CLUG 2.0 Exploitation Meeting

3rd April 2025

AGENDA OF THE MEETING

AGENDA

14:00-14:05	Welcome by **Jose Bertolín (UNIFE)**
14:05-14:30	Introduction to CLUG 2.0, **J. Bertolín (UNIFE), V. Barreau (SNCF)**
14:30-15:15	LOC-OB Functional Architecture: high level Architecture, Track Selectivity design, System Data FDE, Position and speed Confident Interval Computation, and Improvement of models and Salsa4Rail performance prediction tool A. Sfeir (ADS), **P. Grandjean (ADS).**
15:15-15:30	Q&A
15:30-15:40	Break
15:40-16:25	CLUG 2.0 Cost Benefit Analysis, **E. Ziese (DB)**
16:25-16:40	Q&A
16:40-17:00	CLUG 2.0 GAP Analysis, **A. Gharios (SNCF)**
17:00-17:15	Q&A
17:15-17:30	**Closing Remarks, J. Bertolín (UNIFE), V. Barreau (SNCF)**
17:30	*End*

Introduction to CLUG 2.0

J. Bertolin (UNIFE) – Coordinator
V. Barreau (SNCF) – Technical Leader

CLUG 2.0 IN A NUTSHELL

Budget: **3.1 M€**
2.87 M€ (EUSPA FUNDED)

Partners: **10**

Duration: **24 months**

Starting date: **Feb 23**

End date: ~~**Jan 25**~~
Extension Jul 25

CLUG 2.0 OBJECTIVES

Develop and demonstrate absolute safe train positioning by applying the existing and future European Global Navigation Satellite System (GNSS) and the European Geostationary Navigation Overlay Service (EGNOS) and multi-sensor functionality for train localization.

The expected objectives of CLUG 2.0 are based on work performed in CLUG (along the track)

- Consolidation of user needs and system requirements (**Along Track**, Start of Mission and Track selectivity)
- Consolidation of safe localization system architecture and prototype new critical functionality
  - Track Selectivity and Safety
  - Sensor and system levels FDE algorithms
  - Confidence Intervals computation and global Integrity concept
- RAMS analysis on the consolidated functional architecture of the system.
- Live demonstration/Replay to consolidate readiness of the CLUG multi-sensor fusion algorithmsv

WP ORGANIZATION

CLUG PROJECT

WP1
Project management and coordination
Duration: M1 to M24

WP2
LOC-OB System Definition & Requirements Specification
Duration: M1 to M8

WP3
RAMS Analysis
Duration: M1 to M24

WP4
Design and Development
Duration: M1 to M24

WP5
Integration & Testing (including Site Demonstrator)
Duration: M1 to M24

WP6
Communication, Dissemination, Exploitation and Business Case
Duration: M1 to M24

CLUG 2.0 PROJECT PLAN

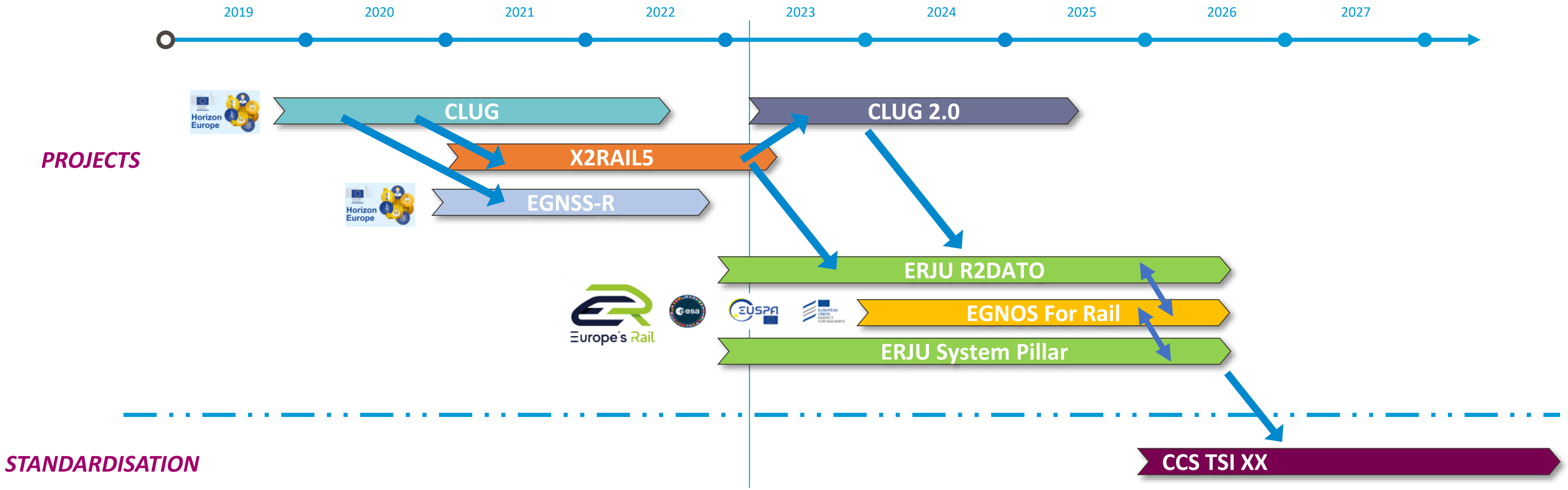
Legend: ◆ Milestones

	2023											2024												2025						
	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul
	Year 1												Year 2														Year 3			
	Phase 1								Phase 2								Phase 3										EXTENSION			
				MS1					MS2							MS3				MS4				MS5 MS						
WP / Tasks	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	M12	M13	M14	M15	M16	M17	M18	M19	M20	M21	M22	M23	M24	M25	M26	M27	M28	M29	M30

ID	WP / Tasks	Deliverables
WP1	Project Management & Technical Coordination	
T1.1	Project Management/Coordination	
T1.2	Consortium Management	
T1.3	Technical Coordination	
T1.4	Administrative and Financial Management	
T1.5	Quality Management	D1.1
WP2	LOC-OB System Definition & Requirements Specification	
T2.1	Operational needs and system capabilities of LOC-OB	D2.1, D2.1
T2.2	Start of Mission and track selectivity	D2.2, D2.2
T2.3	LOC-OB System Boundary, Architecture and External Interfaces incl. Digital Map	D2.3, D2.3
T2.4	LOC-OB System Requirement Analysis and Specification	D2.4, D2.4
WP3	RAMS Analysis	
T3.1	CLUG LOC-OB System context analysis and RAMS Plan	D3.1, D3.1
T3.2	LOC-OB Preliminary Hazard Analysis	D3.2, D3.2
T3.3	CLUG LOC-OB System Failure Modes and Effects Analysis	D3.3, D3.3
T3.4	LOC-OB External Interface Analysis	D3.4, D3.4, D3.4
T3.5	CLUG LOC-OB System Functional Analysis	D3.5, D3.5
T3.6	CLUG LOC-OB Reliability Availability Maintainability System Analysis	D3.6, D3.6
T3.7	CLUG LOC-OB RAMS Evaluation report	D3.7, D3.7
WP4	Design and Development	
T4.1	LOC-OB functional architecture	D4.1, D4.1
T4.2	GNSS+EGNOS unit sensor including data FDE	A4.2/D4.2, A4.2/D4.2
T4.3	IMU sensor and data FDE	D4.3
T4.4	Speed sensor (tacho or eq.) and data FDE	D4.4, D4.4, ALGO
T4.5	Eurobalise reader sensor and data FDE	D4.5, D4.5
T4.6	Along track localization algorithm robustification	D4.6, D4.6, A4.6
T4.7	Confidence Intervals computation & Integrity algorithm	D4.7, D4.7, A4.7
T4.8	Track Selectivity algorithm	D4.8, D4.8, A4.8
T4.9	Start of Mission preliminary definition	D4.9, D4.9
T4.10	On board Digital Map Integration	D4.10, D4.10
T4.11	CLUG LOC-OB system Performances engineering (Integrity Availability)	D4.11, D4.11
T4.12	EGNOS data generation made available for tests	D(a)4.12
WP5	Integration & Testing (includ Site Demonstrator)	
T5.1	Raw Data Collection System	
T5.2	Onboard Site Demonstrator	D5.1, D5.1
T5.3	Data Collection and Live Demonstration	D5.2, D5.2
T5.4	Data Post Processing	
T5.5	Data Analysis and Interpretation	D5.3, D5.3
WP6	Communication, Dissemination, Exploitation and Business Case	
T6.1	Develop the Communication, Dissemination and Exploitation Plan (CDEP)	D6.1
T6.2	Production and maintenance of Data Management Plan	D6.2, D6.2
T6.3	Project communication and dissemination activities	D6.3
T6.4	Scientific Dissemination	
T6.5	Business case for GNSS based absolute safe train positioning	D6.4
T6.6	Definition of Modular and Interoperable LOC-OB system for future Standardisation	D6.5, D6.6
T6.7	Exploitation commitee	

CLUG REASONING & ROADMAP

- Demonstrate the feasibility of using EGNSS in rail signaling solutions (in term of operations and performance)
- Validate the critical points regarding standardization (migration, interfaces, etc)



CLUG 2.0 Progress, status and next steps

System specification (WP2) has been completed, and safety analysis (WP3) is almost completed.
- D3.7 "RAMS evaluation report" will be released publicly on May 25

System design and development (WP4) is mostly completed
- The architecture has been consolidated and
- Fine tuning following the first data analysis is still to be performed alongside the data analysis
- System performance validation through simulation

Integration & Testing (WP5) is ongoing :
- Data collection is ongoing with the associated dataset preparation
- The performance analysis will be performed between April and June 25.
- The Performance report will be publicly released in July 25.

Business case
- The study is almost finalized and will be released publicly in the coming months

Gap Analysis
- The study is almost finalized and will be released publicly in the coming months.
- It will be used as input for R2DATO WP22.5

Public deliverables available on https://www.clug2.eu/deliverables/

LOC-OB Functional Architecture

A. Sfeir – WP4 leader (Airbus)
P. Grandjean – SC representative(Airbus)

Agenda

WP4 LOC-OB Functional Architecture:

- High level functional architecture(s) (Arnault)

Focus on:

- Track Selectivity design (Arnault)
- Confidence Intervals computation concepts and System Data Fault Detection & Exclusion (Pierrick)
- Performance prediction. Improvement of models and Salsa4Rail tool (Pierrick)

WP4 in a nutshell

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WP4 in a nutshell

Budget: **30% of the total CLUG2 budget**

WP4 participants	In percentage
ADS	37%
ENAC	25%
SYNTONY	16%
SMO	10%
SNCF, CAF, DBN; SBB	12%

WP4 Leader: **Airbus Defence and Space**

T4.x Leaders: **ADS, CAF, SYN, SMO, SNCF**

Duration: **extended to 29 months**

Participants

AIRBUS

ENAC

SYNTONY GNSS

SNCF SIEMENS

DB CAF

SBB CFF FFS

LOC-OB High level functional architecture(s)

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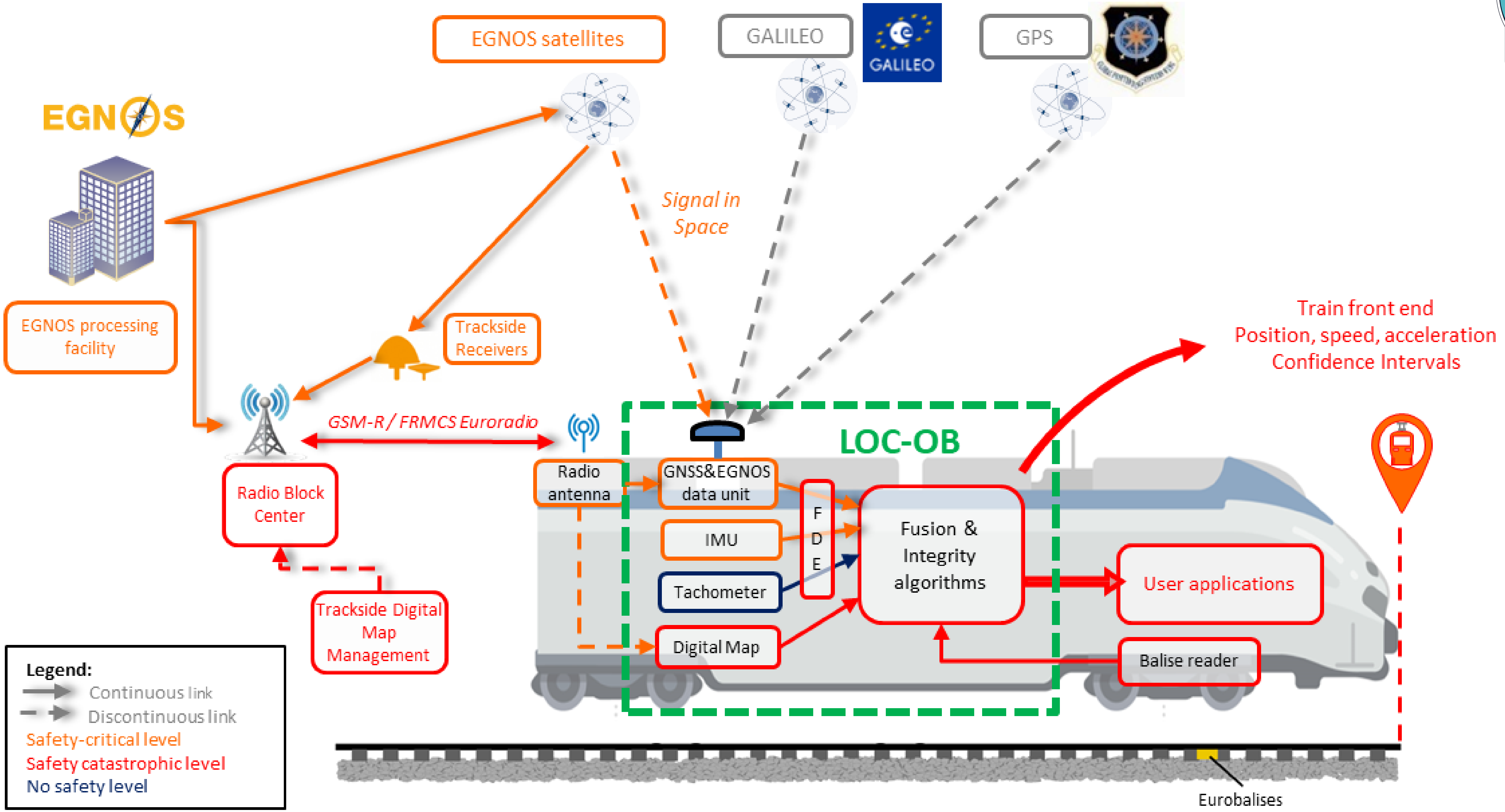
LOC-OB High level functional architecture(s)



