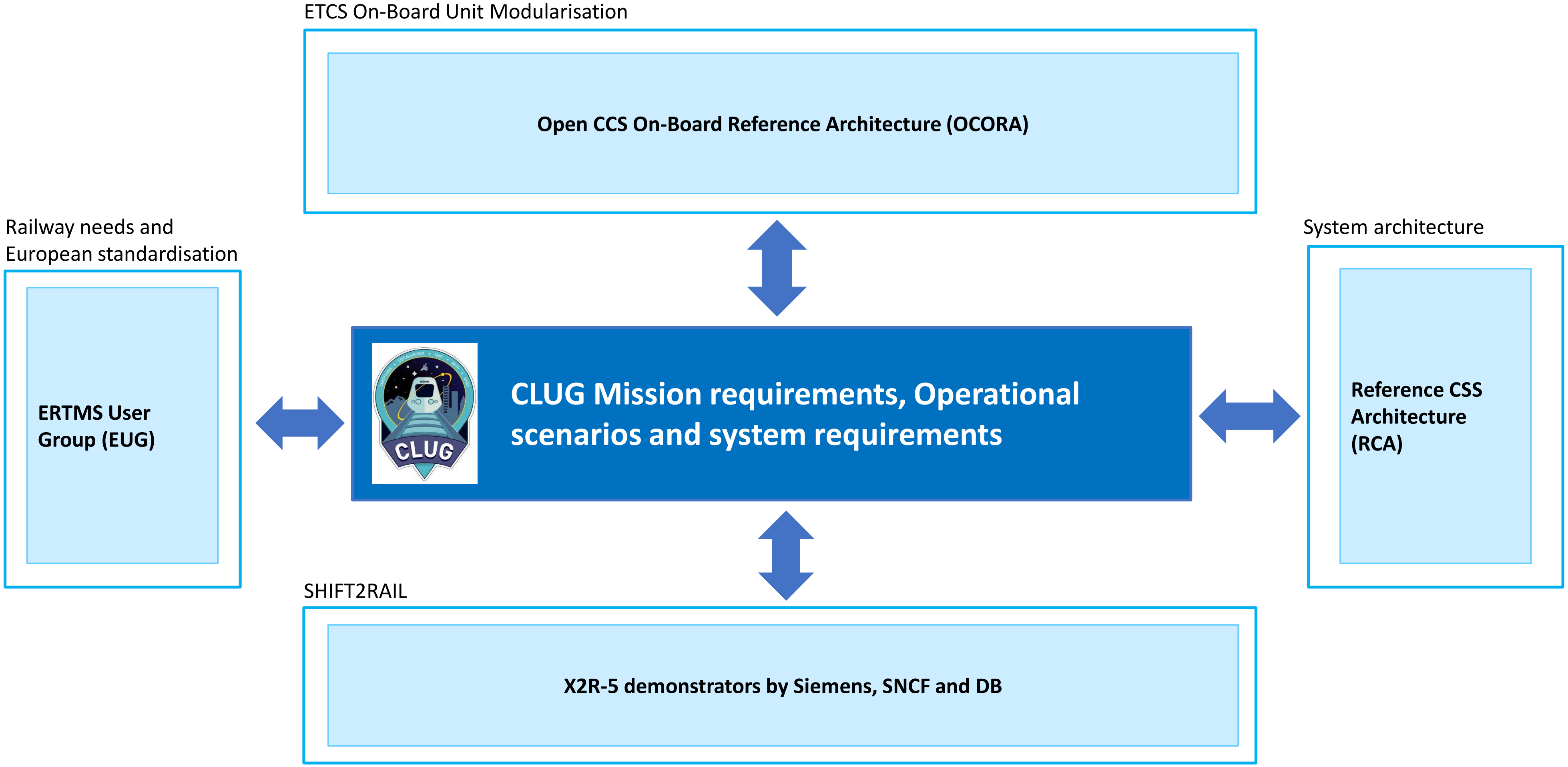
ENABLING OBSTACLE DETECTION

Detect and track objects with respect to the Train Front End.

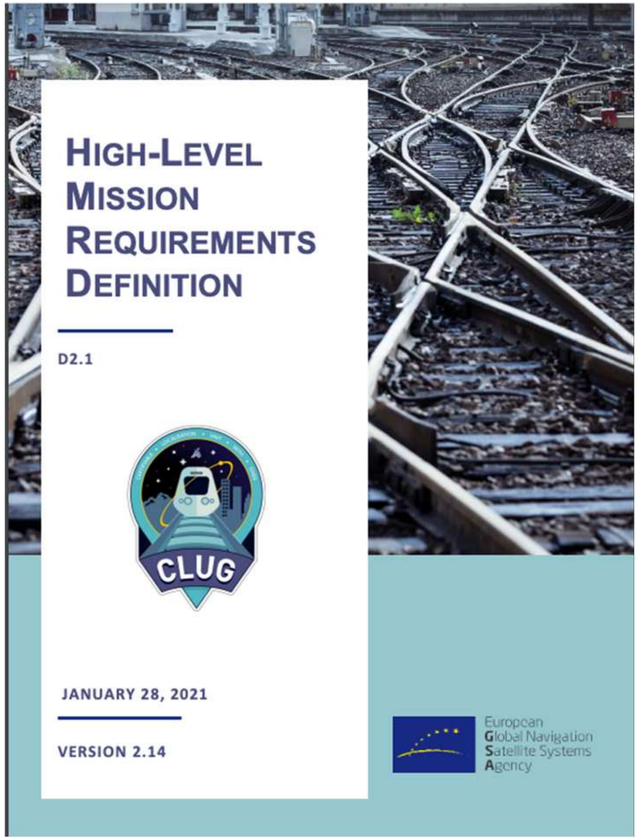
Localisation system needs to provide the heading angle of the train and 3D position.

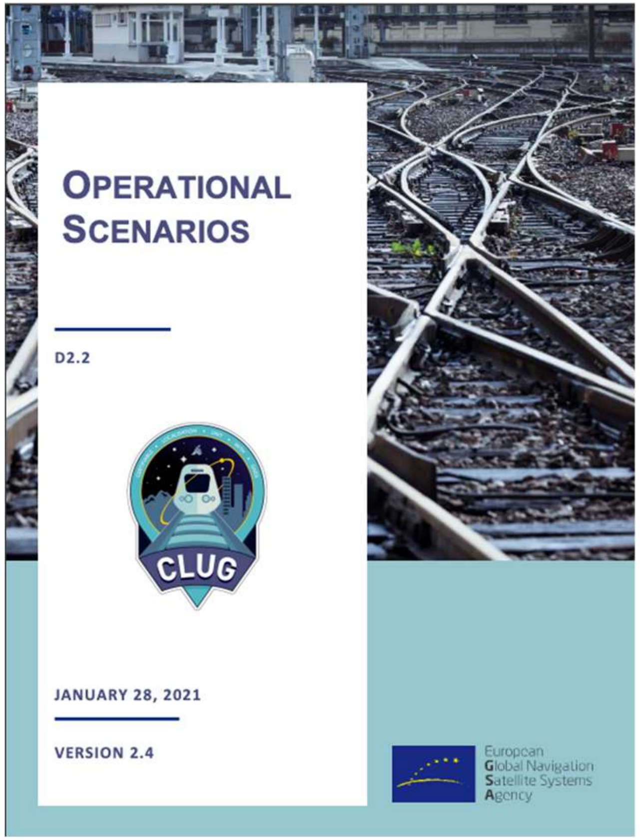


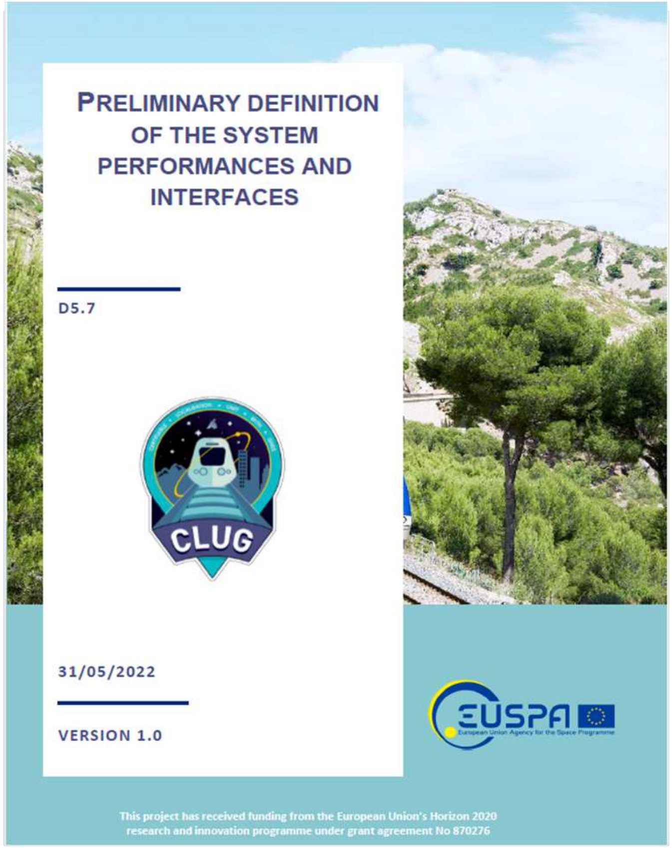
COLLABORATION AND EXCHANGE WITH EUROPEAN INITIATIVES



PUBLIC DELIVERABLES







ANY QUESTIONS

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Train Localisation On-Board Unit (TLOBU)
- Architecture and Interfaces -

SEBASTIAN OHRENDORF-WEISS
PROJEKT MANAGER LOCALISATION, SBB AG

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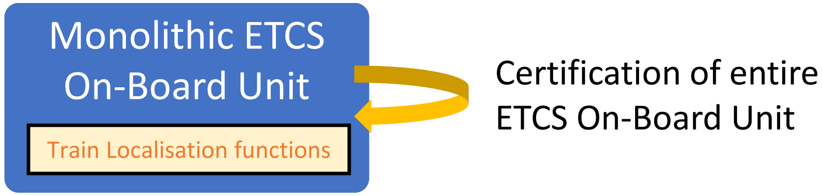
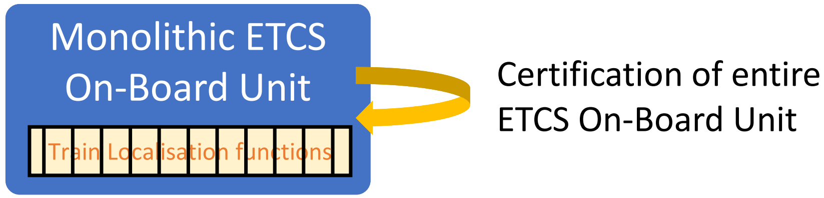
OBJECTIVES OF A SEPARATE TRAIN LOCALISATION ON-BOARD UNIT (TLOBU)



OBJECTIVES OF A SEPARATE TRAIN LOCALISATION ON-BOARD UNIT (TLOBU)



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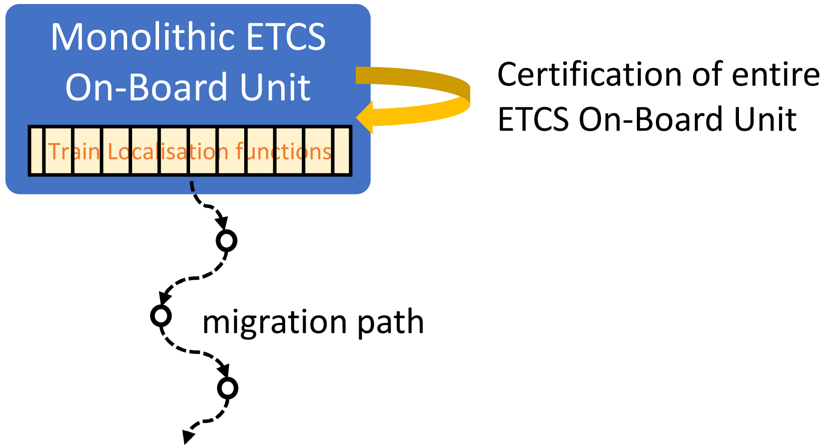

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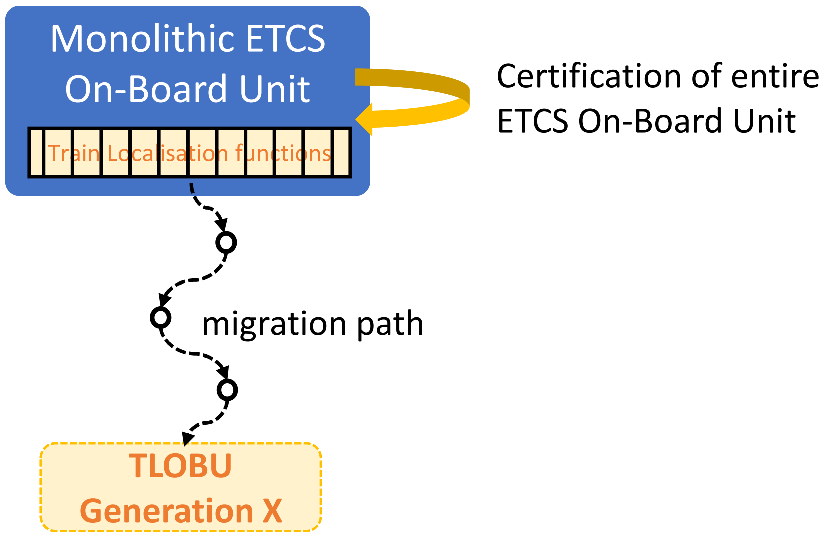

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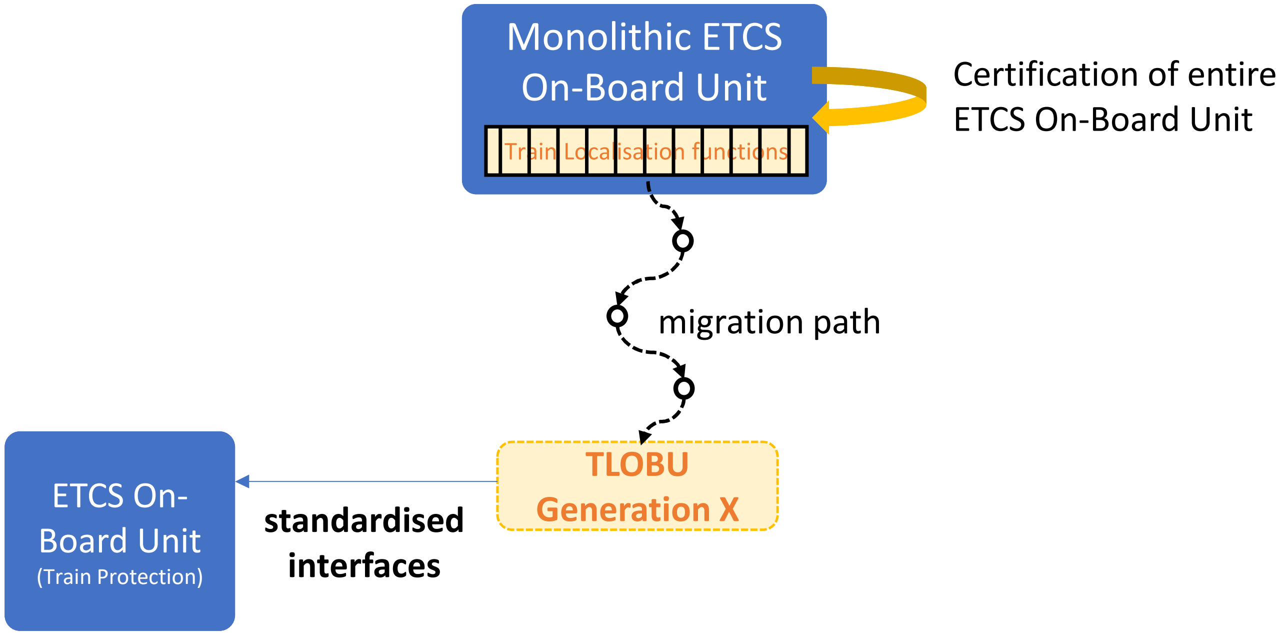

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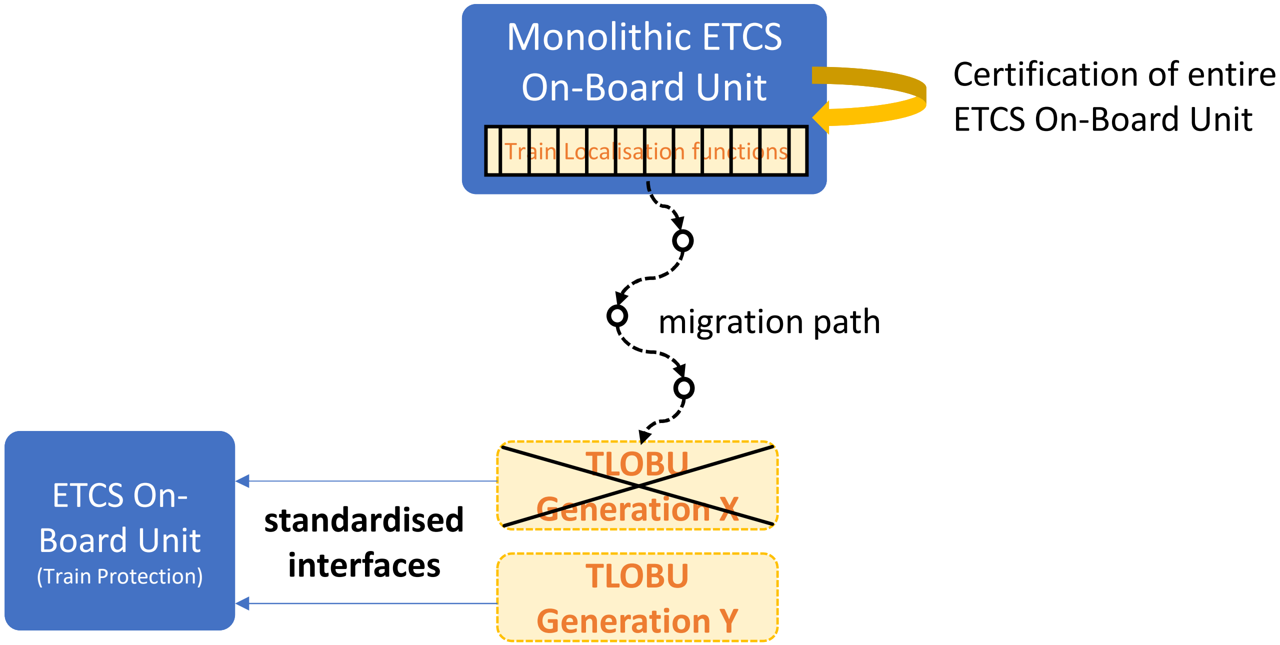

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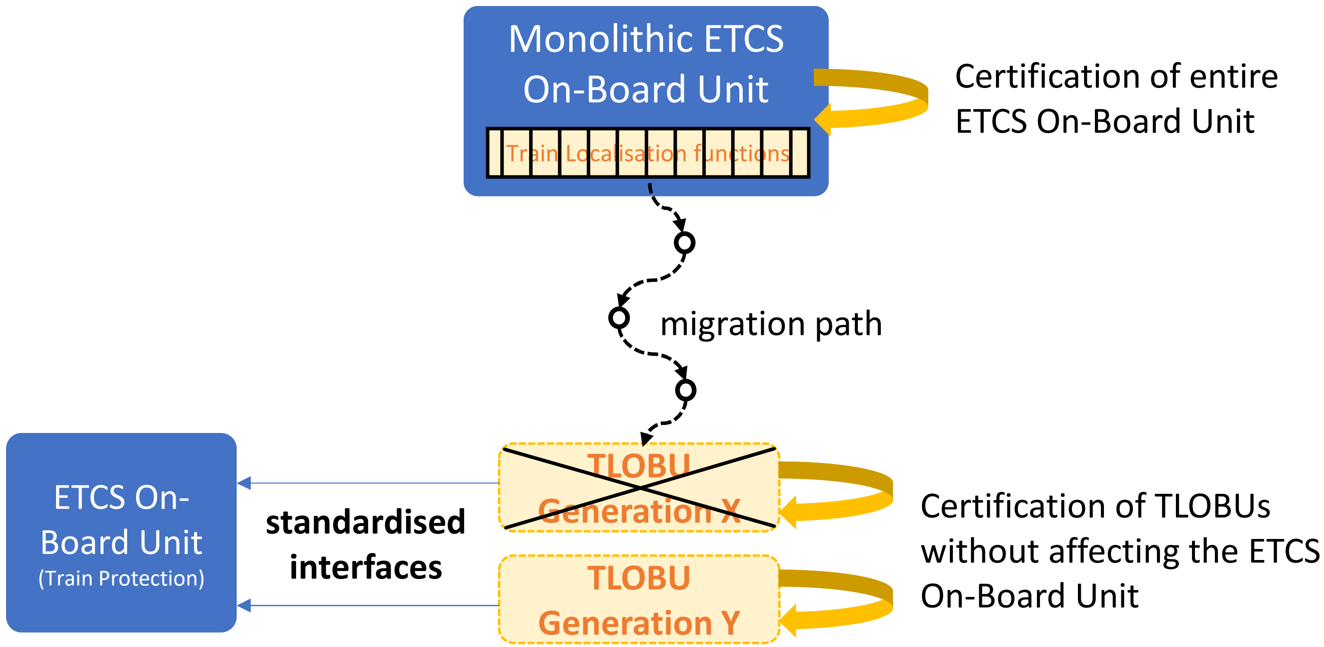
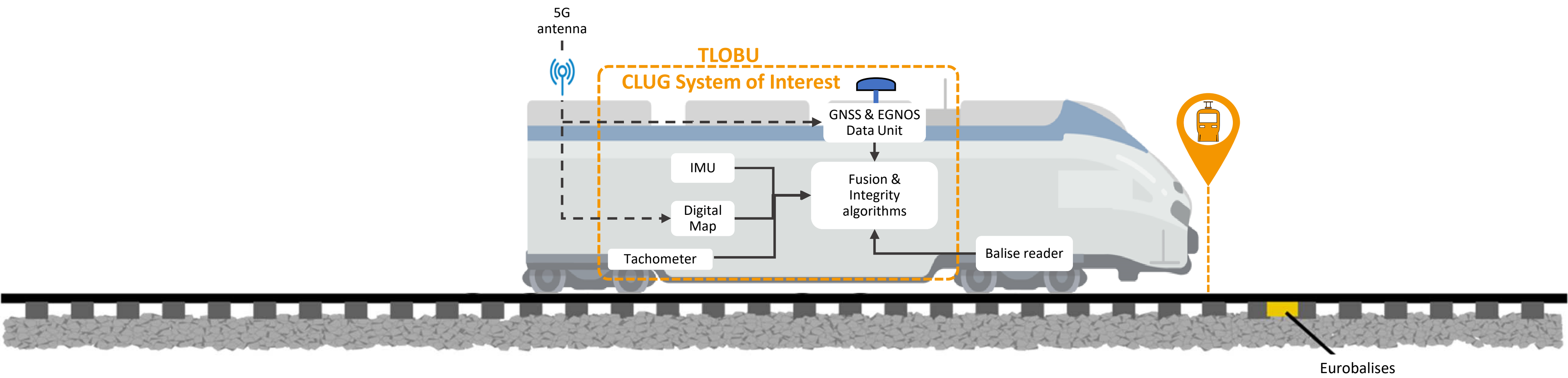


ARCHITECTURE - TLOBU



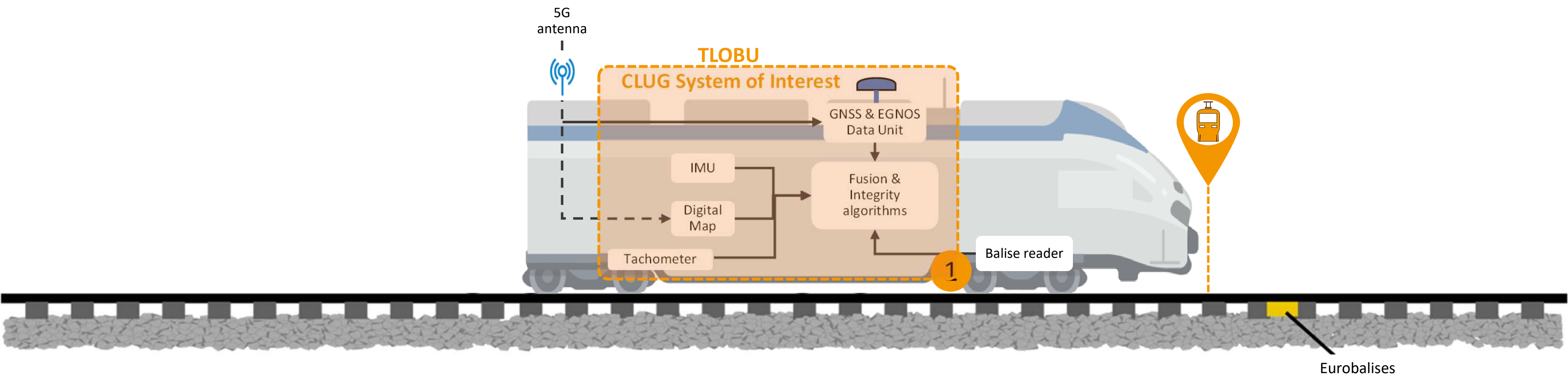
Legend:

→ / - - → Continuous / Discontinuous link

EXTERNAL INTERFACES - TLOBU

Information acquired …

1 from the ground (balises) → *in CLUG only used to determine ground truth*



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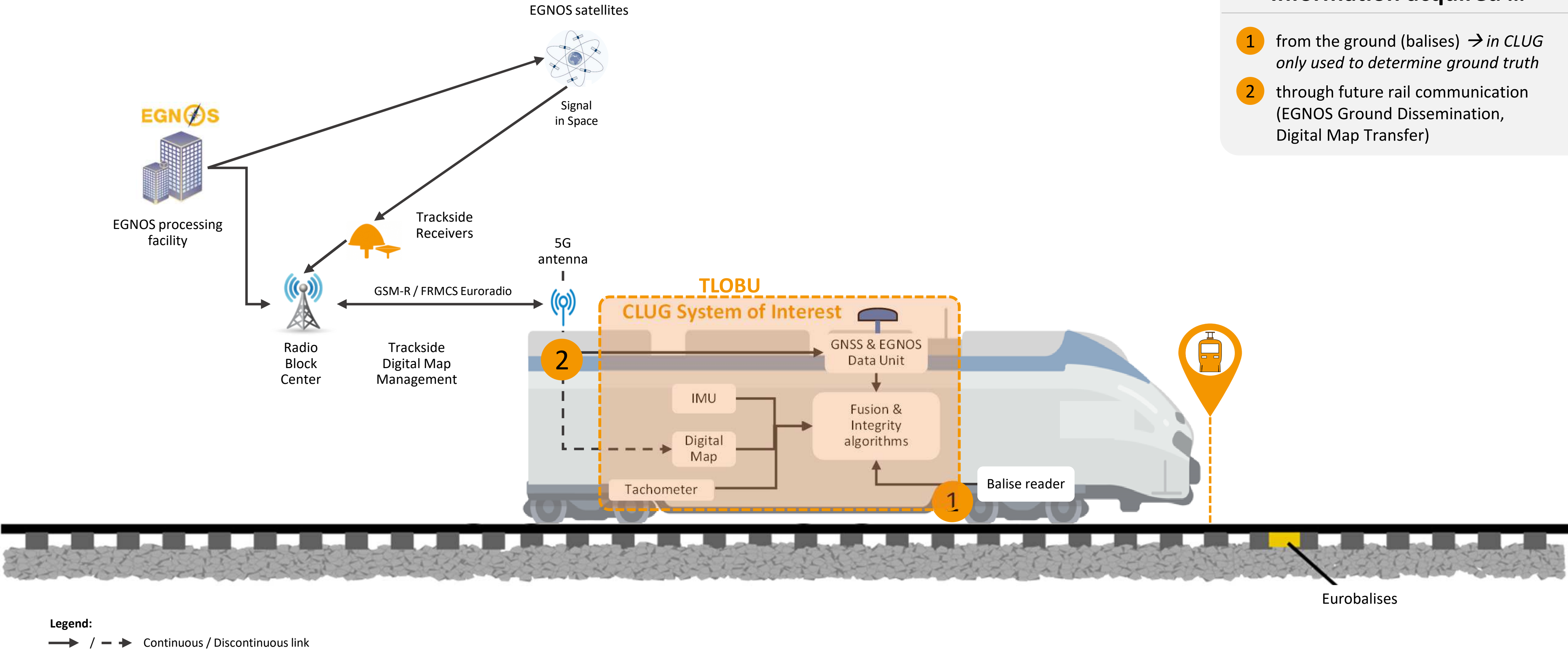

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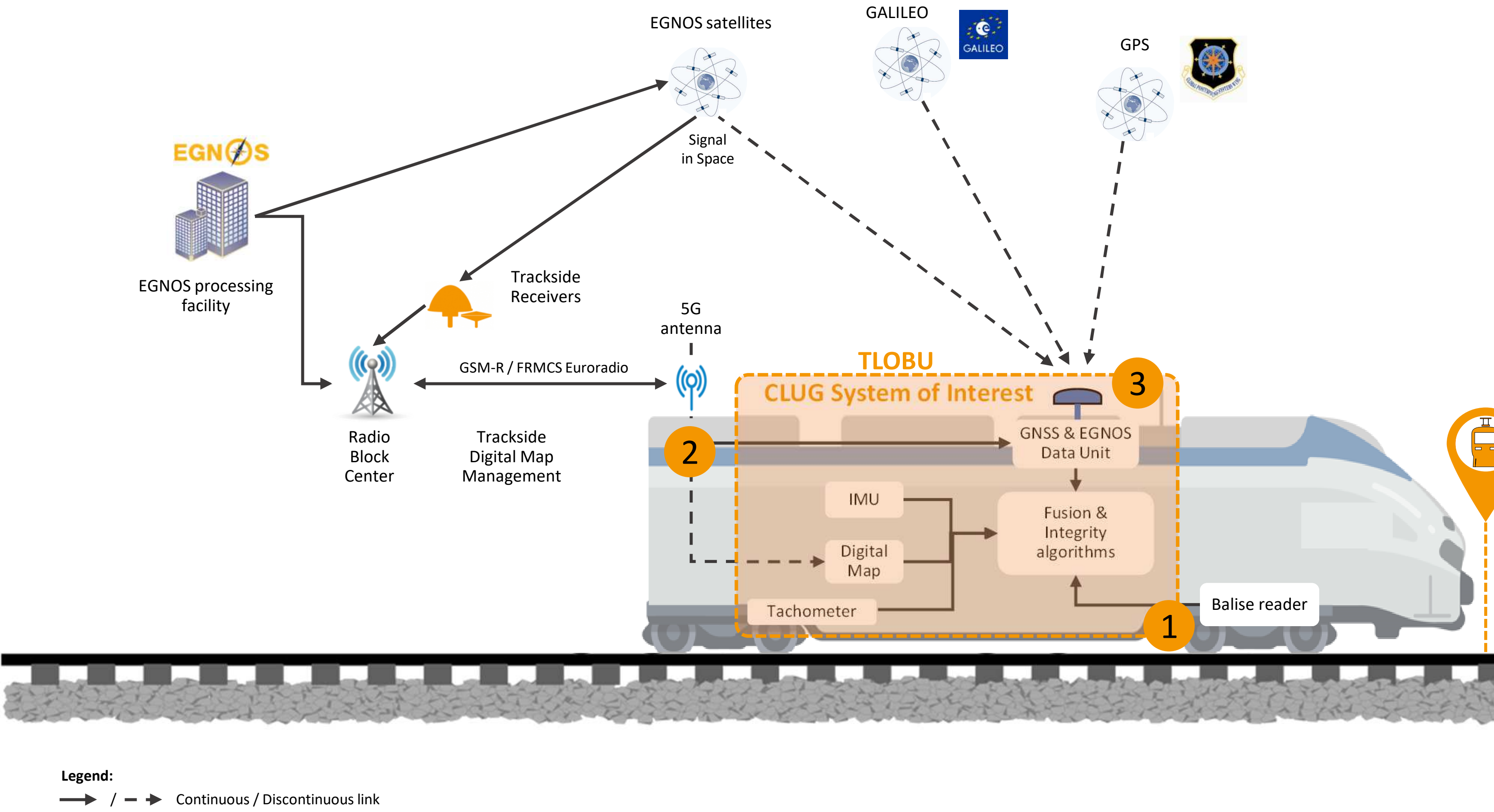

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3. from space (GNSS/EGNOS signals)

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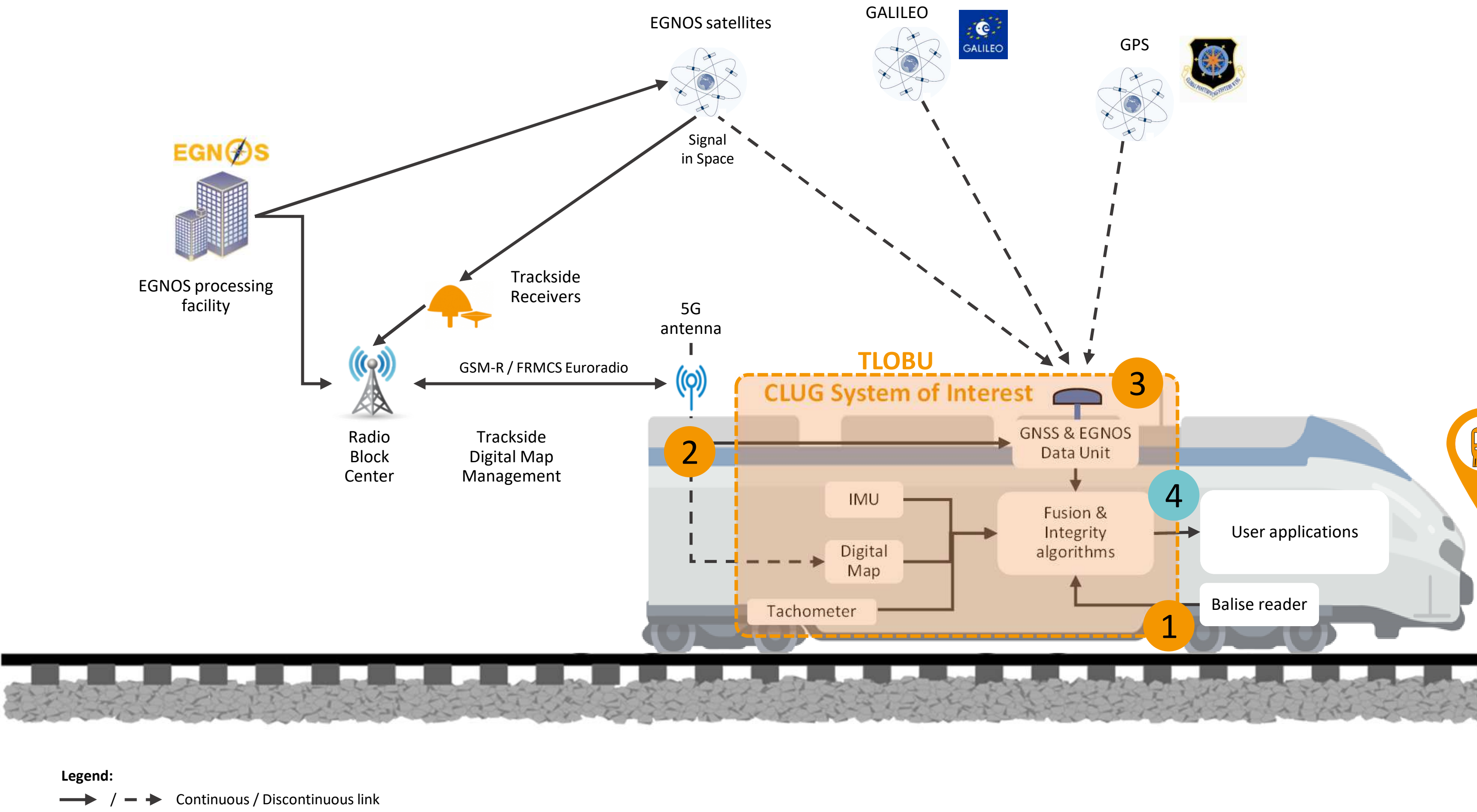


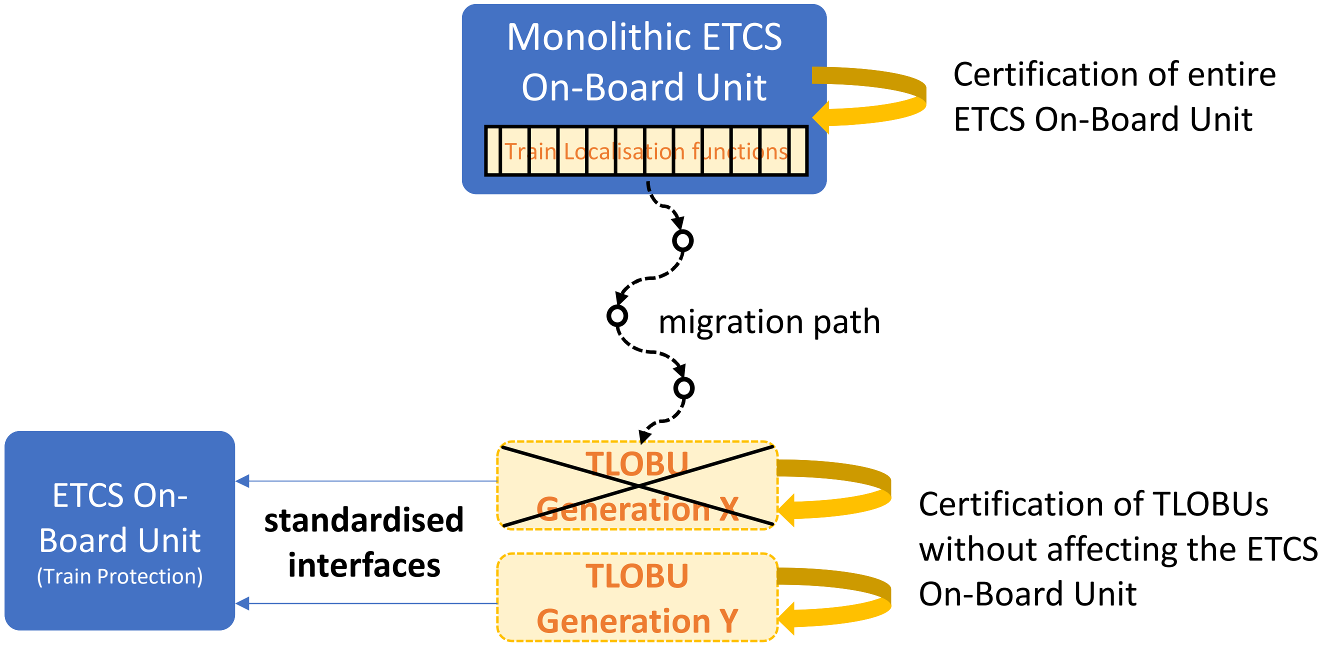
Information acquired …

1. from the ground (balises) → *in CLUG only used to determine ground truth*
2. through future rail communication (EGNOS Ground Dissemination, Digital Map Transfer)
3. from space (GNSS/EGNOS signals)

Information provided …

4. to safe and non-safe user applications (EVC, passenger information system, ATO, driver advisory system, etc.)