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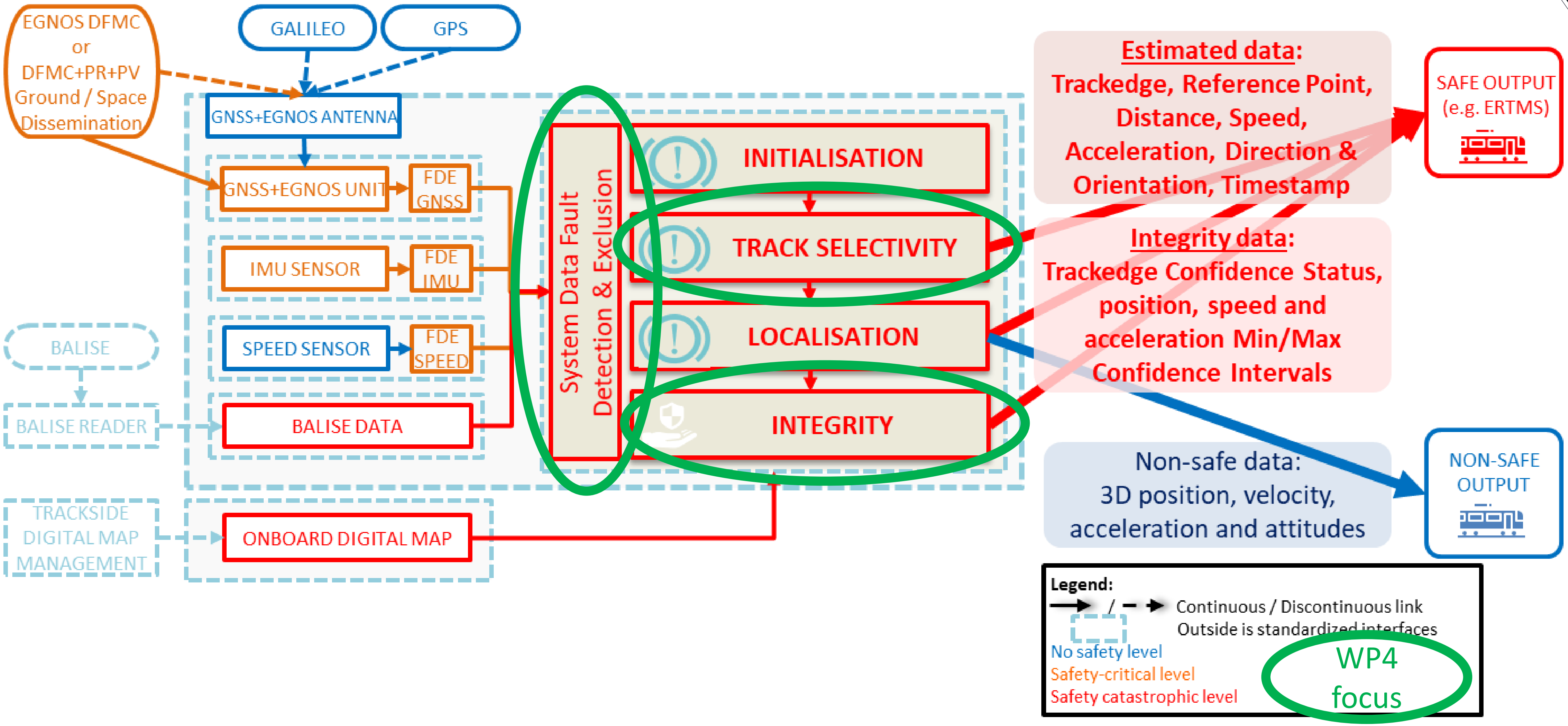
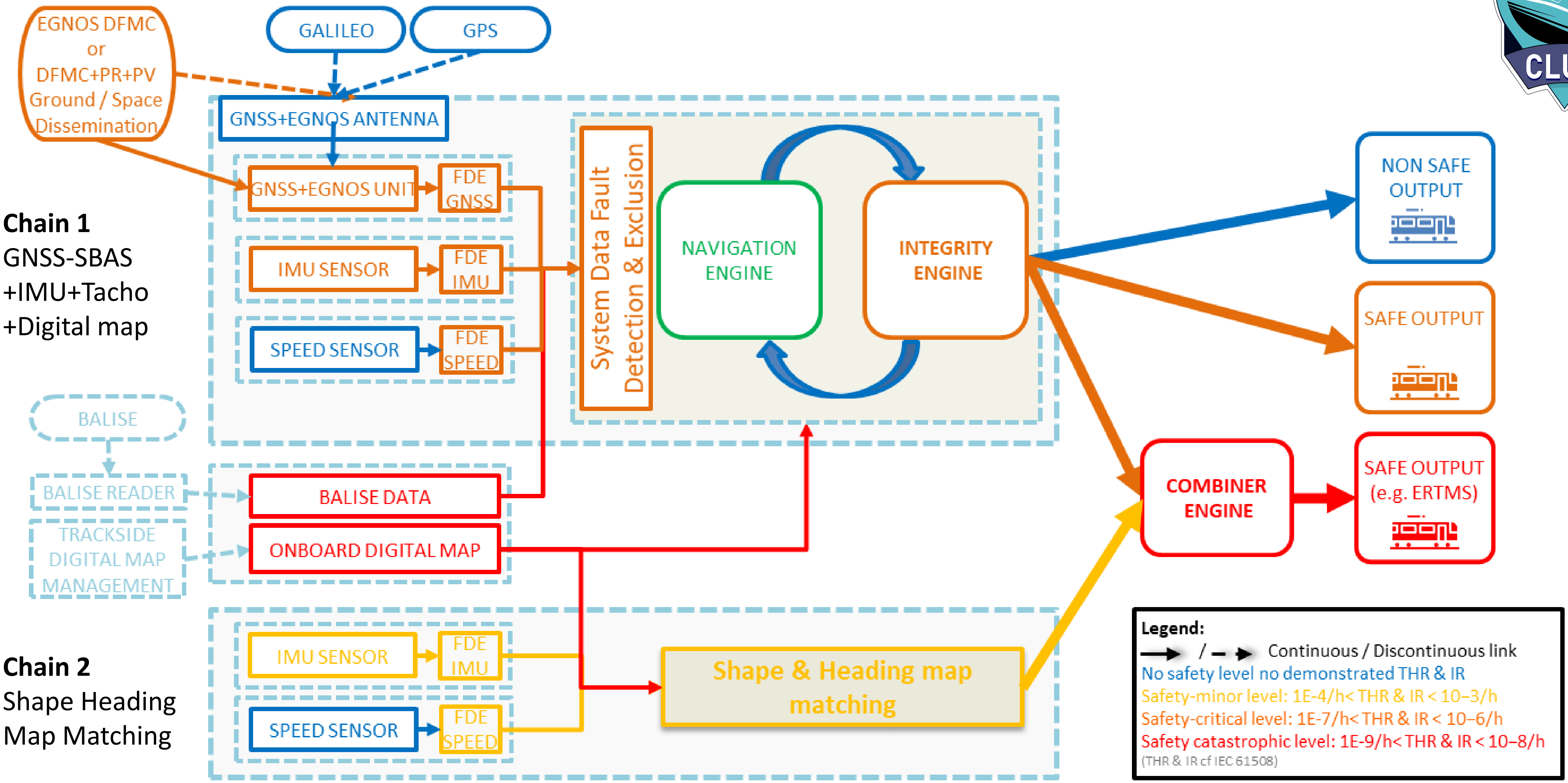
LOC-OB single chain functional architecture



LOC-OB dual chains functional architecture



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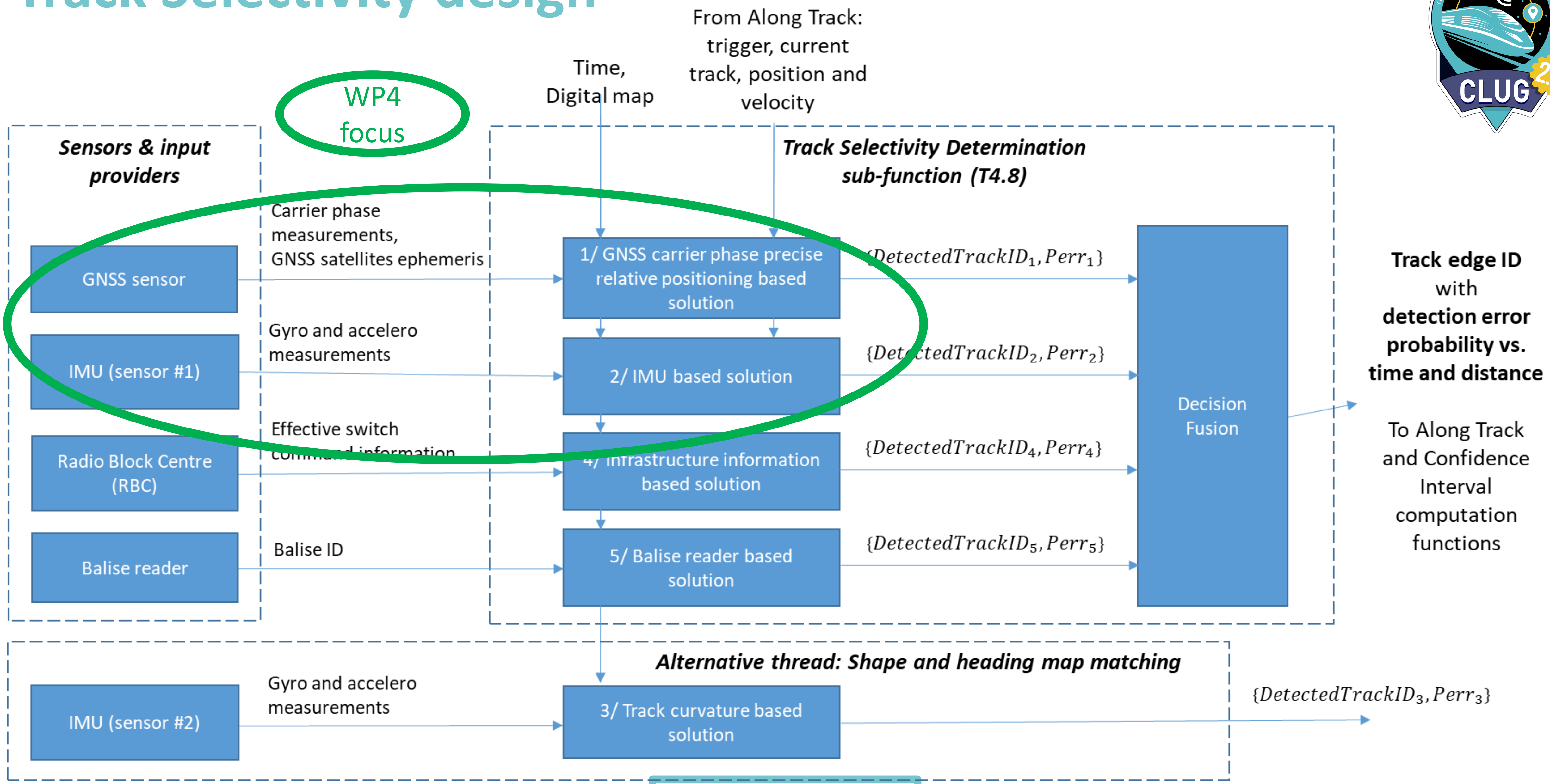
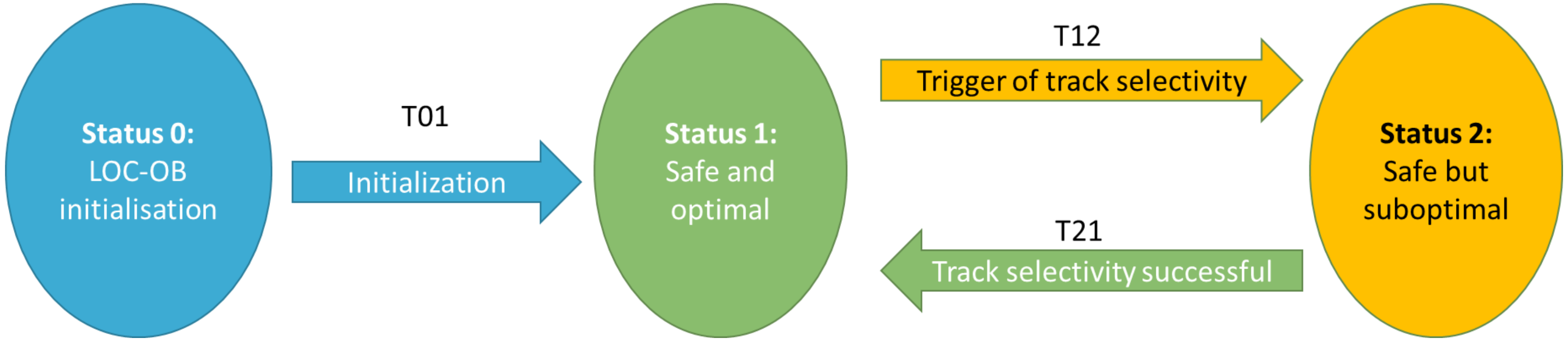
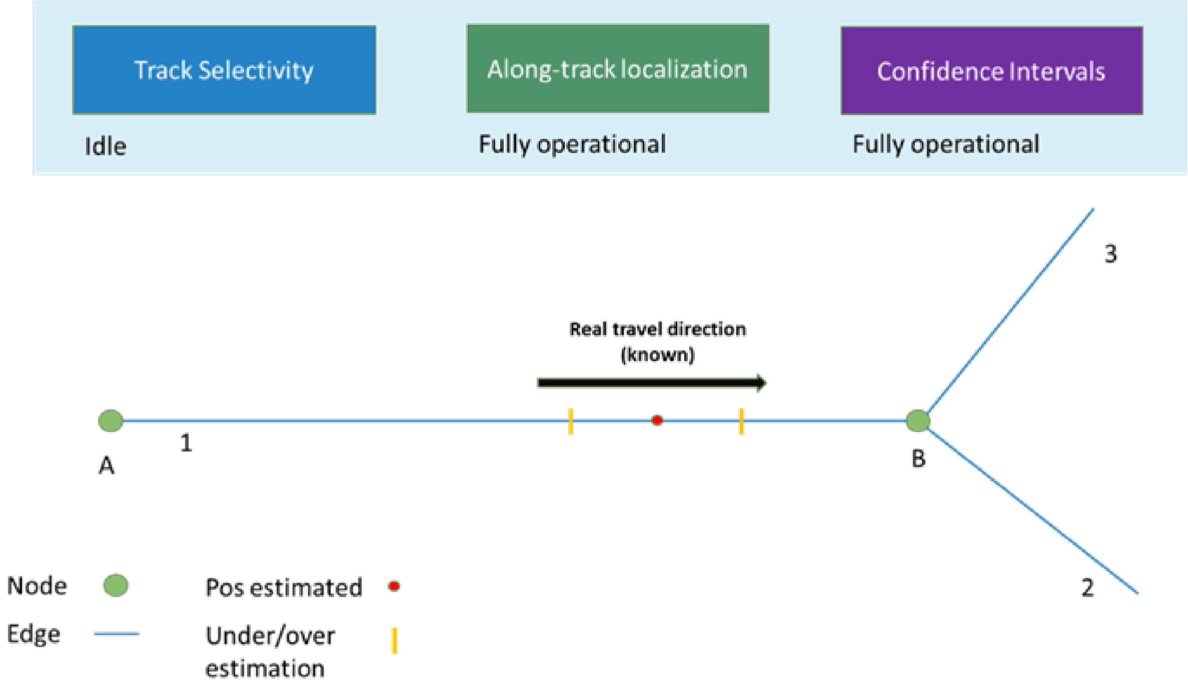
Track Selectivity design