STANDARDISED INTERFACES FOR USER APPLICATIONS



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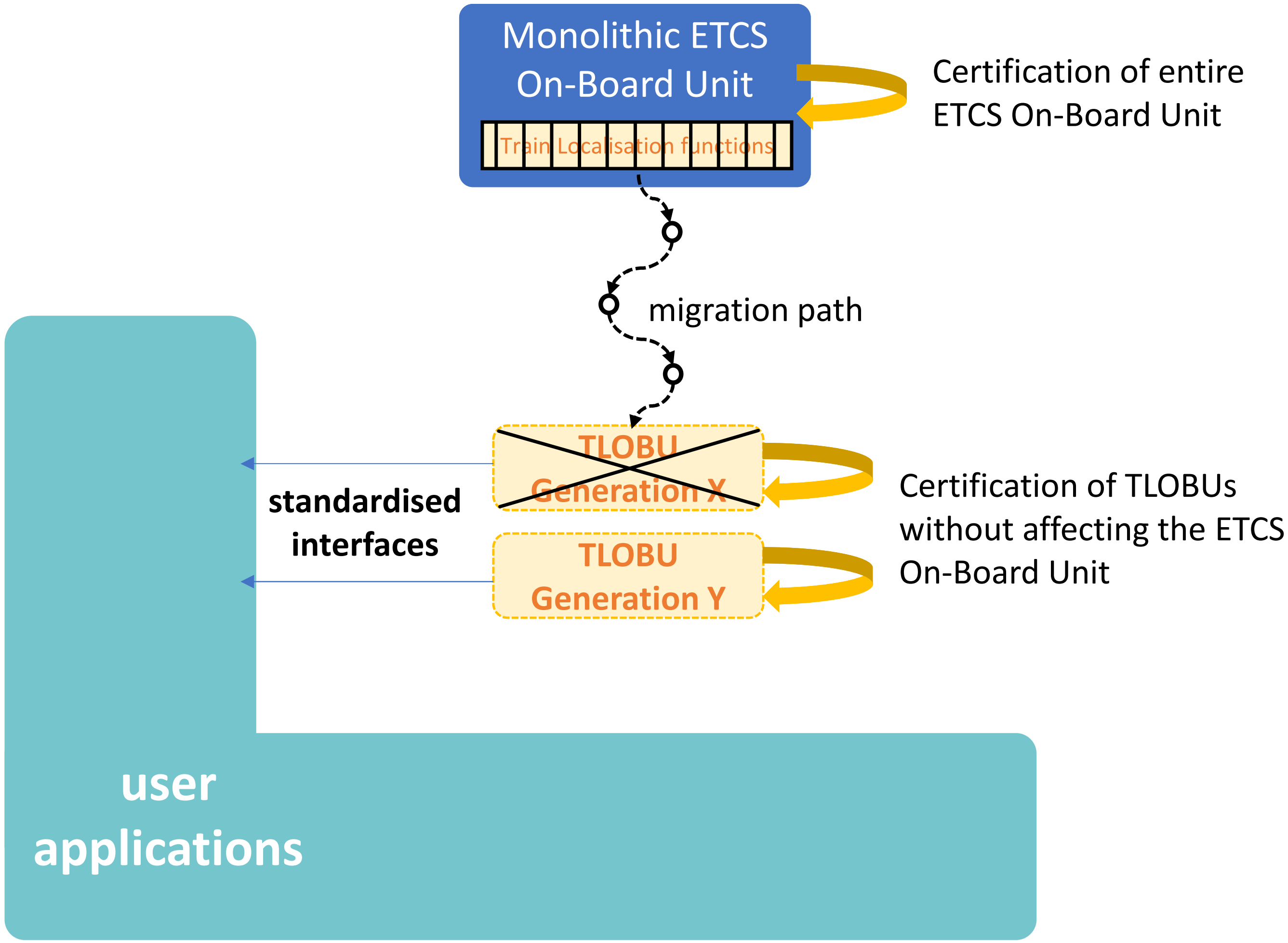

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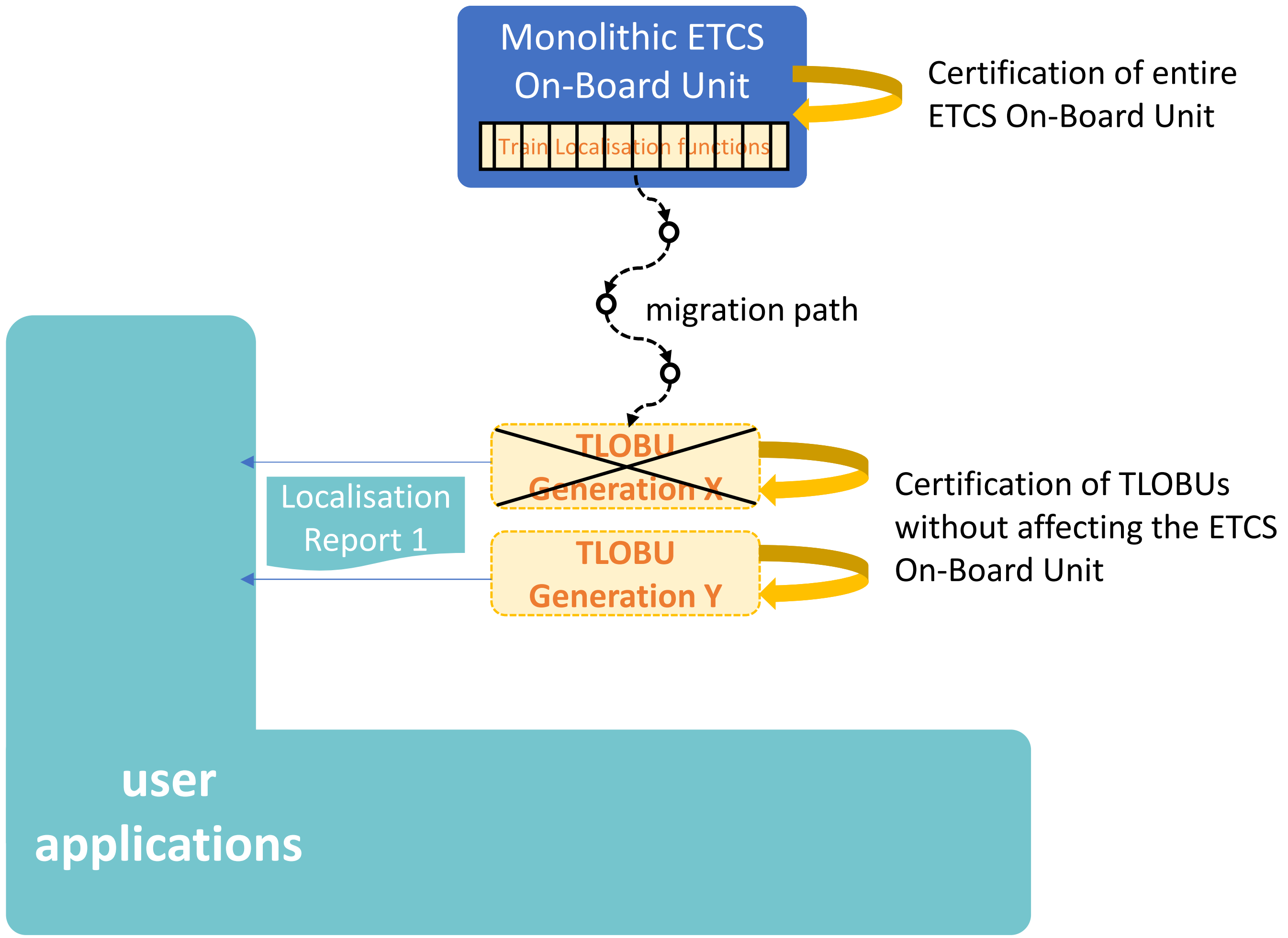

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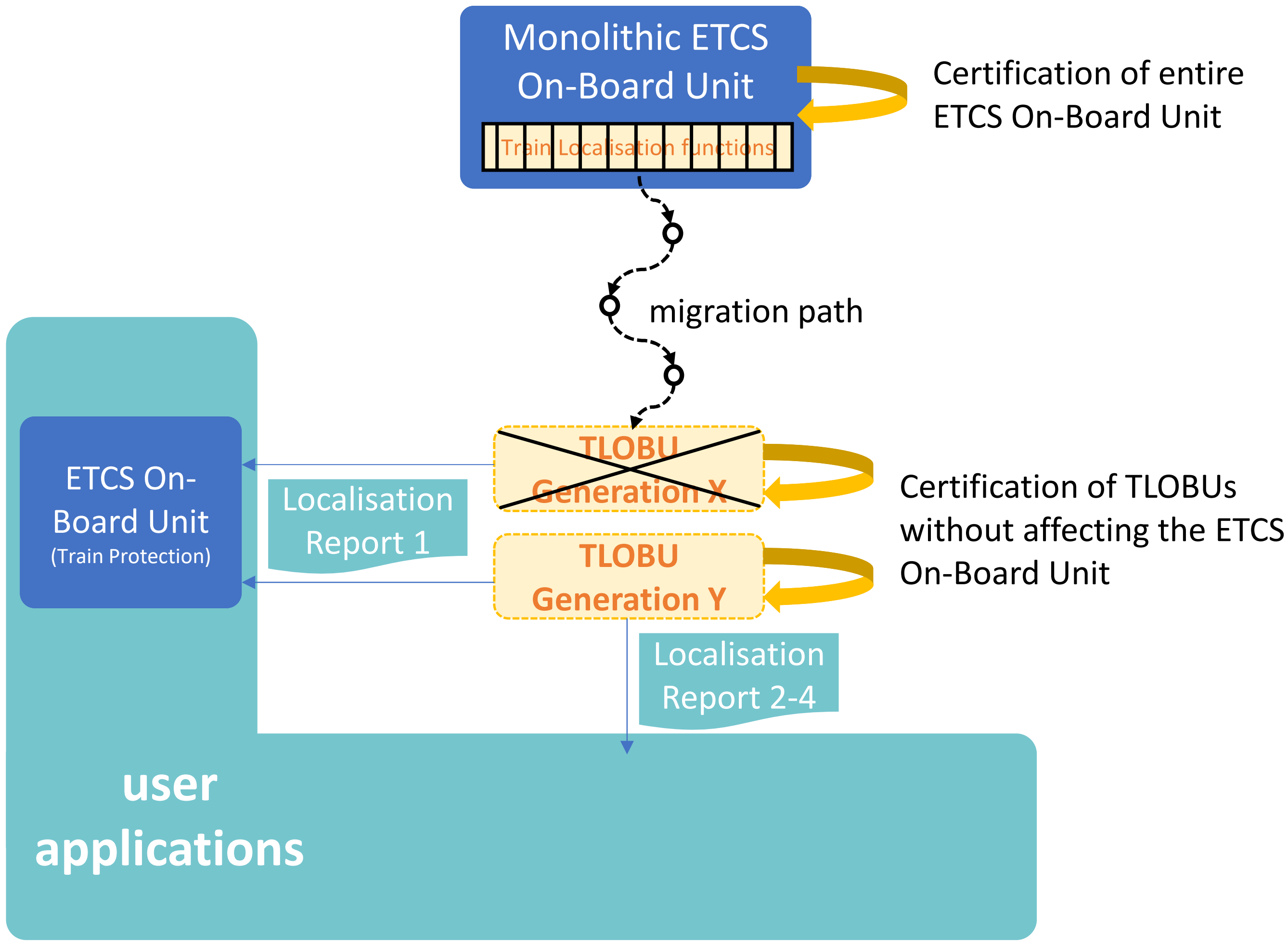

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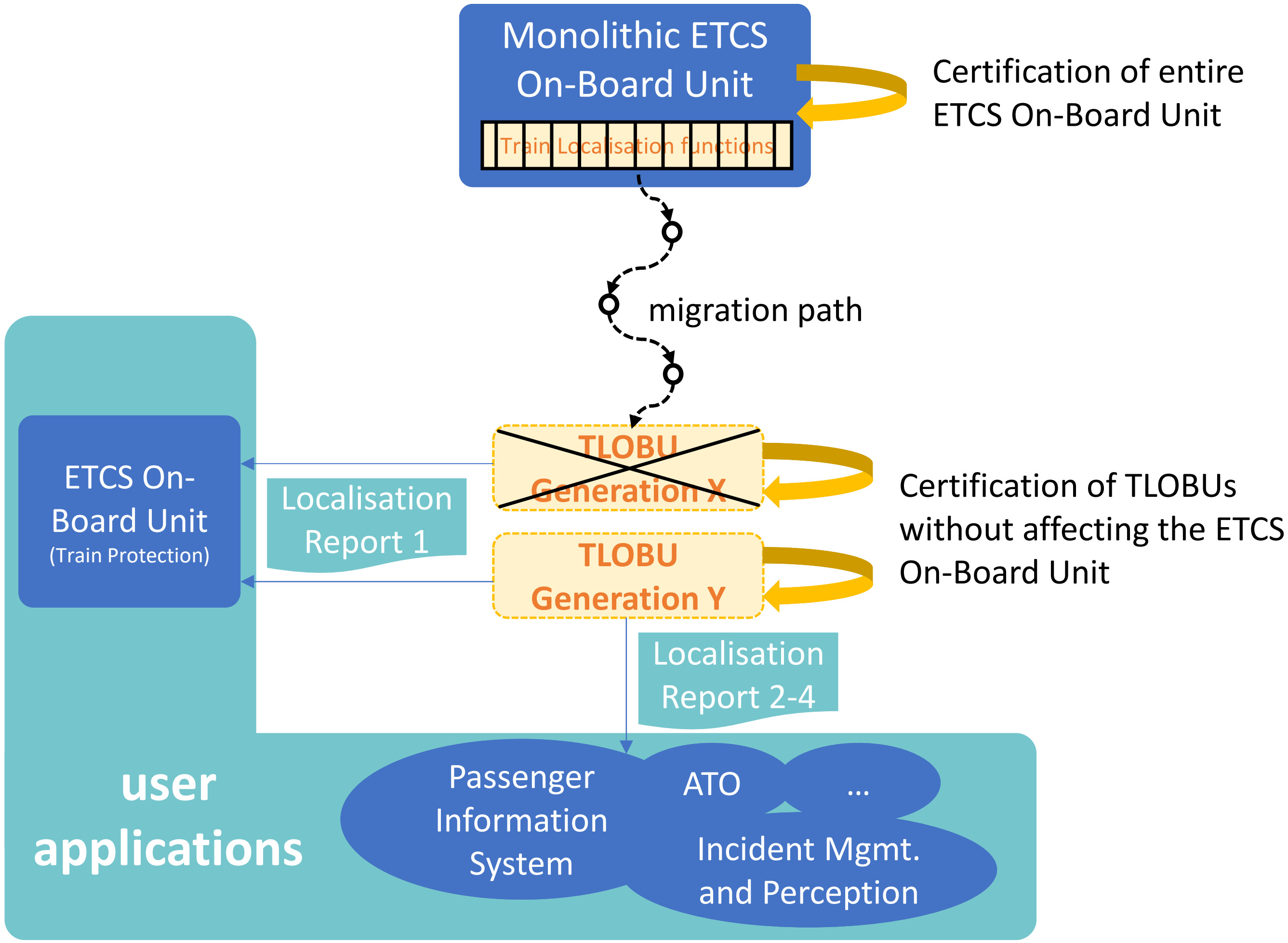

TLOBU OUTPUT – 4 LOCALISATION REPORTS

Various on-board **user applications** need localisation information such as **train position, velocity** (speed and direction of travel), **acceleration, confidence intervals** and a **safety profile** (SIL0 – SIL4). According to different needs four Localisation Reports are defined.

Localisation Report 1	Localisation Report 2	Localisation Report 3	Localisation Report 4
1-D Position	1-D Position	1-D Position	3-D Position
SIL 4 Output rate = 200ms	SIL 2* Output rate = 200ms	SIL 0* Output rate = 100ms	SIL 0 Output rate = 50ms
Input to the ETCS On-Board for e.g. TPR generation, Information on the DMI, supervision of the braking curve	Train Control Management System, ATO stopping at a platform, etc.	ATO with train driver, pantograph positioning, etc.	Passenger Information System, Driver Advisory System, etc.

**safety declarations are preliminary and need to verified through detailed safety analysis*

CONCLUSION

Factor 10 between today's elements for **trackside train detection** compared to number of **On-Board Units** in Switzerland.

Standardisation of interfaces & modular architecture **enables:**

1. Sharing a broad range of **localisation information from a single source** with various on-board user applications.
2. Separation of the **TLOBU** function to **locate safely and reliably the train** and its orientation on the track.
3. Leveraging **new localisation technologies** without the need to recertify the remaining part of the ETCS On-Board Unit.
4. Updating the **TLOBU independently** from the remaining part of the ETCS On-Board Unit.

Localisation system design

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Michael JÜTTNER <michael.juettner@naventik.de>

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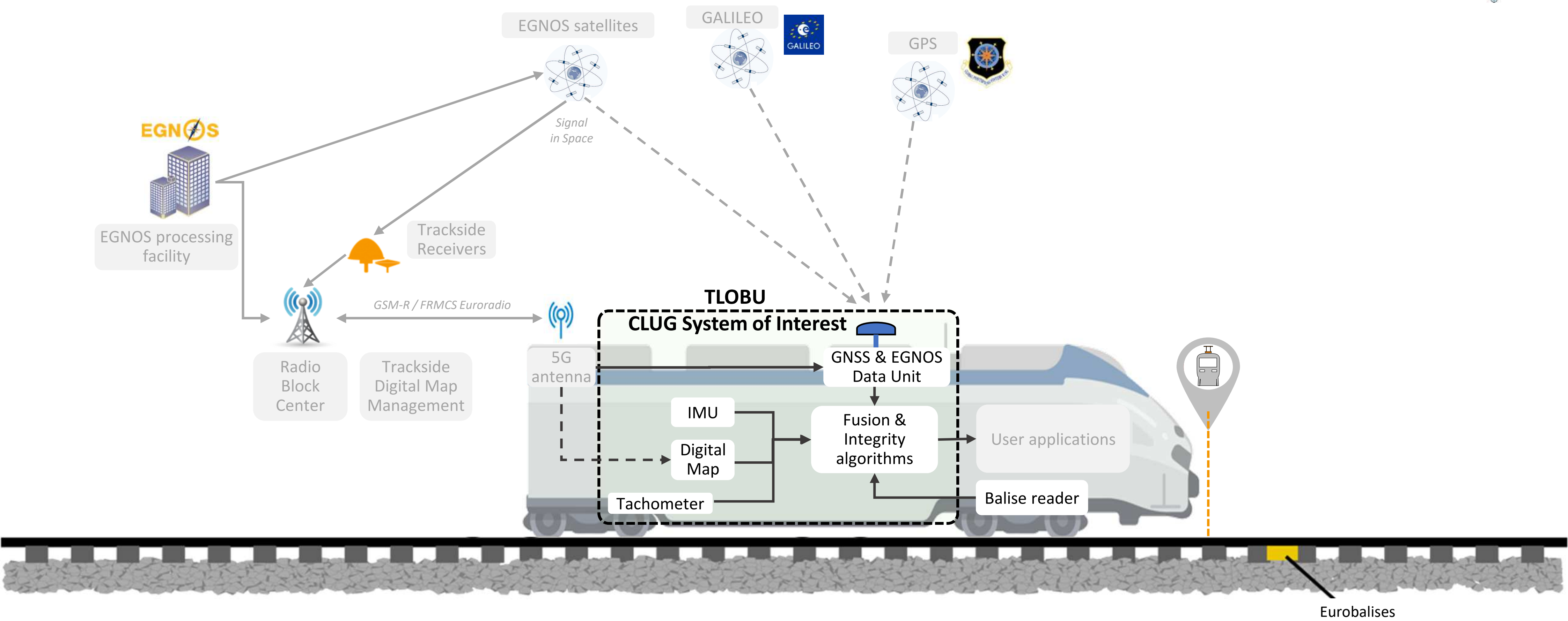
European Union Agency for the Space Programme

AIRBUS

CLUG DESIGN RECALLED TARGETS

- Future localization design for ERTMS level 2 & 3 (preparing autonomous), fostering a sustainable system for the entire European railway network.
- CLUG is fostering the **transition from trackside-centric to train-centric localization**
- **trackside equipment** for localization **reduced as much as possible**
- **Safety-of-Life** design

TLOBU DESIGN PERIMETER



WHAT SAFE LOCALIZATION DATA NEEDED FOR RAIL?

ALL ALONG TRACK (1D) ⇒ SAFE EQUIPMENT FOR LOCALIZATION

Currently

TRAIN NEEDS	PHYSICS	SENSORS
Continuous absolute position	Distance: d(t)	**Trackside Balises** Non-continuous absolute position **Odometer system** Continuous relative position
Continuous absolute speed	Speed: v(t)	**Odometer system** Continuous absolute speed
~~Continuous absolute acceleration~~	~~Acceleration: a(t)~~	

Derivative

Derivative

Integral

Integral

WHAT SAFE LOCALIZATION DATA NEEDED FOR RAIL?
ALL ALONG TRACK (1D) ⇒ SAFE EQUIPMENT FOR LOCALIZATION

CLUG

Future = CLUG

TRAIN NEEDS	PHYSICS	SENSORS
Continuous absolute position	Distance: d(t)	GNSS+SBAS (+ few Balises) Non-continuous absolute position Speed sensor + IMU Continuous relative position GNSS+SBAS Non-continuous absolute velocity
Continuous absolute speed	Speed: v(t)	Speed sensor Continuous absolute speed IMU Continuous relative velocity / speed Speed sensor Continuous absolute acceleration
Continuous absolute acceleration	Acceleration: a(t)	IMU Continuous absolute acceleration

Derivative

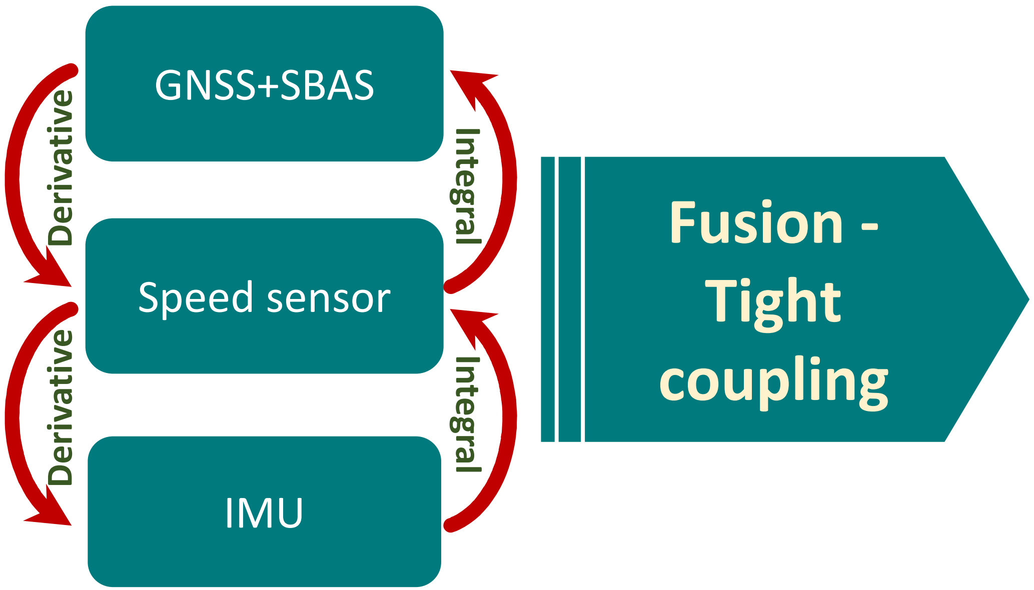
Integral

Derivative

Integral

SAFE EQUIPMENT FOR LOCALIZATION
⇒ TIGHT COUPLING FUSION

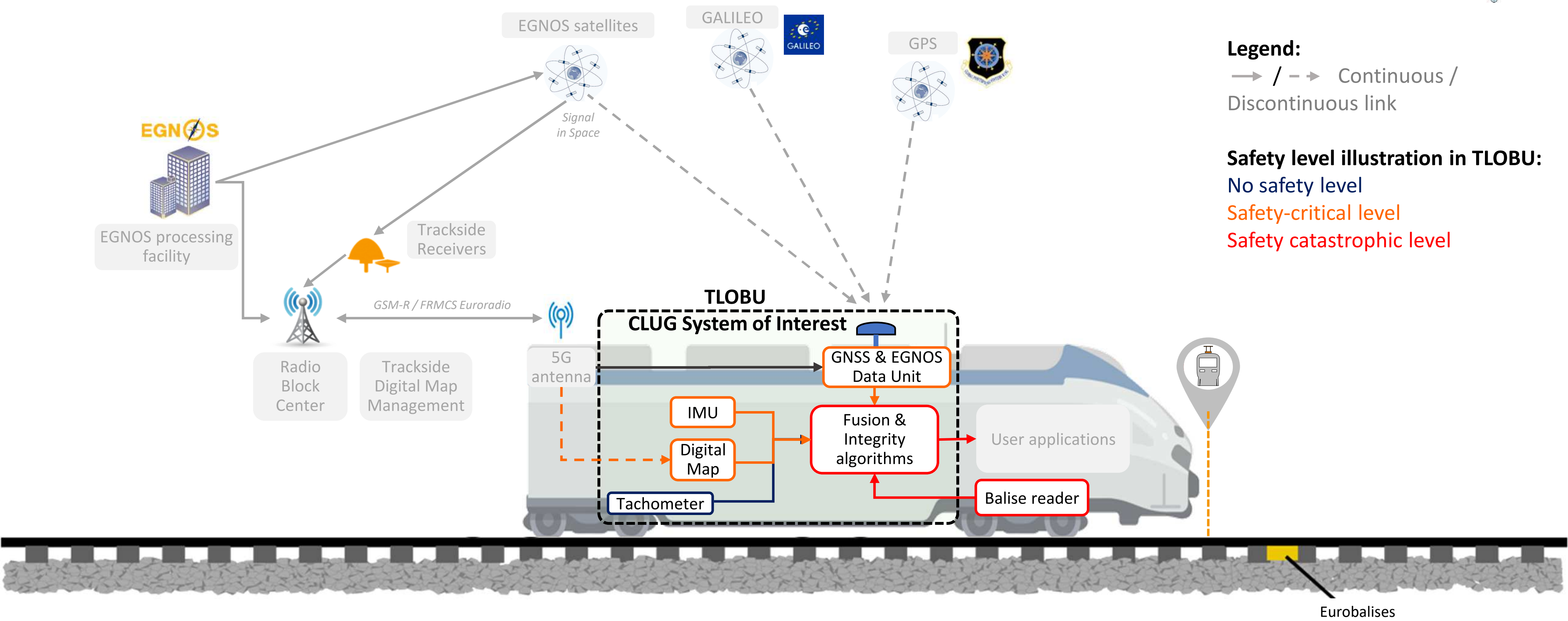
Future = CLUG



Train safe localisation data subset
Position along a track (**1D**) = **{** track edge identifier on which the train is, + the last reference point, + along track distance from the last reference point **}**
along track speed (**1D**)
along track acceleration (**1D**)
Forward direction (train heading)
Time

Each sensor technology complements each other perfectly to remove/reduce regularly any bias affecting Kalman fusion

TLOBU PERIMETER AND SAFETY ALLOCATION



Legend:

→ / - - → Continuous / Discontinuous link

Safety level illustration in TLOBU:

No safety level

Safety-critical level

Safety catastrophic level

TRAIN LOCALIZATION ON-BOARD DESIGN

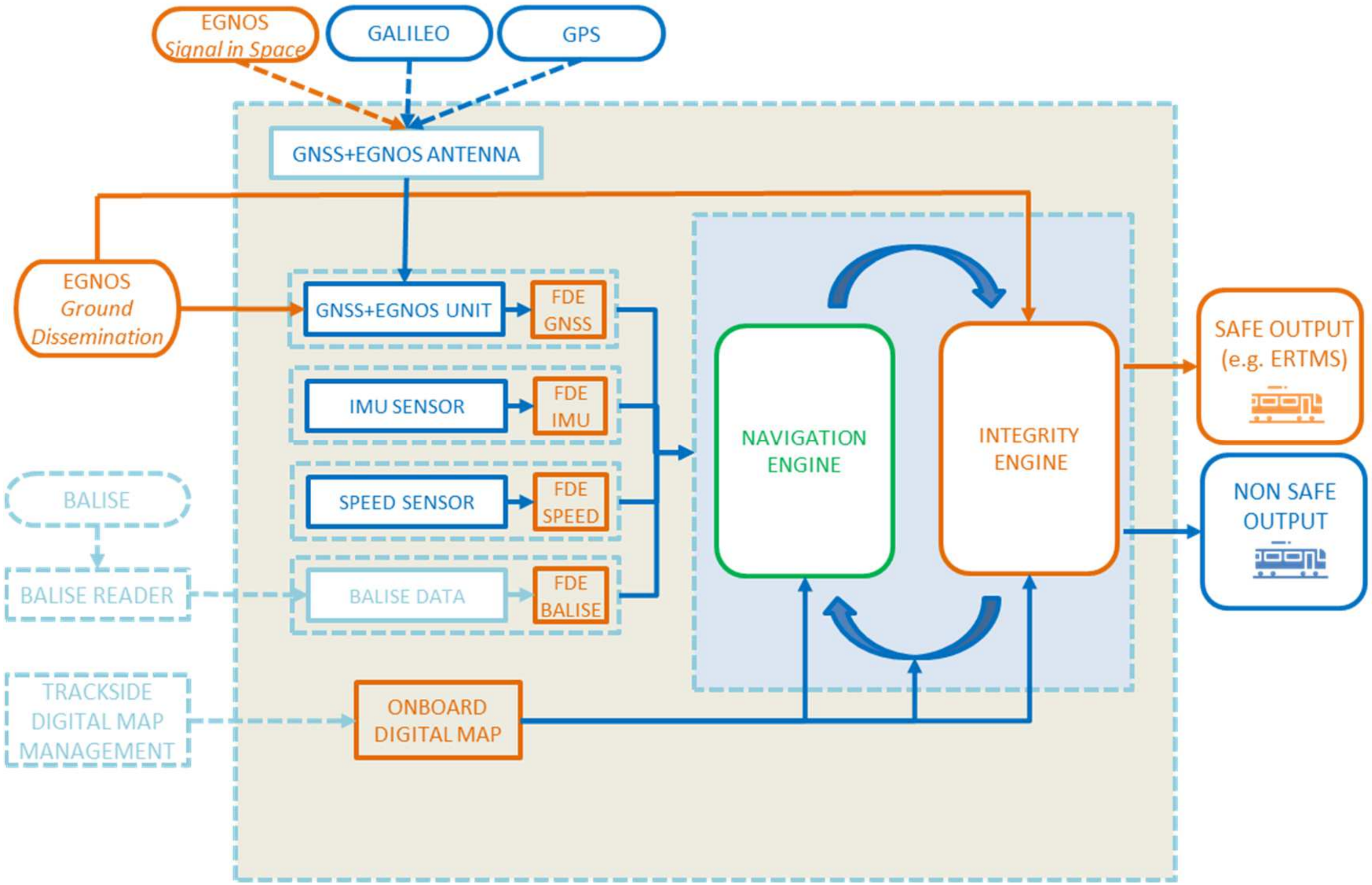
2 design solutions:

- "Solution A" led by Airbus:
  - driven by the safety requirements as well as targeting full compliance to rail requirements,
- "Solution B" led by Naventik:
  - disruptive adaptation of Naventik automotive Pathfinder product to the rail context,
  - do not cover all the requested perimeter, so reusing some solution A functions

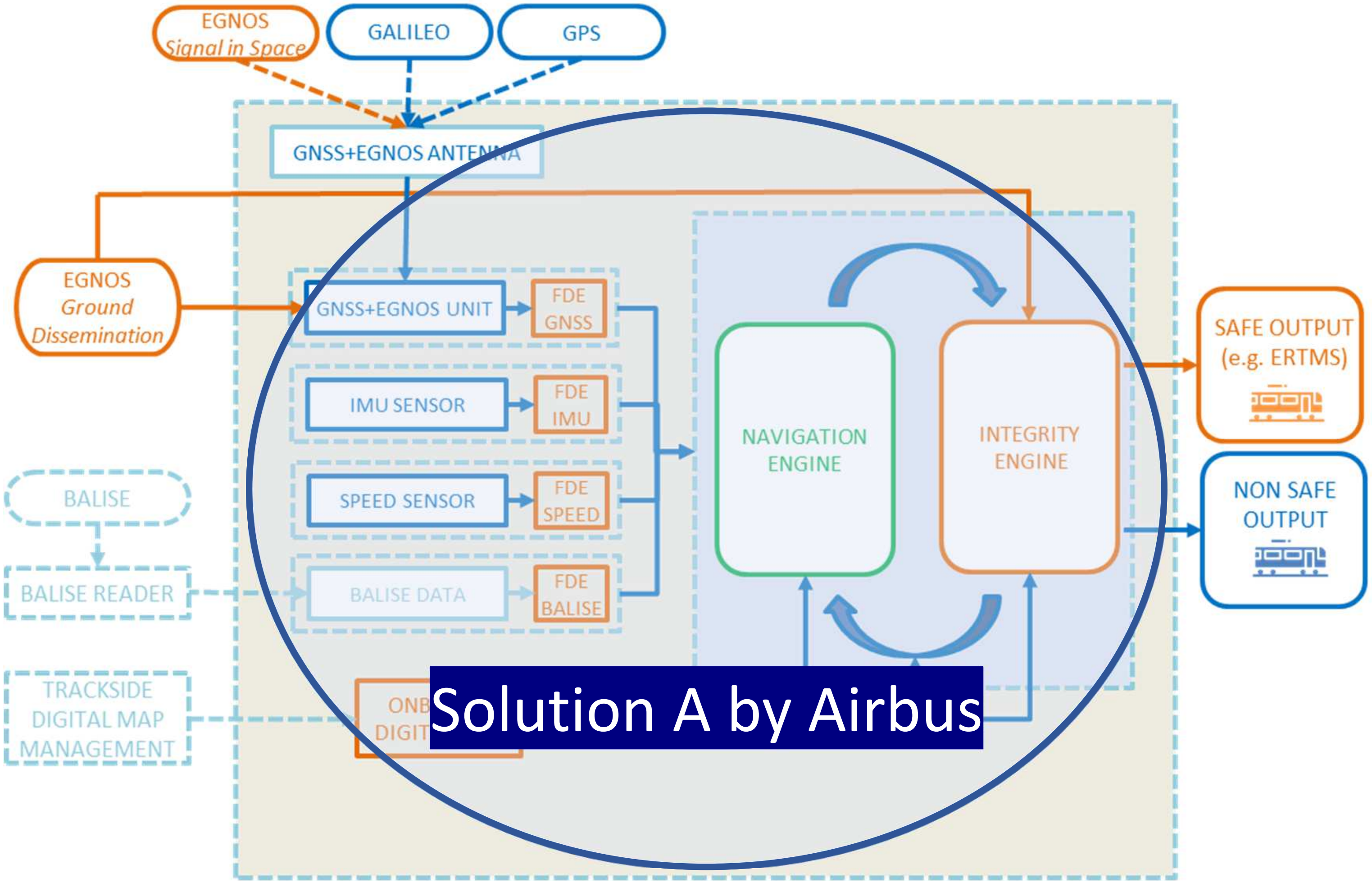
Common general functional architecture

- Same set of sensors,
- Same TLOBU **safe** requested outputs with their integrity (Safe Confidence Intervals)
- Similar strategy targeting fusion / tight coupling via Kalman filters
- + additional unsafe data are implicitly available: 3D position/velocity/acceleration, attitude angles & rates (Yaw, Pitch & Roll)

FUNCTIONAL COMMON DESIGN FOCUS



SOLUTION A (AIRBUS) FUNCTIONAL DESIGN FOCUS



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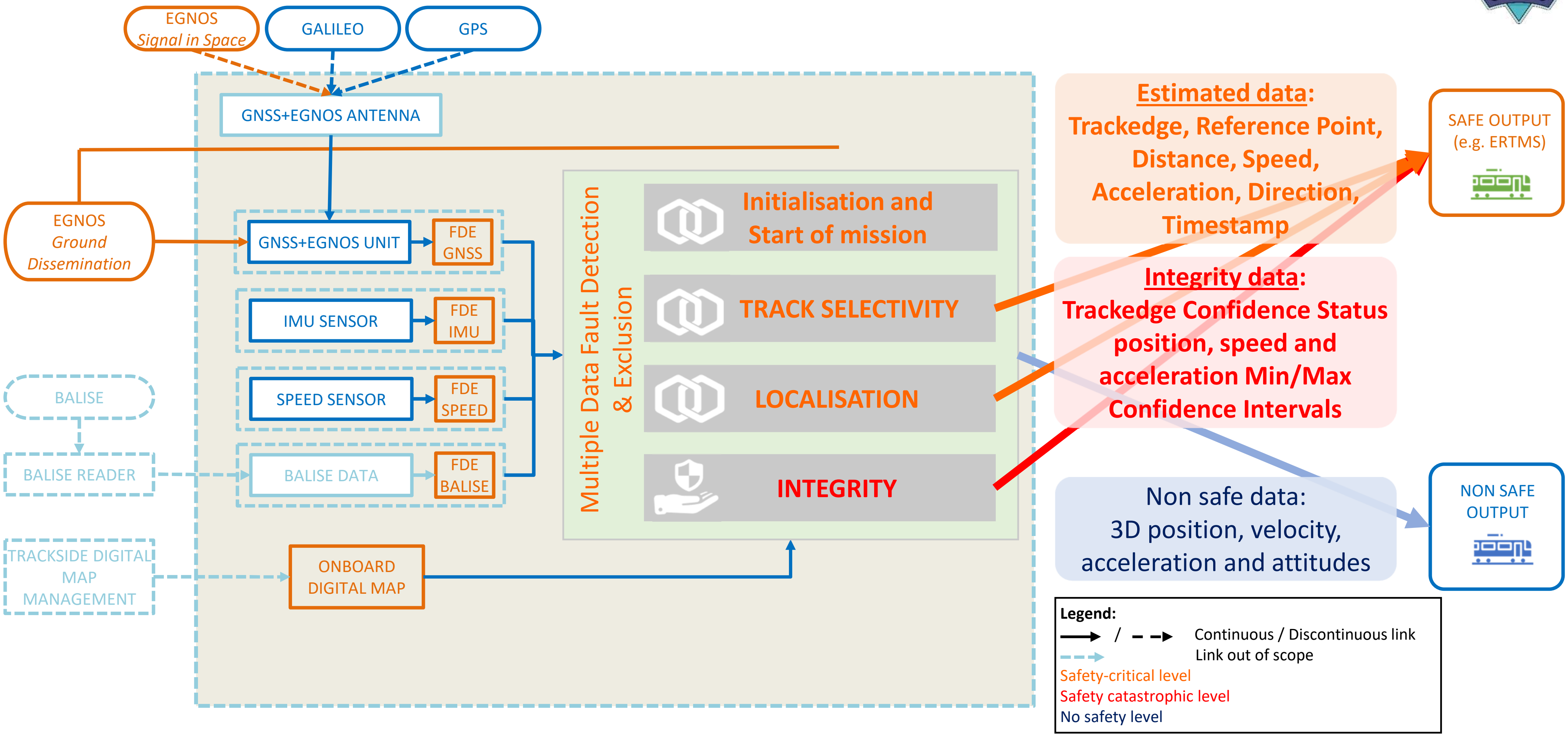