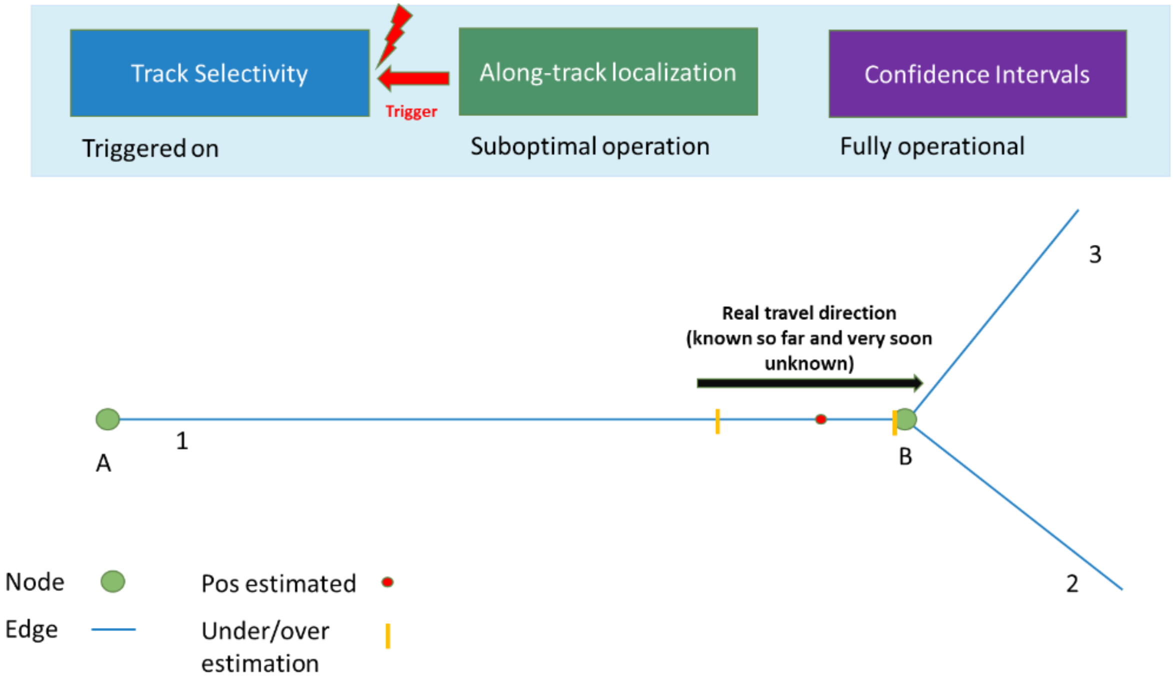
Track Selectivity design



Track Selectivity, estimates and CIs when switching







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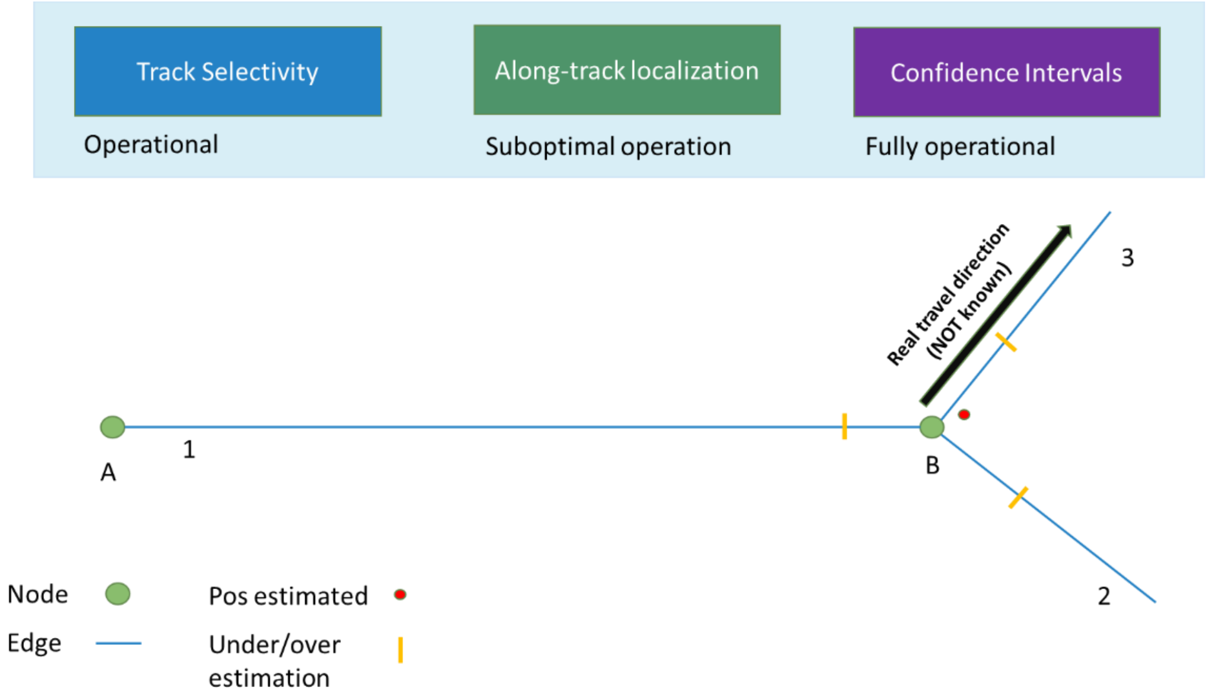
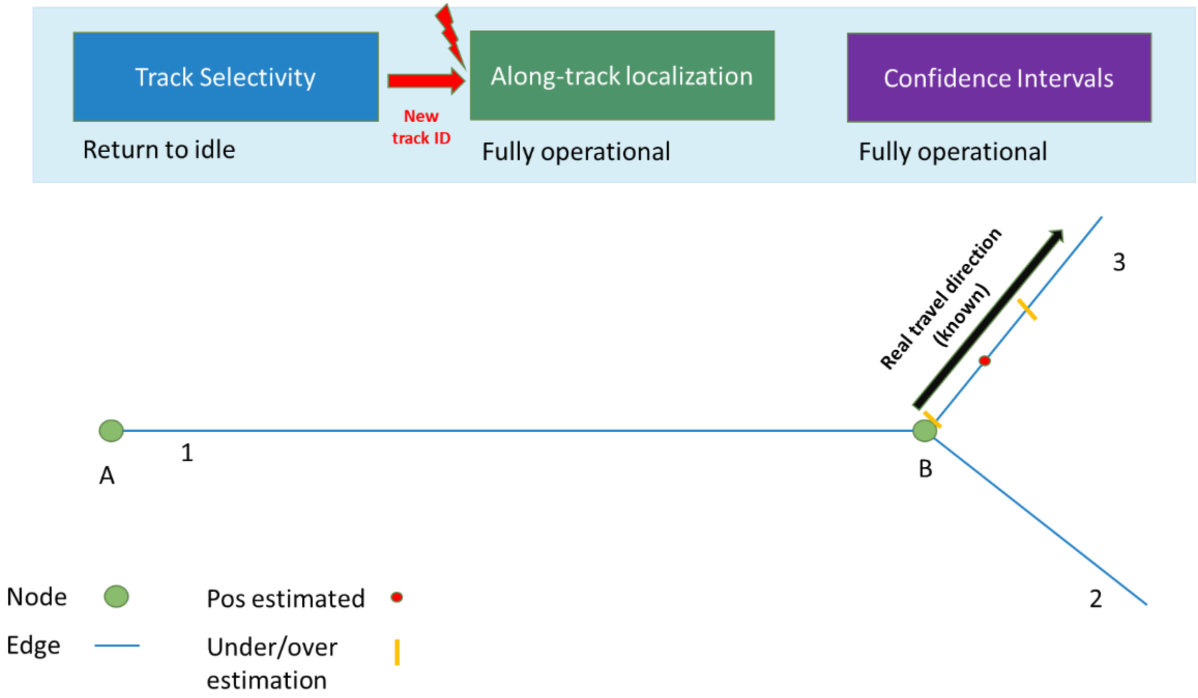
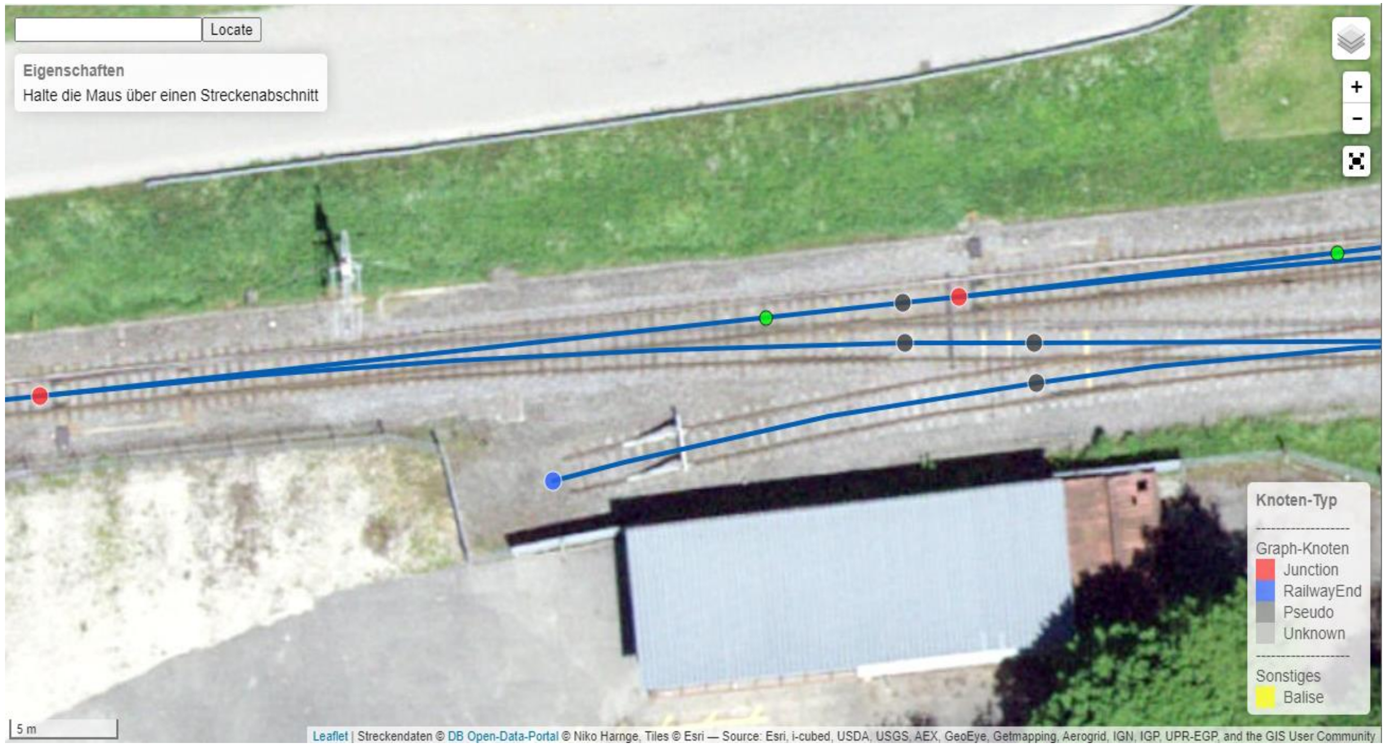
Track Selectivity, estimates and CIs when switching





Track Selectivity first experimentation results



Post processing test case:

Real dataset with its associated multitrack digital map:

- Red dots are the location of track switches,
- black dots are Digital Map nodes.