SOLUTION A (AIRBUS) MAIN OUTCOMES

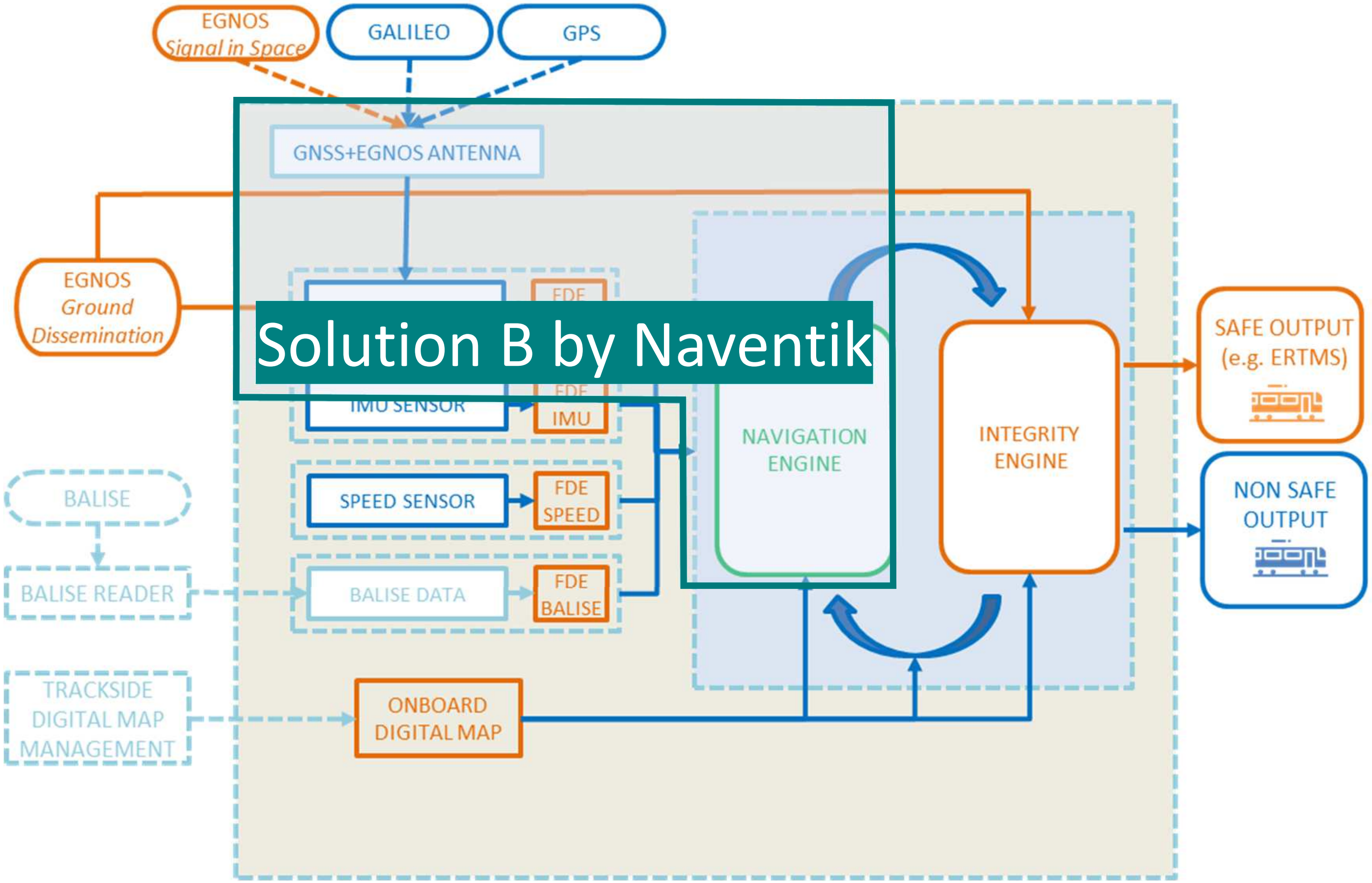
Reached TRL (Technology Readiness Levels):

- Sensors:
  - TRL 6 *Technology demonstrated in relevant environment*
- Digital map:
  - TRL 4 – 5 *Technology validated in lab - in relevant environment*
- Fusion Along track & Map matching:
  - TRL 5 *Technology validated in relevant environment*
- Data FDEs, GNSS+EGNOS data unit, Start of Mission & Init, Track Selectivity, Integrity Confidence Intervals & status:
  - TRL 2 – 4 *Technology concept - proof of concept - Technology validated in lab*

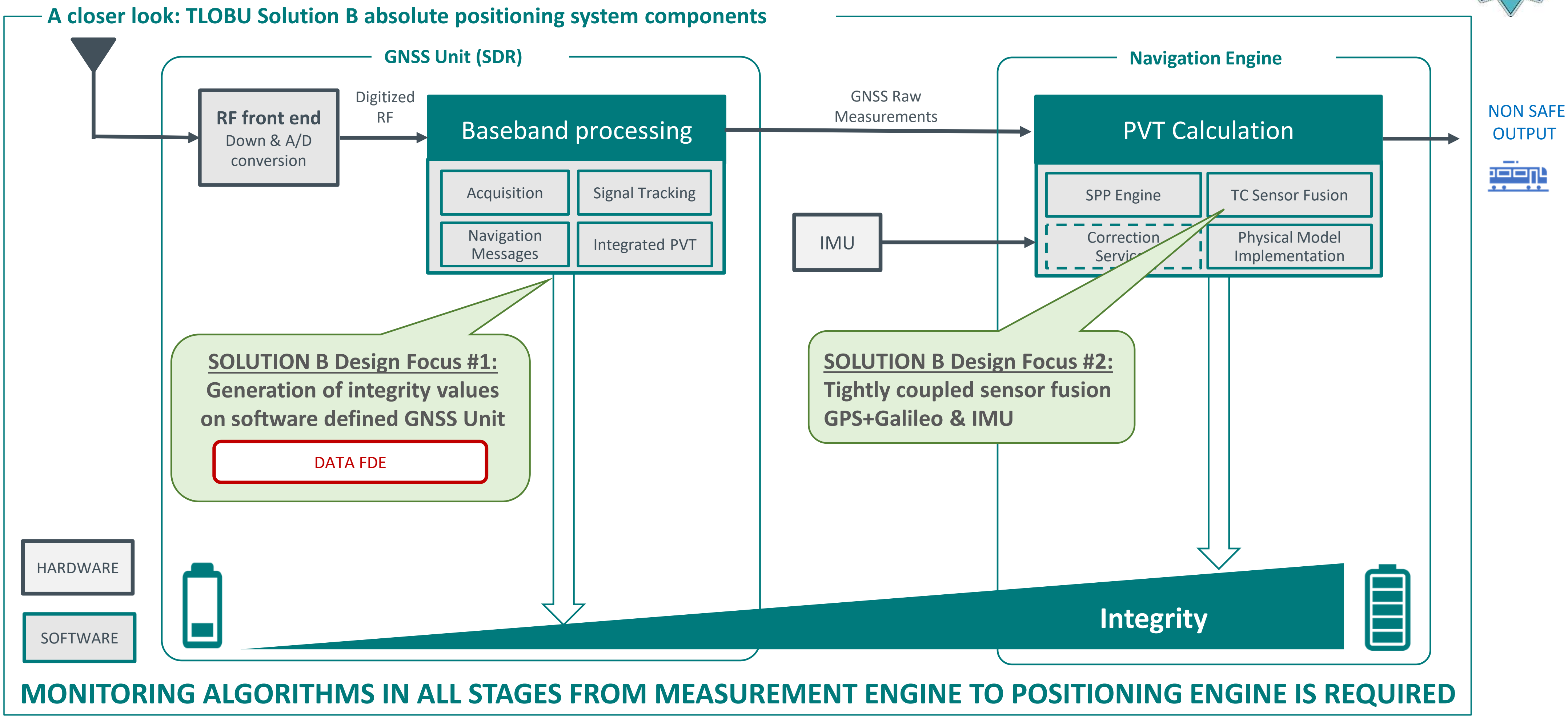
➢ **This reached TRL enabled first simulated safety performances (WP3.9), and experimentations with real data without integrity (WP4)**

✓ **Promising outcomes… to be continued…**

SOLUTION B (NAVENTIK) FUNCTIONAL DESIGN FOCUS



SOLUTION B (NAVENTIK) FUNCTIONAL DESIGN FOCUS



Source: Company information

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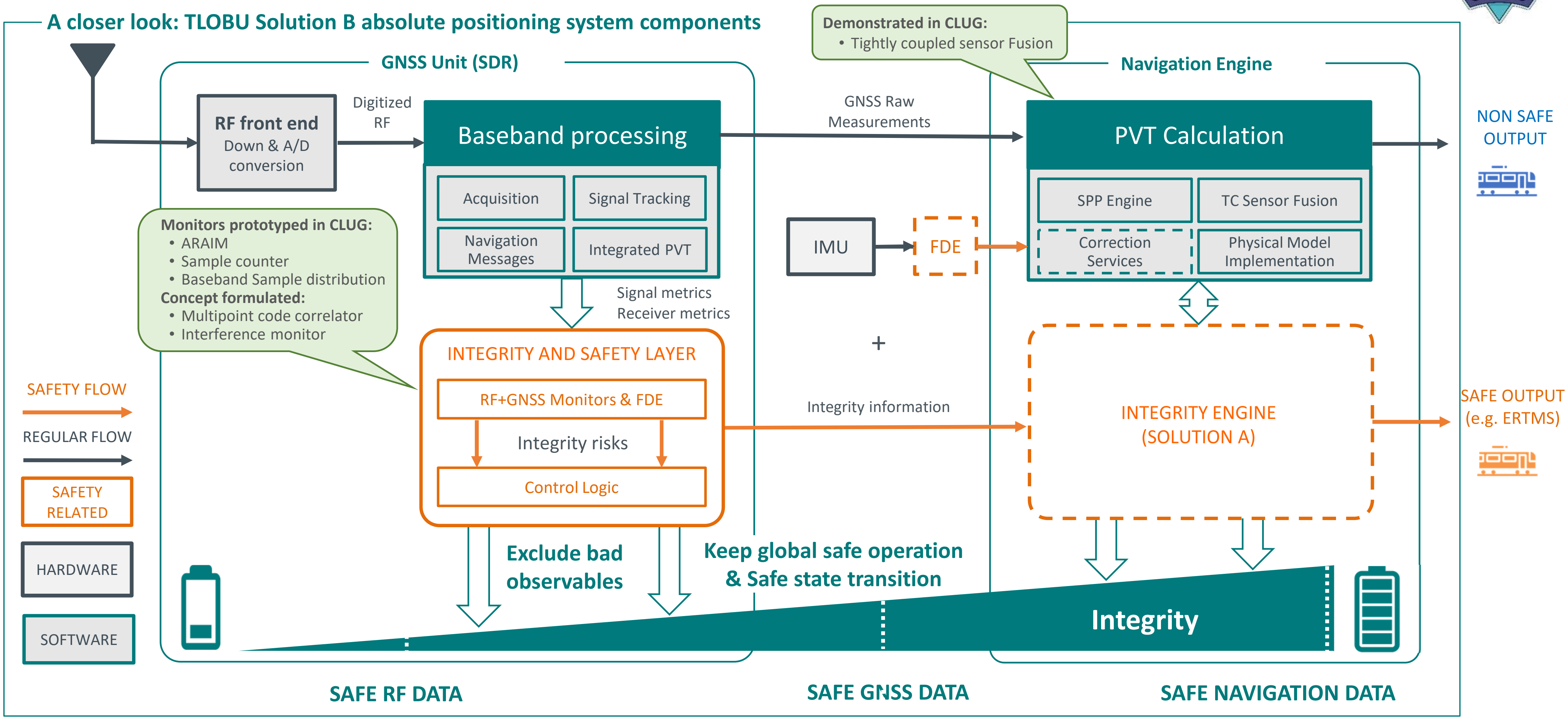
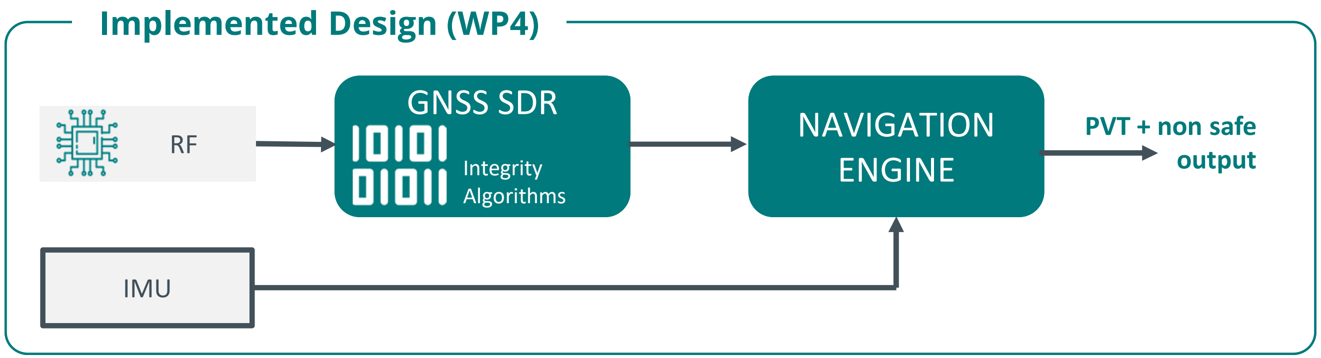


Source: Company information

SOLUTION B (NAVENTIK) MAIN OUTCOMES

Reached TRL (Technology Readiness Levels)

- Sensors (GNSS software defined receiver)
  - TRL 5 Technology validated in relevant environment
- GNSS FDE (ARAIM)
  - TRL 2 – 4 Technology concept formulated - proof of concept - Technology validated in lab
- Functions Navigation Engine (tightly coupled sensor fusion)
  - TRL 5 Technology validated in relevant environment



Reached maturity and prototyped algorithms tested in WP4 (Domino)

ANY QUESTIONS ?

Arnault.sfeir@airbus.com

Michael Jüttner:
michael.juettner@naventik.de

EGNOS usage in Rail

Pierrick Grandjean, Airbus Defence and Space

GALILEO, GPS AND EGNOS

- Galileo and GPS are global Satellite Navigation systems (GNSS)
  - Positioning services (Open Service for standard users)
  - Not for Safety-of-Life (SoL) positioning for critical applications, e.g. train signaling
- EGNOS is the European Geostationary Navigation Overlay Service (SBAS)
  - Improvement of accuracy (corrections on satellites orbit & clocks and ionospheric errors)
  - Integrity bounds and alerts for SoL applications
- EGNOS V2 augments GPS, soon EGNOS V3 DFMC will augment also Galileo

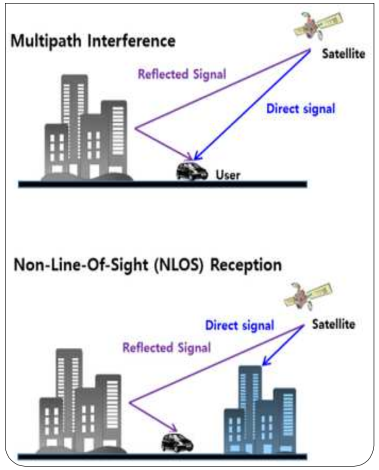
EGNOS CURRENT USAGE

- EGNOS first designed for aviation needs
- A success : in Europe, 700+ airport certified approach procedures using EGNOS
- European Commission, European Union Agency for Space Programmes EUSPA and European Space Agency ESA support other segments to adopt EGNOS for Safety of Life applications, such as Rail

(credit EUSPA)

STRINGENT RAILWAY NEEDS

- High grade integrity requirements
  - Position : 10 m CI at low speed
  - Speed : 2 km/h CI at low speed
  - Integrity Risk 1E^{-9}/h

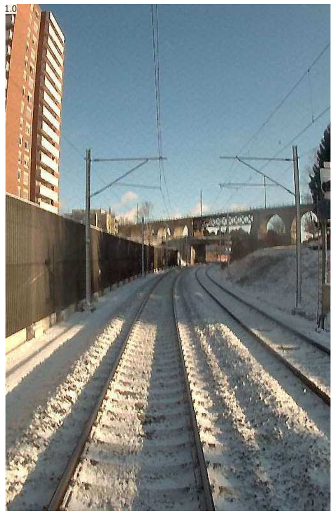


- Railway operations environment much more challenging than for aviation (open sky)
  - Satellites signals masked by slopes, buildings, tunnels
  - Satellites signals reflected / diffracted by environment

- Multi-sensor fusion with GNSS tight-coupling
  - Detection and exclusion filters
  - Confidence Interval innovative algorithm

- For this type of solution,
  foreseen EGNOS evolutions


(credit Siemens)



EGNOS EVOLUTIONS FOR RAIL

- EGNOS service performance at pseudo-range level

- Short-term: EGNOS V3 DFMC Dual-Frequency Multi-Constellation
  - Improved availability and accuracy wrt EGNOS V2

- Mid-term: new EGNOS safety service for Rail
  - Additional augmentation data

    ⇨ Reduced Confidence Intervals

  - Dissemination by terrestrial network

    (in addition to GEO satellite broadcast)

    ⇨ Improved accessibility on-board trains

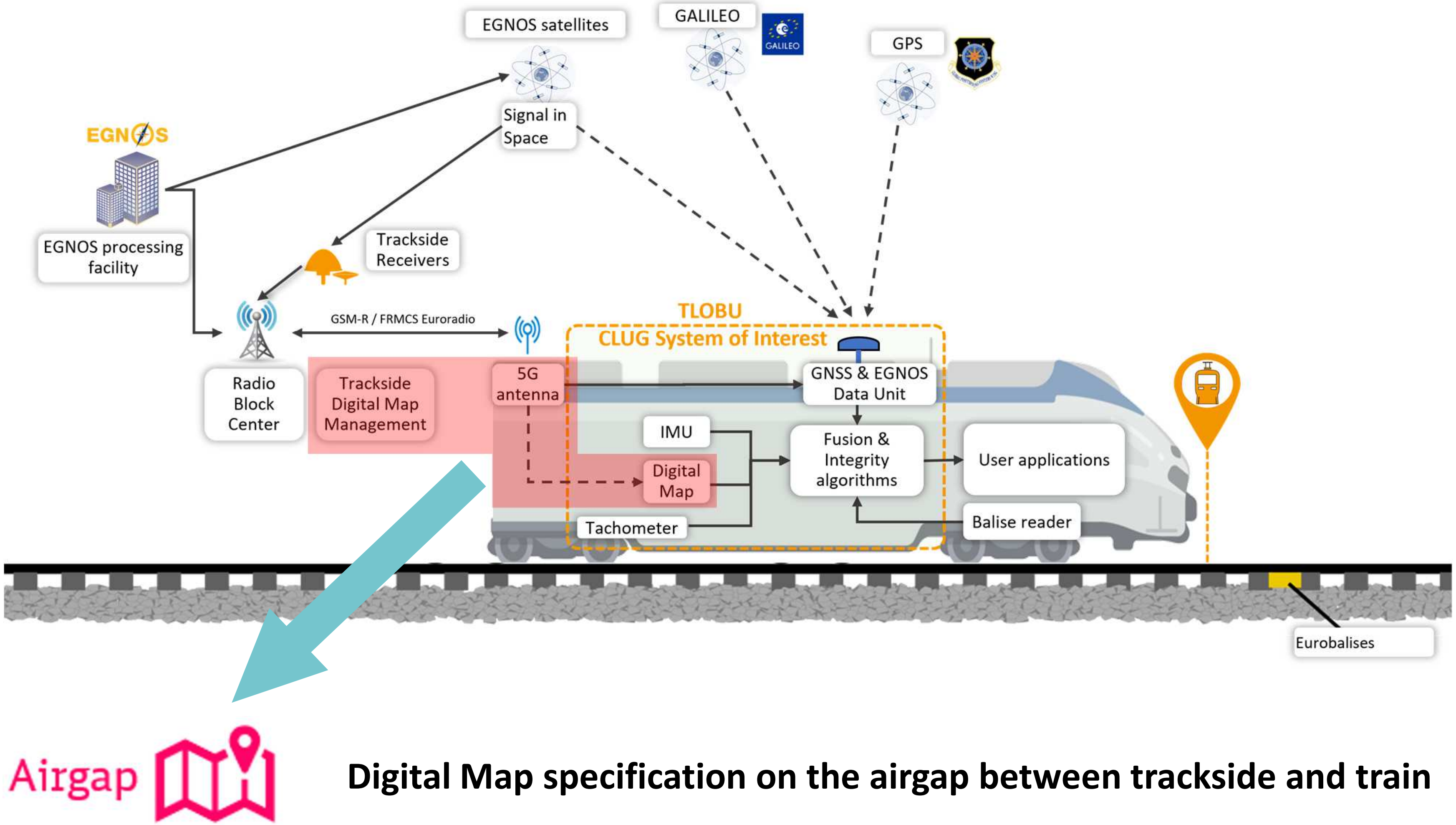
Digital maps for failsafe localisation

HENNING NITZSCHKE,

PRODUCT OWNER, DIGITAL MAPS, DB NETZ AG

European Union Agency for the Space Programme

TARGET PICTURE DIGITAL MAP



Digital Map specification on the airgap between trackside and train

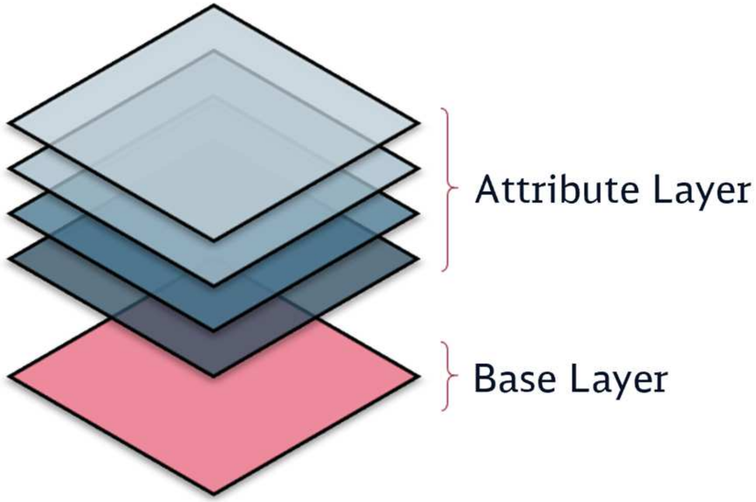
GENERAL ASSUMPTIONS

Enabler for following system functionalities:

- Map matching of the 3D position to a linear movement along the current TrackEdge
- Track selectivity algorithm to determine the current TrackEdge ID
- Bounding the errors of the inertial sensors

Map design criterias:

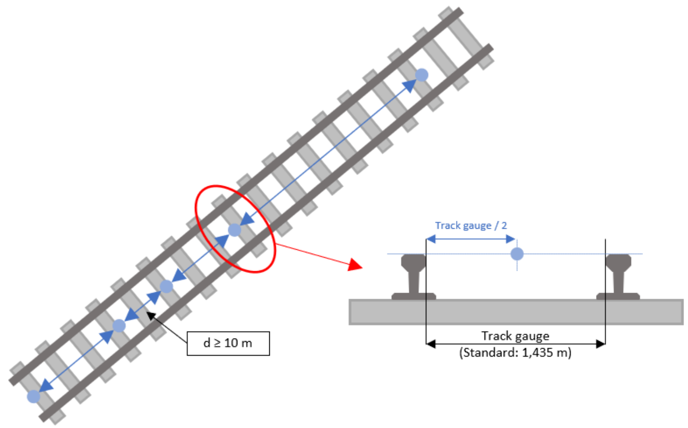
- Machine-readable
- Be usable for a long term
- Universally extandable
- Structured as simple as possible
- Without redundancies



MAP CONTENT

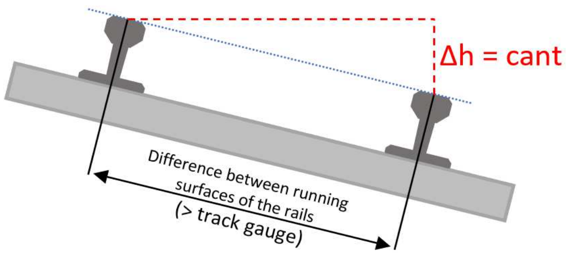
Mandatory data:

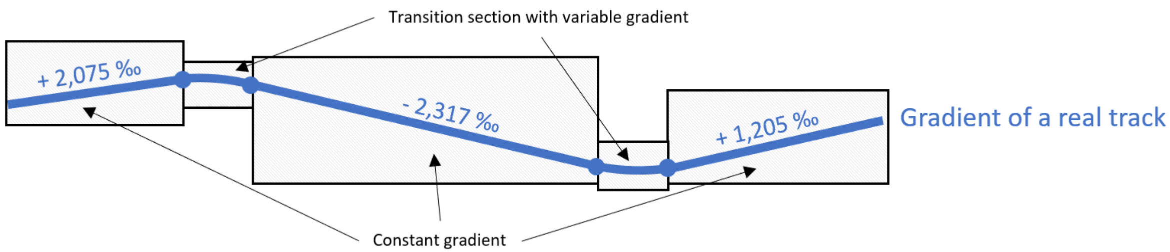
- Topology / Node-Edge-Model
- Absolute position (WGS84, Long / Lat / Alt) of track centerlines



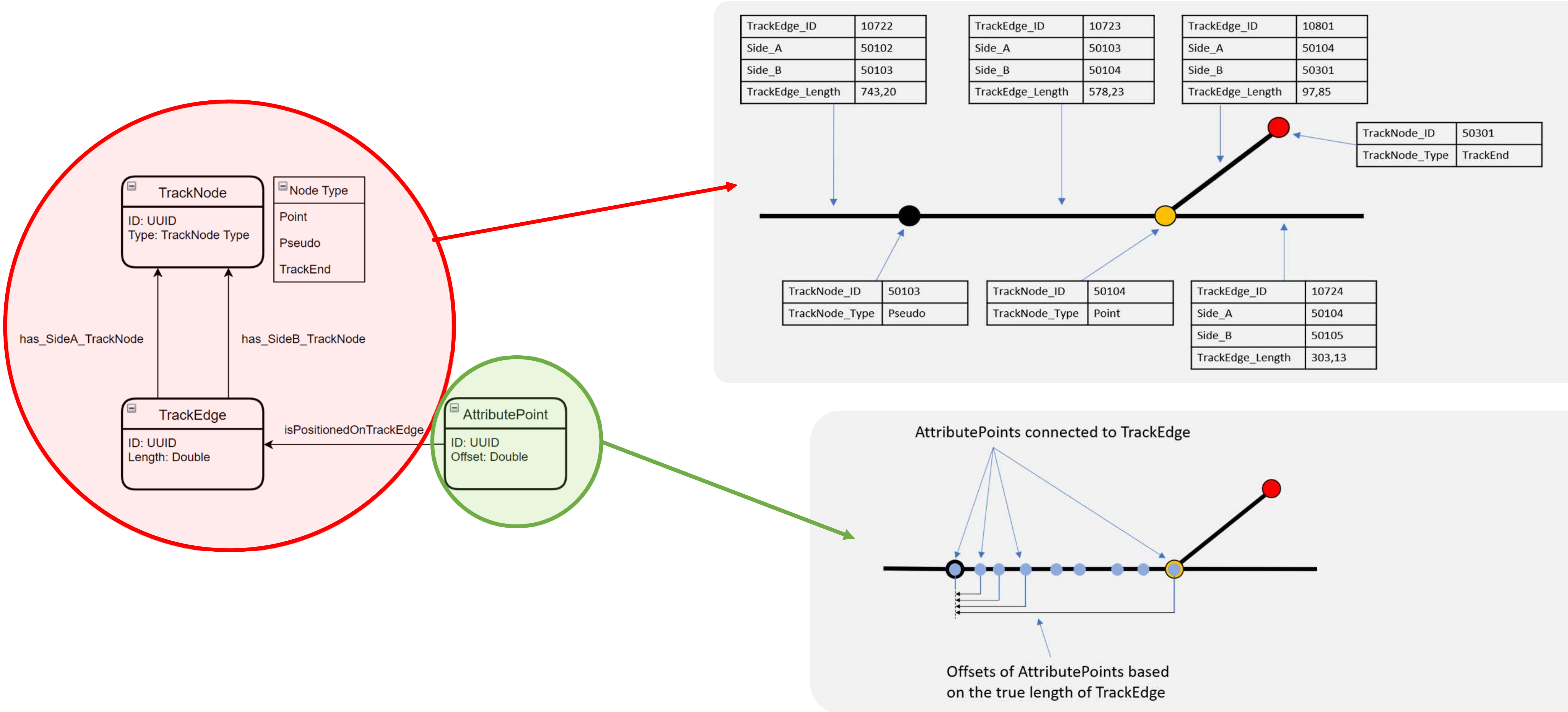
Optional data:

- Balise positions
- Track geometry (curvatures, cants, gradients)



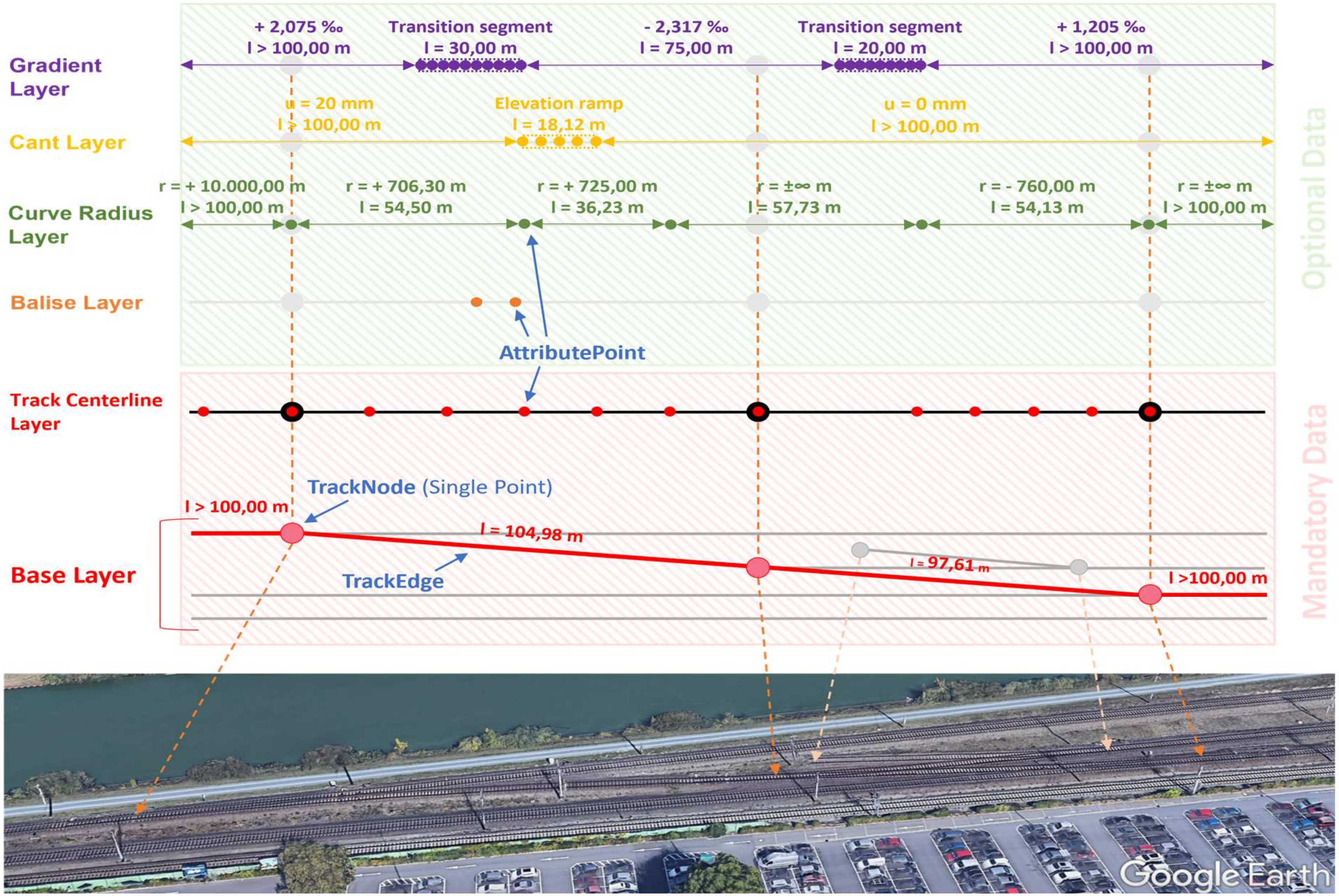


DATA MODEL



TrackNode
ID: UUID
Type: TrackNode Type
Node Type
Point
Pseudo
TrackEnd
has_SideA_TrackNode
has_SideB_TrackNode
TrackEdge
ID: UUID
Length: Double
isPositionedOnTrackEdge
AttributePoint
ID: UUID
Offset: Double
TrackEdge_ID 10722
Side_A 50102
Side_B 50103
TrackEdge_Length 743,20
TrackEdge_ID 10723
Side_A 50103
Side_B 50104
TrackEdge_Length 578,23
TrackEdge_ID 10801
Side_A 50104
Side_B 50301
TrackEdge_Length 97,85
TrackNode_ID 50301
TrackNode_Type TrackEnd
TrackNode_ID 50103
TrackNode_Type Pseudo
TrackNode_ID 50104
TrackNode_Type Point
TrackEdge_ID 10724
Side_A 50104
Side_B 50105
TrackEdge_Length 303,13
AttributePoints connected to TrackEdge
Offsets of AttributePoints based
on the true length of TrackEdge

MAP STRUCTURE



OPEN POINTS

TrackEdgeProperty_Type	Curve_Radius
TrackEdge_ID	6107_00_1809
Iterations	3
AttributePoint_Offset (1)	0,00 m
Curvature (1)	0,001415829 (1/+706,30 m)
AttributePoint_Azymuth (1)	1,4357 rad
AttributePoint_Offset (2)	54,50 m
Curvature (2)	0,001379310 (1/+725,00 m)
AttributePoint_Azymuth (2)	1,5414 rad
AttributePoint_Offset (3)	90,73 m
Curvature (3)	0,00000 (1/∞ m)
AttributePoint_Azymuth (3)	1,5928 rad

TrackEdgeProperty_Type	Curve_Radius
TrackEdge_ID	6107_00_1810
Iterations	2
AttributePoint_Offset (1)	43,48 m
Curvature (1)	-0,001315789 (1/-760,00 m)
AttributePoint_Azymuth (1)	1,5200 rad
AttributePoint_Offset (2)	97,61 m
Curvature (2)	0,00000 (1/∞ m)
AttributePoint_Azymuth (2)	1,4957 rad

CONCLUSION AND NEXT STEPS

Conclusion:

- Approach which ensure interoperability
- Future proven map specification for localisation use cases and beyond

Next steps / What‘s missing

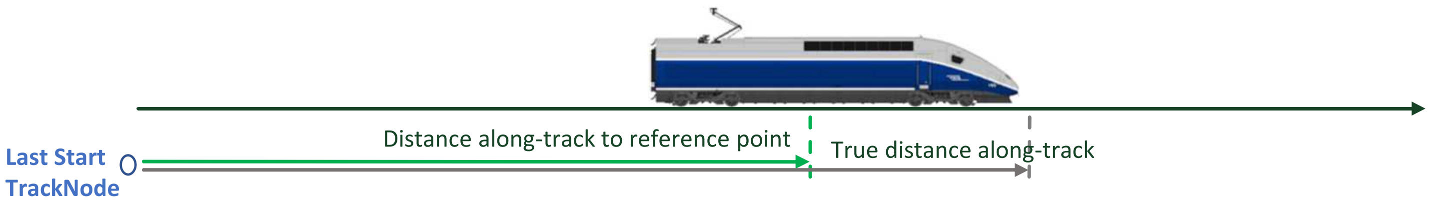
- European aligned data management for the Infrastructure Managers
- Standardised data distribution processes

Performance and Safety analyses (solution A)

PIERRICK GRANDJEAN, AIRBUS DEFENCE AND SPACE

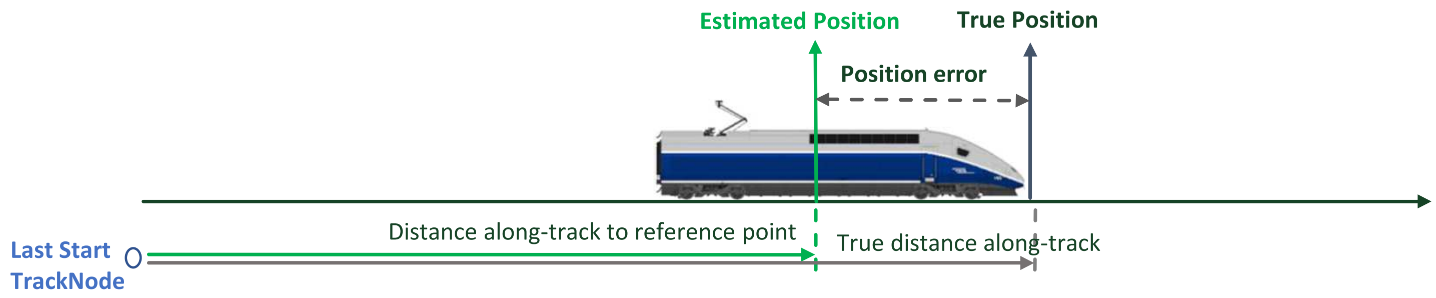
PERFORMANCE TERMS DEFINITIONS

Performance	Definition
Position state parameters	**Distance along-track**, Track ID, Velocity along-track, Acceleration



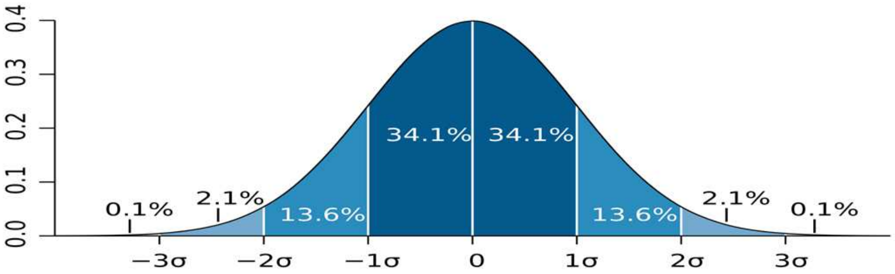
PERFORMANCE TERMS DEFINITIONS

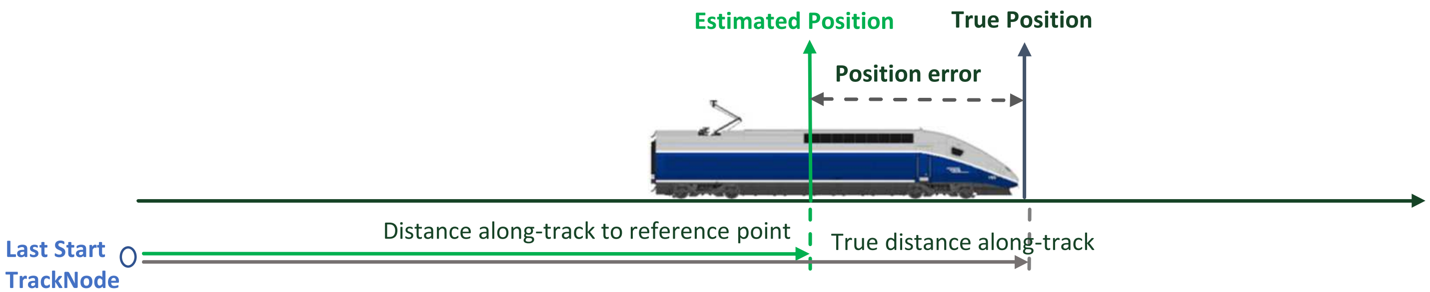
Performance	Definition
Position state parameters	**Distance along-track**, Track ID, Velocity along-track, Acceleration
Position error	Difference between estimated and true values of state parameters