The train was running from the left to the right

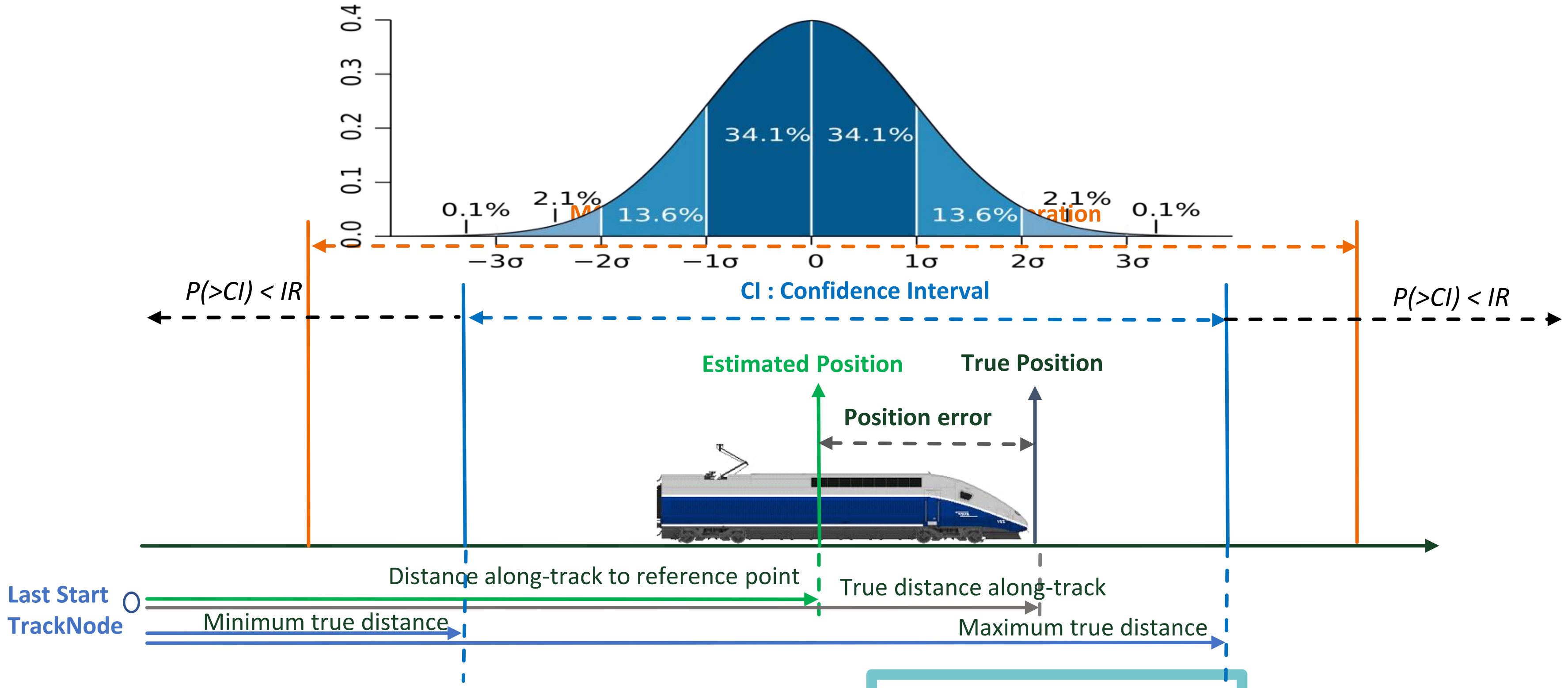
Track electivity function implementing only the GNSS-based chain and the IMU-based chain:

- green dots is the location where the decision is sufficiently safe at 10^{-10} Hazard Rate

Confidence Intervals computation concepts and System Data Fault Detection & Exclusion

Performance terms definitions

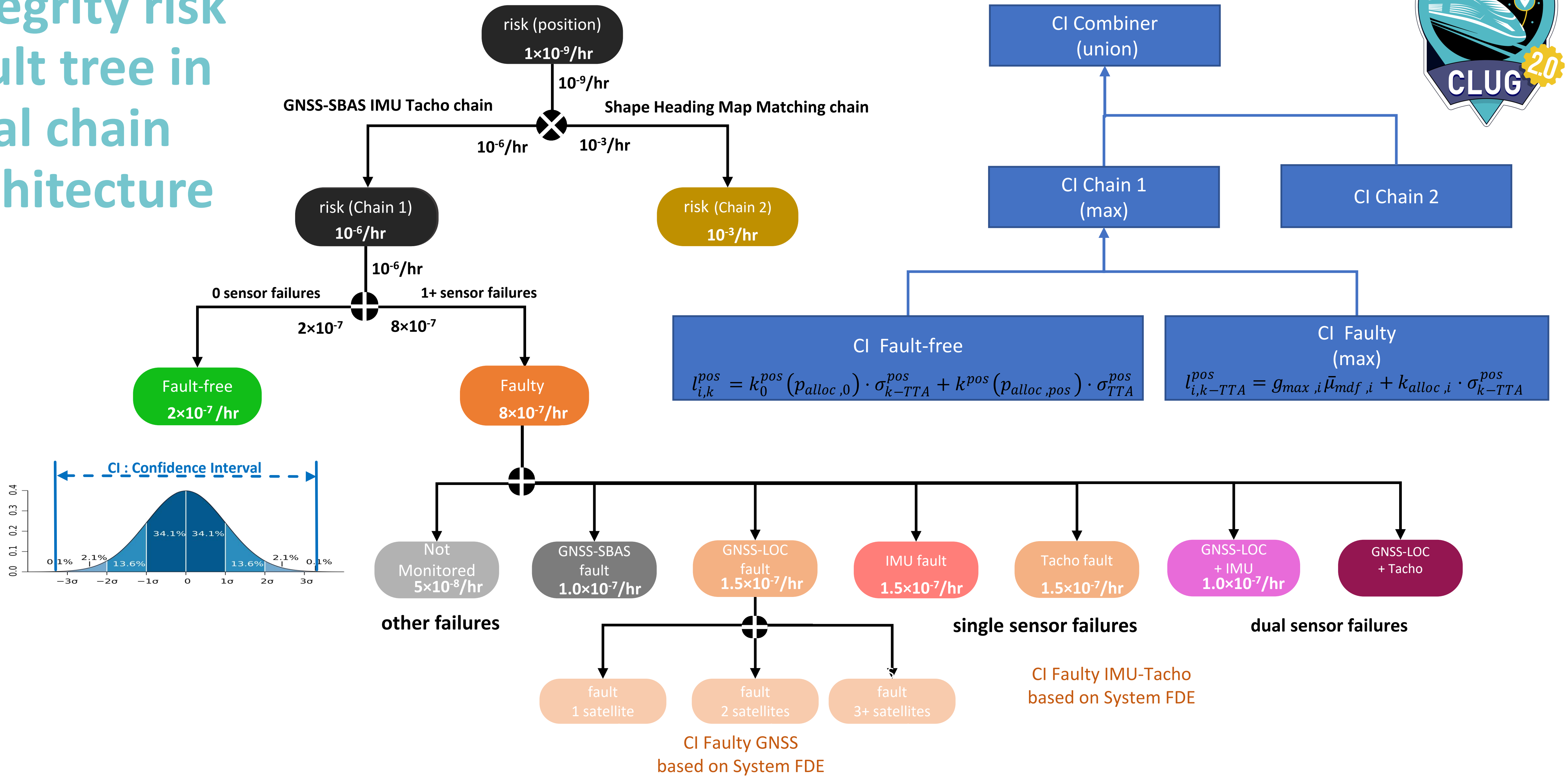
Performance	Definition
Position state parameters	**Distance along-track**, Track ID, Velocity along-track, Acceleration



Integrity risk is a Safety issue

Maximum Confidence Interval is a performance availability requirement

Integrity risk Fault tree in dual chain architecture



System data FDE

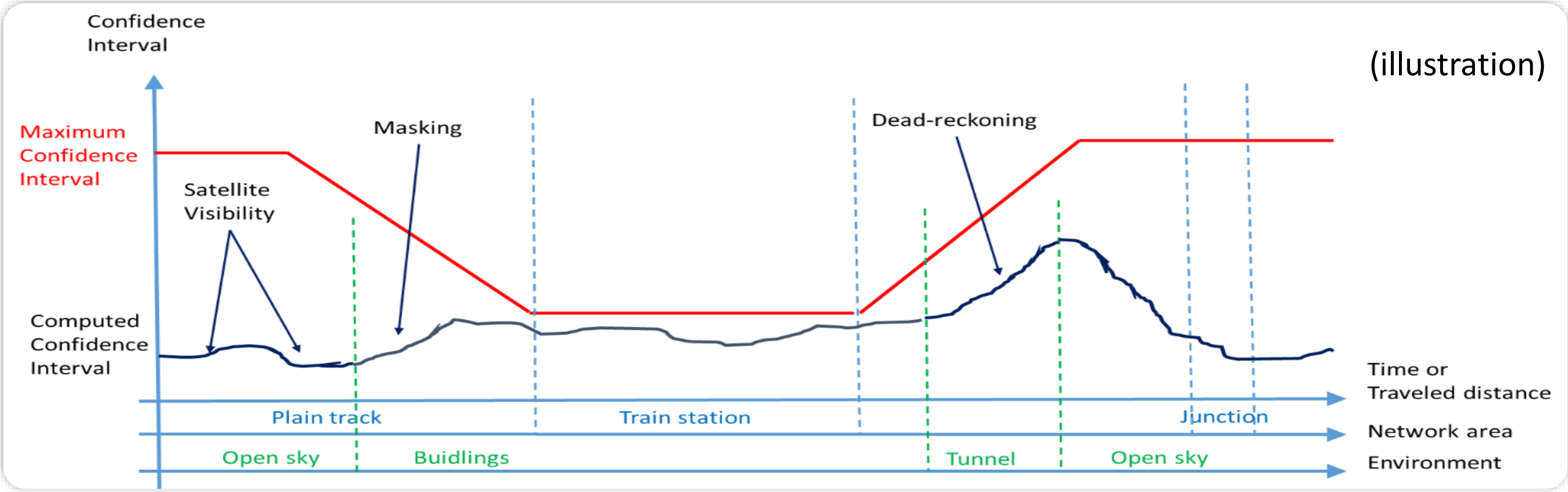
System data FDE protect against GNSS faults, IMU faults and Tacho faults by employing innovation sequences.

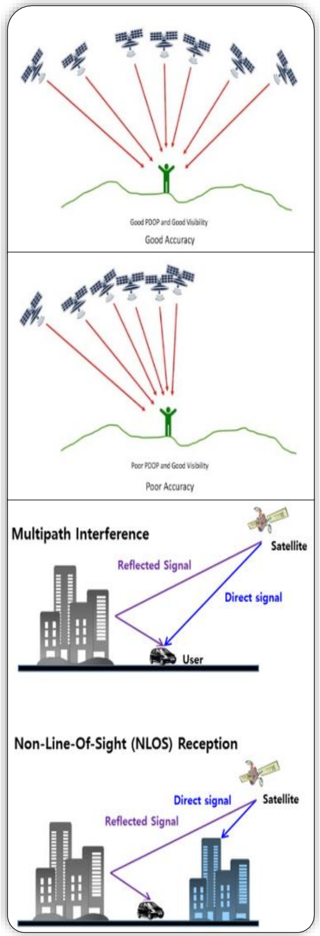
- **Innovation** ➢ difference between predicted and measured sensor data (GNSS pseudo-range, Tachometer, IMU) after EKF state update
- **Sequences** ➢ capability to detect not only “sudden faults” but also “slowly growing faults”
- Detection thresholds (specific to each sensor) determined from target Pfa (Probability of False Alarm)
- Minimum Detectable Fault magnitude determined from target Pmd (Probability of Misdetection)

- **Faulty Confidence Interval** based on
    - Worst-case slope (gmax) based on EKF matrices, sensors update rate in EKF
    - Minimum Detectable Fault (MDF) based on System FDE Pfa, Pmd, max nb of simultaneous faulty pseudo-ranges
    - EKF state covariance

Performance prediction Improvements of models and Salsa4Rail tool

Confidence Intervals drivers (new items CLUG 2.0)





- GNSS pseudo-range measurements availability
  - Satellites visibility/geometry (number, elevation, dilution of precision)
  - Masking and Data FDE exclusion (depending on environment – Opensky, Suburban, Urban)
  - **GNSS-denied areas (specific CI model)**
- GNSS/SBAS errors and integrity models — EGNOS **DFMC / +PR+PV**
  - GNSS system error models : GPS, Galileo, EGNOS
  - GNSS time correlation model **+ CI algorithm**
  - Local error models (depending on environment - 6 categories)
- Management of SBAS Time-To-Alert: 6 seconds coasting
- IMU, Tachometer and Track Map error models

- Faulty scenarios Confidence Intervals (System data FDE)
- Dual-chain / Single chain
  - Tolerable Hazard Rate (THR) : 10^{-6}/h+ 10^{-3}/h - 10^{-9}/h
  - Shape Map Matching performance model (CI statistics)

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CI performance prediction tool Salsa4Rail (new items CLUG 2.0)

Geographical / time / track direction sampling
Simulation of satellites in train reference frame

↓

Models of masking & exclusion by Data FDE
Available GNSS measurements

↓

Fusion algo, all sensor Error models, Track direction projection (DFMC / +PR+PV EGNOS, Time correlation, Local errors)
Prediction of state covariance

↓

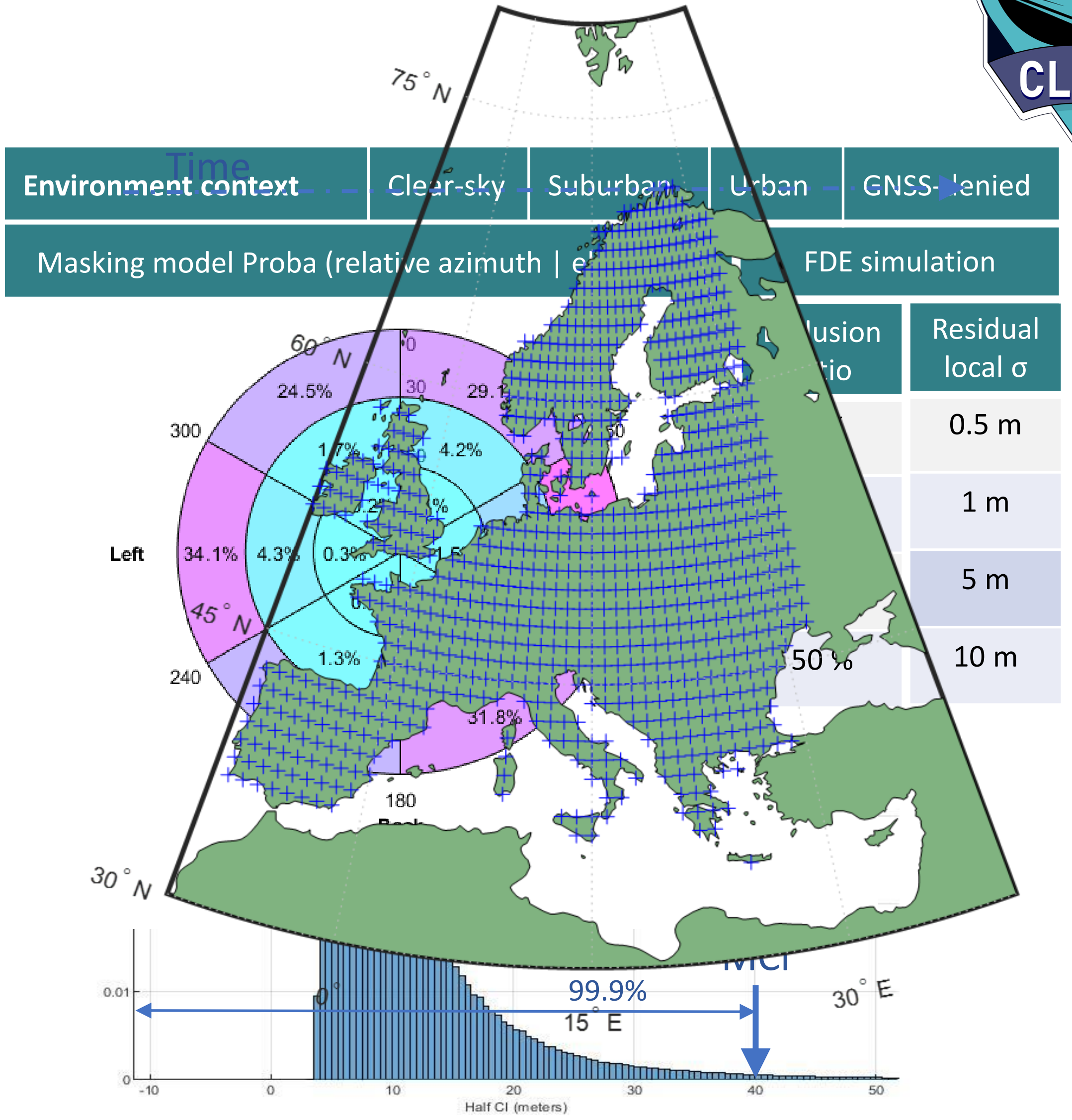
Fault-free + Faulty scenarios (Safety factor IR + System Data FDE)
GNSS-SBAS chain Confidence Interval distributions

↓

Shape-Map-Matching algo + Combiner model
Dual-chain CI distributions

↓

Statistics on CI values for 99%-99.9% availability
Reachable Maximum Confidence Interval



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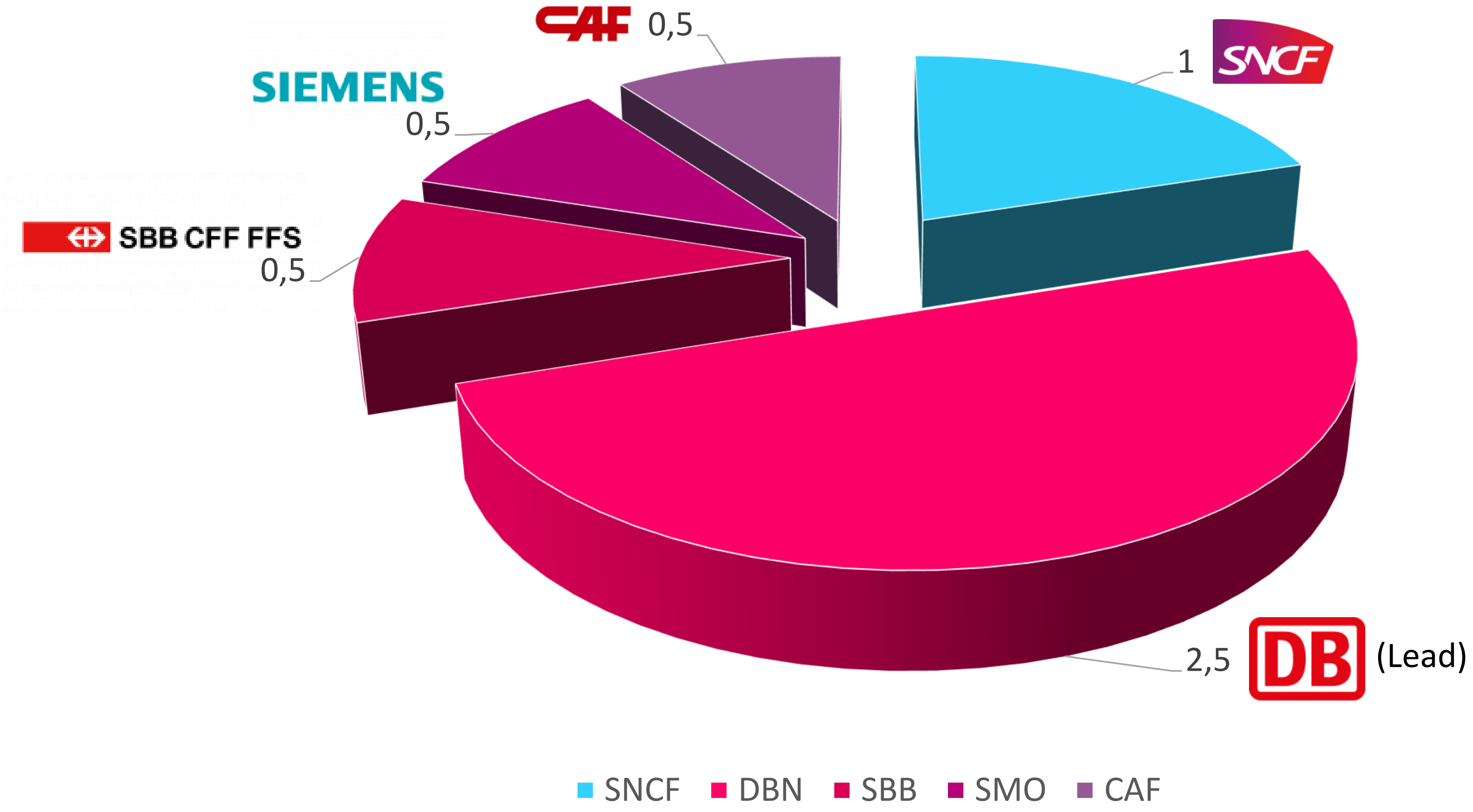
CLUG 2.0 CBA

Eric Ziese – CBA leader (DBN)
Chinenye Azubuike – CBA Deputy (DBN)

Task participants

Duration: 02/2024-03/2025

T6.5 Effort (person months) distribution among partners



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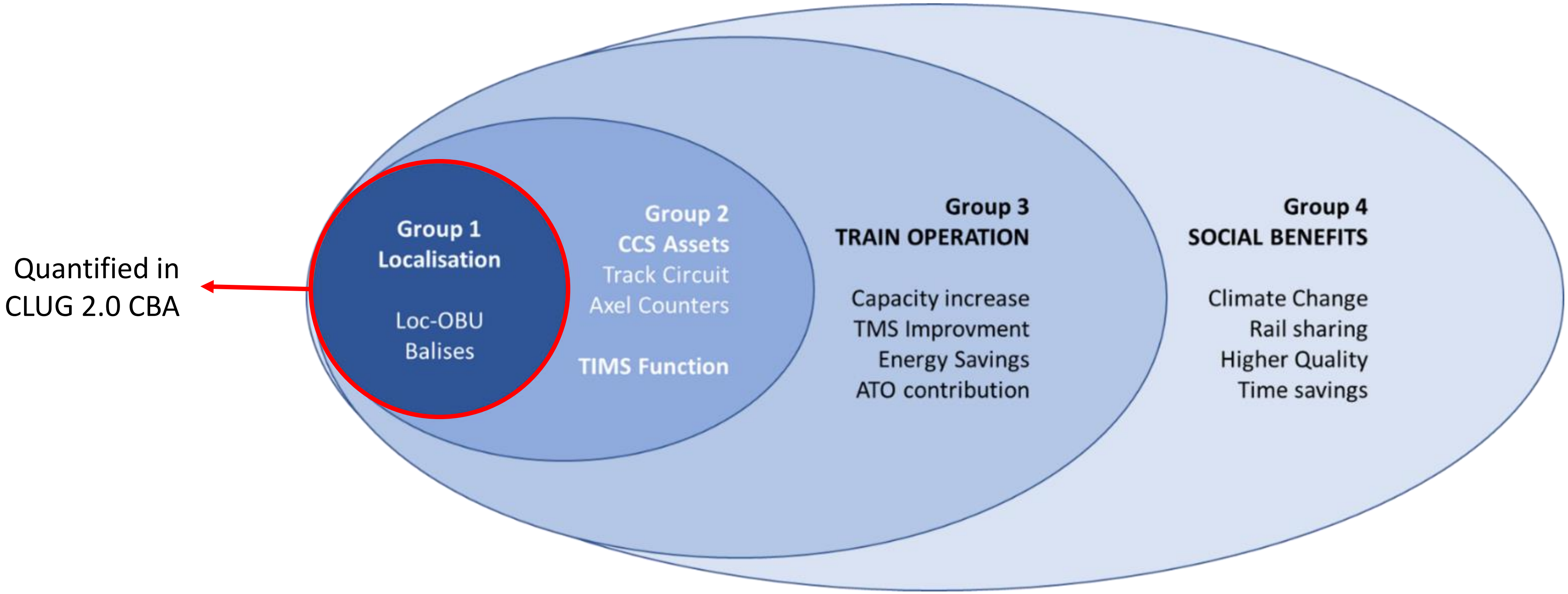
Agenda

CBA scope

- CLUG 2.0 only considers safe localization solution
  →Scope of CBA is limited only to onboard localization, odometry systems & balises



General CBA mechanism

Cost transfer from trackside to onboard

Additional onboard costs

→Equipment of vehicles with LOC-OB, including:
- →Engineering costs
- →Hardware costs
- →Obsoloscence costs
- →Operation & maintenance costs

Reduced trackside costs

→No further requirement of Eurobalises only serving localisation function

→Implementation of reduced Eurobalise layout, leading to lower:
- →Hardware costs
- →Operation & maintenance costs

Profitability of LOC-OB implementation will be achieved if cost savings for reduced Eurobalise requirements outweigh additional costs for vehicle equipment

Considered business cases

	DB	SBB CFF FFS	SNCF
Scope	National	Line	National
Track type	Mixed	Mixed	Mixed
Track usage	Passengers & freight	Passengers & freight	Passengers only

Agenda

General methodological approach

- CBA model generally based on EUG TO CBA but applying more conservative approach & assumptions by:

Inclusion of LOC-OB engineering costs

Inclusion of LOC-OB obsolescence costs

Modelling of transition period from legacy odometry to LOC-OB

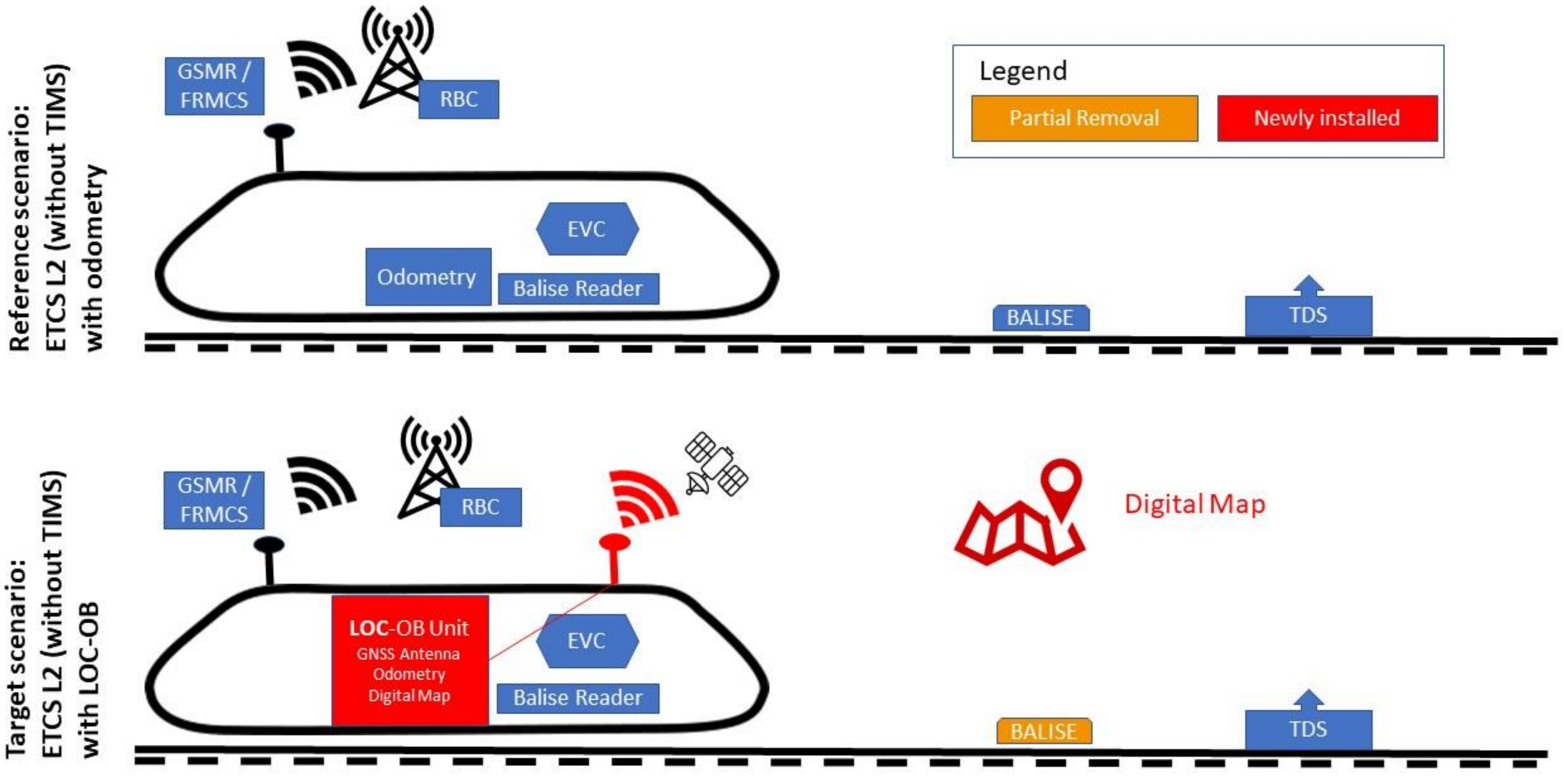
Sensitivity analysis for Eurobalise reduction ratio