PERFORMANCE TERMS DEFINITIONS

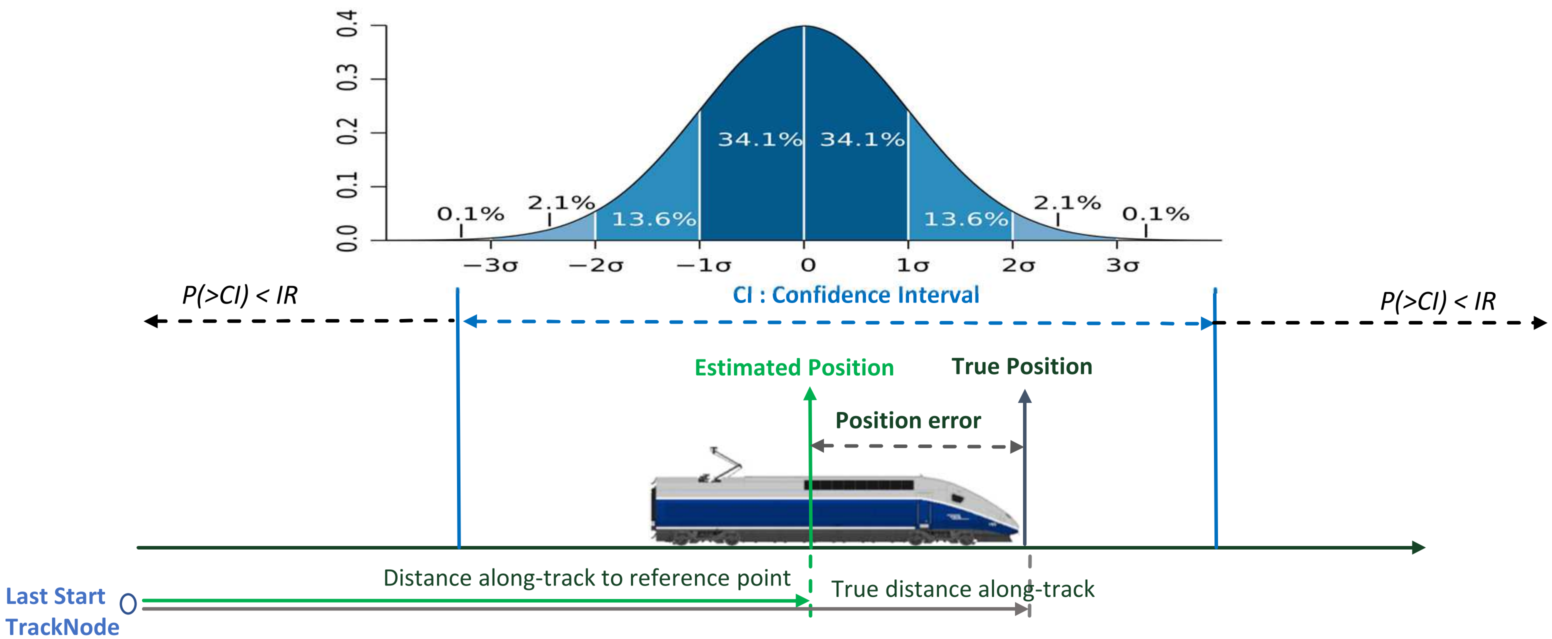
Performance	Definition
Position state parameters	**Distance along-track**, Track ID, Velocity along-track, Acceleration
Position error	Difference between estimated and true values of state parameters
Accuracy	Statistical range of the position error, usually 95% (2σ) or 99% (3σ)





PERFORMANCE TERMS DEFINITIONS

Performance	Definition
Confidence Interval (CI)	Interval within which the error on a given state parameters must be contained within the Integrity Risk probability
Integrity Risk (IR)	Probability that the error exceeds the bounds of the Confidence Interval



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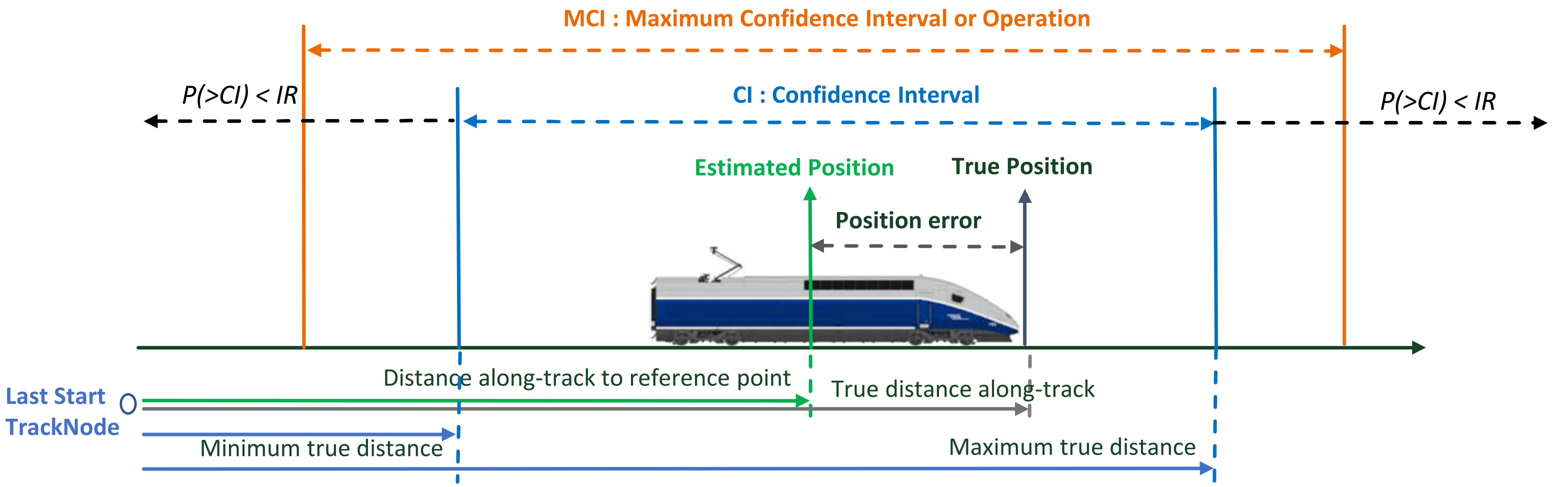
Maximum Confidence Interval for Operation (MCI)	Maximum extent of the Confidence Interval compatible with nominal operations If CI > MCI, operations may be impacted, e.g. timely arrivals, traffic density, …



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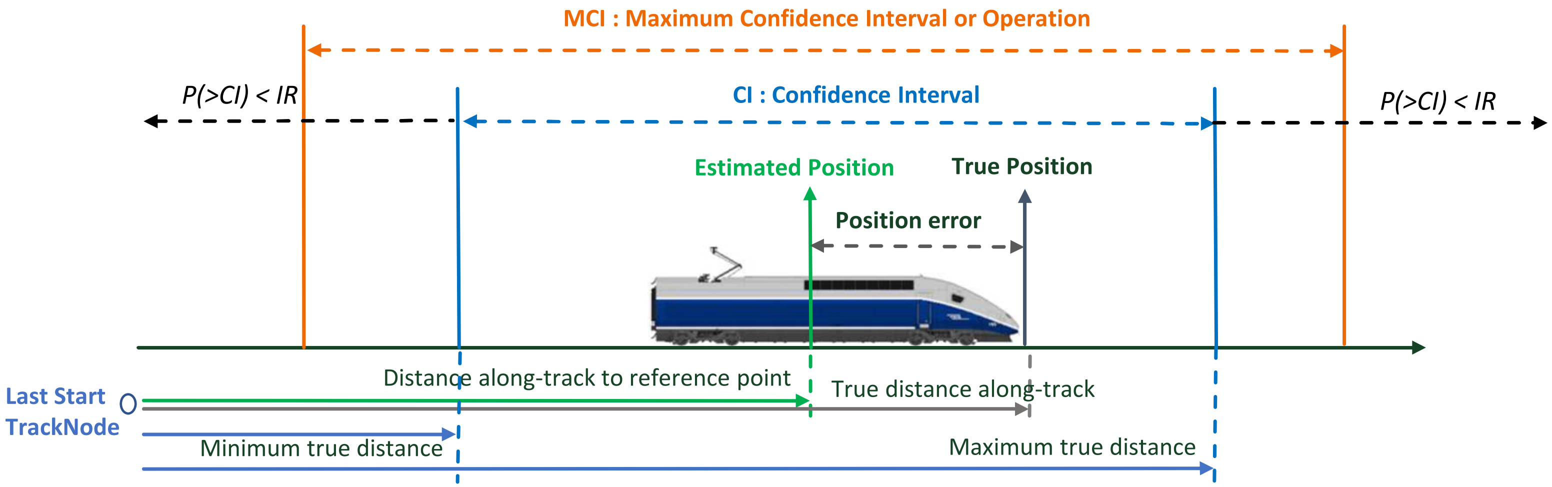
Availability	Portion of time when the function provides the required performance (e.g. CI < MCI)



Integrity risk is a Safety issue

Maximum Confidence Interval is an operational concern

DEPENDABILITY METHODOLOGY APPROACH

Focus on safety Feared Events (SIL4) : position/speed out of Confidence Interval

Proof-of-concept stage: no HW available data for performing classical quantitative approach

- 1st step: Qualitative analysis (top-down)
- 2nd step: Quantitative analysis to demonstrate reachable SIL

Based on some assumptions:

- Defining two mission phases/areas to tackle dynamic behaviour (fusion data, Kalman filter)
  - Clarifies which data is required for each phase to provide Safe TLOBU outputs

Area	GNSS availability	Provide Min/Max Safe Frond End	Provide Safe Speed
Clear sky	GNSS signal reception is good	GNSS data is sufficient	Combination of GNSS and IMU data is sufficient
Masked	GNSS signal reception is poor and not sufficient to be used safely	IMU data is used	IMU + Speed sensor to enhance performance

- TLOBU Detection capacities (FDE: Fault Detection and Exclusion): GNSS local FDE < $1E^{-8}$/h, else $1E^{-9}$/h
- Sensor & internal TLOBU data failure probabilities: IMU < $1E^{-7}$/h, EGNOS < 2.4 $1E^{-6}$/h, else $1E^{-9}$/h

DEPENDABILITY ANALYSIS RESULTS

1- Qualitative analysis: some single failure mays lead to CAT events

- To prevent from single failure, future HW/SW design shall:
  - Add redundancy and independency principles
  - Complete design of failure detection and exclusion algorithms

2 - Quantitative analysis (solution A)

- TFFR are compliant with SIL 3 target
  for the TLOBU safety functions
  ➔ very promising at CLUG maturity stage
  (proof of concept, functional architecture)

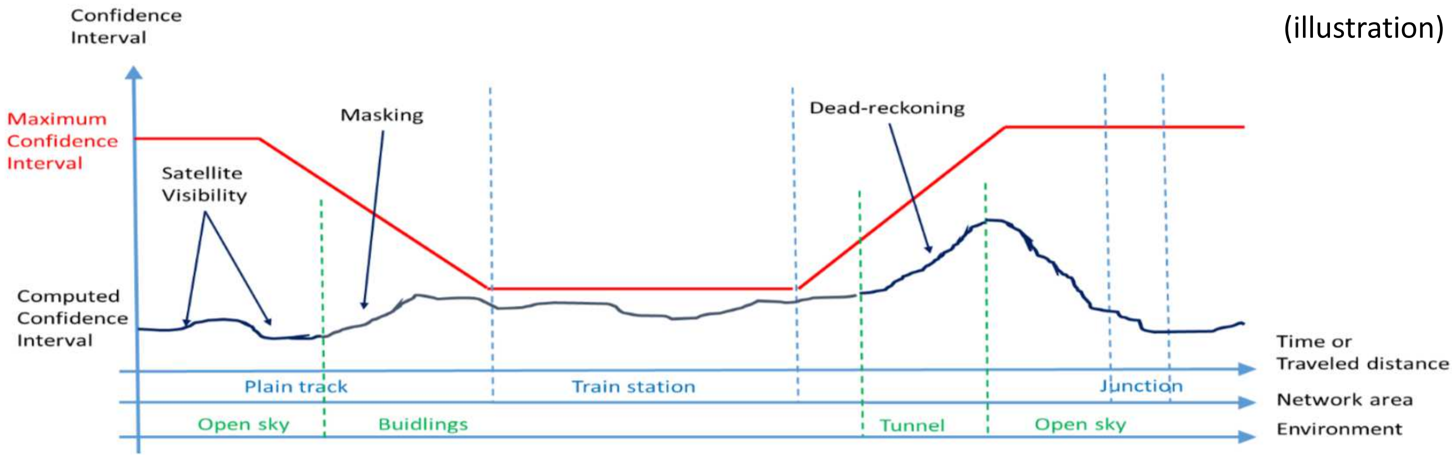
Quantitative demonstration results	Result
Provide Minimum and Maximum Safe Front End Position	
In clear sky area: TFFR =	2.24E-8/h
In masked area: TFFR =	9E-9/h
Provide Minimum and Maximum Safe Accurate Front End	
Same as function Minimum and Maximum Safe Front End Position	
Provide Safe TU Speed	
In clear sky area: TFFR =	1.94E-8/h
In masked area: TFFR =	5E-9/h
Provide Safe TU Along-track Acceleration	
TFFR =	5E-9/h

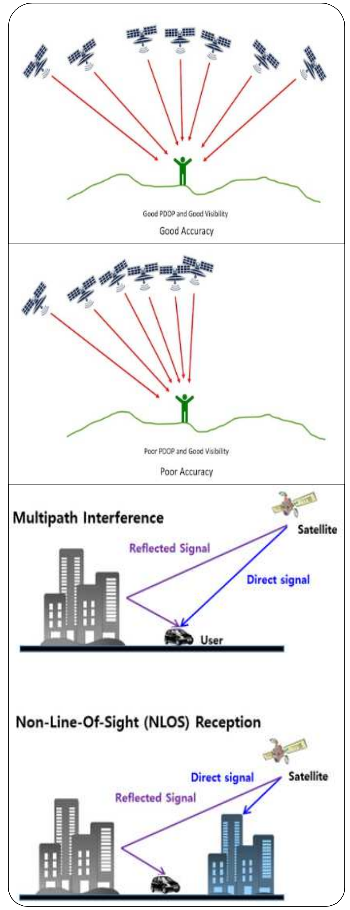
Solutions ahead:

- SIL 3 or 4 requirement refinement (per parameter)
  thanks to more detailed Safety allocation
  from system level feared events to TLOBU functions
- SIL 4 thanks to redundancy in the TLOBU
  localization chain industrial solution

COMPUTED CONFIDENCE INTERVAL DRIVERS

(illustration)





Computed Along-Track Confidence Interval value depends on:

- GNSS measurements availability
  - Satellites visibility (number, elevation, dilution of precision)
  - Discarded measurements due to masking and Data FDE exclusion (depending on environment)
- GNSS error and integrity models (after correction by SBAS)
  - GNSS system error models (GPS, Galileo, EGNOS)
  - Local environment error and integrity models (feared events)

EGNOS DFMC

- IMU and Track Map error models
- No physical balises considered for this analysis

CI PERFORMANCE PREDICTION GENERAL APPROACH

Geographical / time / track direction sampling

Simulation of satellites positions in train reference frame

↓

Simulation of masking and exclusion by Data FDE

Available GNSS measurements

↓

Fusion filter equations + Error models incl. EGNOS model

Prediction of state covariance

↓

Track direction projection + Safety factor (1^{E}-6/h THR)

Prediction of Confidence Interval

↓

Statistics on CI values for 99.9% availability

Reachable Maximum Confidence Interval

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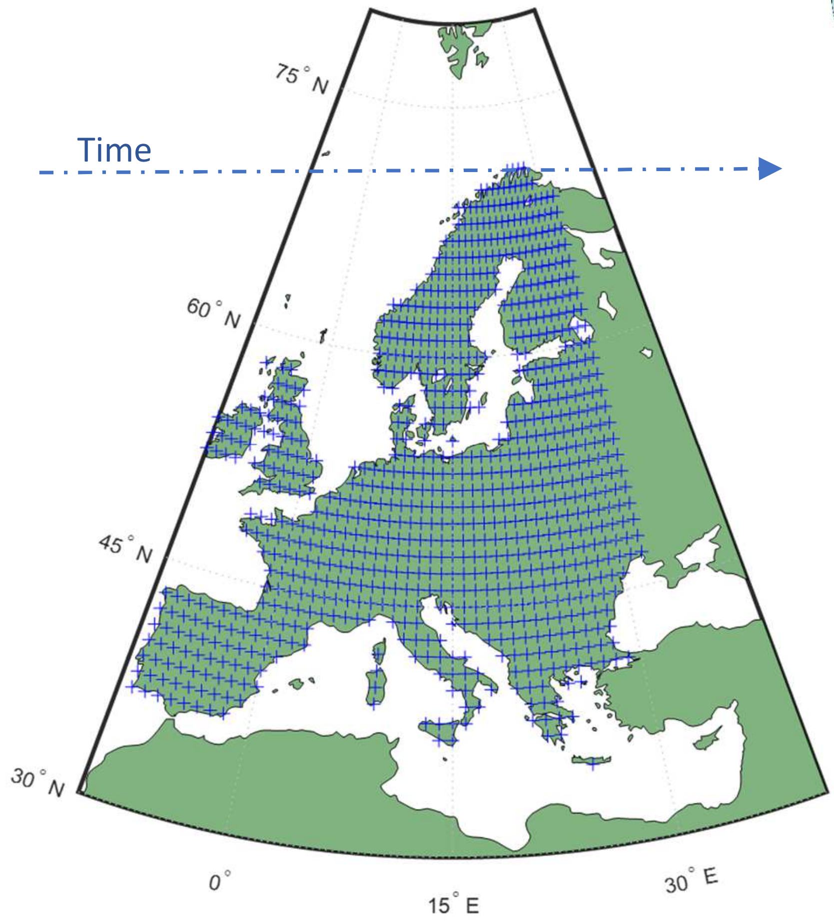

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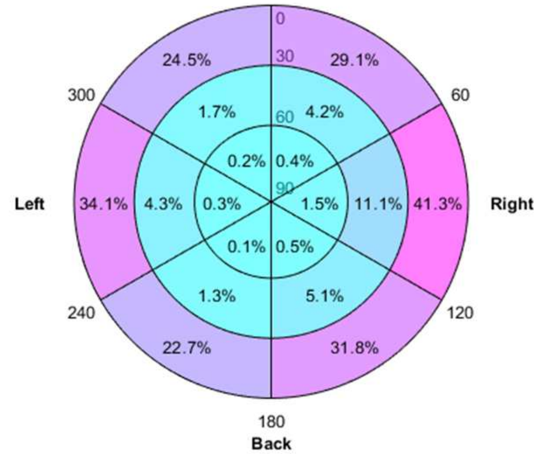
Environment context	Clear-sky	Suburban	Urban

Masking model Proba (relative azimuth | elevation)



FDE simulation

Exclusion ratio	Residual local σ
0 %	0.5 m
10 %	1 m
25 %	5 m
50 %	10 m

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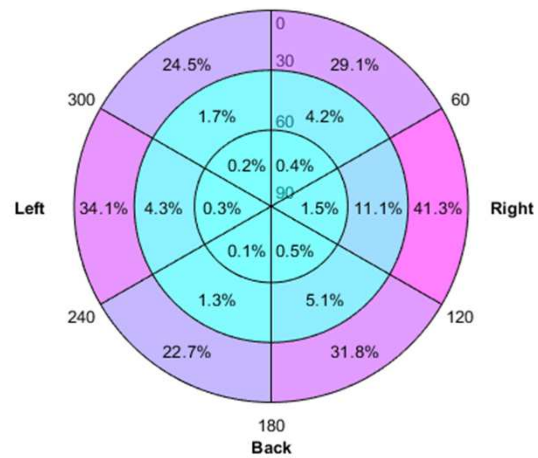

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↓

Fusion filter equations + Error models incl. EGNOS model
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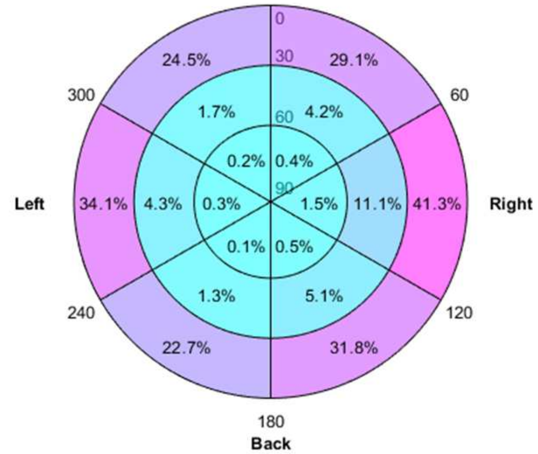

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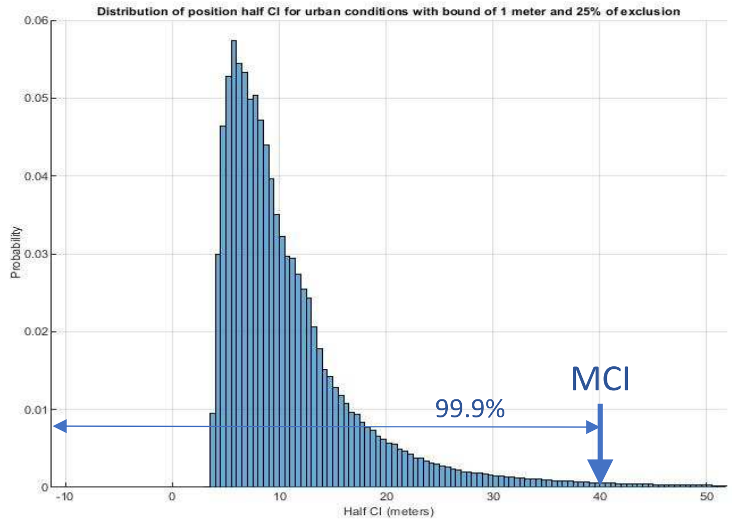
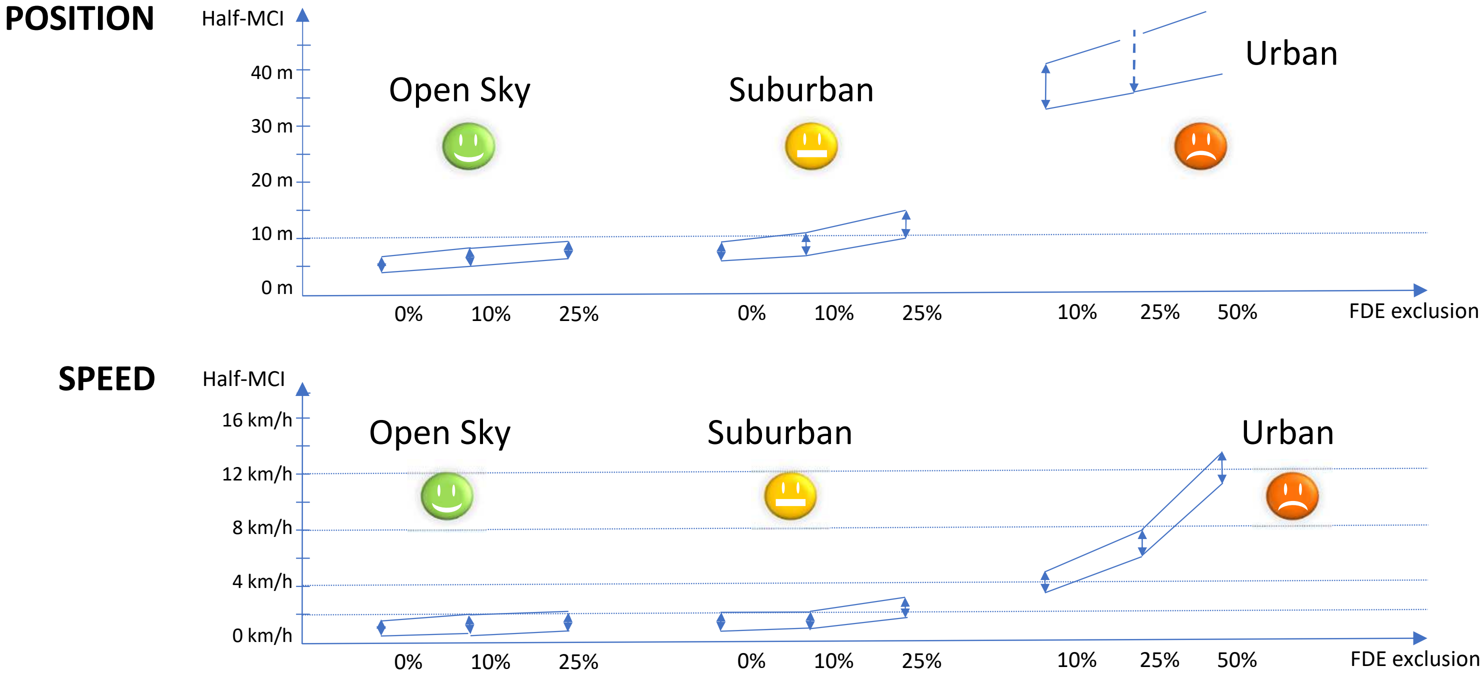


RESULTS

REACHABLE MCI @ 99.9% USING EGNOS DFMC & NO BALISE



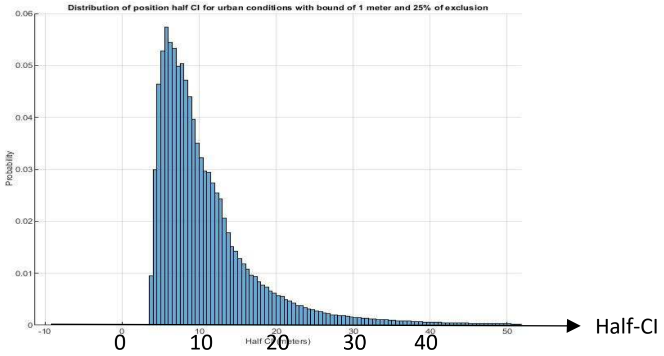
Conclusions:

- High performance in Open Sky
- Improvement in Urban / Suburban
  - Physical balises in critical areas
  - Enhanced service « EGNOS for Rail »

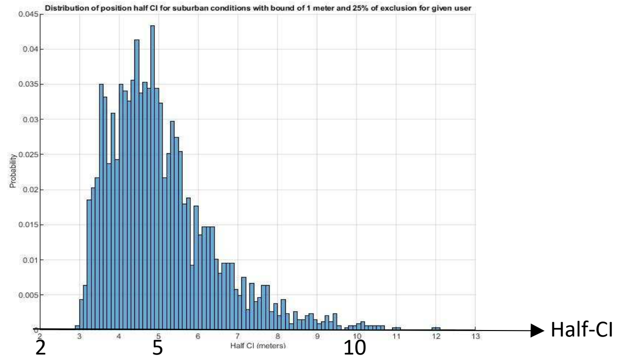
Way forward:

- More precise modeling of CI computation algorithm, Data FDE behavior, correlations and biases
- Account for GNSS-denied areas in train route scenarios
- Performance prediction with future enhanced service « EGNOS for Rail »

RESULTS: REGULAR CI VALUES DISTRIBUTION

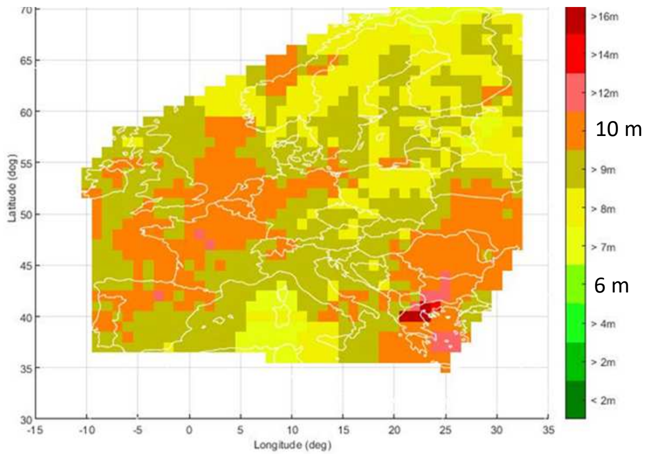


Global Half-CI position (Urban, 25% exclusion, σ=1m)

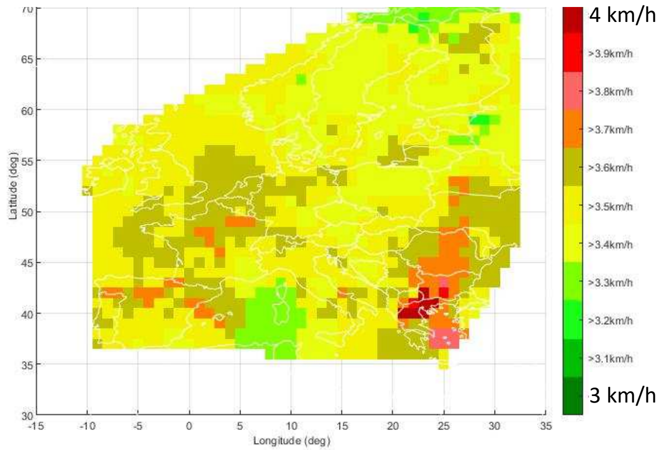


Half-CI position for a single location (Suburban, 25% exclusion, σ=1m)

Geographical distribution over Europe
(half-MCI position , Suburban, 25% exclusion, σ=1m)



Geographical distribution over Europe
(half-MCI speed , Suburban, 25% exclusion, σ=1m)



DEPENDABILITY METHODOLOGY CONTEXT

Inputs (WP2): Preliminary Hazard Analysis (PHA)

- Identification of Feared Events and associated targets (THR/TFFR + SIL).
- Safety requirements definition (worst case):
  - based on high-level train control assumptions
  - TLOBU contribution considered TFFR = Half of THR

THR = Tolerable Hazard Rate
TFFR = Tolerable Functional Failure Rate

Safety Requirements (from PHA – WP2)	TFFR for TLOBU
Provide Minimum and Maximum Safe Front End Position	5E-10/h
Provide Minimum and Maximum Safe Accurate Front End	5E-8/h
Provide Safe TU Speed	5E-10/h
Provide Safe TU Along-track Acceleration	5E-10/h

Extract of most stringent Safety requirements (from PHA – WP2)

Data Collection and Processing

BERNHARD STAMM

CLUG WP4 TESTING AND EVALUATION LEADER

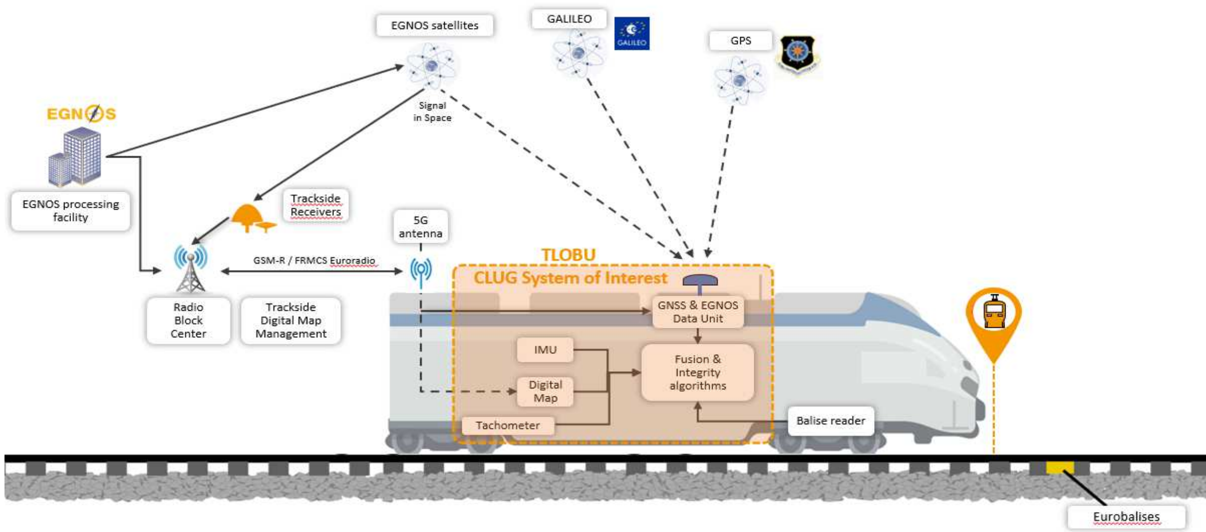
INTRODUCTION

The purpose of WP4, Data Collection and Processing, was to evaluate the performance of the positioning solutions developed by Airbus and Naventik, as if these systems would be tested onboard a train.

The solutions under test are based on the fusion of data from multiple sensors, such as GNSS, tachos, accelerometers, gyros, a track map and EGNOS augmentation data.

A fusion algorithm then produces speed, position and auxiliary data, such as attitude, as well as corresponding error estimations and confidence intervals.

In order to analyse the performance, a reference is required, which we call Ground Truth. This reference also had to be generated as part of the data collection.

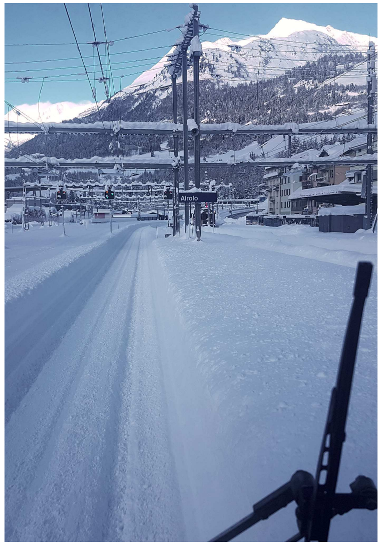


MAIN CHALLENGE

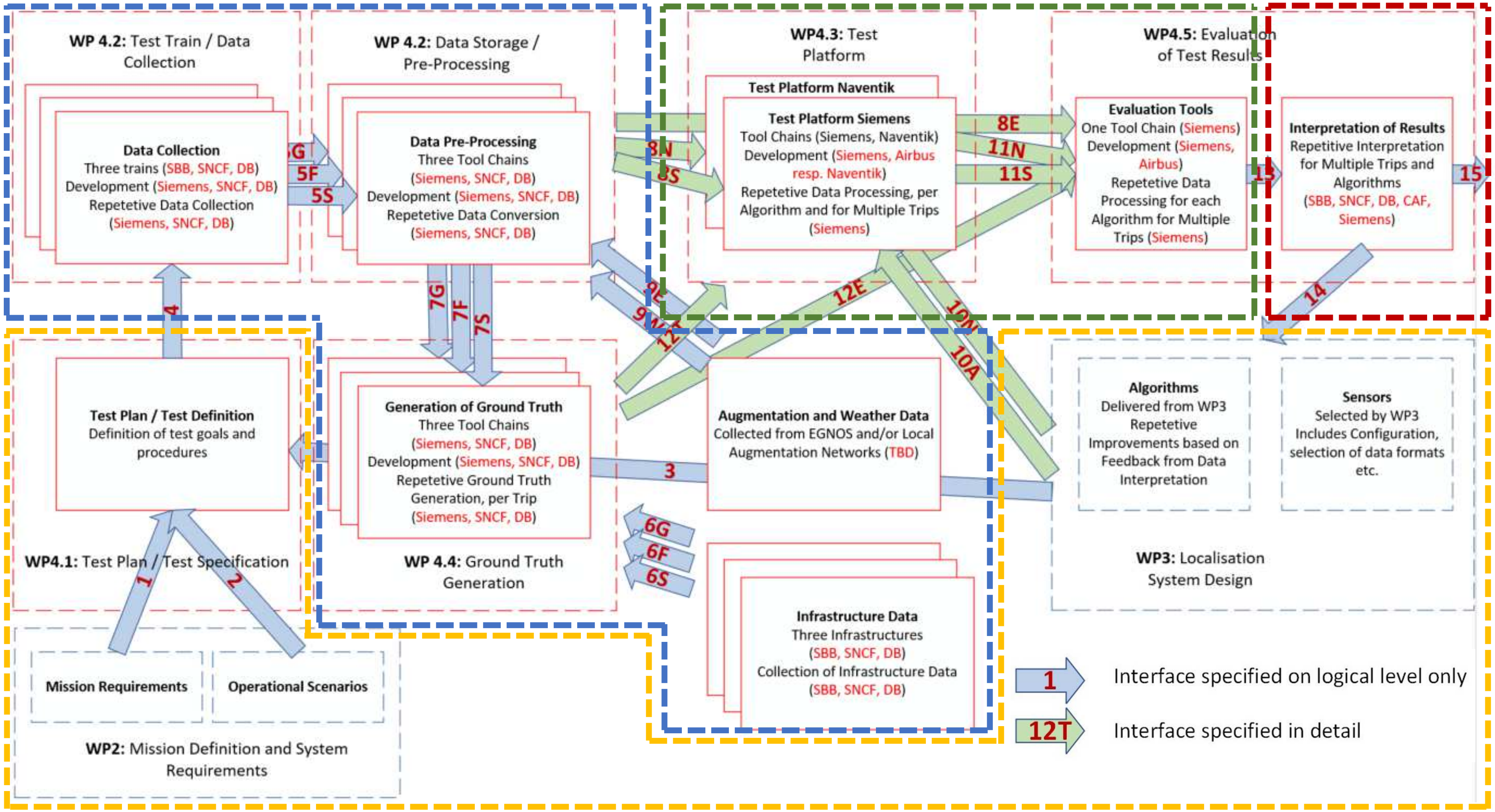
The performance of the positioning solutions developed in CLUG, which currently only consist of fusion algorithms, is impacted mostly by the environment in which trains operate, by train operation as well as by the trains themselves.

Environmental and operational effects are too complex to be generated artificially, especially where the same effect impacts multiple sensors. This resulted in the need to collect data from the relevant sensors in real operation on different trains and in different railway environments.

Various tools and processes therefore had to be developed in WP4 to collect sensor data onboard trains with the required resolution and time synchroneity, to convert it to harmonise data formats, to process that data with the algorithm and to evaluate the results generated.



WORKFLOW



WP 4.2: Test Train / Data Collection
Data Collection
Three trains (SBB, SNCF, DB)
Development (Siemens, SNCF, DB)
Repetetive Data Collection
(Siemens, SNCF, DB)
WP 4.2: Data Storage / Pre-Processing
Data Pre-Processing
Three Tool Chains
(Siemens, SNCF, DB)
Development (Siemens, SNCF, DB)
Repetetive Data Conversion
(Siemens, SNCF, DB)
WP4.3: Test Platform
Test Platform Naventik
Test Platform Siemens
Tool Chains (Siemens, Naventik)
Development (Siemens, Airbus resp. Naventik)
Repetetive Data Processing, per Algorithm and for Multiple Trips
(Siemens)
WP4.5: Evaluation of Test Results
Evaluation Tools
One Tool Chain (Siemens)
Development (Siemens, Airbus)
Repetetive Data Processing for each Algorithm for Multiple Trips (Siemens)
Interpretation of Results
Repetitive Interpretation for Multiple Trips and Algorithms
(SBB, SNCF, DB, CAF, Siemens)
Test Plan / Test Definition
Definition of test goals and procedures
WP4.1: Test Plan / Test Specification
Generation of Ground Truth
Three Tool Chains
(Siemens, SNCF, DB)
Development (Siemens, SNCF, DB)
Repetetive Ground Truth Generation, per Trip
(Siemens, SNCF, DB)
WP 4.4: Ground Truth Generation
Augmentation and Weather Data
Collected from EGNOS and/or Local Augmentation Networks (TBD)
Infrastructure Data
Three Infrastructures
(SBB, SNCF, DB)
Collection of Infrastructure Data
(SBB, SNCF, DB)
Algorithms
Delivered from WP3
Repetetive Improvements based on Feedback from Data Interpretation
Sensors
Selected by WP3
Includes Configuration, selection of data formats etc.
WP3: Localisation System Design
Mission Requirements
Operational Scenarios
WP2: Mission Definition and System Requirements
5G
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8S
11N
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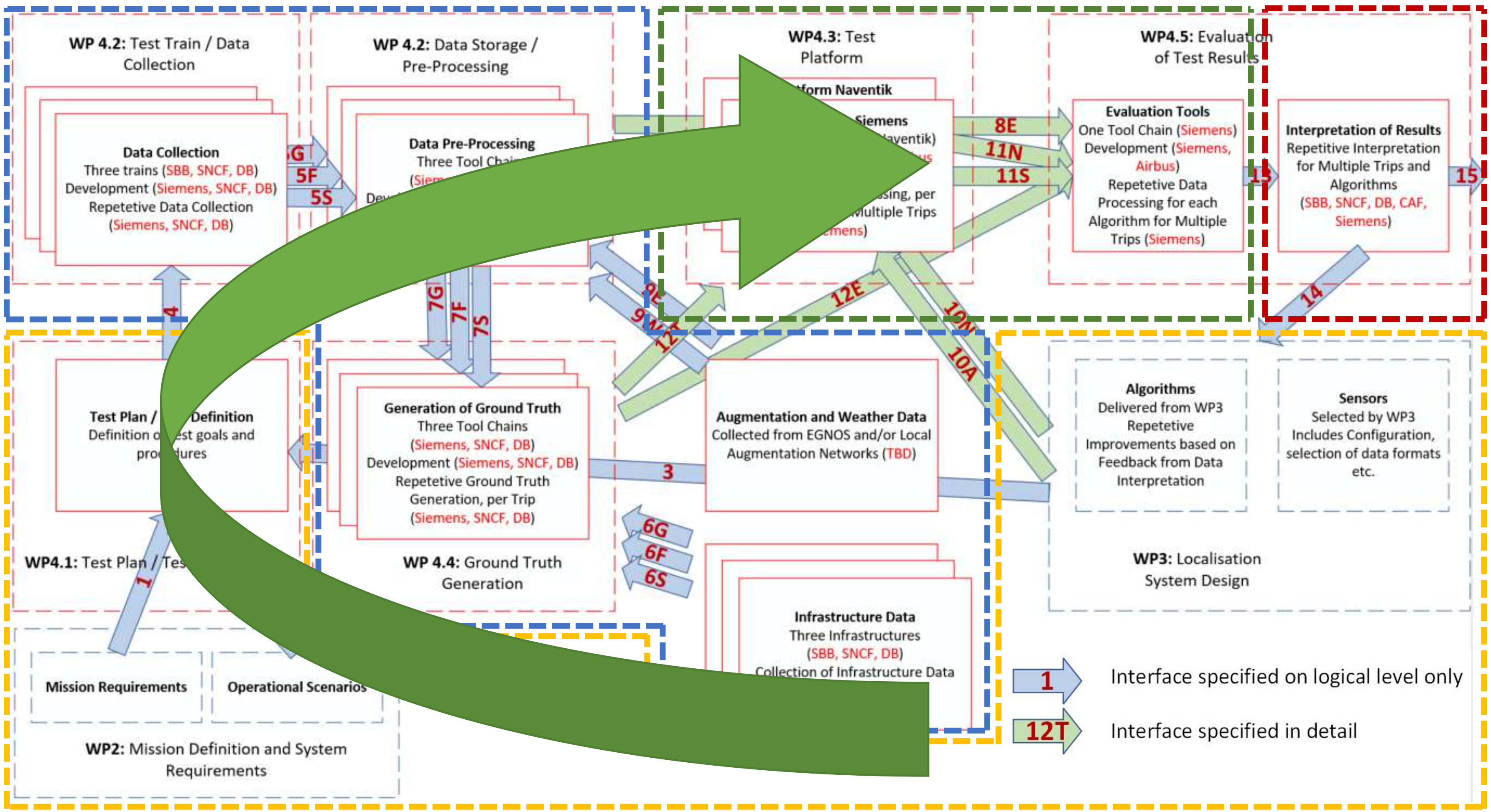
Interface specified on logical level only
12T
Interface specified in detail

WORKFLOW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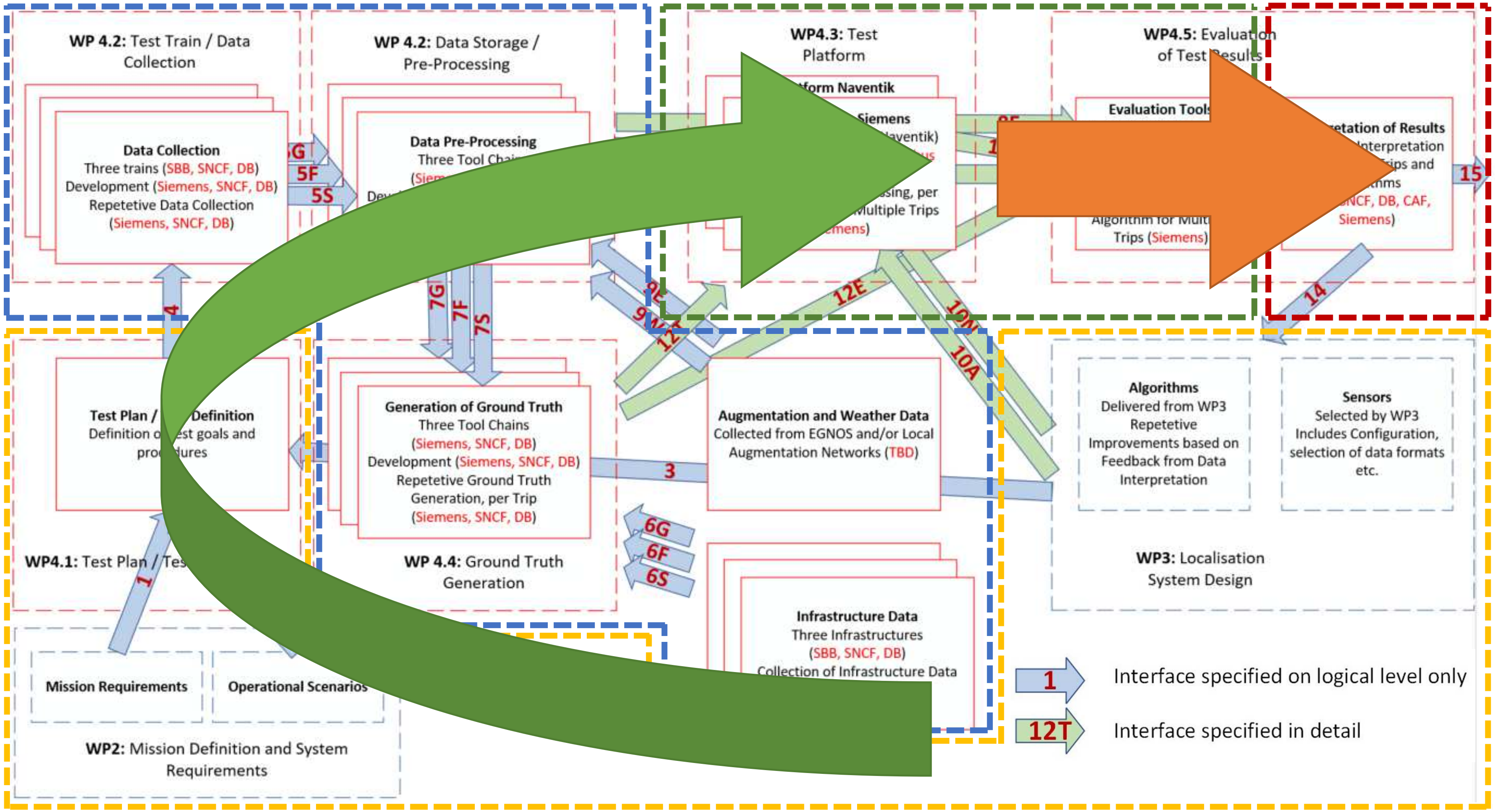
WORKFLOW



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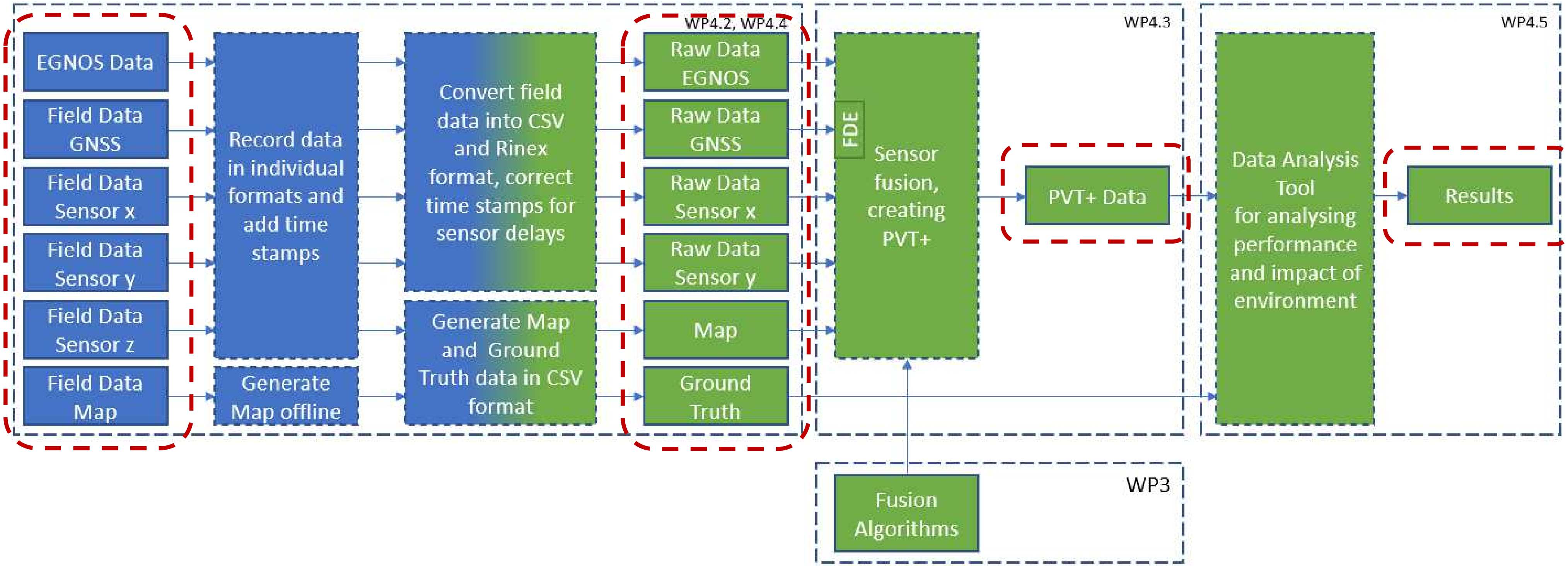
12T Interface specified in detail

DATAFLOW

The figure below shows the flow of data through the various processing steps in WP4, from raw sensor data on the left to the final analysis of the fusion results on the right side. The blue parts are site specific, while the green parts are based on harmonised tools, formats etc.



DATA COLLECTION, TEST TRAINS

Test trains then had to be selected, on which the required antennas, sensors and equipment could be installed and which could then be used to collect data.

These train also had to operate under different environmental and operational conditions, which are representative for the European railway network.

Many environmental and operational conditions only occur under rare operating conditions or at specific locations, which are difficult to predict or control. To get a good coverage of environments and operation conditions, data therefore had to be collected over many hours and kilometres, covering different environments (lines), different situations (season, weather, time of day) and operating conditions (speed etc.).

THE DOMINO TRAIN OF SBB

The lead test train was a Domino trainset from SBB, which operates daily in commercial service. Built in the late 90's, it still has a baggage compartment, which is however not used anymore operationally, and thus provides ample space for the installation of test equipment.

The specific example used in the frame of the CLUG project is equipped with ETCS Level 2 and can operate on any line in Switzerland. It has already been used in the STARS project for data collection, from which significant parts of the installed equipment could be reused.

THE DOMINO TRAIN OF SBB

For the CLUG project, additional antennas and sensors had to be installed.

This included:

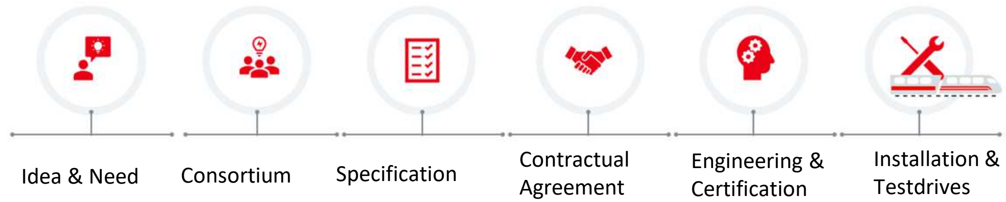
- a second GNSS Multiband Antenna for dual antenna measurements
- a Corrail Speed Sensor for generating the Ground Truth
- An updated Radar sensor, again for generating the Ground Truth
- Various GNSS receivers and IMUs

After some delays due to the COVID pandemic, this equipment could be installed between June and October 2020.

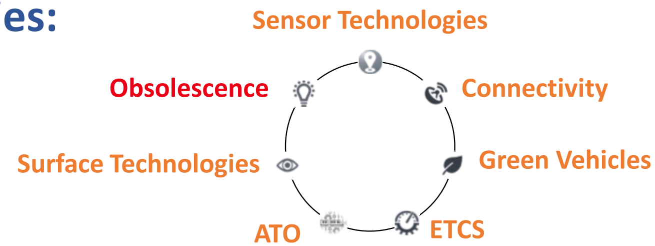
THE ADVANCED TRAINLAB OF DB

In Germany, the advanced Trainlab from DB was used for the CLUG project. It has been created by DB to accelerate the transfer of innovations into the railway system. It is open to test new technologies in cooperation with industry and science. Components, such as antennas, odometry and further sensor technologies, can be tested under real conditions.

Typical Project Process:

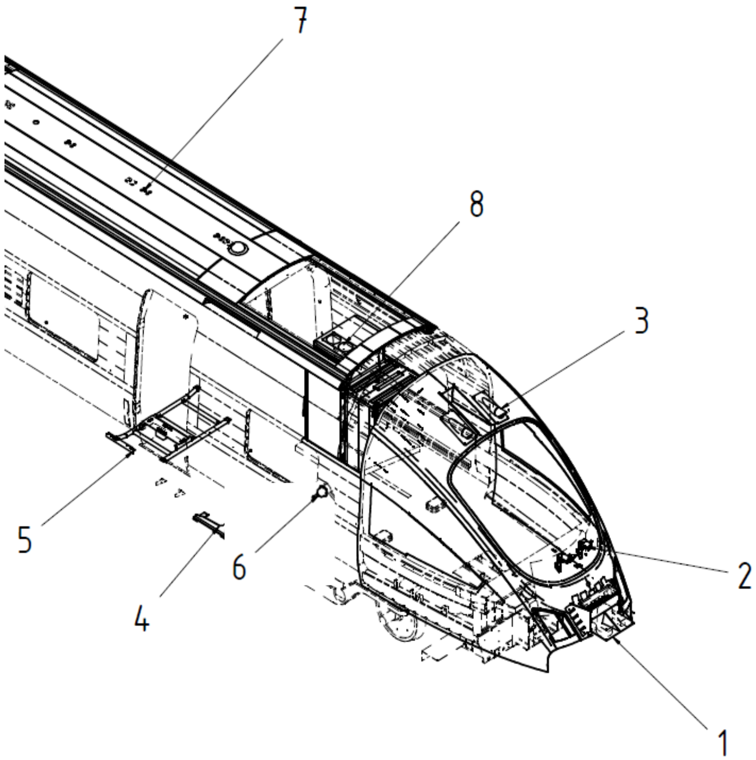


Fields of Technologies:



THE ADVANCED TRAINLAB OF DB

Also on the Advanced Trainlab, various additional antennas and sensors had to be installed for the CLUG project.



THE MARTINE TEST TRAIN OF SNCF

In France, a former passenger / baggage coach from SNCF called Martine, which has been converted into a test lab, has been used to perform measurements for the CLUG project. Martine can be pulled by different locomotives, and thus be used on any electrified or non-electrified line in France.

Also on Martine additional antennas and sensors had to be installed specifically for the CLUG project.

Just like Domino and ATL, also Martin was an already existing test vehicle, so significant elements required for testing could be used from previous projets.

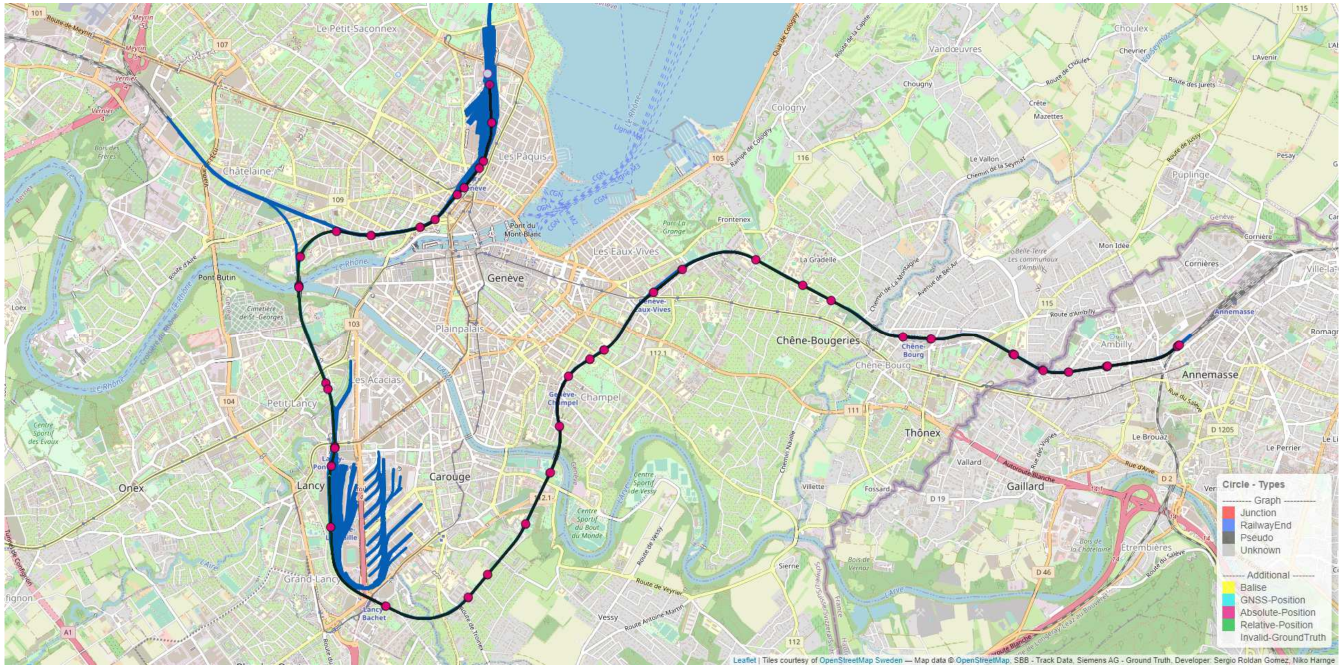
DATA COLLECTION

In France, measurements were performed with Martine on test runs specifically scheduled for the CLUG project.

In Germany, measurements were performed with the Advanced Trainlab on test runs specifically scheduled for the CLUG project, as well as on test runs scheduled for other projects.

In Switzerland, most data has been collected with the Domino train in commercial operation.

Several dedicated test campaigns outside commercial operation were however organised with SBB, each lasting of two or three days. In these campaigns, lines of interest were visited, and unusual manoeuvres performed.



DATA COLLECTION

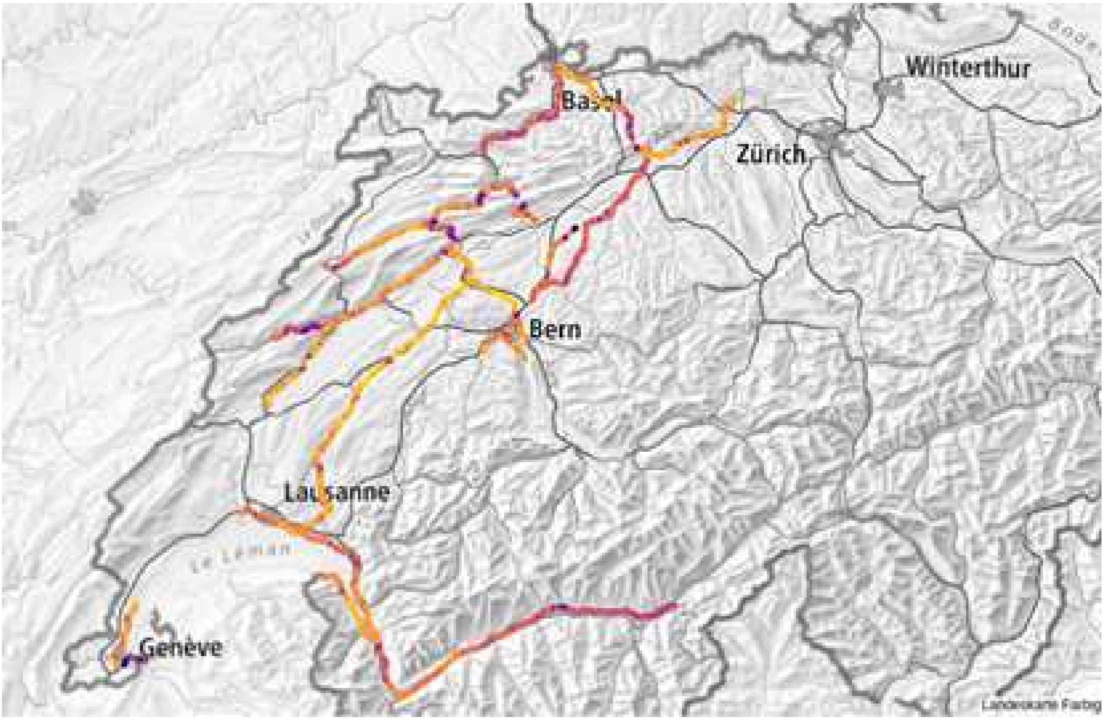
A short video has been prepared by SNCF on test runs performed in March 2022 on the CEVA line, which runs from Genève-Cornavin in Switzerland via Eaux-Vives to Annemasse in France. This line was of specific interest for the CLUG project, as it contains an underground section of 10 km with many curves, changing gradients and multiple stations.

The tests were performed with the Domino train from SBB, which had to be specifically certified for these runs to operate onto the French network.

COLLECTED DATA

Using three test trains, including one operating in commercial service, allowed the project to collect raw data in significant quantity in very different environments, with different train types, in different seasons and also with different sets of sensors.

While the tests on Domino were using a low-cost GNSS receiver, a low to mid-cost MEMS IMU and a wheel tacho on a powered axle, the tests on Martine and ATL were using a high-end GNSS receiver, high-end FOG IMU and a wheel tacho on a non-powered axle.



Data from various alternative sensors was however also recorded, whose impact on performance might also be investigated in further analysis work.

COLLECTED DATA

	Domino regional train	Advanced Train Lab	Martine test train
Time	4’500 hours	300 hours	100 hours
Distance	100’000 km	10’000 km	5'000 km
Lines	Approx. 50% of Swiss network	10	4
GNSS baseband data	yes	no	yes
Environments	Regional, Urban, Gorges, Mountainous, Long tunnels	Urban with Bridges, Regional with Bridges and Forest, Small Tunnels	Urban with Bridges, Regional with Bridges and Forest, Small Tunnels

DATA PROCESSING

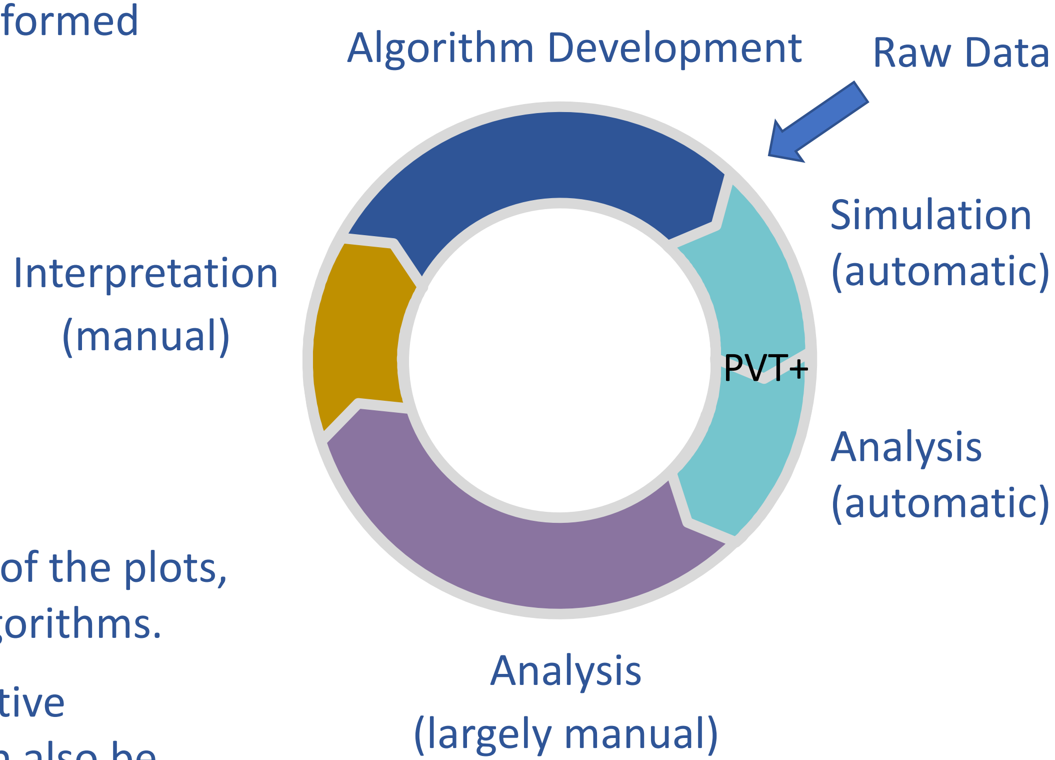
A process and tools have then been defined and developed, by which the actual testing of the fusion algorithms is performed offline with the collected field data.

The process starts with a tool specifically developed for CLUG, in which the field data is processed with the algorithms, generating the already mentioned speed, position and auxiliary data (PVT+).

In the next step the PVT+ data is compared with the Ground Truth data, and the results documented in various plots for analysis

This is then followed by an analysis and interpretation of the plots, generating input to the further development of the algorithms.

Once the algorithms have been updated by the respective partners, the cycle can be repeated. New field data can also be inserted at that stage.



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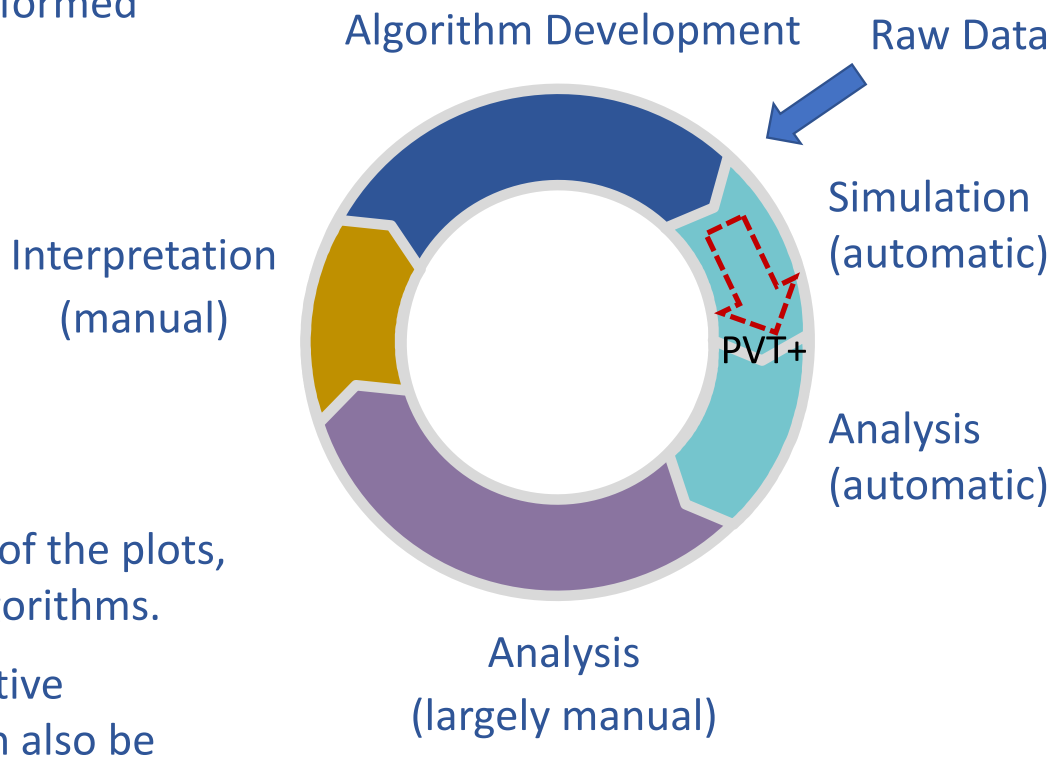

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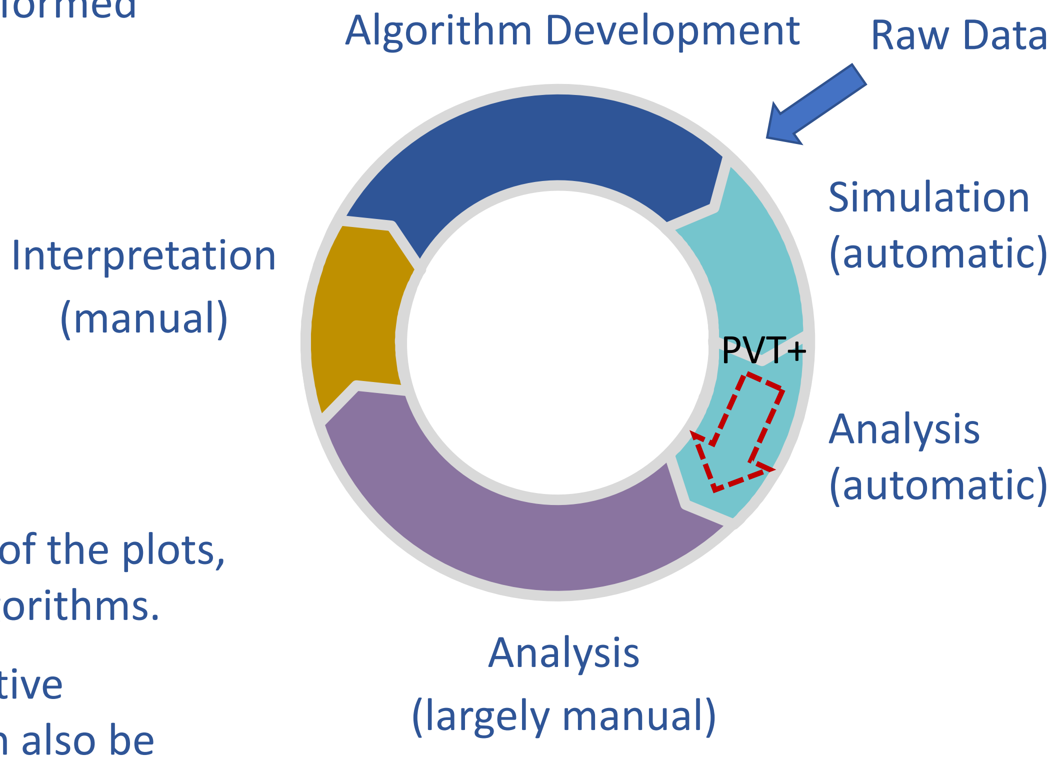

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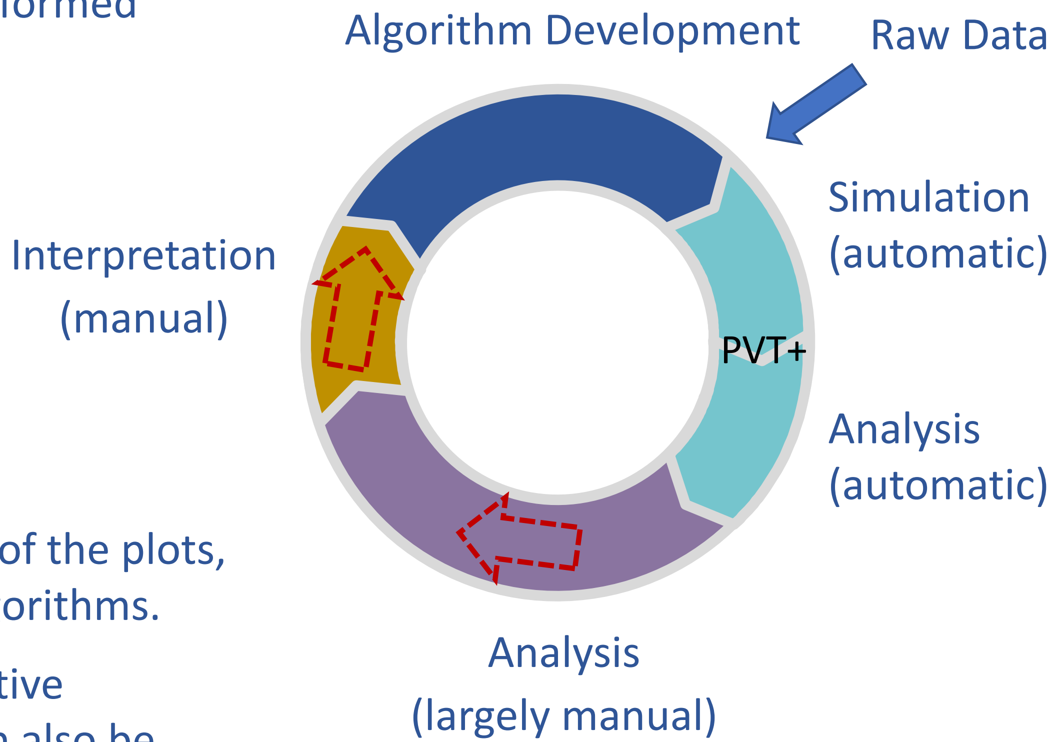

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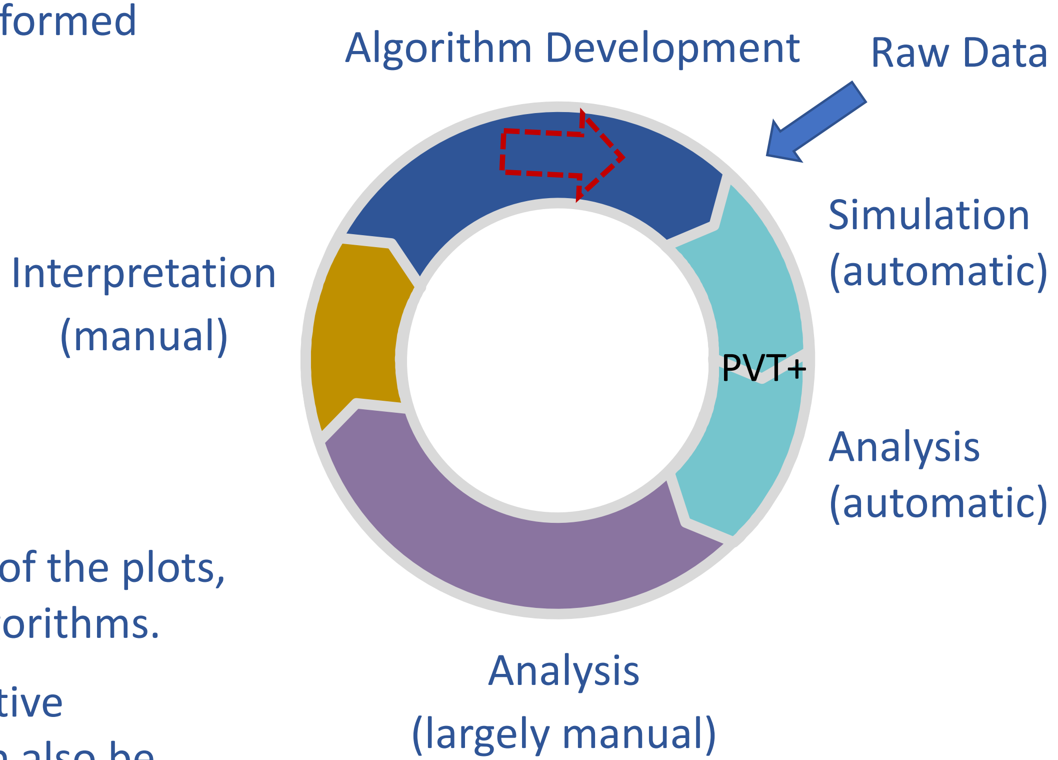
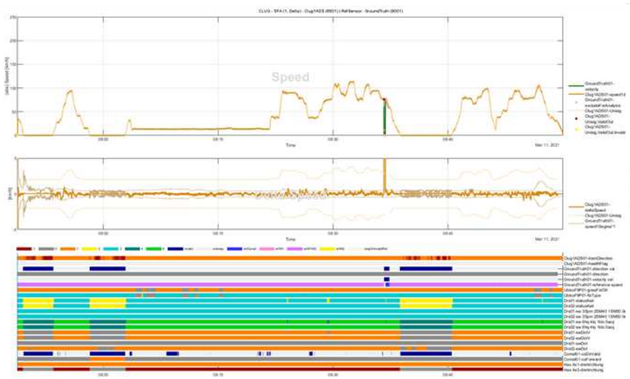


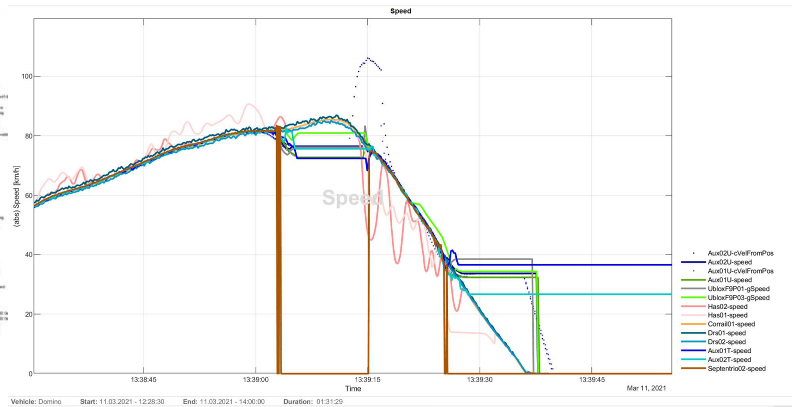
DATA PROCESSING

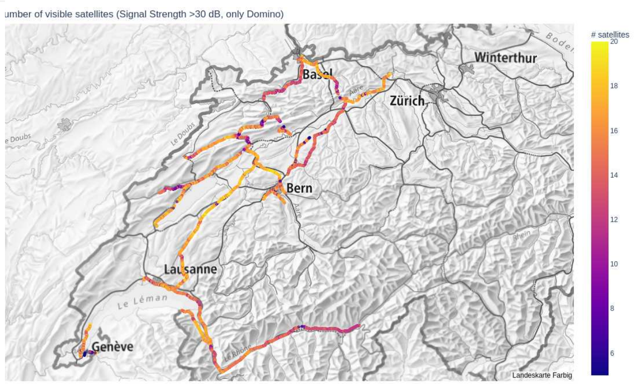
Aim of the data analysis was not only to show the achieved performance, but to identify areas of reduced performance as well as the root causes behind any performance degradation.