Scenario overview

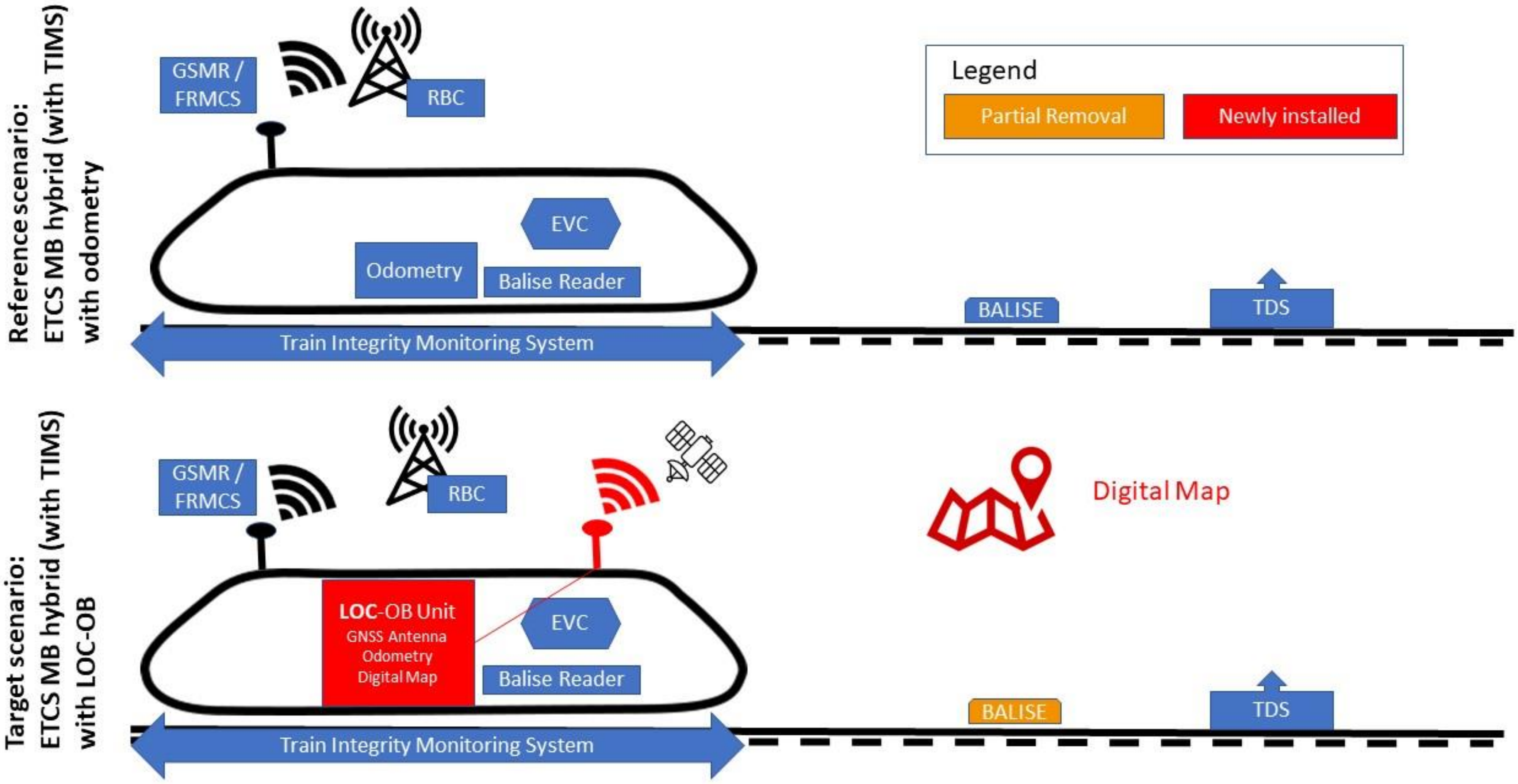
CBA conducts two scenario comparisons:

	Sub-comparison 1 (ETCS L2 fixed block)	**Sub-comparison 2 (ETCS L2 MB hybrid)**
Reference scenarios	ETCS L2 (without TIMS) with odometry	ETCS MB hybrid (with TIMS) with odometry
Target scenarios	ETCS L2 (without TIMS) with LOC-OB	ETCS MB hybrid (with TIMS) with LOC-OB

Sub-comparison 1: ETCS L2 fixed block

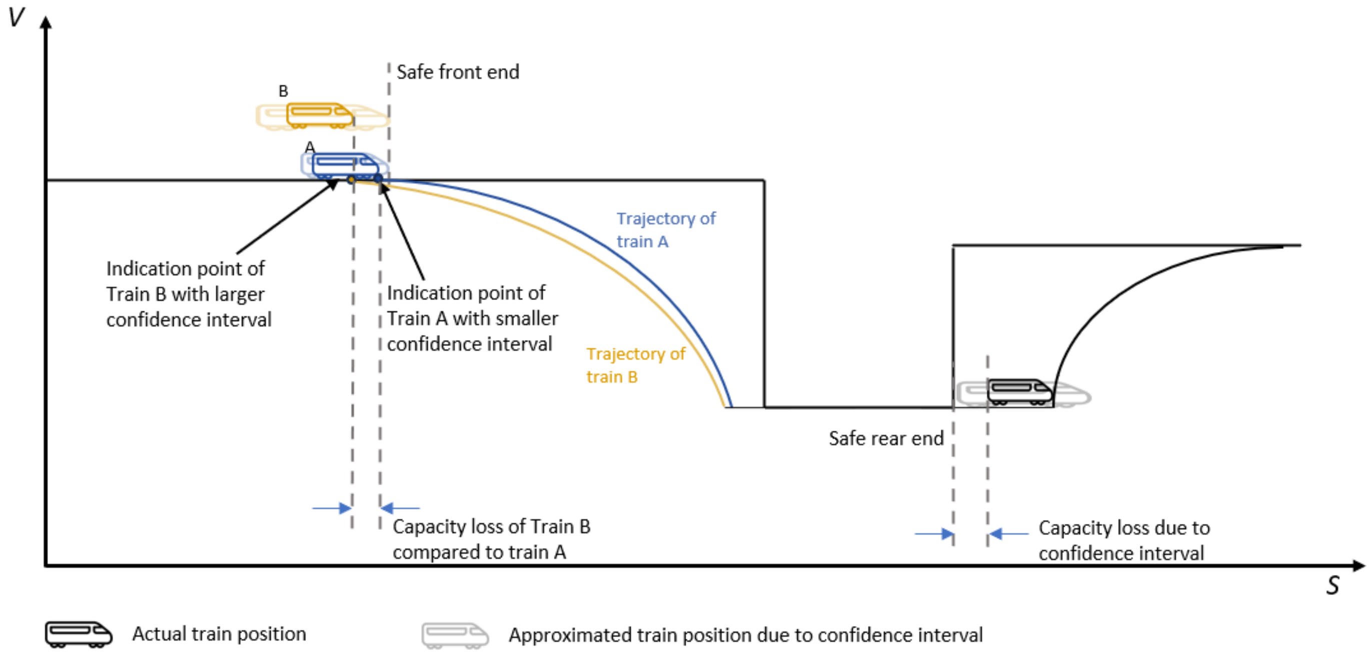


Sub-comparison 2: ETCS L2 moving block hybrid



Reasoning ETCS MB hybrid scenario

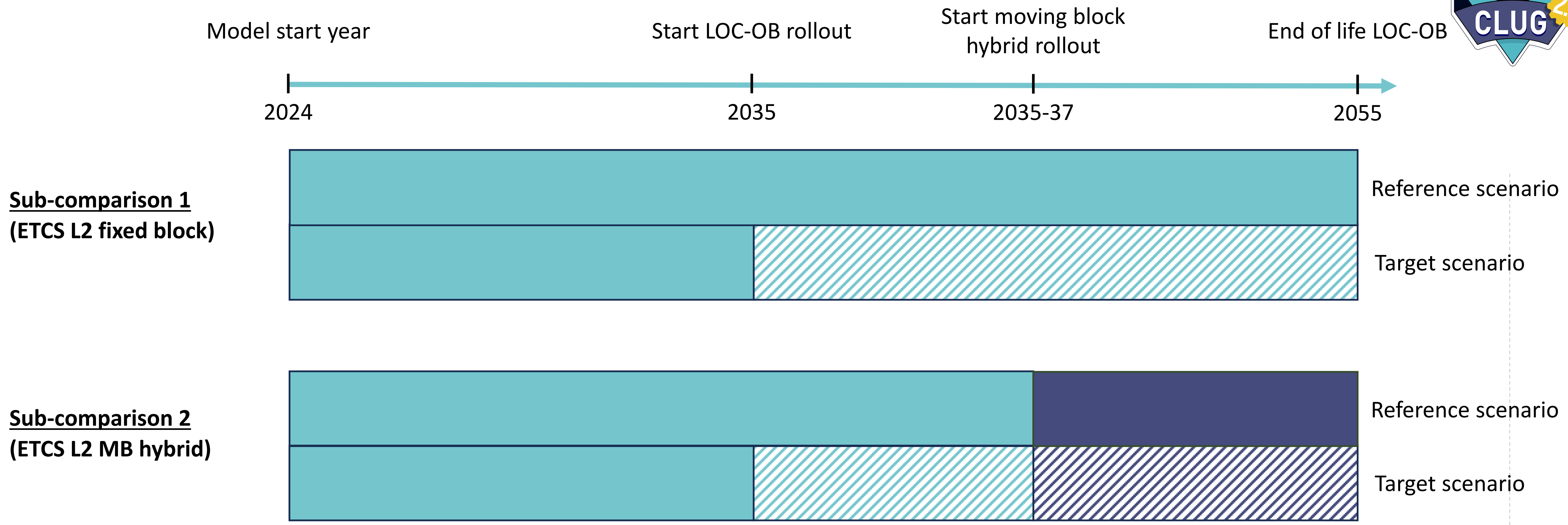
- Evaluation of MB hybrid based on additional potential for Eurobalise reduction



Mechanism:

- Continuous localisation by LOC-OB enables lower average confidence interval
- Lower confidence interval enables better operational performance under moving block hybrid
- To reach same operational performance using legacy odometry, additional balises are required

Scenario sequence modelling



Legend

- ETCS L2 rollout with regular Eurobalise layout
- ETCS MB hybrid rollout with regular Eurobalise layout
- ETCS L2 rollout with reduced Eurobalise layout
- ETCS MB hybrid rollout with reduced Eurobalise layout

CBA model limitations

- Selective vehicle equipment will incur further costs or hinder operational restrictions
- No consideration of equipment costs for new vehicles
- No consideration of costs for EGNOS transmission
- No consideration of balise reduction for existing parts of ETCS track

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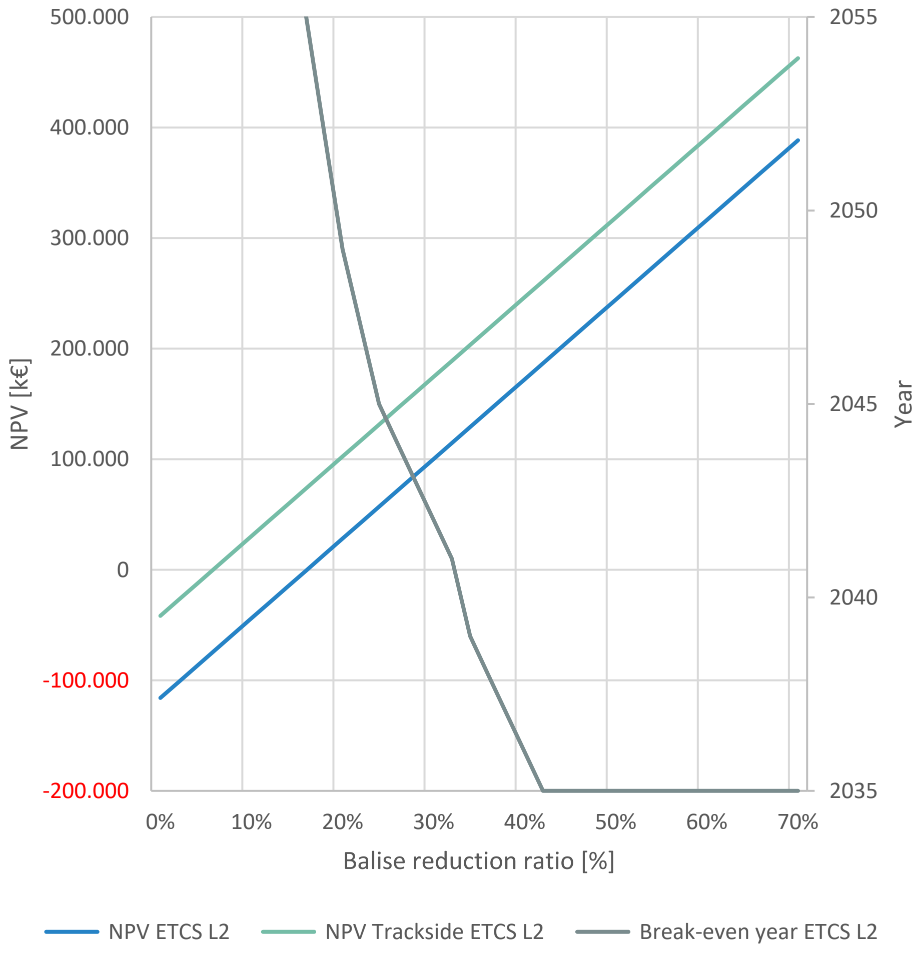
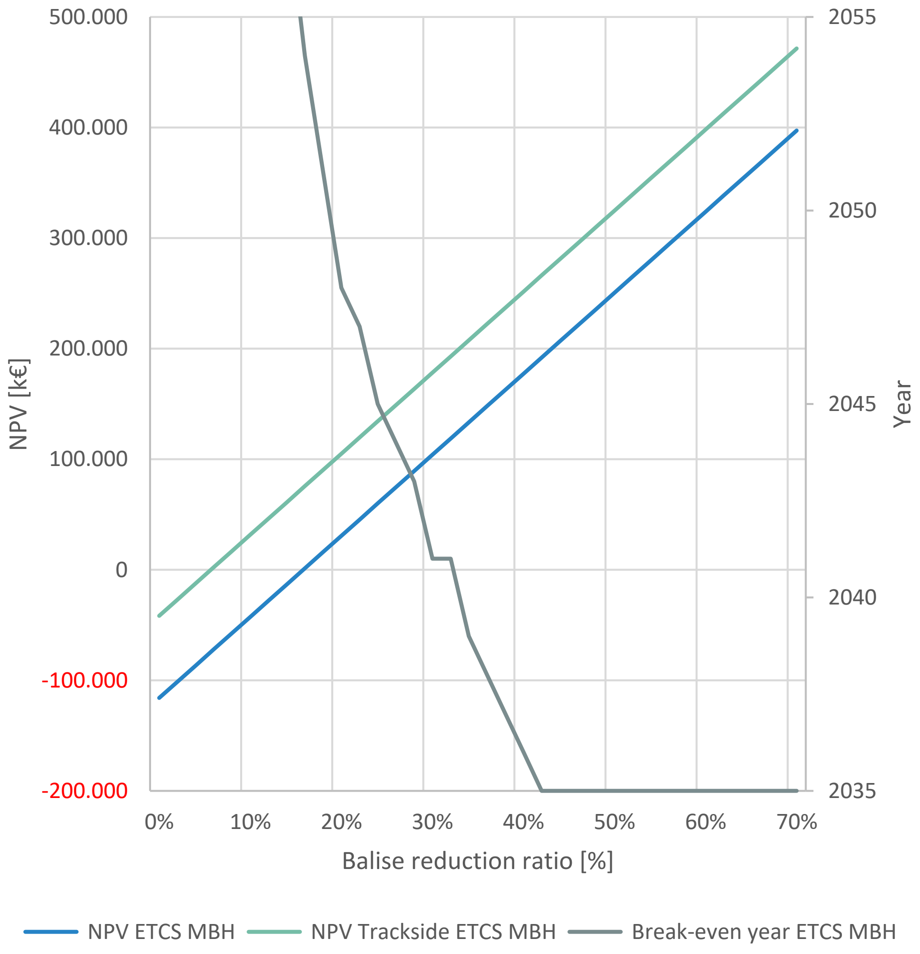
DB: Sensitivity analysis results