The tools have been developed by Siemens for that purpose and shared with all partners. They are based on MatLab and allow all partners to analyse and interpret the data on their own, and to continue to do so also after the end of the project. The tools analyse results and visualise them, also in combination with raw data, in various plots.

Statistics have also been produced by SBB, including visualisation. These statistics can visualise various performance criteria over single or larger number of trips.







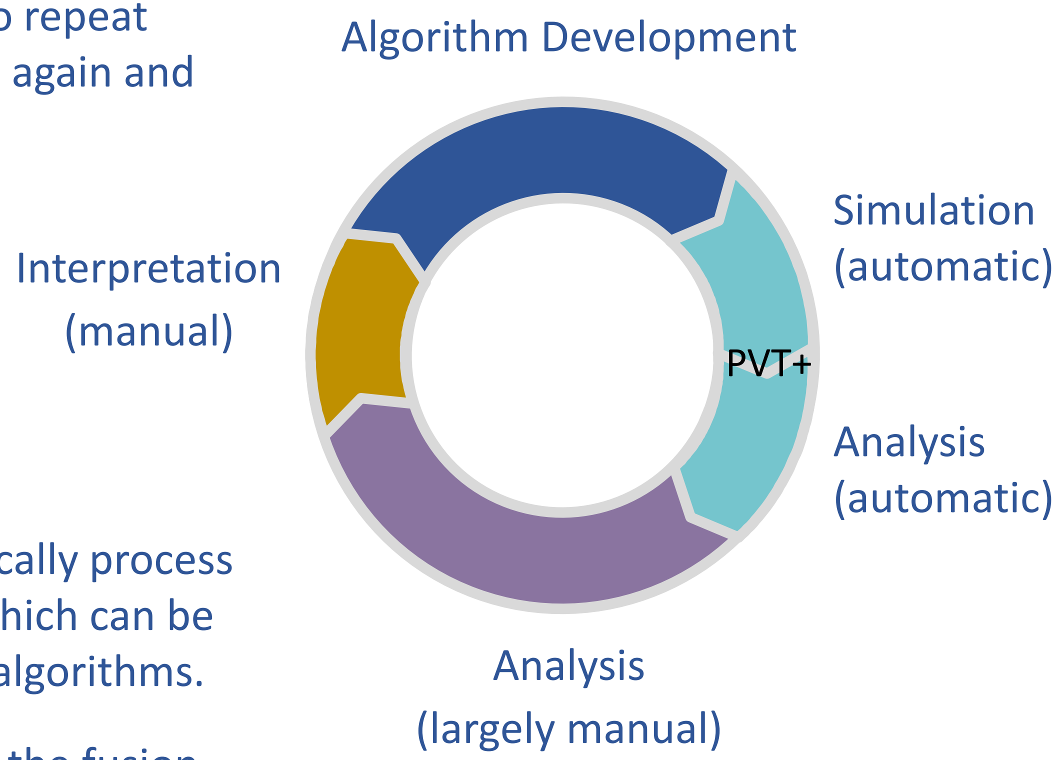
ADVANTAGE OF APPROACH

The main advantage of the chosen approach and of the test environment developed in CLUG is that it allowed us to repeat tests with the same field data, but updated algorithms again and again with minimal effort.

Improvements in the performance of updated algorithms could therefore be analysed quickly and reliably, which would not be possible when testing onboard trains, as such test would be costly and time consuming, and conditions would always be different.

The software was designed from the start to automatically process datasets from multiple trips in one processing cycle, which can be used to generate statistics on the performance of the algorithms.

This test method is a key asset for the development of the fusion algorithms in the CLUG project.



GROUND TRUTH

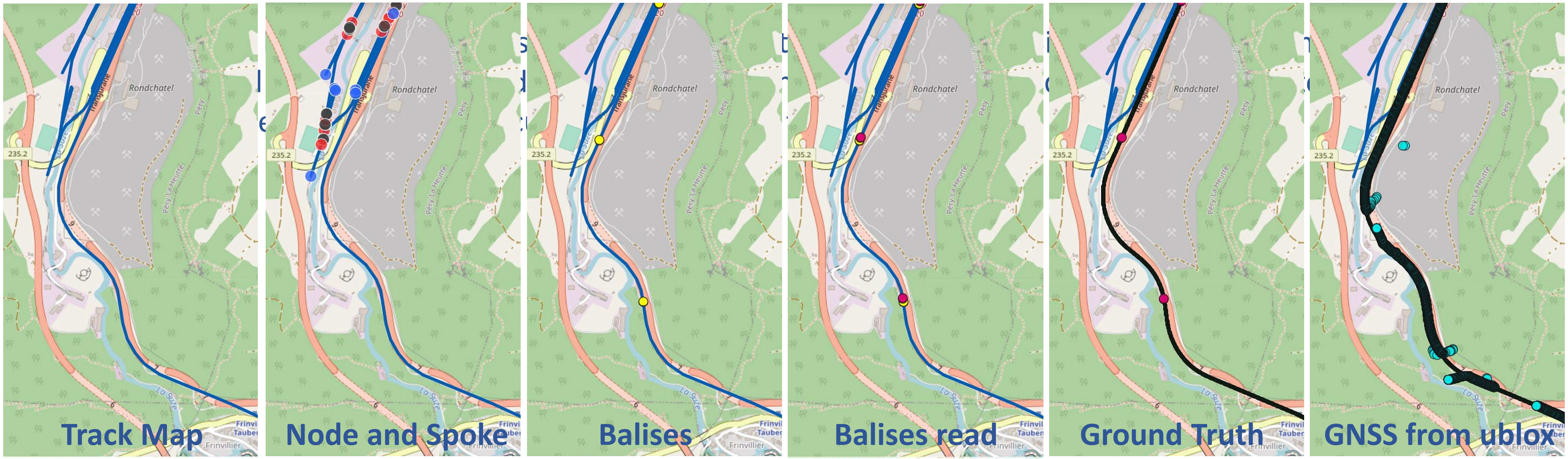
An accurate knowledge of the true position, speed etc. of the train is of course required to analyse the performance of the positioning solution. This knowledge is called the Ground Truth.

The Ground Truth generated for Germany and France is based on the use of high end, GNSS supported IMUs, combined with post processing of the recorded data. This methods depends on a certain GNSS coverage and is therefore not suitable for extended operation in areas without GNSS coverage.

In Switzerland, where GNSS is not available for extended times and over extended distances due to the many tunnels, but also terrain, a solution to produce GroundTruth independent from GNSS had to be developed. Due to the usage of the train in many different areas, this method also had to be applicable to the entire network.

GROUND TRUTH

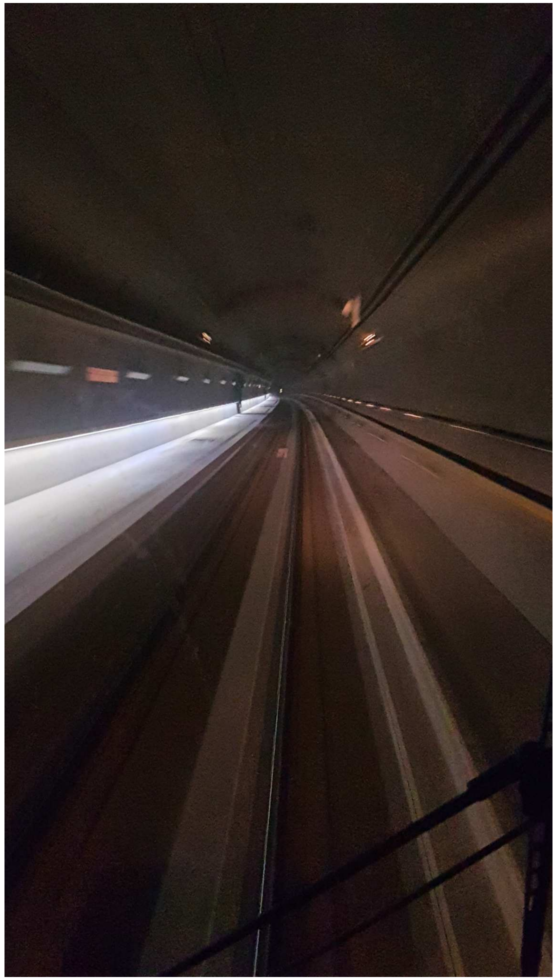
The Swiss Ground Truth is based on the accurate, geo-referenced track map provided by SBB and around 30’000 Eurobalises, serving as absolute position references. The track map is then used to determine the path between the balises. A combination of odometry sensors, notably a CorRail sensor in combination with tachos, is then used to produce intermediate positions between balises along the track centreline data from the track map.



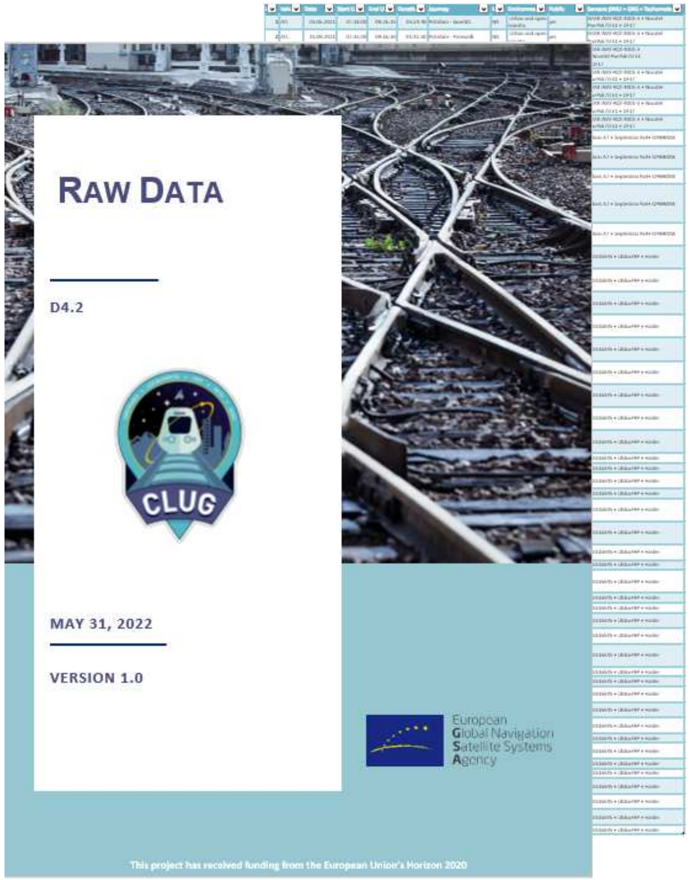
DATA COLLECTION, GROUND TRUTH

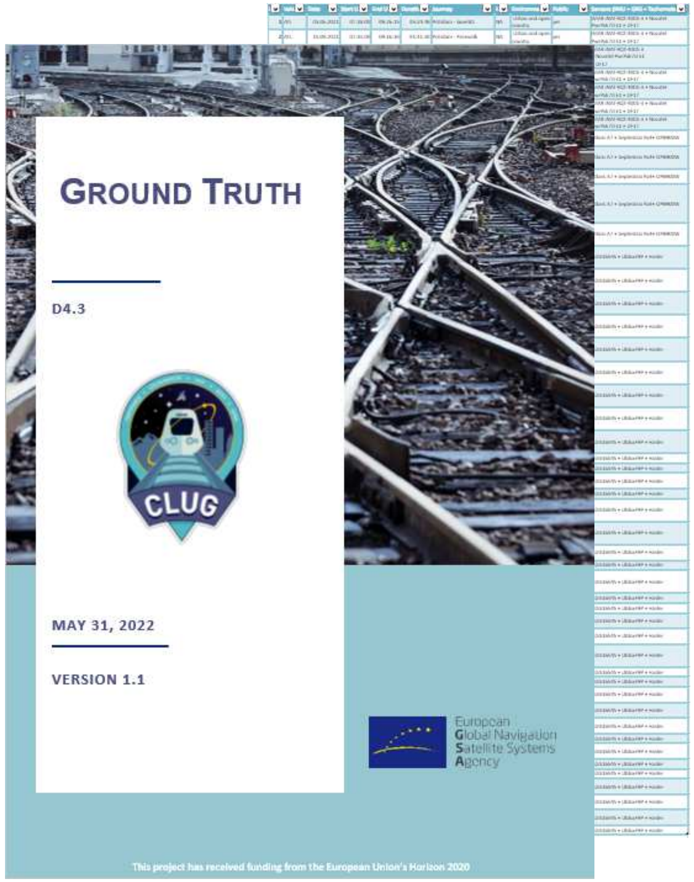
The Swiss Ground Truth has the advantage that it is generated completely independent from GNSS or IMU data. It can therefore be generated even for trip which take place completely underground, or for tunnels of any length. It has even been used on a trip through the 57 km long Gotthard Base Tunnel.

It however currently only produces speed and position information, to also provide attitude and heading information some additional changes will have to be made.



PUBLIC DELIVERABLES





ANY QUESTIONS

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http://clugproject.eu/en

https://www.linkedin.com/company/the-clug-project/

Test Results and Performance

Bernhard Stamm

CLUG WP4 Testing and Evaluation Leader

European Union Agency for the Space Programme

INTRODUCTION, LIMITATIONS

Notes and Limitations:

Only a subset of the collected data has so far been processed and analysed. Data analysis will continue beyond the end of the CLUG project.

Processing and analysis of data has been done under a number of specific limitations, which were defined from the start:

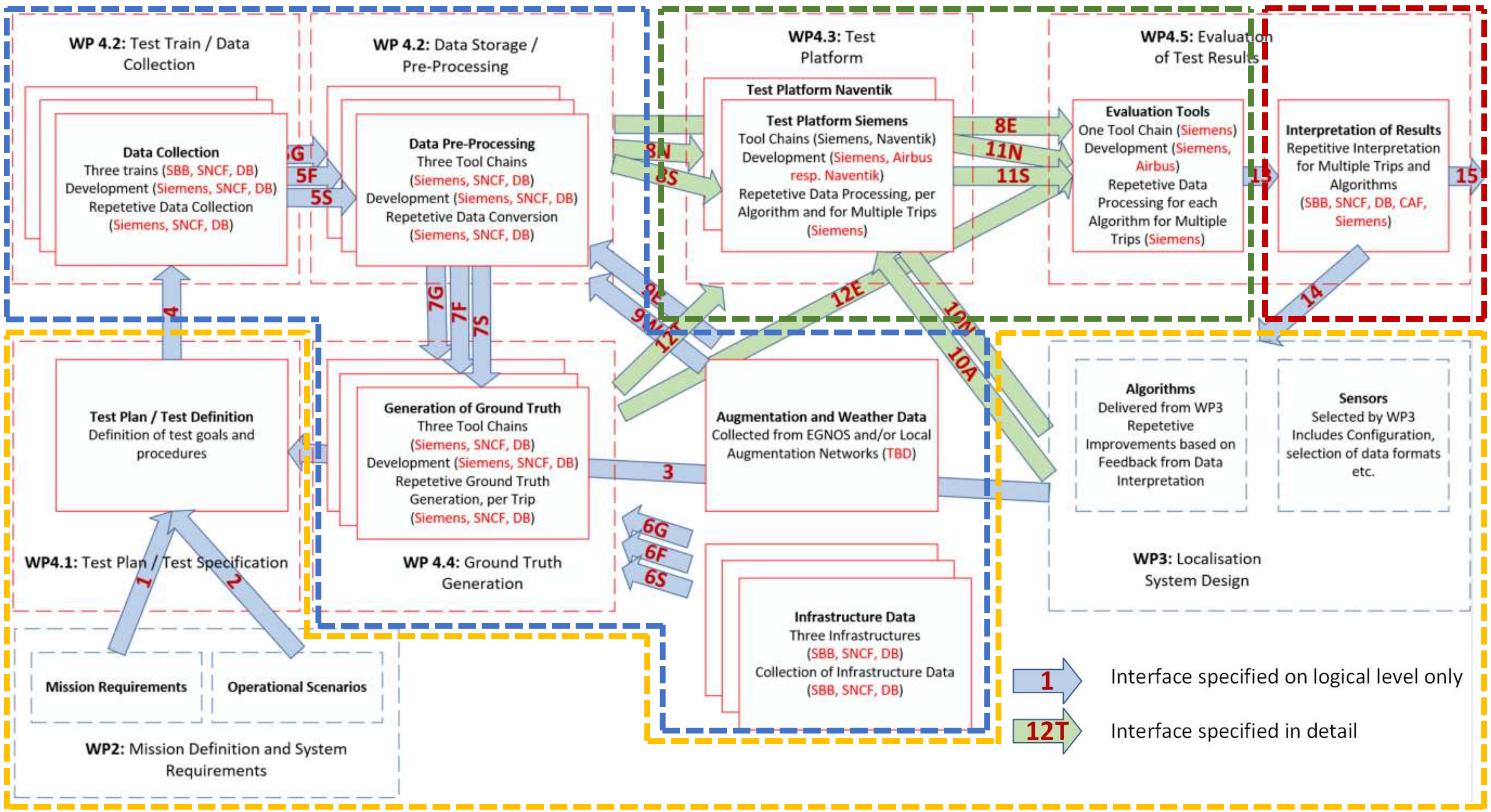
- GNSS and EGNOS usage
  - GNSS data has only been used from Galileo, GPS and EGNOS V2 (GPS L1 augmentation only)
  - Currently only L1 / E1 (single frequency) data is being used in the sensor fusion in both solutions.
  - The Airbus algorithm (Solution A) uses EGNOS data downloaded from the EDAS service, simulating full EGNOS coverage.
  - The Naventik algorithm (Solution B) does not yet use EGNOS data, neither from space nor from EDAS.

INTRODUCTION, LIMITATIONS

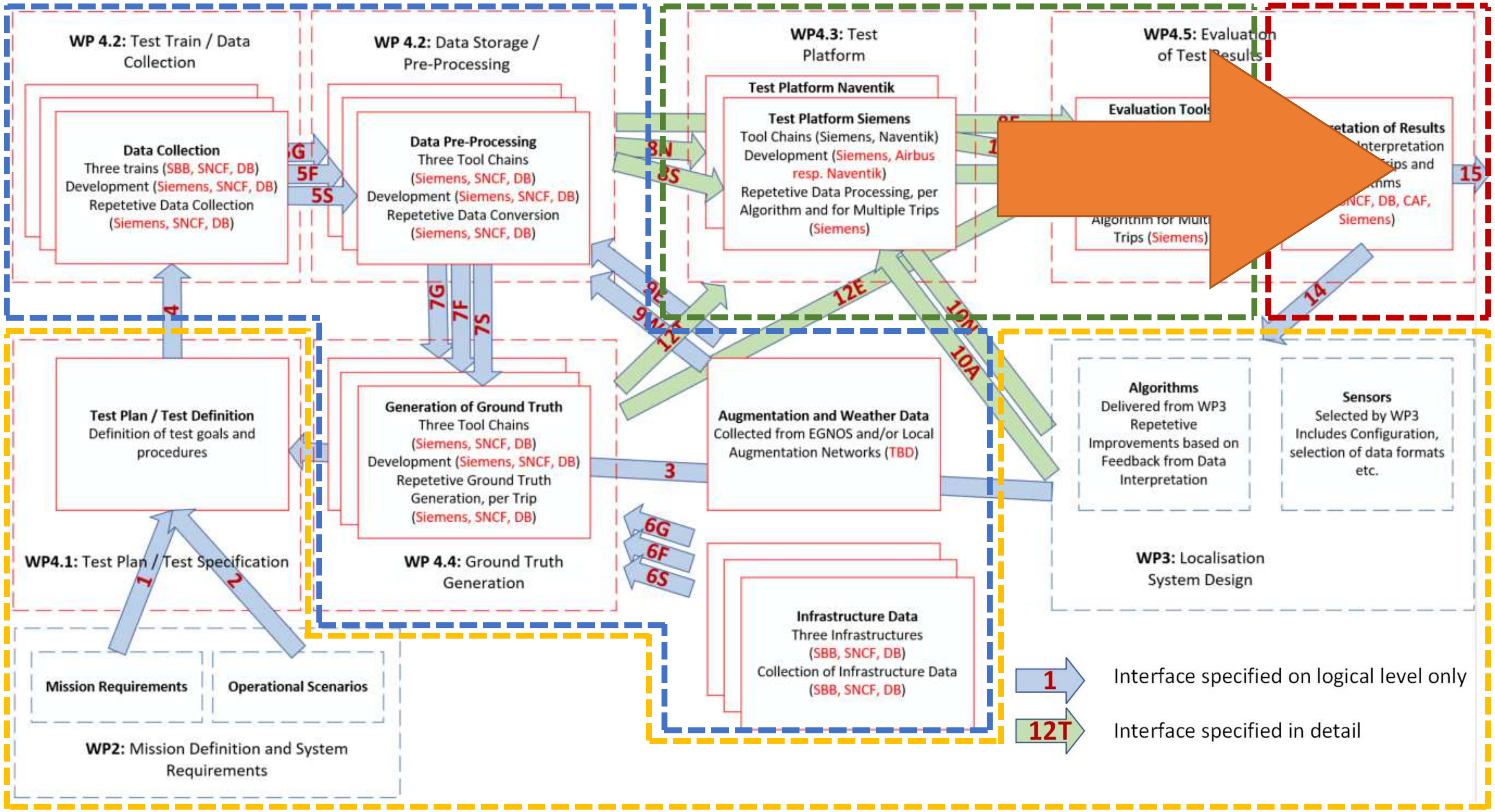
- Algorithm outputs:
  - Along track position, speed and all other data is calculated on the basis of predetermined track knowledge (no track selection).
  - The integrity filters are currently not part of the algorithms, no safe confidence intervals have therefore been calculated. Only some error estimates have been calculated.

- GroundTruth and Maps
  - GroundTruth and Map data have gone through some quality checks, but there may still be some errors.

INTRODUCTION / WORKFLOW



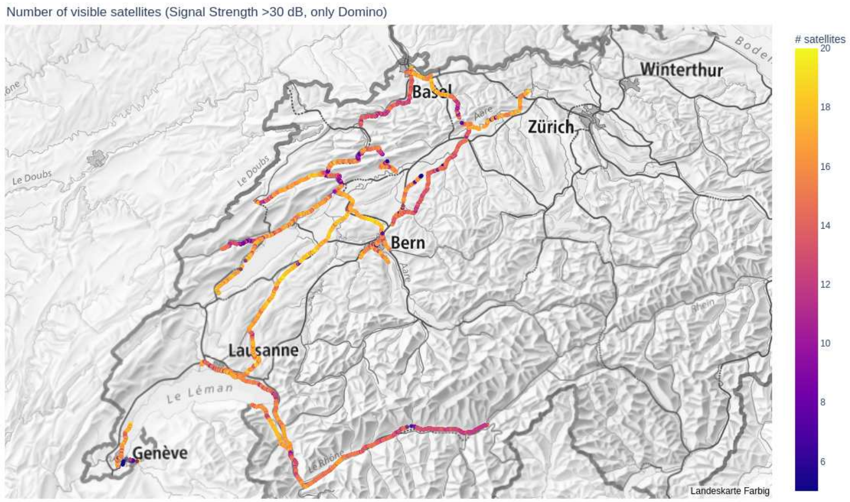
INTRODUCTION / WORKFLOW



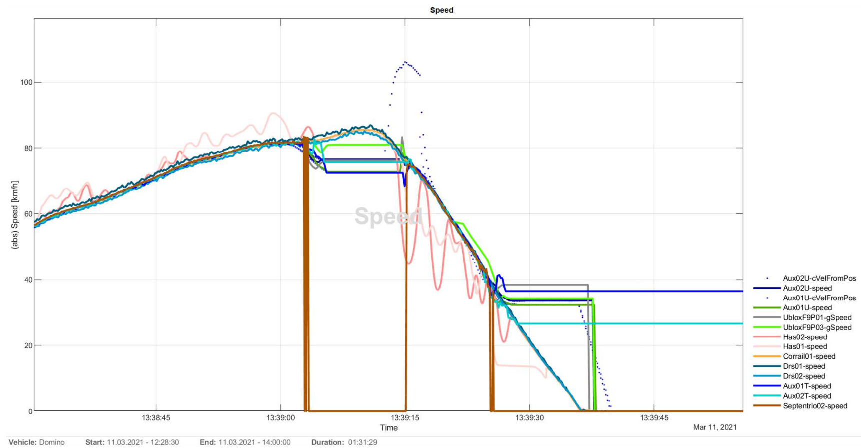
BASIC CONCEPT OF DATA ANALYSIS

Data analysis has been performed in two different ways:

- Statistical analysis are being performed to demonstrate the achieved availability / coverage of the solutions across a railway network, as well as over time, seasons etc. Results from statistical analysis can be used in a future certification of the solutions, but also for other purpose, such as e.g. for the business case



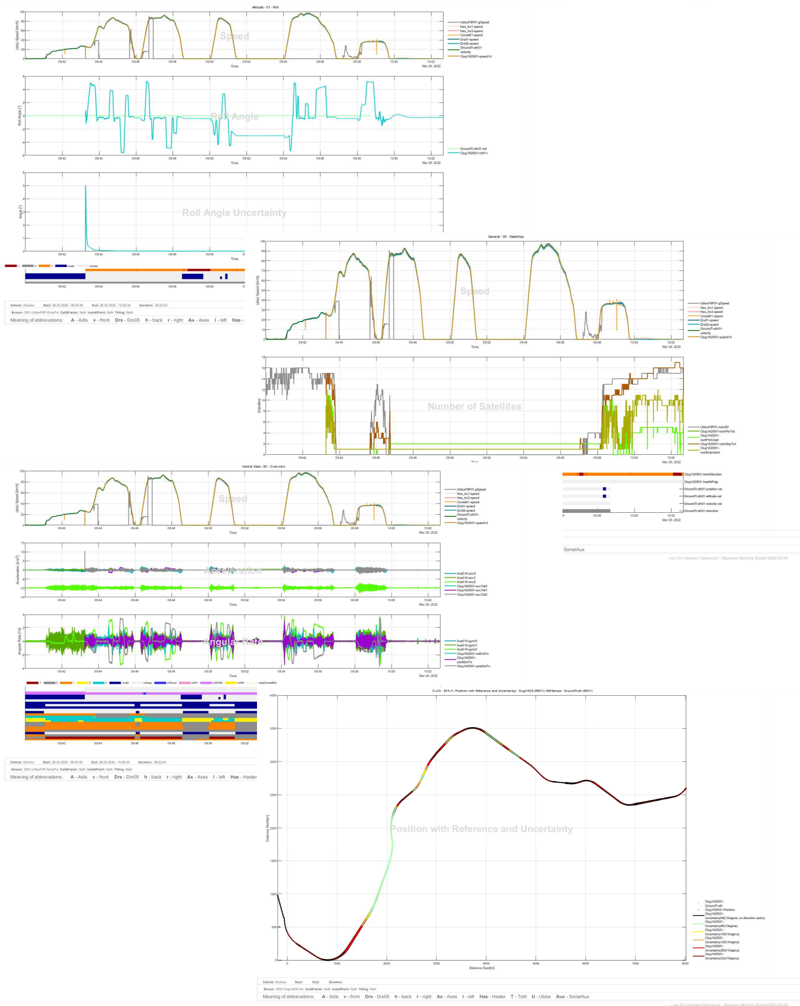
- Detailed analysis are being performed to understand the achieved the behaviour of the fusion algorithms in detail, identifying root causes which impact the outputs generated by the algorithms. Results from detailed analysis have been used for the development of the solutions, detailed analysis will also be used for future certification.



TOOLS USED FOR ANALYSIS

For detailed data visualisation and analysis, Siemens produced a version of it’s internal, MatLab based Ranalyzer tool to:

- use input data from all sensors in the formats specified in CLUG
- compare speed, position and other data produced by the CLUG algorithms with GroundTruth data as specified and generated in CLUG
- generate more than 40 specific plots requested by the CLUG partners



Data from all three test trains as well as from both solutions have been analysed with Ranalyzer.

In order to allow all partners to freely use the tool, a P-code version has been produced and shared, so that all partners can use the tool even beyond the end of the project.

TOOLS USED FOR ANALYSIS

Statistical analysis of data against GroundTruth, as well as visualisation of these statistics have been performed by Swiss Federal Railway, using their internal big data platform, which is based on Apache Hadoop.

In this platform, raw data is ingested and interpolated to a common frequency. The data can then be visualised and combined using Spark and basic Python libraries, allowing an exact comparison of different time series.

Note that the following limitations have been applied:

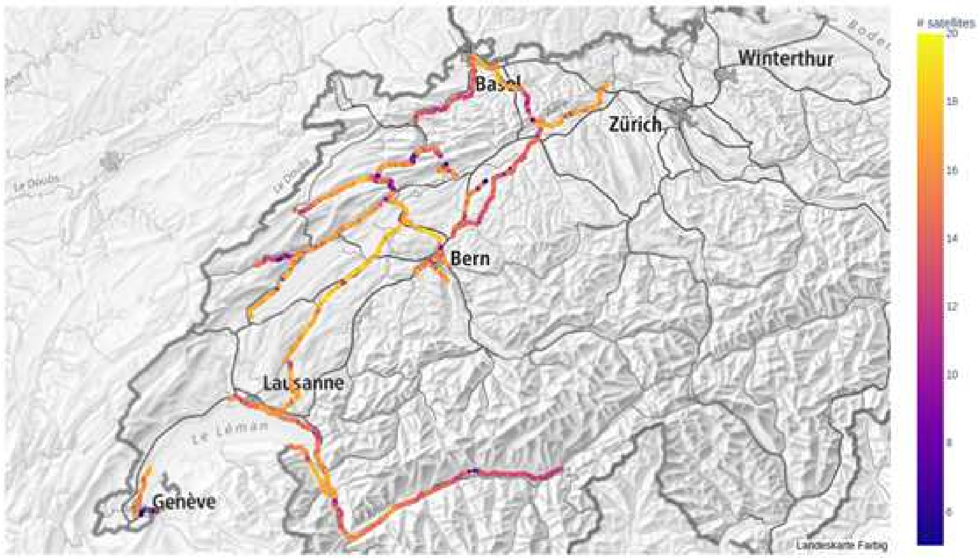
- Speed outliers beyond 1 m/s are excluded for histograms
- Speed outliers beyond 1 m/s are however included for map
- Position outliers beyond 10 m are excluded for histograms
- Position outliers beyond 10 m are however included for map

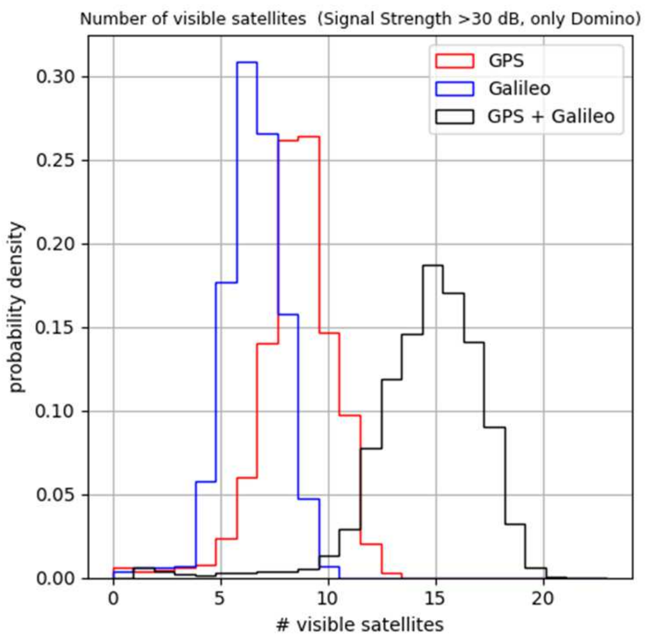
SAMPLES OF STATISTICAL ANALYSIS

GPS AND GALILEO VISIBILITY

Plots are based on data from around 30 trips with the Domino train on multiple lines, including rural, urban and mountainous terrain.

Around 22 Galileo and 30 GPS satellites are currently operational, around 4 to 8 Galileo satellites and 6 to 12 GPS satellites are typically visible.





--------- GPS ----------

mean # sats:	8.43
std # sats:	1.84
median # sats:	9.0
max # sats:	13
min # sats:	0

--------- Galileo ----------

mean # sats:	6.35
std # sats:	1.44
median # sats:	6.0
max # sats:	11
min # sats:	0

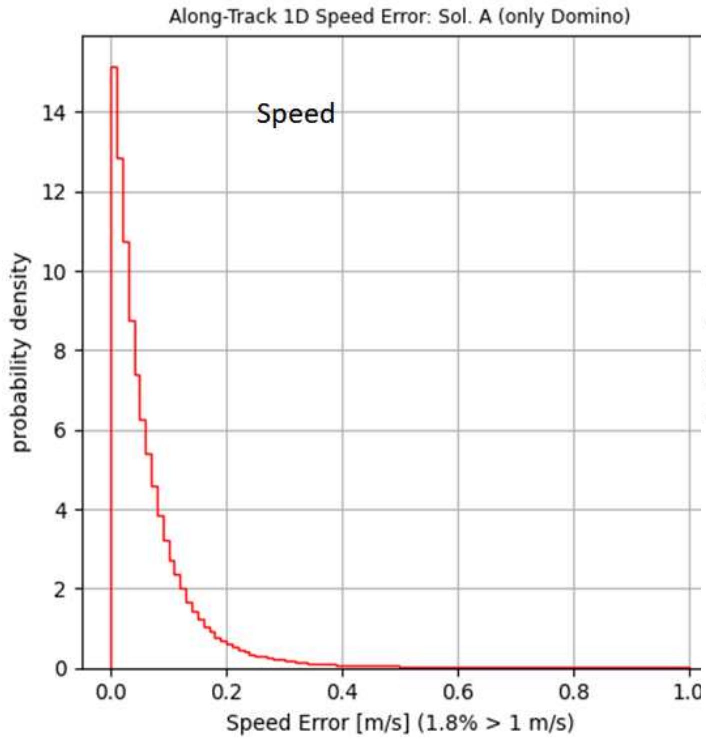
--------- GPS + Galileo ----------

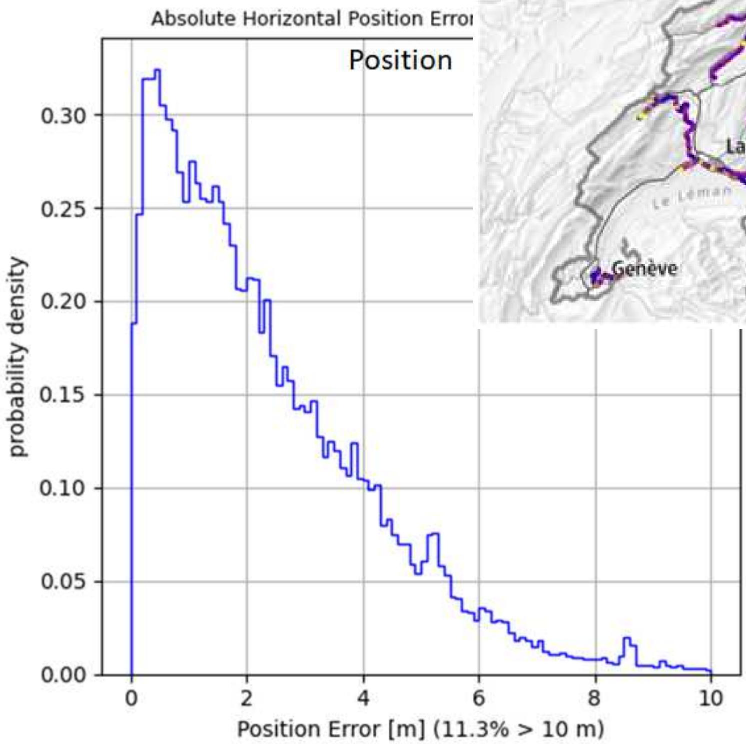
mean # sats:	14.78
std # sats:	2.72
median # sats:	15.0
max # sats:	22
min # sats:	1

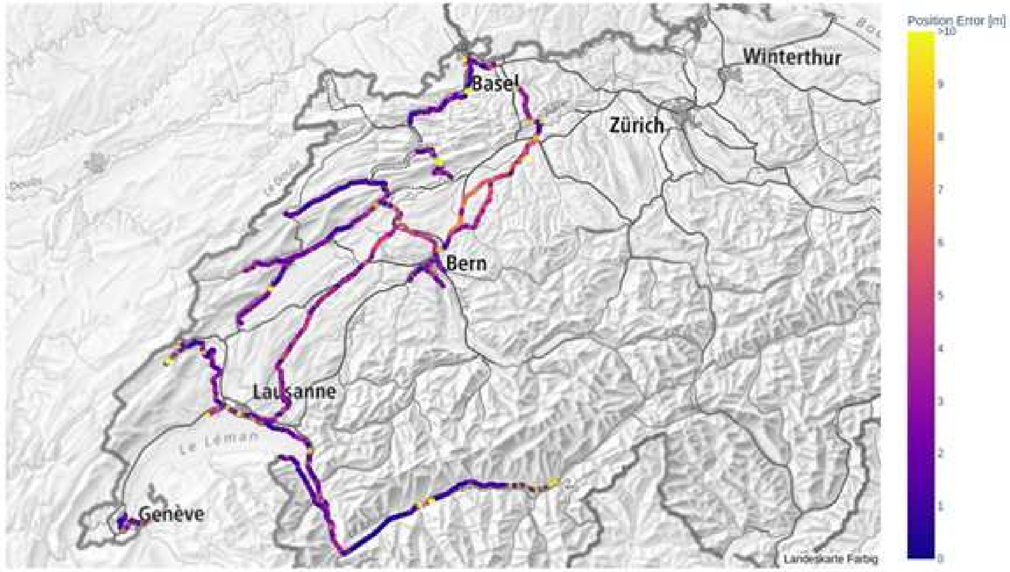
SAMPLES OF STATISTICAL ANALYSIS

SPEED AND HORIZONTAL POSITION ERROR

Statistics for solution A over around 30 trips with the Domino train on multiple lines, including rural, urban and mountainous terrain.