Sub-comparison 1: ETCS L2



Sub-comparison 2: ETCS MB hybrid



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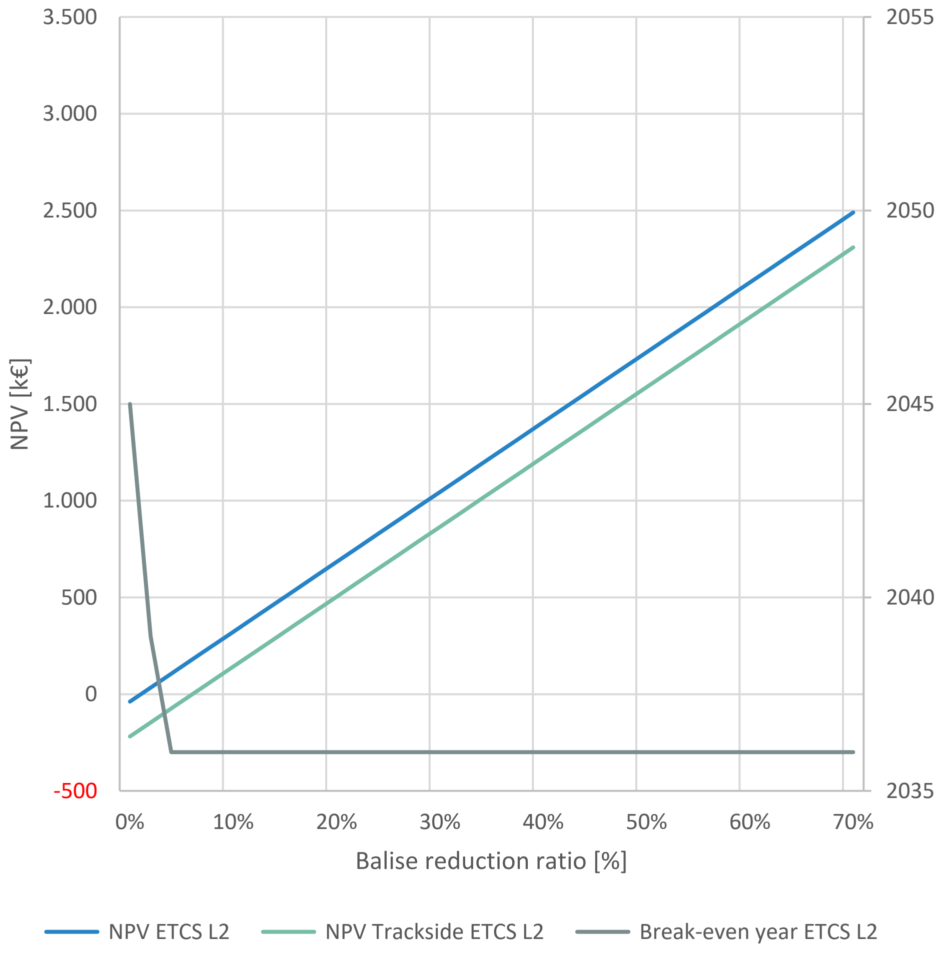
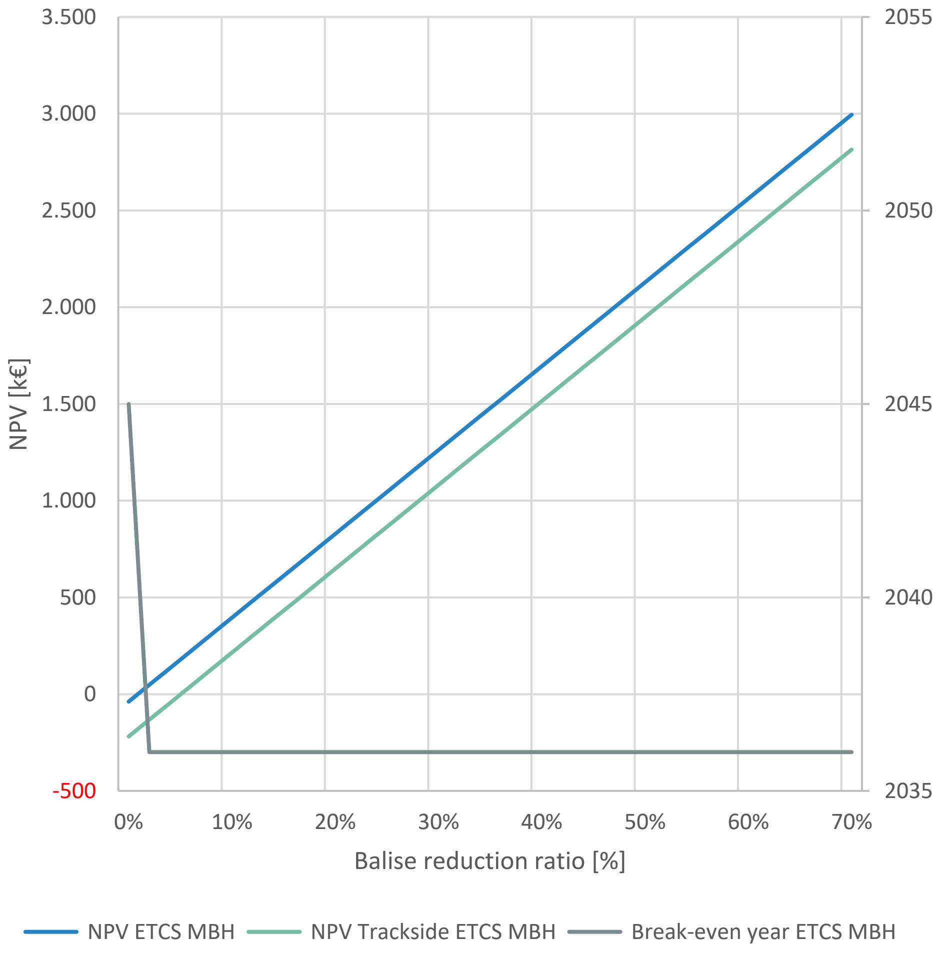
SBB: Sensitivity analysis results

Sub-comparison 1: ETCS L2



Sub-comparison 2: ETCS MB hybrid



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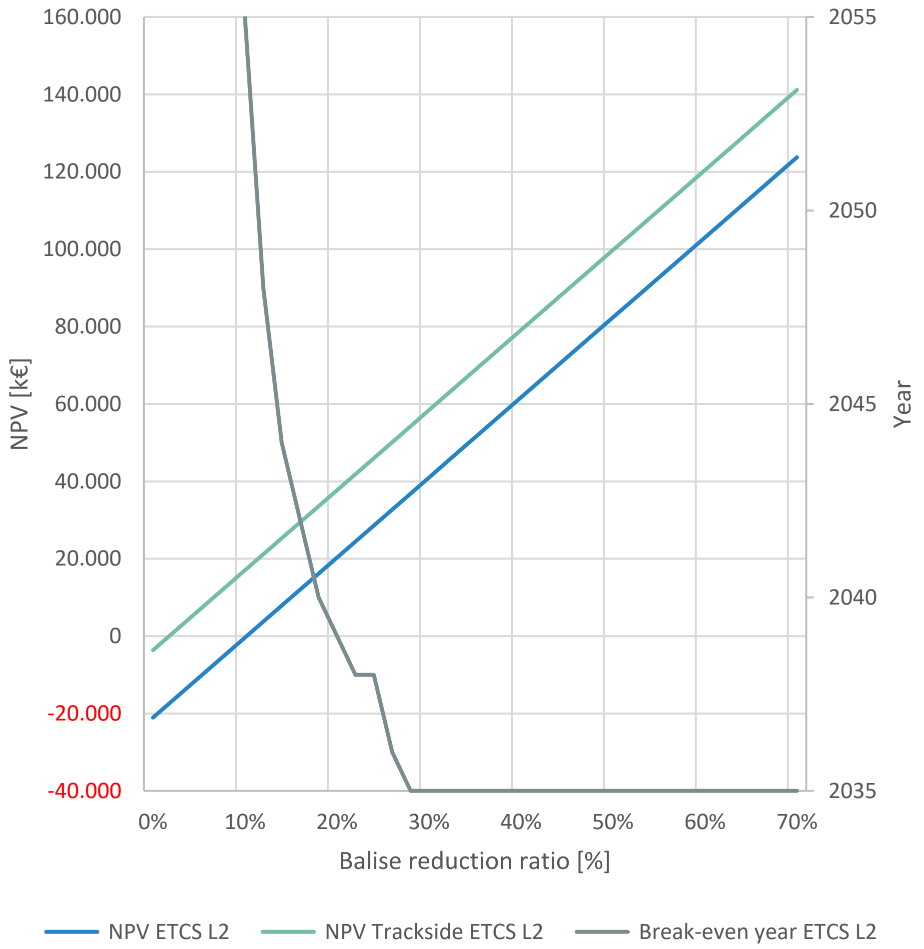
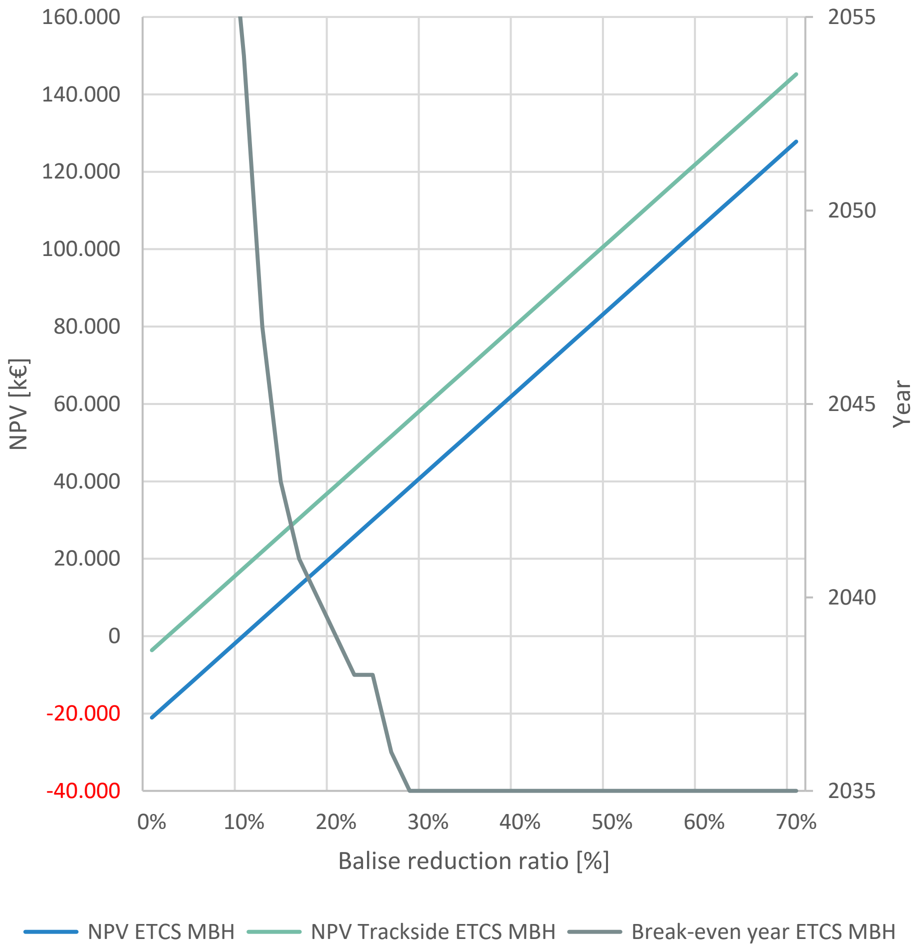
SNCF: Sensitivity analysis results

Sub-comparison 1: ETCS L2



Sub-comparison 2: ETCS MB hybrid



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Main CBA takeaways

- LOC-OB shows potential for profitability even for Eurobalise reduction ratios <50%
- Larger scale implementation yields overall better results
- Delay in LOC-OB availability diminishes benefits as ETCS rollout advances
- LOC-OB implementation results in cost shift from trackside to onboard

CLUG 2.0 GAP ANALYSIS

Adrien Gharios – GAP analysis leader (SNCF)

Reminder of CLUG 2.0 interaction with other ongoing initiatives (definitions alignment)

- System Pillar : train CS domain
  - LOC-OB = Full ASTP.
  - Basic ASTP is not tackled on in the scope of CLUG2.0.

- Innovation pillar : FP2 WP21/WP22
  - LOC-OB = ASTP.
  - Basic ASTP is not tackled on in the scope of WP21/22.

Reminder of CLUG 2.0 Gap Analysis

CLUG2.0 Gap Analysis is divided in three main tasks :

1. Re-evaluation of the system requirements
2. ETCS gap analysis
3. Overall Gap analysis

The results of the CLUG2.0 gap analysis are formalised in D6.6 that will be publicly available soon.

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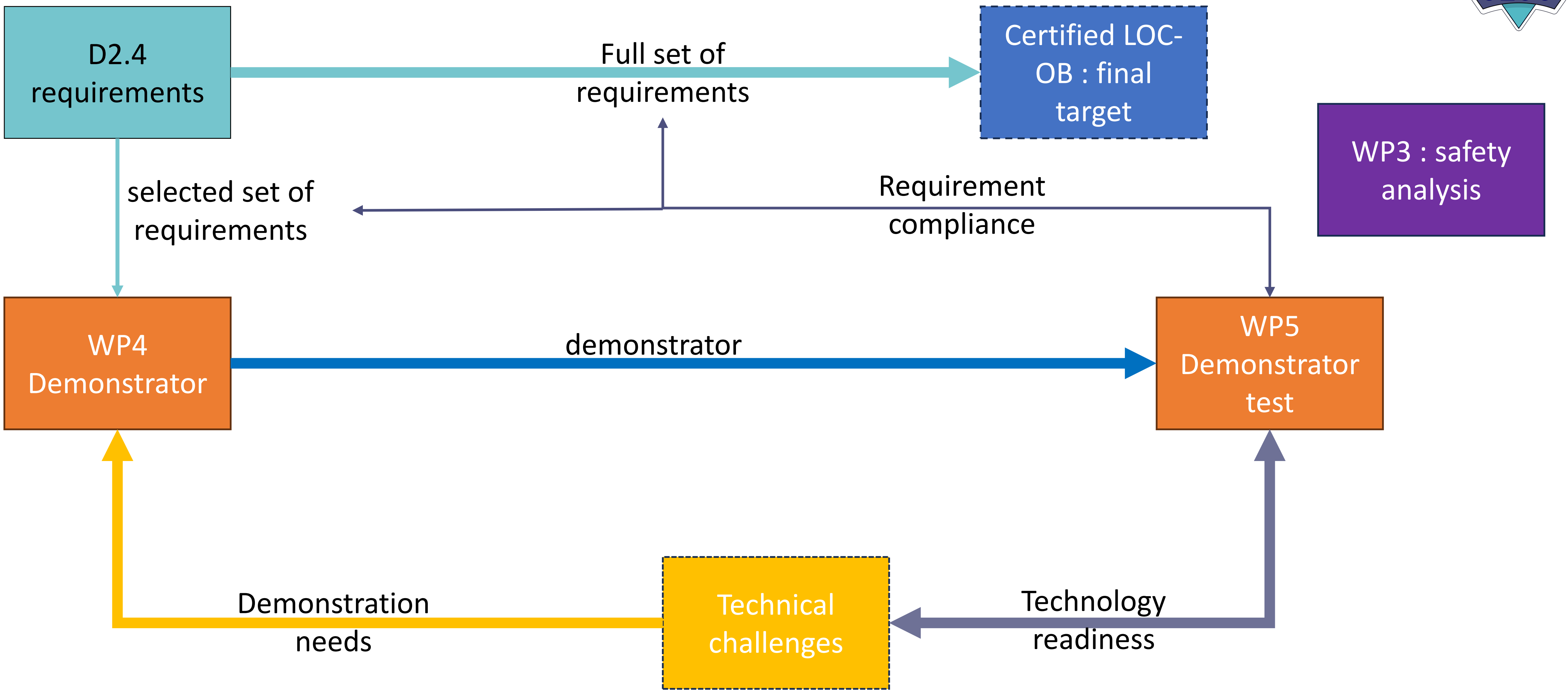
Re-evaluation of the system requirements

Re-valuation of the system requirement : overview



Re-valuation of the system requirement : main facts

- Performance requirements where not consider since test results are not yet available.

- Most of identified discrepancies are related to the unavailability of a CCS onboard architecture and unclear functional allocation between the CCS-Onboard constituents.

- Significant effort is still needed from the sector. Most of the needed clarifications are not purely technical and require the sector to take decisions.

ETCS gap analysis

Reminder of the subsets

Objectives :

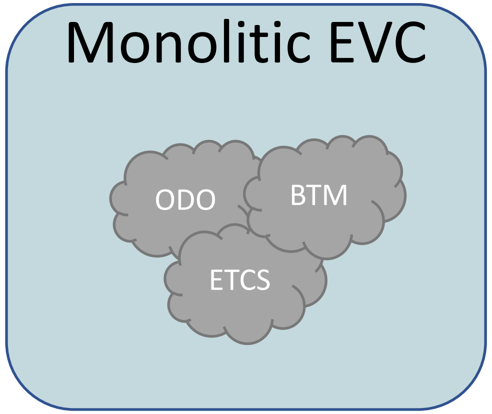
- Interoperability
- European harmonisation
- "High-level" specifications where only the critical points for interoperability are defined

Facts :

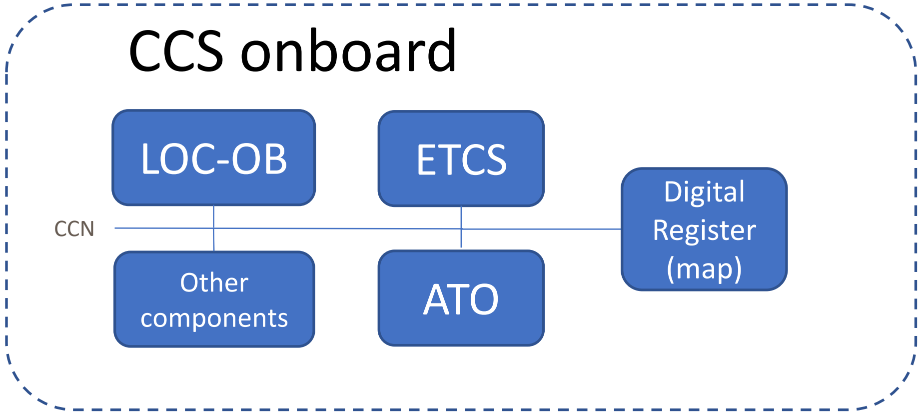
- Interpretability
- Top-down but also bottom-up approach
- ETCS / EVC seen as a monolithic component

Introduction of LOC-OB, main disruptions :
Architecture, functional allocation and interfaces

Today’s architecture
(simplified view)



Future targeted architecture, LOC-OB replacing the odometry constituent



ODO : odometry
BTM : Balise Transmission Module
ETCS : European Train Control System
ATO : Automatic Train Operation
CCS : Control Command and Signalling

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Introduction of LOC-OB, main disruptions :

Architecture, functional allocation and interfaces

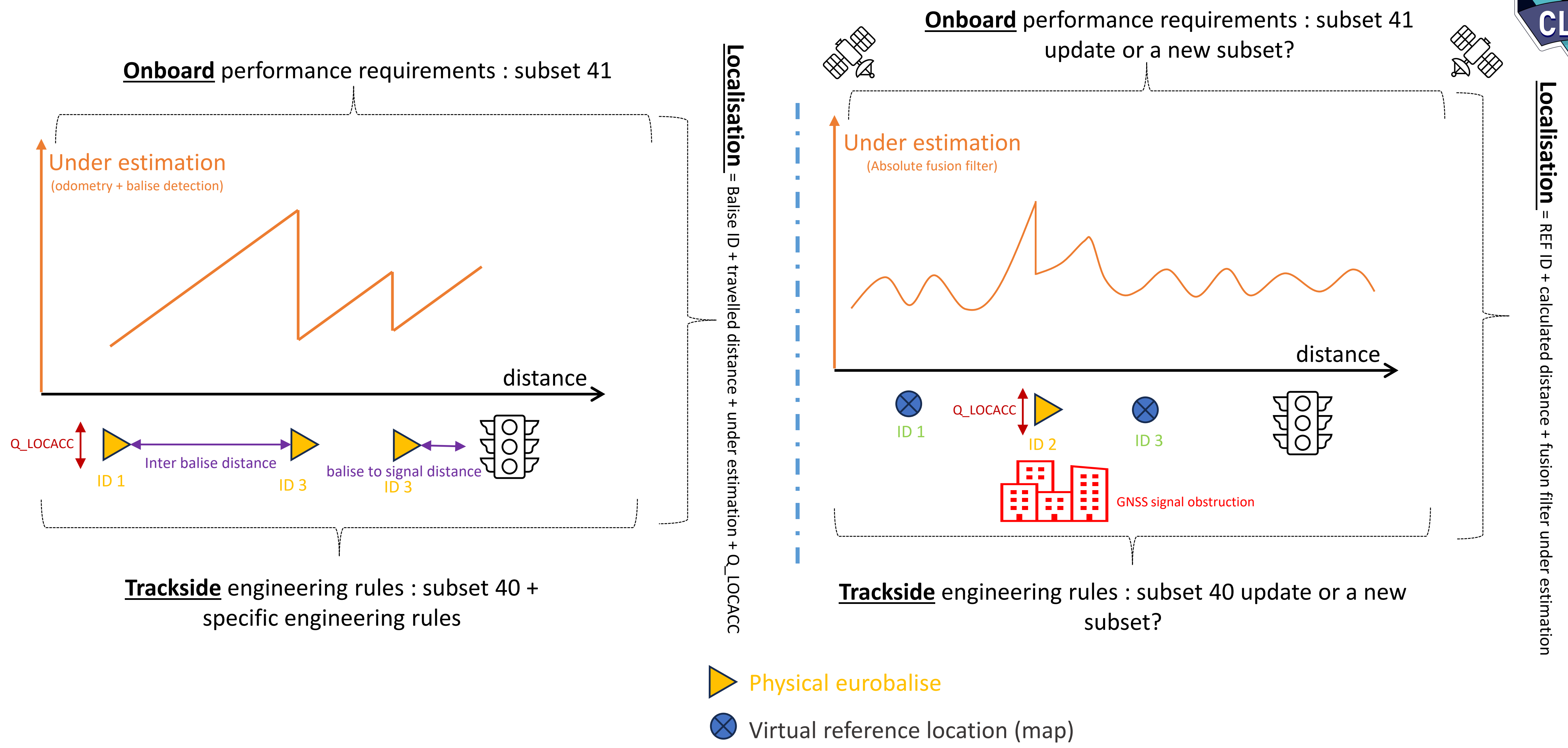
- Agreement on functional allocation (for illustration, which component translate the LOC-OB localisation to the train front end position)

- Definition of standardised interfaces : LOC-OB to users
  - Definition of standardised application data depending on the functions allocated to LOC-OB
  - Definition of the FFFIS

- Definition of standardised interfaces : LOC-OB supporting information
  - Identification of the mandatory supporting information
  - Definition of standardised application data
  - Definition of the FFFIS

Introduction of LOC-OB, main disruptions :

From Odometry / Balise technology to GNSS based technology



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Introduction of LOC-OB, main disruptions :

From Odometry / Balise technology to GNSS based technology

- EUROBALISE concept is a corner stone of ETCS :
  - Can we reduce the number of physical balises without impacting safety and performance?
  - How to handle physical balises and Virtual reference locations in parallel?

- New model of accuracy :
  - What is the real impact on ETCS if over estimation and underestimation is not following the "sawtooth" model?

- Specific exported constraints to trackside :
  - How to handle exported constraints to trackside (tunnels, Multipath areas, etc)?

- What about retro compatibility :
  - LOC-OB onboard on a line without a map?
  - ODO / Balise onboard on a line with reduced number of balises?

Introduction of LOC-OB, main disruptions :

illustration on the subsets impact

SUBSET	Impacted by the LOC-OB introduction
Subset 026: System requirement specification (V4.0.0)	Major impact, general description and mechanisms, modification of the model of accuracy, extension of Balise Group to any type of reference location.
Subset 034: Train interface FIS (V4.0.0)	Introduction of LOC-OB to train interface.
Subset 040: Dimensioning and Engineering rules (V4.0.0)	Major impact related to the balise removal and the introduction of new rules related to areas where GNSS may struggle.
Subset 041: Performance requirements for interoperability (V4.0.0)	Major impact related to the model of accuracy and performances.
Subset 088: ETCS Application Levels 1 & 2 - Safety Analysis (V3.7.0)	Major impact related to the balise removal.
Subset 091: Safety Requirements for the Technical Interoperability of ETCS in Levels 1 & 2 (V4.0.0)	Major impact related to the balise removal.
Subset 119: Train Interface FFFIS (V4.0.0)	Introduction of LOC-OB to train interface.
Subset 125: ERTMS/ATO: System Requirements Specification (V1.0.0)	ATO receive the train localisation through ETCS. The introduction of LOC-OB can impact this principle.

Overall Gap analysis

Overall Gap analysis : main conclusions

- Technology readiness : Positive results from CLUG2.0, TRL still need to be improved to trigger a change request.

- Safety demonstration : No blocking points identified but several demonstrations are still to be consolidated and can be considered as risks.

- Impact on ETCS : Still numerous questions to be tackled. Depending on the sector decision, impacts on the subsets can be consequent.

Follow up activities

- System Pillar Train CS
  - Focus on the introduction of ASTP into the TSI
  - Two step approach
    - Basic ASTP = Enhanced odometry
    - Full ASTP = LOC-OB

- Innovation Pillar R2DATO FP2 (WP21/WP22)
  - Focus on the technology readiness
  - Basic ASTP is not in the scope on the project

THANK YOU

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EUSPA European Union Agency for the Space Programme

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