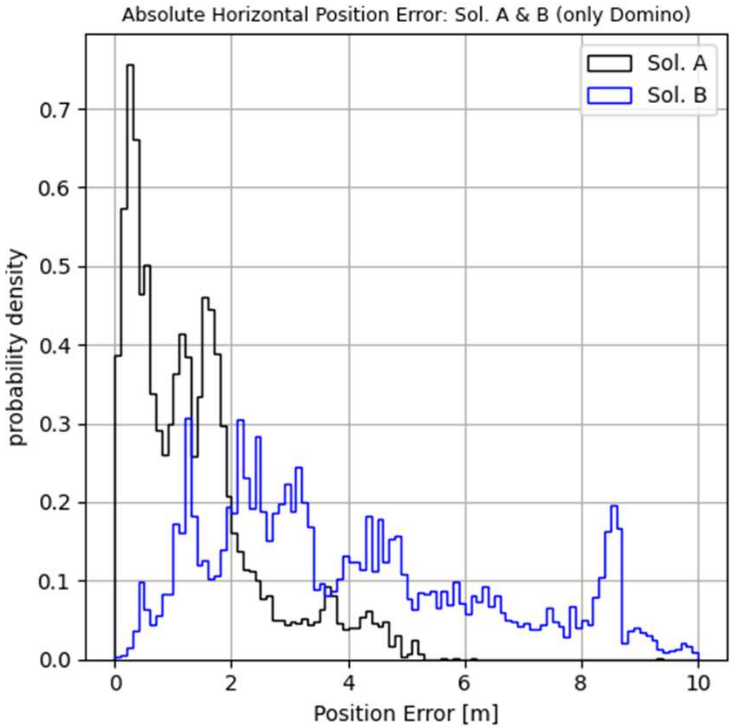




SAMPLES OF STATISTICAL ANALYSIS

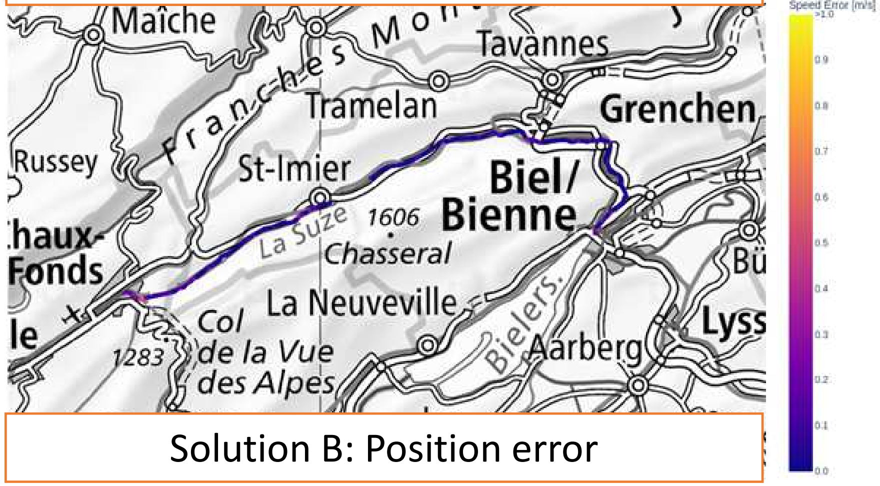
HORIZONTAL POSITION ERROR OF SOLUTIONS A AND B

Shown in reference to the GroundTruth position for a single trip from Biel/Bienne to La-Chaux-de-Fonds through difficult terrain.



rows in dataset: 37619
---- Position Stats Comparison -----
mean ADS position error: 1.33 m
mean NAV position error: 6.65 m
std ADS position error: 1.13 m
std NAV position error: 11.29 m
median ADS position error: 1.13 m
median NAV position error: 3.86 m
90% q ADS position error: 2.96 m
90% q NAV position error: 8.98 m

Solution A: Position error



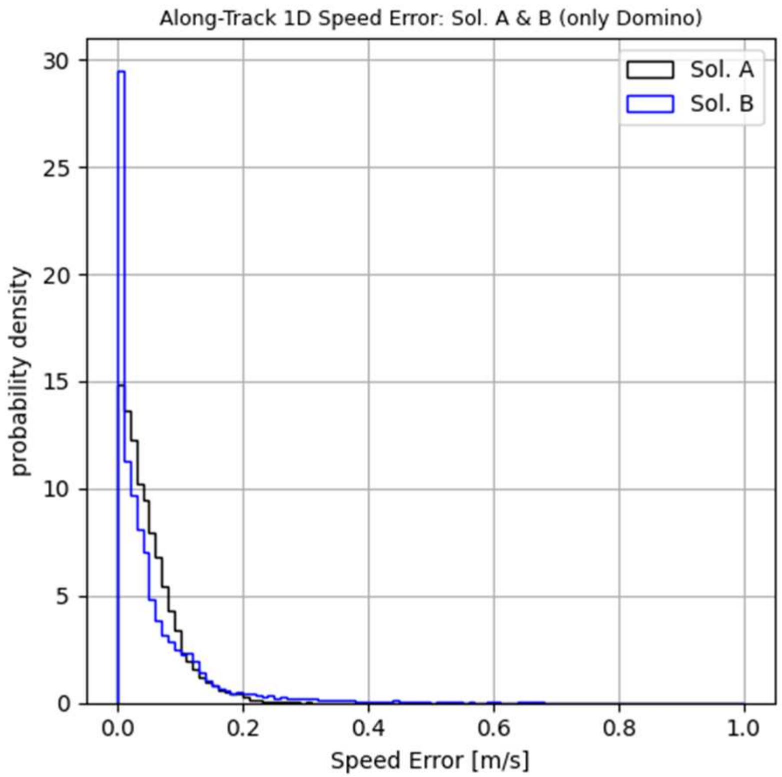
Solution B: Position error

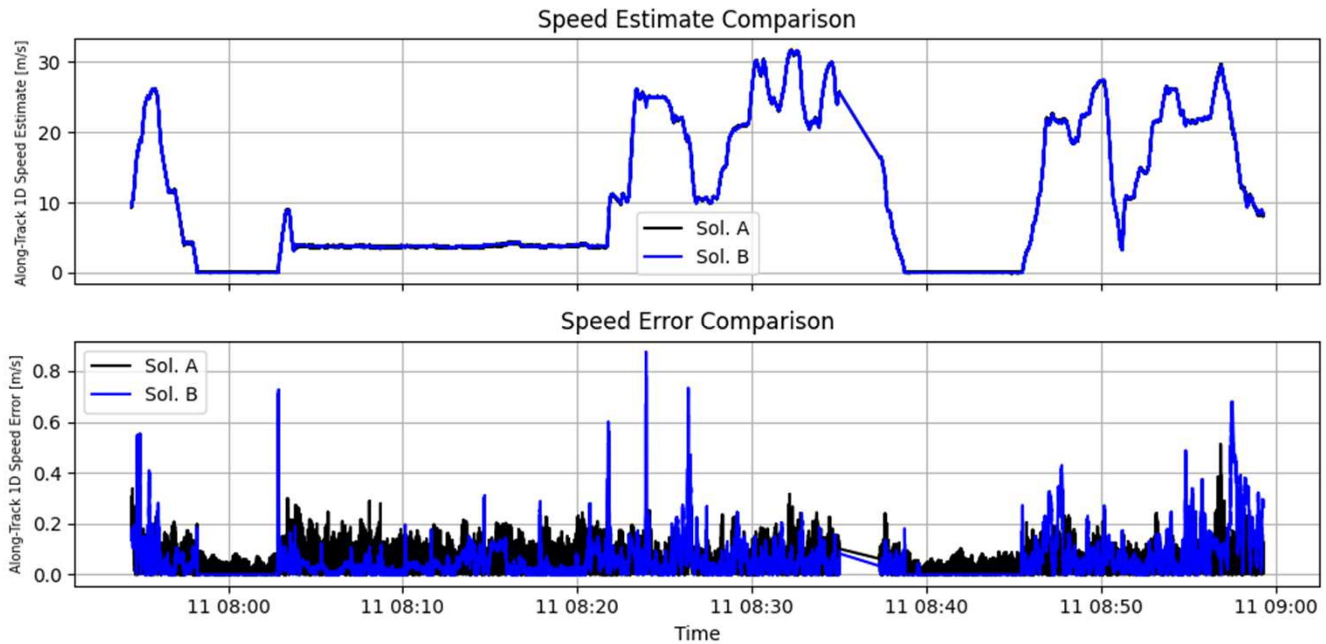
SAMPLES OF STATISTICAL ANALYSIS

ALONG TRACK SPEED ERROR OF SOLUTIONS A AND B

Shown in reference to the GroundTruth speed for a single trip from Biel/Bienne to La-Chaux-de-Fonds through difficult terrain.

# rows in dataset: 37619	
---- Velocity Stats Comparison ----	
mean ADS speed error:	0.05 m/s
mean NAV speed error:	0.05 m/s
std ADS speed error:	0.04 m/s
std NAV speed error:	0.08 m/s
median ADS speed error:	0.04 m/s
median NAV speed error:	0.03 m/s
90% q ADS speed error:	0.11 m/s
90% q NAV speed error:	0.13 m/s





SAMPLES OF DETAILED ANALYSIS

On the following slides, a number of samples of the analysed data are shown for the following environments:

- Open sky conditions (Olten – Burgdorf – Ostermundigen)
- Cities & tunnels (Genève-Cornavin – Annemasse)
- Braking & tunnels (Biel/Bienne – Neuchâtel – Les Verrières)

For each trip, speed and position results will be show, as well as some additional data to show some specific issues from those trips.

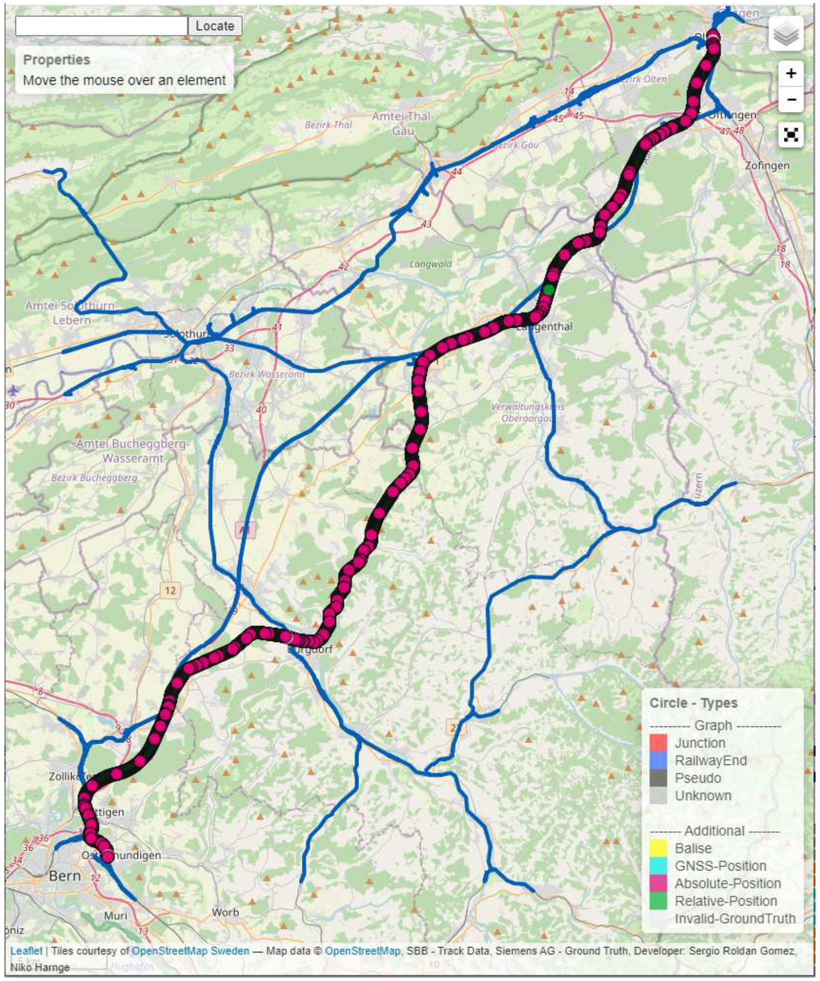
OLTEN – BURGDORF - OSTERMUNDIGEN

The line from Olten via Burgdorf to Ostermundingen can be considered representative for many lines in Switzerland. It combines stretches in rural settings with some urban sections and includes short tunnels as well as one long one.

The data shown is from a dedicated test run performed in April 2021.

This test run was scheduled with a typical timetable of an interregio train, in order do have some reference data to analyse typical performance.

Only in the Grauholz-Tunnel were some manoeuvres performed.



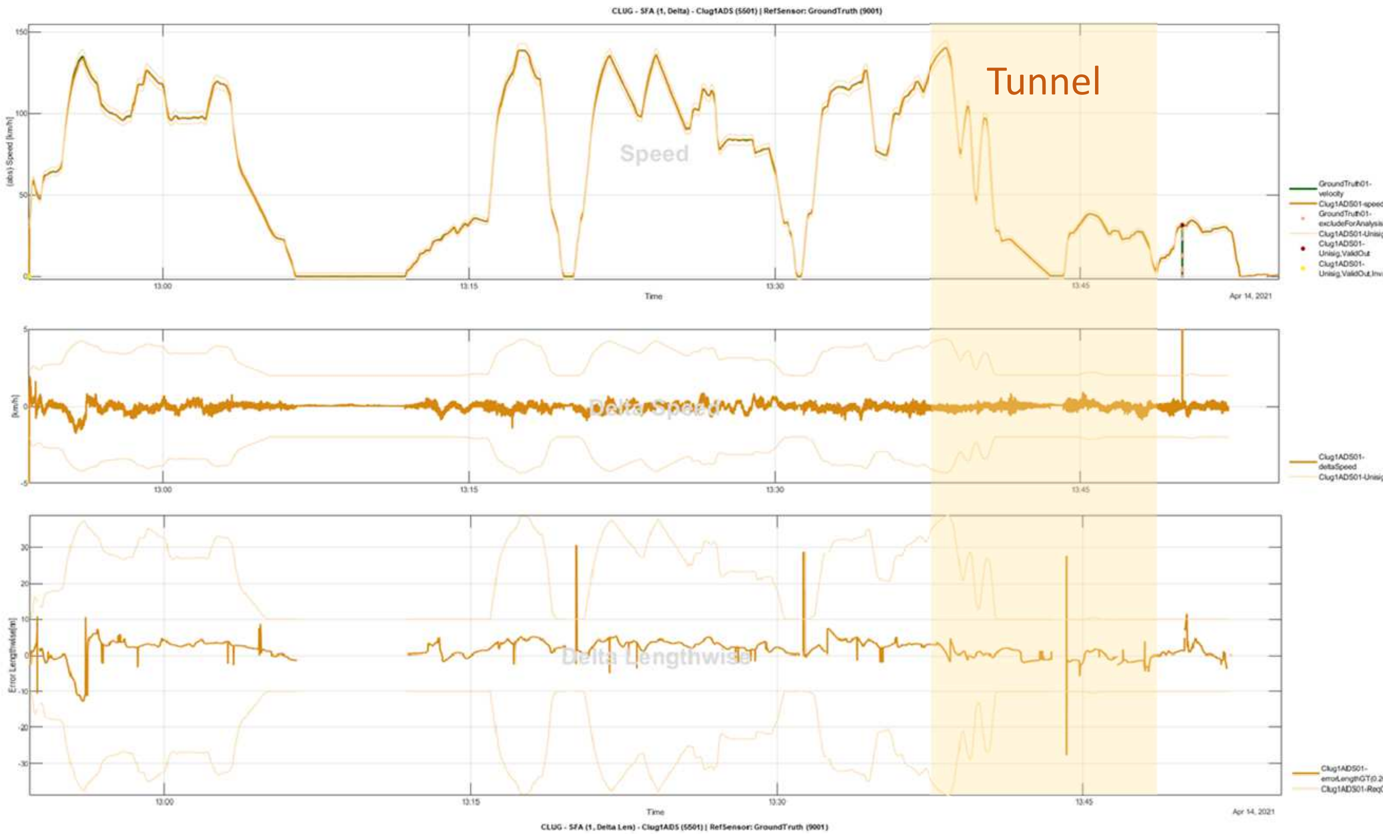
OLTEN – BURGDORF - OSTERMUNDIGEN

The plot shows speed and along track position errors in reference to the absolute speed over time. For speed the performance requirements as defined in Subset-041 of the TSI is shown, for position accuracy the error estimated by the algorithm .

The speed error remains below 1 km/h over most of the trip, with only a few locations where the error reaches 2 km/h.

The along track position error remains over most of the trip in the range of +/- 5 m.

The spikes are caused by the input data, respectively the GroundTruth.

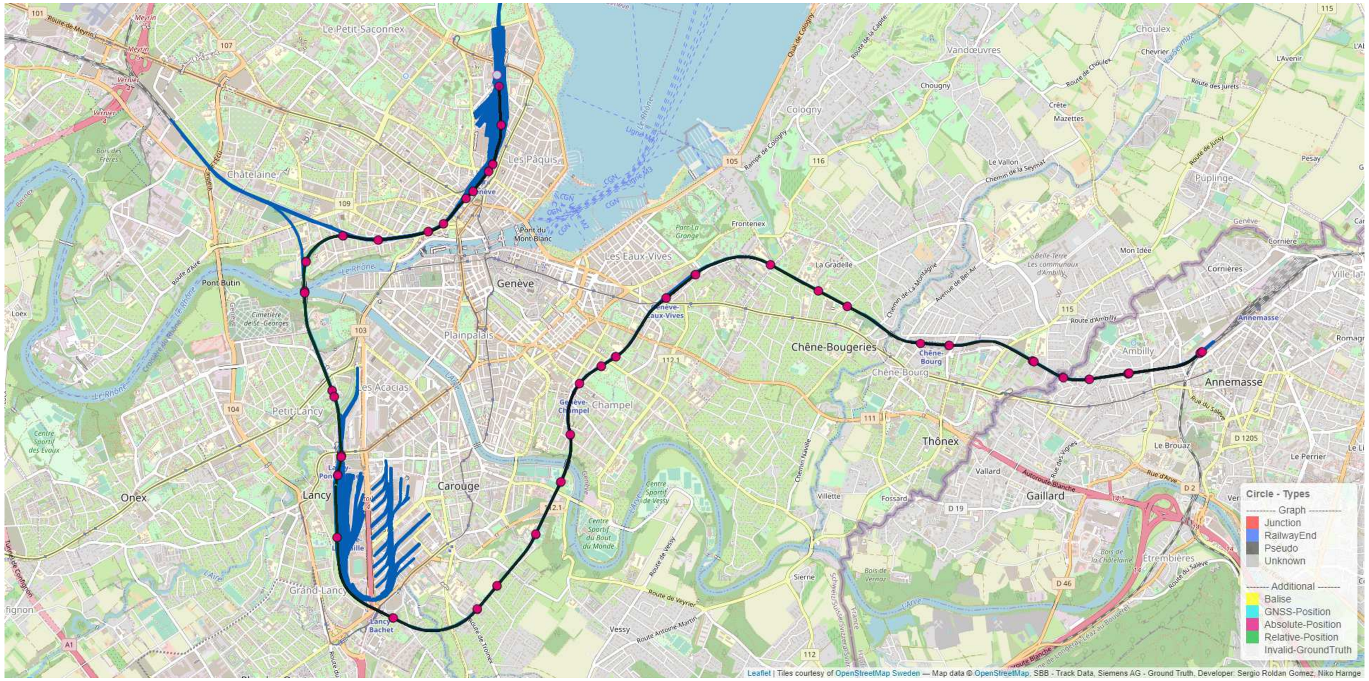


GENÈVE - ANNEMASSE

The line from Genève-Cornavin to Anneasse is an exceptional case for CLUG, as a large section is underground, including four stations. While GNSS coverage is available on both sides, the CLUG algorithm has to depend on odometry, IMU and map matching for around 10 km / 20 minutes. In addition, the underground section includes multiple curves and changes of gradient.

The data shown on the following slides is from a dedicated test run performed in April 2022.

This test run was performed outside commercial operation, as the Domino train is not certified for commercial operation on that line and required certification even for a test run into the station of Annemasse.

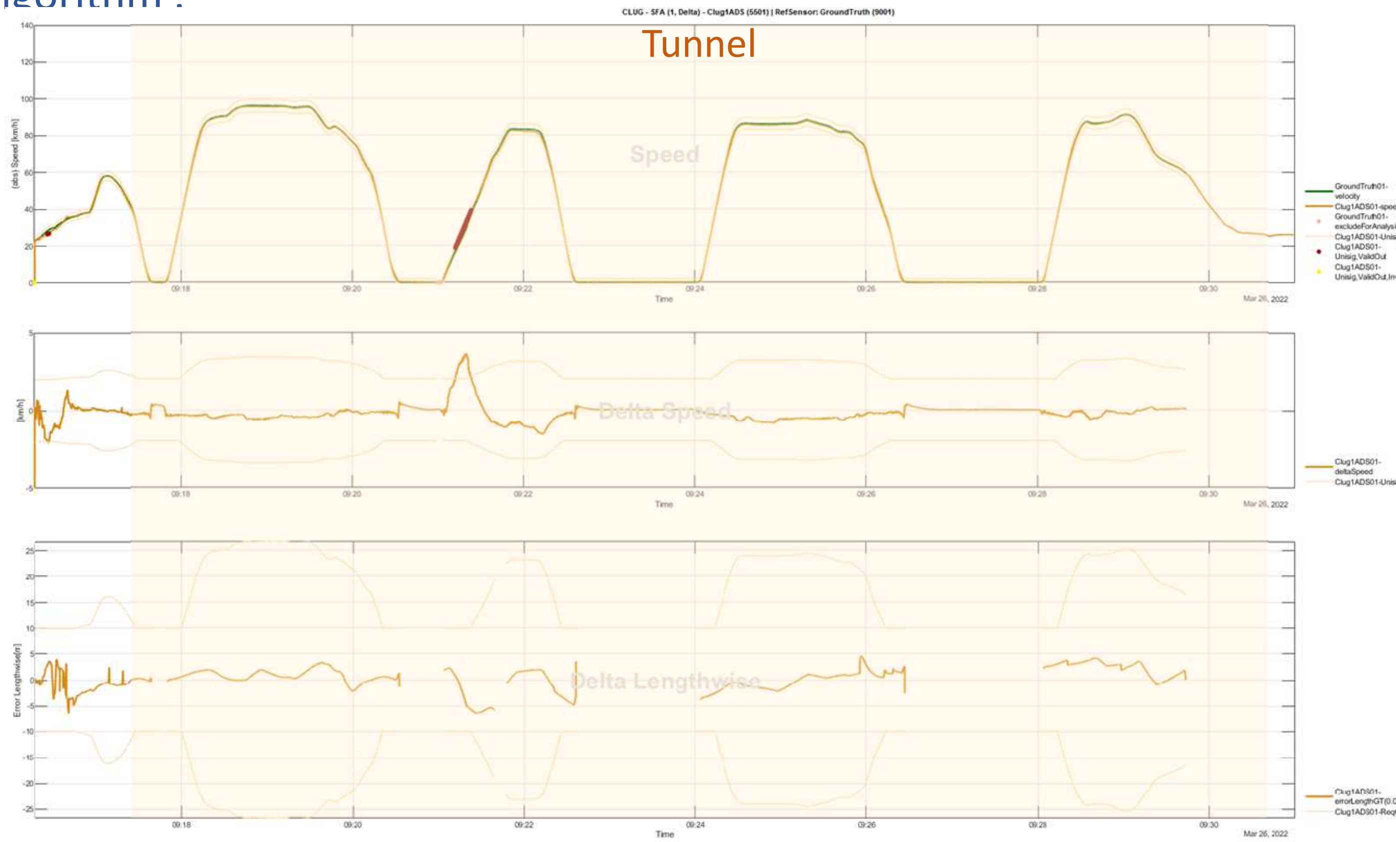


GENÈVE - ANNEMASSE

The plot shows speed and along track position errors in reference to the absolute speed over time. For speed the performance requirements as defined in Subset-041 of the TSI is shown, for position accuracy the error estimated by the algorithm .

The speed error remains below 0.5 km/h over most of the trip, with the exception of a short time slot where it reaches 3.3 km/h, which is slightly outside the requirement defined in the TSI.

The along track position error remains mostly in the range of +/- 5 m, where significant slip occurs it reaches 6 m.

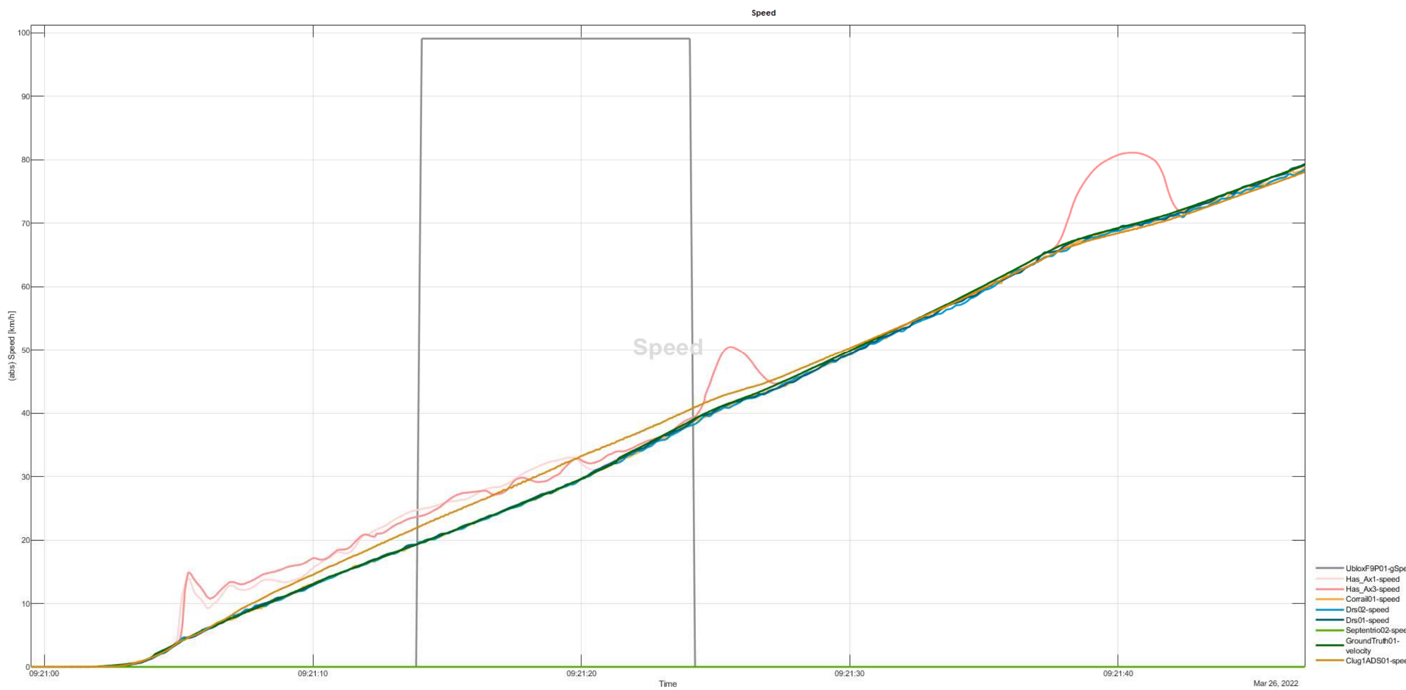


GENÈVE - ANNEMASSE

A closer look at the mentioned time slot shows that a nearly constant slip of around 5 km/h occurs on both axles with a duration of 15 second.

As can be seen, the speed calculated by the CLUG algorithm follows the slip with some delay, and with a reduced amplitude.

Such examples are helpful to improve the performance of the algorithm, as the weighing of the different sensors might be adjusted.

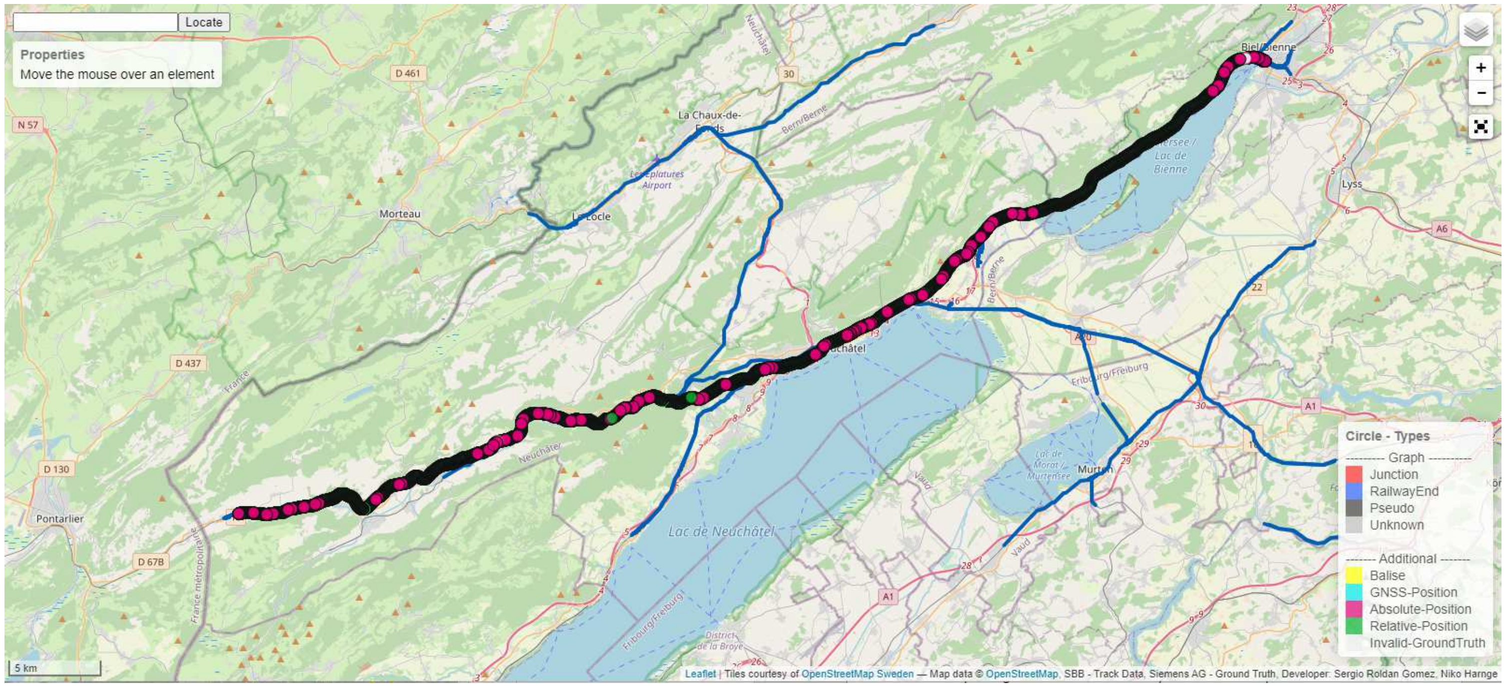


BIEL/BIENNE – LES VERRIÈRES

The line from Biel/Bienne via Neuchâtel to Les Verrières is a bit more challenging than the average line in Switzerland regarding the use of GNSS. Like most line, it covers stretches in rural and urban environments, and includes shorter as well as longer tunnels. In addition, however, there is also a section through a narrow gorge with restricted satellite visibility and many short tunnels.

The data shown is from a dedicated test run performed in March 2021.

In the last section between Travers and Les Verrières attempts were made to provoke slip and slide, both by rough driving and by triggering an emergency stop when entering a tunnel.

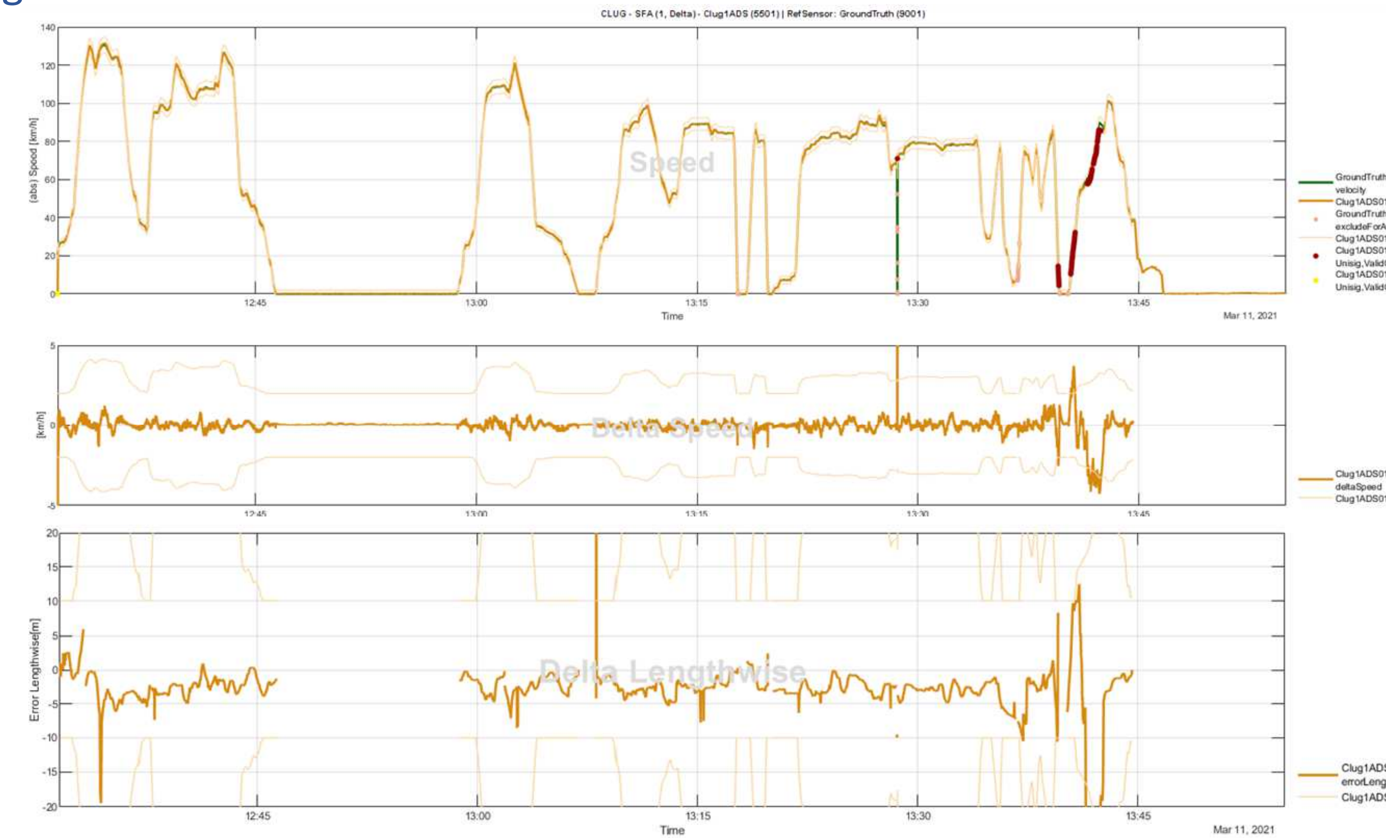


BIEL/BIENNE – LES VERRIÈRES

The plot shows speed and along track position errors in reference to the absolute speed over time. For speed the performance requirements as defined in Subset-041 of the TSI is shown, for position accuracy the error estimated by the algorithm .

The speed error remains within approximately +/- 2 km/h over most of the trip, the position error remains within approximately +1/-5 m. The only exceptions occurred towards the end of the trip, where the emergency stop was triggered and where slip was provoked by aggressive driving.

Slippery track contributed to these errors.



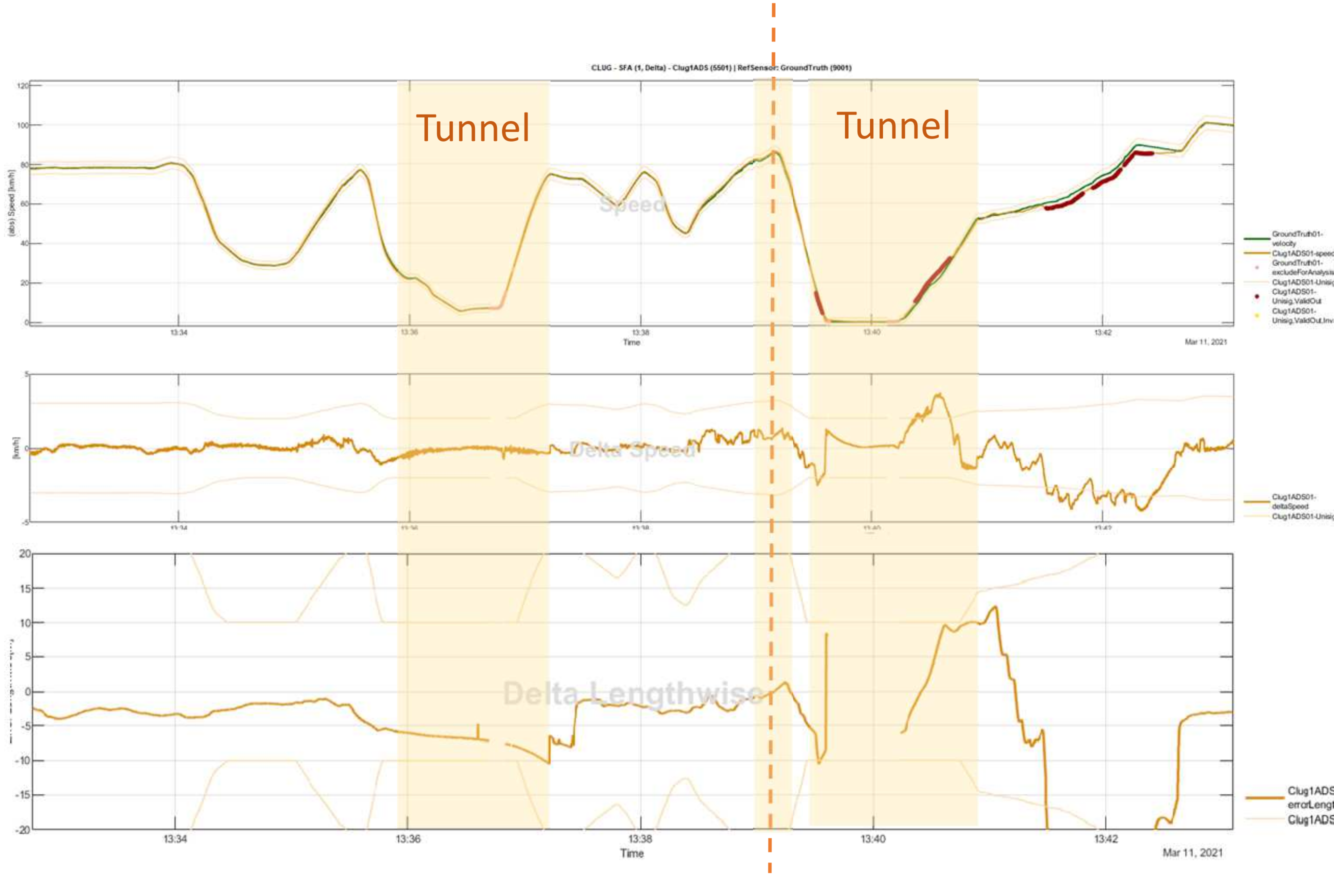
BIEL/BIENNE – LES VERRIÈRES

This plot show again the speed generated by the CLUG algorithm vs. the speed reference, but only for the section where significant slip and slide was provoked an where the emergency brake was applied.

The maximum speed error is around 4 km/h, which slightly exceeds the performance requirement of the TSI.

The position error also reaches it's maximum in this location. It initially stays within the window of +/- 5 m, then enlarges to +/- 10 m where sharp braking and accelerating is performed and finally to +10/-35 m where significant slip occurs when accelerating after the emergency stop.

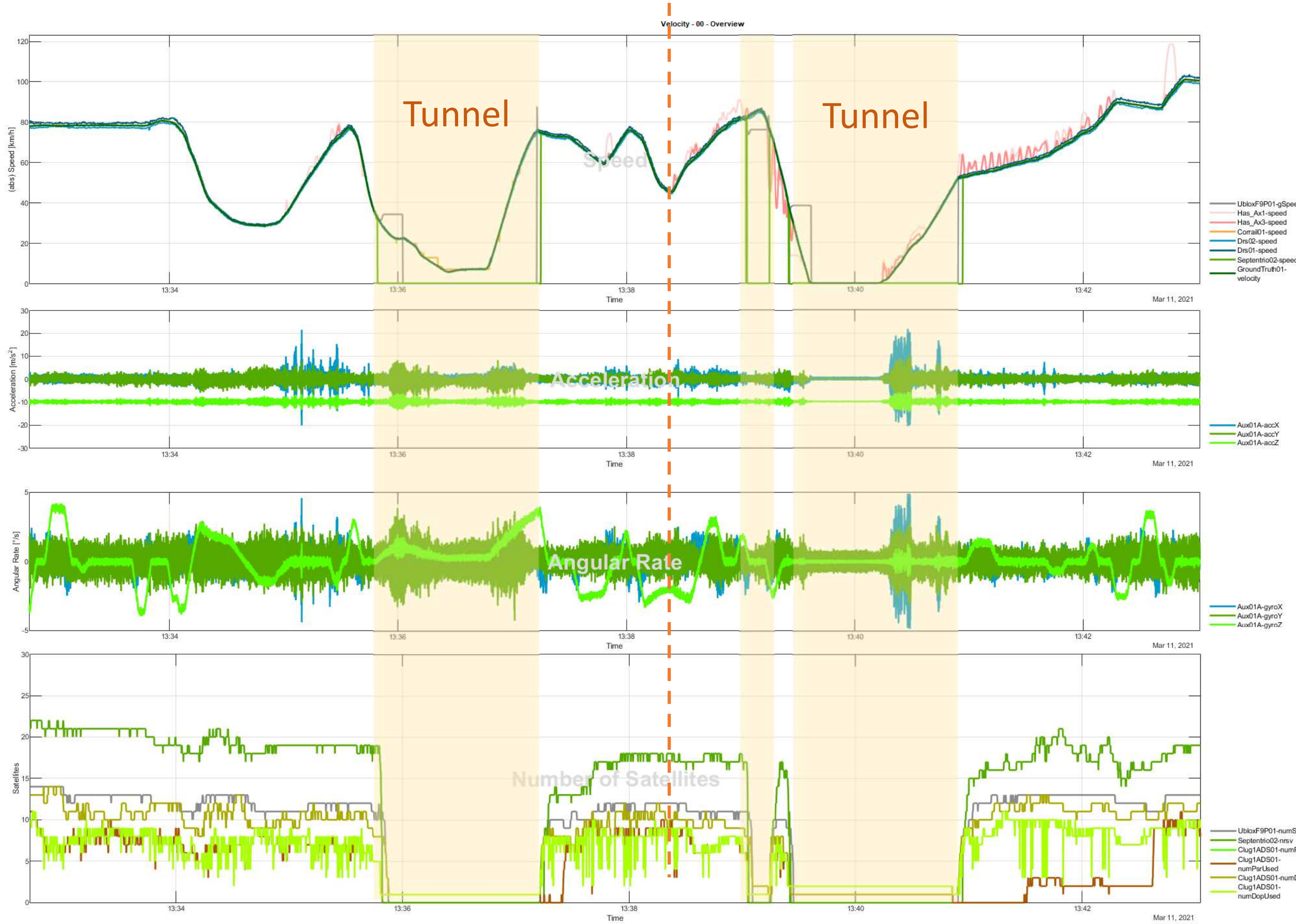
The biggest impact happens when the train leaves the tunnel.



BIEL/BIENNE – LES VERRIÈRES

Optimising the algorithm to better cope with these extreme conditions will be done by looking at data from individual sensors.

Significant amplitudes on both gyro and accelerometer data can be seen where slip and slide occurs.



CONCLUSIONS

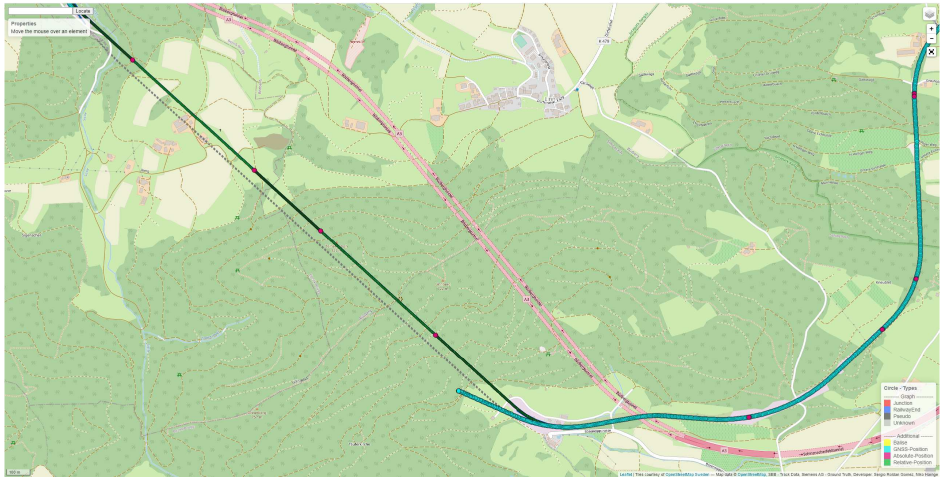
The following, conclusions can be drawn for the data, which has so far been analysed:

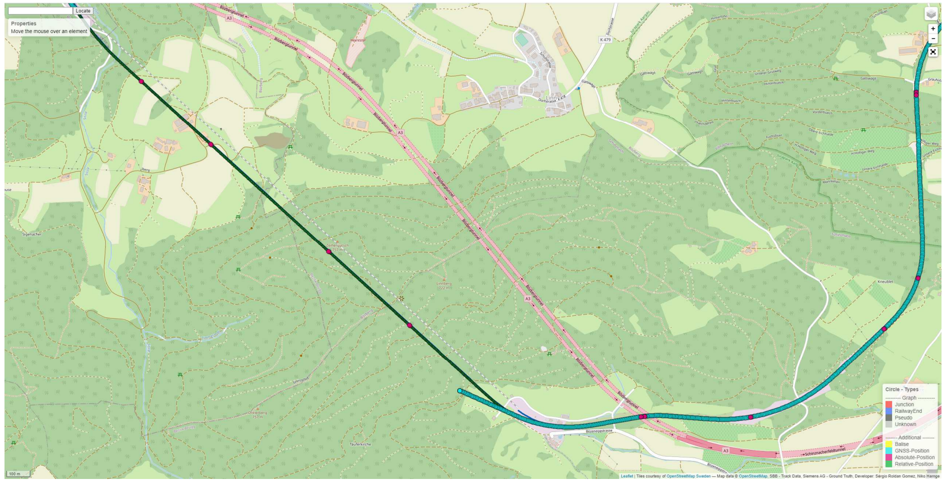
- Both streams show very promising results for speed and along track position accuracy
- This is valid also in challenging environments, such as in the gorge from Biel/Bienne to La-Chaux-de-Fonds as well as on the underground line from La Praille to Annemasse.
- Map matching plays a major role in achieving this performance.
- Detailed data analysis helps improving the algorithms.
- Some tuning of the algorithms might improve performance even further
- Wheel tachos have been used, as they are of low cost and easy to install and maintain, some form of pre-processing or sensor redundancy might however improve performance on critical rolling stock.

NOTABLE LEARNINGS

A number of issues have been detected with the map data, which need further attention:

- A map format has been specified in CLUG.
- Apart form the format, maps need to be accurate, which is currently not always the case. Many inaccuracies have been detected when analysing data, which could be traced to map data.
- Maps also need to be up-to-date, which is currently also not the case. Some of the issue found could be solved by using data which was issued many months after the trips, where changes in track layout were finaly include in the maps.
- Finally, maps and their distribution methods will need to be standardised as well.





NEXT STEPS

The following issues have not been covered by the current project and will have to be covered in a future project:

- The use of GNSS dual frequencies: GPS L1 & L5, Galileo E1 & E5
- The use of EGNOS V3 DFMC: Safe augmentation with integrity of GPS & Galileo
- The evolution of the GroundTruth to provide attitude and heading
- A detailed analysis of the quality of the GroundTruth
- The impact of sensor quality on position, velocity and auxiliary data generated by the algorithms
- The calculation of confidence intervals

In addition, the functions limited to proof of concept will have to be fostered for prototyping:

- Track selectivity along tracks
- Track selectivity over points
- Generating an initial position at startup

ANY QUESTIONS

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https://www.linkedin.com/company/the-clug-project/

CLUG

CERTIFIABLE LOCALISATION UNIT WITH GNSS

EUSPA

European Union Agency for the Space Programme

Identification of Prototypical Certification Methodology

Ernst Phillip Mrohs –NavCert GmbH

Sravan Machiraju -NavCert GmbH

European Union Agency for the Space Programme

CERTIFIABILITY OF TRAIN LOCALISATION SYSTEM

Objective: Certifiability of the safety-relevant train localization system

- Assessment of methods and concepts for validation according to standardization framework
- Development of a voluntary prototypical certification for the train localization system

WP 5 - Application to the train localisation system

- WP 5.1 Preliminary definition of the system
- WP 5.2 Definition of the requirements
- WP 5.8 Prototypical Certification

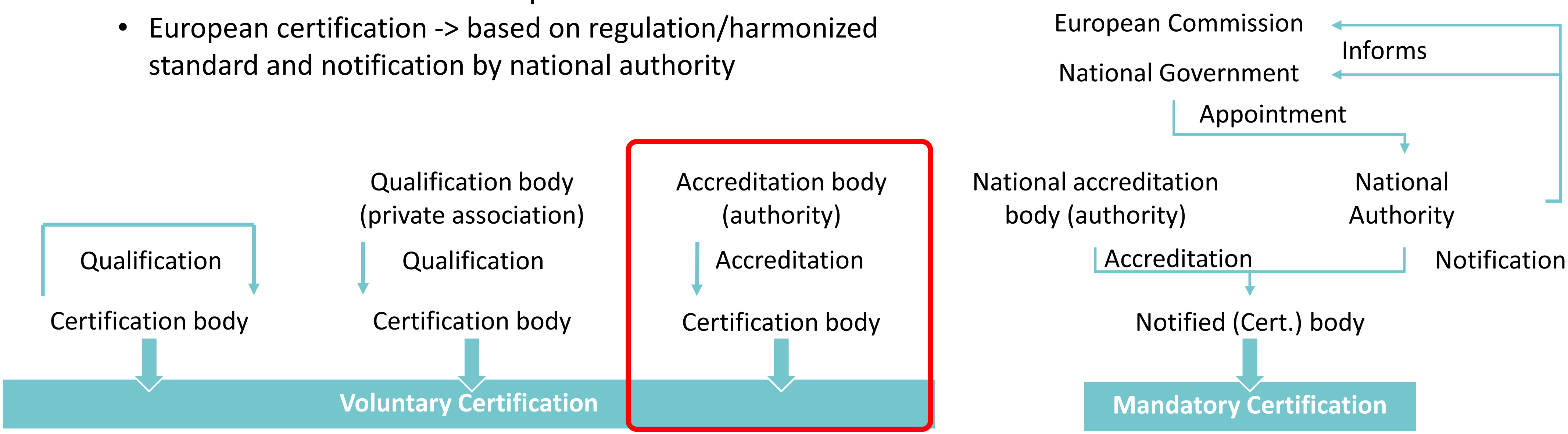
WP 2 - Mission definition and system requirements

- WP 2.1 High Level Mission Requirements
- WP 2.2 Operational Scenarios
- WP 2.3 High Level System Requirements
- WP 2.4 Preliminary Hazard Analysis
- WP 2.7 Identification and validation of certification methods

METHODS FOR CERTIFICATION

Certification

- Independent nomination -> I MAY (Apple)
- Organization (company/association) -> defines rules for nomination (GSMA)
- National Accreditation by national authority -> Federal Railway Authority (Germany EBA) national mandatory certification
- National Accreditation by national authority for European -> EA appoints national authorities like DAkkS for European accreditation
- European certification -> based on regulation/harmonized standard and notification by national authority



OVERVIEW

Prototypical Voluntary Certification

- Requirements for testing
- Requirements for certification
- Definition of conformance test procedures (=CTP) for requirements
  - Project internal standard
  - An important aspect included in the CTP was the identification of the inputs, outputs, and the test pass/fail criteria.
- Testing
  - Simulation tests
  - Record & Replay Tests
  - Field tests

Action	Tests	Review of tests results	Certification review	Certification decision
Resulting Documents	Test report	Signed test report	Reviewed test report	Signed certification report
Reference	ISO 17025	ISO 17025	ISO 17065	ISO 17065

Voluntary Certificate & certification mark

- Scope of voluntary certification: Position, Velocity and Time (PVT)-systems for the train localization
  - PVT Reliability, Availability, Performance and Continuity validated for train localization
  - PVT Safety validated for train localization

PROTOTYPICAL VOLUNTARY CERTIFICATION

Implemented validation process corresponds to defined process defined from ISO 17025
(required for an acceptance of such scheme by an accredited certification body)

CTP consist in:

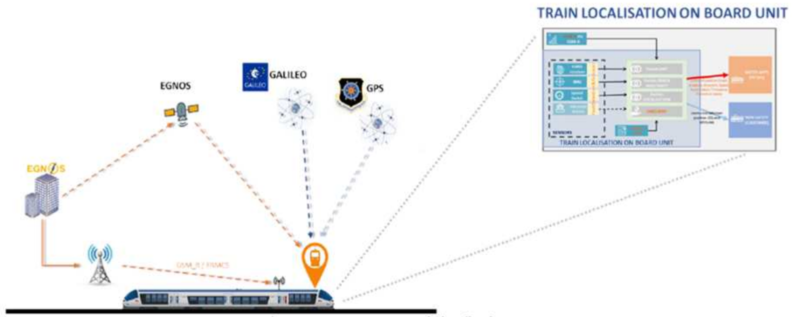
- Identified KPI, requirement, … for TLOBU
- Identification of the inputs, outputs
- Test pass/fail criteria
- References information

Acknowledgment of work other work packages, especially WP 4

High-level validation implemented -> Indicating practicability of defined scheme

Scope of voluntary certification in connection of defined CTPs grouped into 2 classes

- Reliability, Availability, Performance and Continuity validated for train localization
  - “Basic” assessment of system under consideration of defined use cases
- Safety validated for train localization
  - E.g. behavior of system in critical scenarios



NEXT STEPS

Goals:

- Assurance of reliability, availability, performance and continuity for safety relevant PVT based components with focus on GNSS
- Transfer prototypical voluntary certification to final voluntary certification scheme

Solutions:

- **Finalization of prototypical certification scheme**
  - Finalization of validation especially PVT reference through calibration, qualification, …
    - Elaboration of sensor and design specific validation scheme for applicable ground truth systems (e.g., fused corrected GNSS with Odometry and IMU) following ISO 17025 requirements (e.g., impacting factor analysis, measurement analysis, ….)
    - Setup connection to SI-constants
    - Analysis of used ground truth systems upon common cause with TLOBU (e.g. jamming), performance, etc.
  - Verification of test scheme and method
    - E.g., real world testing campaign
- **Identification of necessary topics for mandatory certification**
  - E.g., development of standards (CEN)

CLUG project summary, achievements and issues for future investigation

VALENTIN BARREAU, SNCF

MUTHUKUMAR KUMAR, DB NETZ

CLUG WEBINAR 09/06/2022

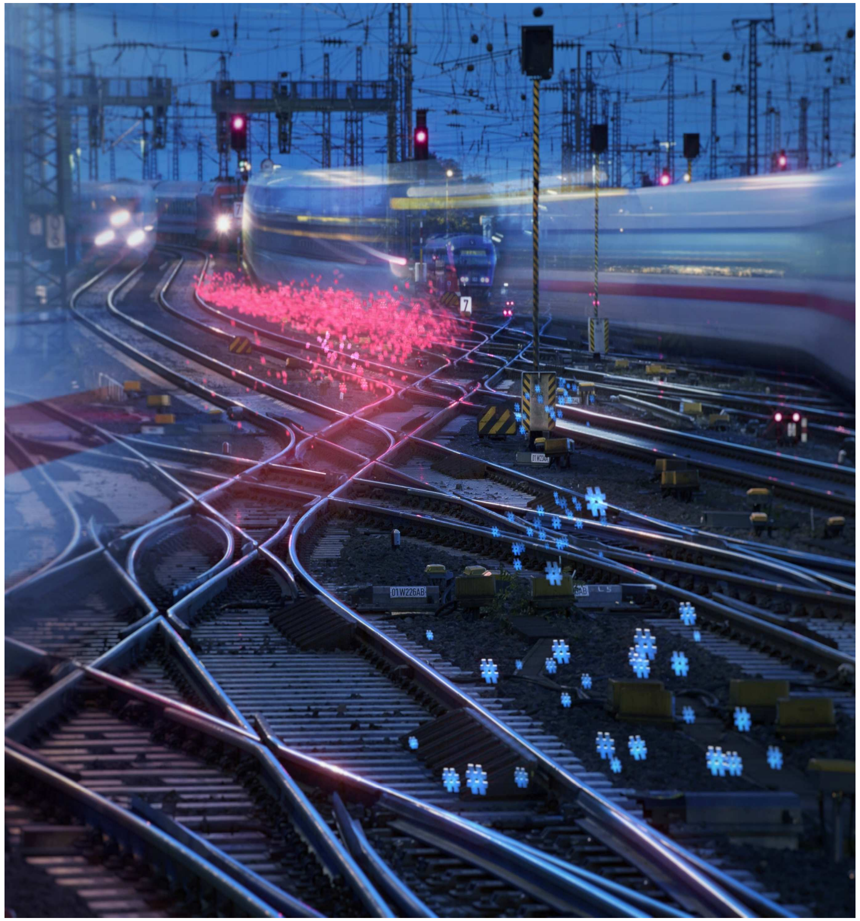
European Union Agency for the Space Programme

AN INNOVATIVE APPROACH FOR TRAIN LOCALISATION

Our vision:
Bring the ERTMS/ETCS train localisation system to a new era with an innovative multi-sensor approach using digital maps and European satellite navigation system (GNSS)

Localisation as a key enabler:

- Foster concepts such as intelligent traffic management, automated train operation (GoA2 to GoA4), ERTMS/ETCS Level 3
- Improve operational quality through localisation performance
- Decrease capital expenditure (CAPEX) and operational expenditure (OPEX) of field elements needed for localisation, e.g. less Eurobalises
- Standardised interfaces to enable modularisation of ETCS On-Board

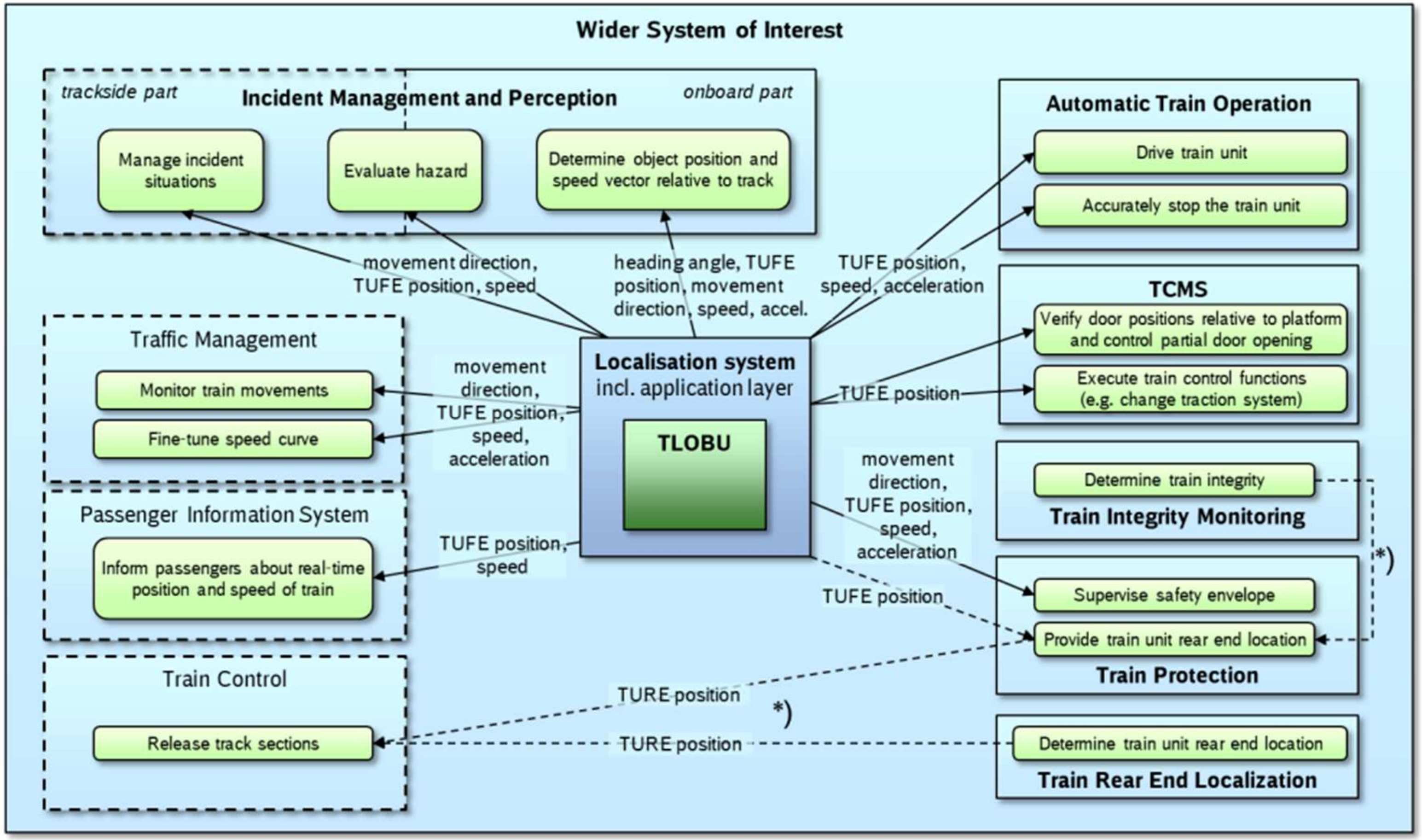


CLUG WP ORGANISATION AND SCOPE

CLUG PROJECT

- **WP1** Project Management and coordination
- **WP2** Mission definition and System requirements
- **WP3** Localization System Design
- **WP4** Testing and evaluation
- **WP5** Application to the Train Localisation System

WIDER SYSTEM OF INTEREST

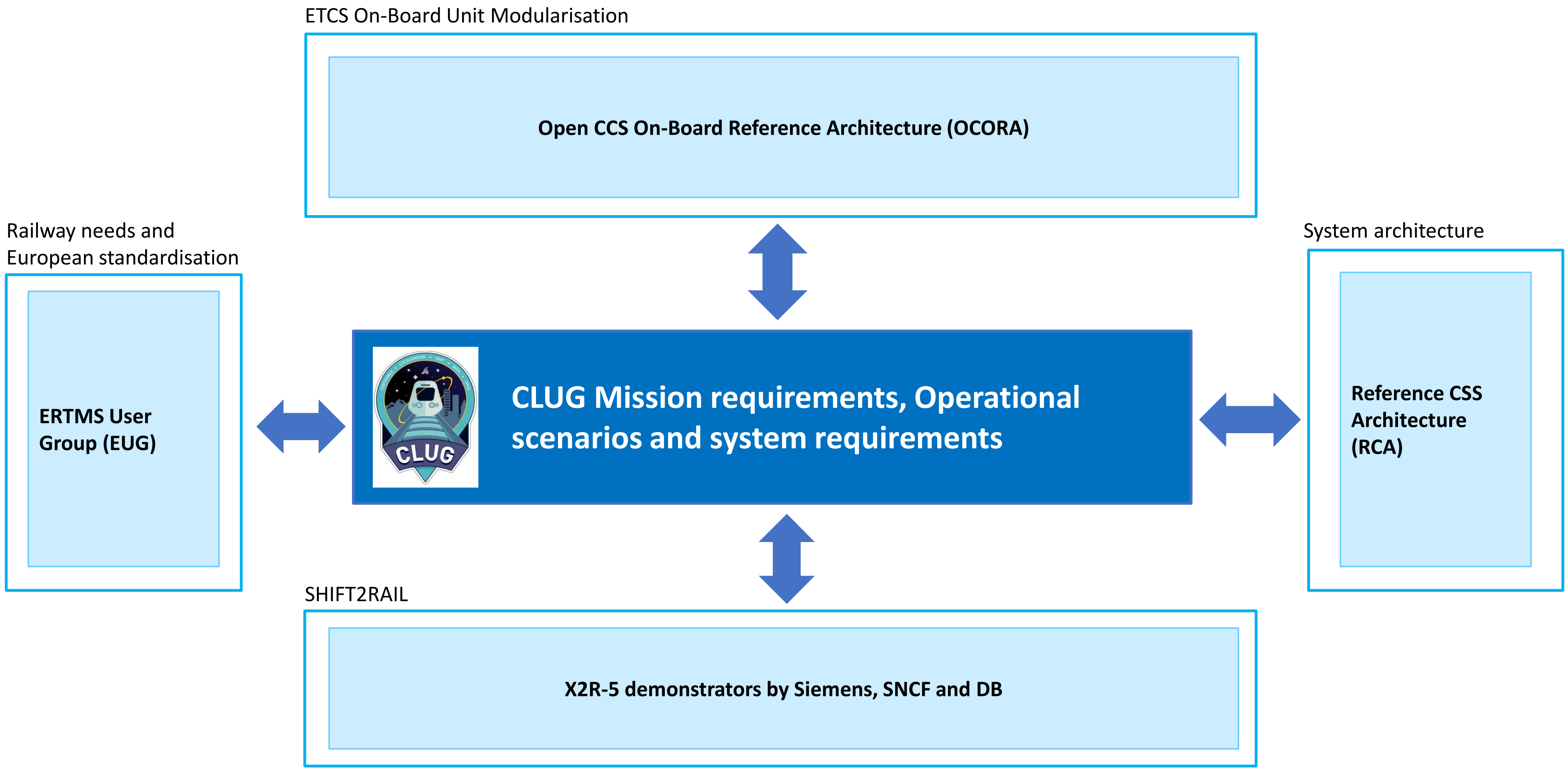


Trackside system

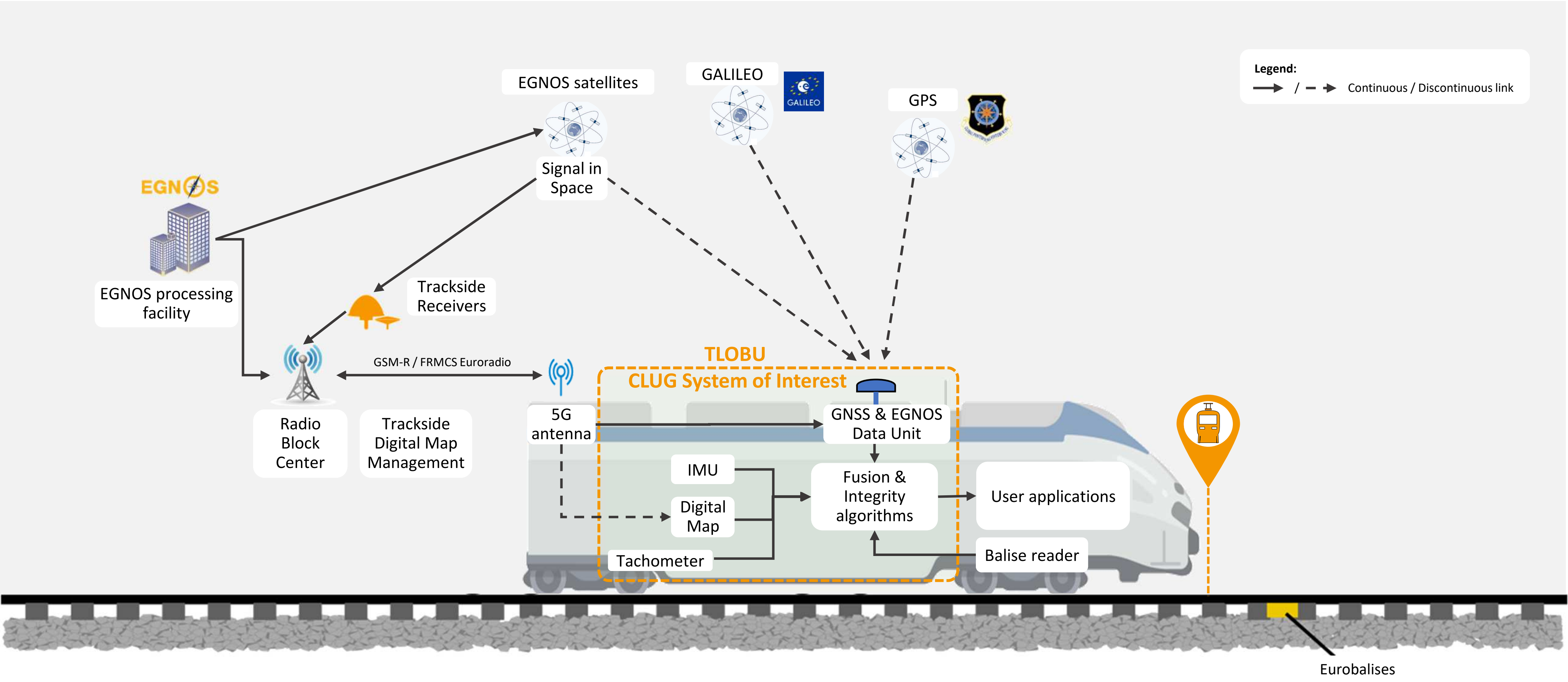
Onboard system

*) Depending on their type, some trains will determine their rear end indirectly with help of train integrity monitoring and others by a dedicated rear end localization system. The exact distribution of functions for this purpose is outside the scope of CLUG. (see 2.1.5)

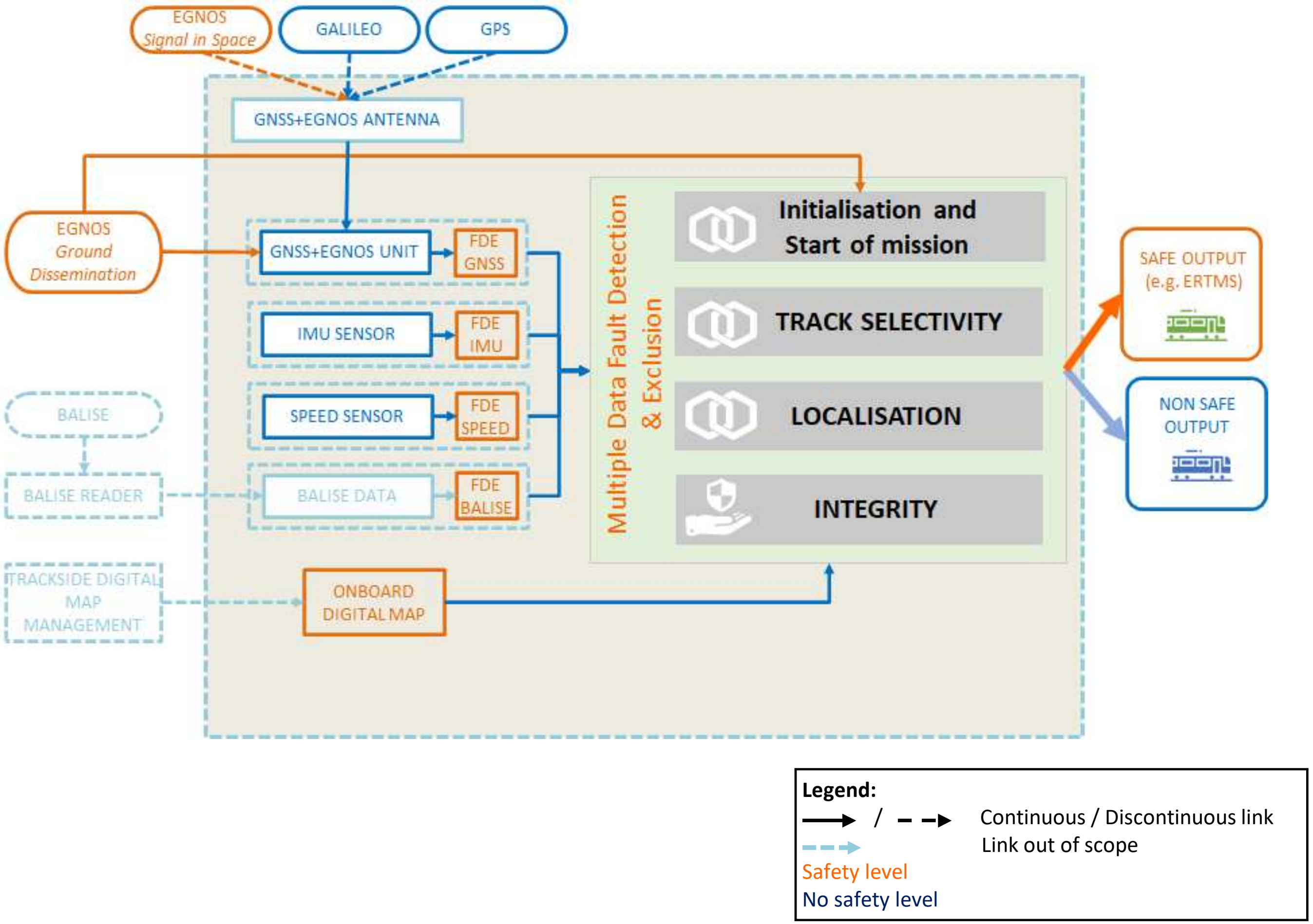
COLLABORATION AND EXCHANGE WITH EUROPEAN INITIATIVES



THE CLUG CONCEPT



TLOBU FUNCTIONAL DESIGN

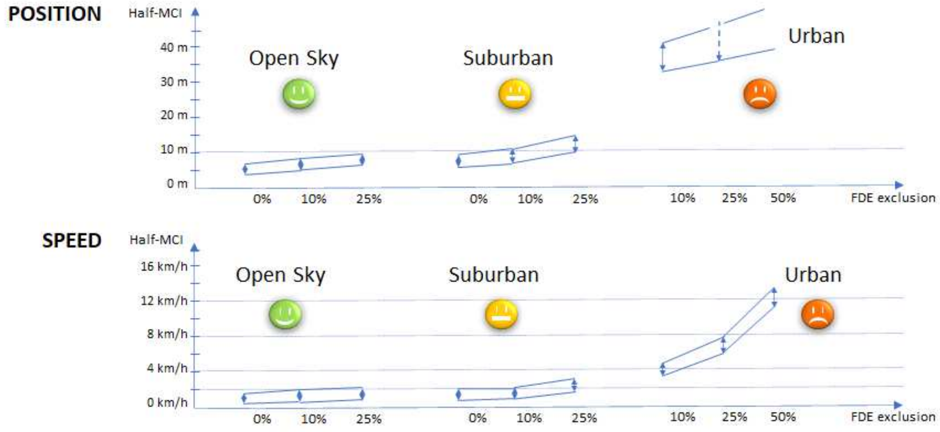


Solution not fully developed

- Missing DFE
- Cold-start and track selectivity
- Fusion filter: EGNOS DFMC service for rail
- Integrity filter: concept only defined on paper
- Real-time localisation

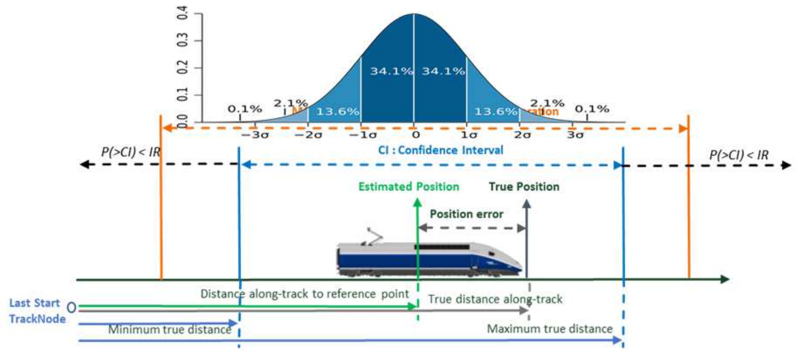
INTEGRITY & SAFETY ANALYSIS
PERFORMANCE & WAY FORWARD

Integrity analysis:
- High performance in Open Sky
- Improvement in Urban / Suburban
  - Physical balises in critical areas
  - Enhanced service « EGNOS for Rail »
- More precise modeling of CI computation algorithm, Data FDE behavior, correlations and biases



Reachable MCI @ 99.9% using EGNOS DFMC & no balise

Safety analysis :
- Very promising SIL3 level is reached
- Functional architecture will need to be reviewed:
  - Requirement refinement
  - Redundancy and independency principles
  - FDE design
- HW/SW architecture design (single failure prevention)



SOLUTION A&B ACCURACY ANALYSIS

- Both solutions first accuracy results are very promising,
  ⇒ Several industrial solutions / designs can answer CLUG requirements

- A good along track position and speed accuracy can be achieved with Solution A

- Promising position results and good speed accuracy is achieved with Solution B.

TOPICS FOR FUTURE INVESTIGATION

Requirement specification

- Consolidation of the preliminary performance requirements
- Operational aspects around start of mission and track selectivity
- Standardisation of external interfaces of the localisation module

Technical challenges

- Real-time localisation
- Implementation of new modules or functionalities
- Functional architecture consolidation
- HW/SW architecture design
- Detailed safety analysis for train-centric localisation

DISSEMINATION

- Several public deliverables available on the CLUG website
  - D2.1: High Level Mission Requirements → Published
  - D2.2: Operational Scenarios Definition → Published
  - D3.1.1: GNSS augmentation usage for CLUG → Published
  - D3.4: GNSS augmentation needs for rail → Published
  - D2.7: Identified Validation Certification Methods → Published
  - D5.4: Definition of the required map for localization → To be published (06/2022)
  - D5.7: Preliminary definition of the system performances and interfaces → To be published (06/2022)

- Some data sets will also be made public (07/2022)
  - See D4.2/D4.3 deliverable on the CLUG website for more information
  - See D5.6 Final Dissemination Report → To be published (06/2022)


THE CLUG PROJECT
CLUG
EUSPA

ANY QUESTIONS

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