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Stand Alone Fail-Safe Train Positioning Demonstrator Definitions and Test Scenarios

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1 Executive Summary

In the context of X2RAIL-5 Work Package (WP) 7, a demonstrator for Stand Alone Fail-Safe Train Positioning is planned. In [1] and [2] the system requirements specification (SRS) and the common architecture is defined respectively, which leads to the next step of definition of demonstrator and test scenarios presented in this document.

The objective of this document is to present the demonstrators and the intended operational scenarios under which the system shall work. Consequently, the followed methodology is that each demonstrator has proposed its own solution respecting the architectural interfaces in [2]. As a result, this document describes the common view of all demonstrators and a common agreed file formatting for all demonstrators' data presentation. This allows developing common tools for data visualisation and evaluation purposes. In addition, a full section on desired operational scenarios is described which should be used as a reference for demonstrators, although the authors are aware that not all of them may be covered by the demonstrators.

In conclusion, the document is a description of the intention of work to be done by each demonstrator in response to the SRS and architectural definition.

2 Table of Contents

2.1 Table of Figures

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3 Abbreviations and acronyms

Abbreviation / Acronyms	Description
Acc	Accelerometers
AO	Algorithm Output
Absolute Position	Absolute position refers to a position that defines the train location unambiguously. For instance, an absolute position can be given by WGS84 coordinates but it can also be given by a track identifier and the travelled distance from a reference point within a specific track.
ASSx	Assumption
CLUG	Certifiable Localisation Unit with GNSS in the railway environment
CMD	Cold Movement Detector
Confidence Interval	It refers to a range of values so defined that there is a specified probability that the value of a parameter lies within it.
DFMC	Dual Frequency Multi Constellation
DOF	Degree Of Freedom
ECEF	Earth Centred Earth Fixed
EDAS	EGNOS Data Access Service
EKF	Extended Kalman Filter
E_ODO_TS	Enhanced ODOmetry Track Side.
E_ODO_OB	Enhanced ODOmetry On-board.
ESSP	EGNOS Satellite Service Provider
ETCS-OB	European Train Control System - On-board
FIx	Functional Input x
Fox	Functional Output
FSTP	Fail Safe Train Positioning
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GT	Ground Truth
Gyro	Gyroscope
ID	Identifier
IGS	International GNSS Service
IMU	Inertial Measurement Unit
INS	Inertial Navigation System
ITRF	International Terrestrial Reference System and Frame
LiDAR	light detection and ranging
LRBG	Last Relevant Balise Group
MEMS	Micro Electro Mechanical System
NA	Not Available
NGTC	Next Generation Train Control
OBU	On Board Unit
OPG	Odometer Pulse Generator (with wheel turning direction)
OSM	OpenStreetMap, the free wiki world map
PERFx	Performance x
POI	Point of Interest
PVT	Position Velocity and Time

RTK	Realtime Kinematic (with GNSS Carrier Phase Ambiguity Solution)
segment_id	For 1D-positioning got from digital map. In CLUG also referred as TrackEdgeId.
SBB	Schweizerische Bundesbahnen, swiss rail operator
SFA	Sensor Fusion Algorithm (TD and SNCF term) as being a function of the Safe Fusion Algorithm
SFA	Safe Fusion Algorithm
SFTP	Stand-Alone Fail Safe Train Positioning System
SiS	Signal in Space
spoke	edge (representation of a track segment in digital map)
SRS	System Requirement Specification
STARS	Satellite Technology For Advanced Railway Signalling
Train Consist	a set of vehicles comprising cabs and other attached vehicles that define the complete train length.
UTC	Coordinated Universal Time
WAS	Wheel Angular Speed
WIG	Wheel Impulse Generator
WGS84	World Geodetic System 1984
WP	Work Package

4 Background

The present document constitutes WP7's Deliverable D7.2 "Stand Alone Fail-Safe Train Positioning Demonstrator Definitions and Test Scenarios". The Deliverable is part of the framework of the Project titled "Completion of activities for Adaptable Communication, Moving Block, Fail safe Train Localisation (including satellite), Zero on site Testing, Formal Methods and Cyber Security"(Project Acronym: X2Rail-5; Grant Agreement No 101014520). The document is enclosed in the frame of stand-alone positioning demonstrator description where previous work from NGTC [17] and STARS [18] projects lead to a dedicated work package in X2Rail-2, namely WP3. This WP3 is where the system requirement specification (SRS) [1] and architecture interfaces [2] were defined and they are the main inputs to this work.

5 Objective / Aim

The objective of this document is to present the framework upon which the demonstrators for a fail-safe train positioning system are going to be carried out. The document first provides an overview of the System Requirement Specification (SRS) which is used as a reference for interface and sensor scope definition within each demonstrator. The document continues with a description of the demonstrator where two main sections can be distinguished. The former section focuses on demonstrators' description whereas the latter focuses in defining the required standardised interface to be able to assess and compare demonstrators.

In section 8 operational test scenarios are described. The section also identifies potential test case scenarios that could be completed within the frame of this work package. Finally, the document ends with a conclusion section.

6 Overview of the System Requirement Specification

In the next subsections a summary of the System Requirement Specification [1] and architecture proposal [2] is presented. Note that the objective is to facilitate the reader in gaining a snapshot of the current proposal. Nevertheless, as this is the description of the current status, it has by no means the intention to be the final Fail-Safe Train Positioning (FSTP) and further evolution of the proposal shall be expected.

6.1.1 Description of the function

Fail-Safe Train Position in X2Rail-2 WP3 Stream 2 is aimed to provide an absolute train position, a longitudinal speed and a relative distance from a reference point to the front of the active cab of the On-Board Unit (OBU) including the confidence interval for each value".

The FSTP shall use multiple sensors and multiple information units to perform its functions. In Figure 6-1, a proposal of the functional architecture of FSTP is depicted. The FSTP core functions run within the Enhanced ODOmetry of the On-Board Unit, named E_ODO-OB. On the left side, pure sensor information is shown, where the GNSS refers to GNSS raw information, Accelerometer refers to acceleration measurement units, Gyroscopes refer to the angular rate measurement unit and wheel angular speed sensor refer to the angular speed measurement unit converted to longitudinal speed. These sensors are combined in the Safe Fusion Algorithm (SFA) which is responsible to provide the absolute train position, relative distance from a reference point and longitudinal speed values to the ETCS-OB and/or the E_ODO-TS, named after the Enhanced ODOmetry Track Side.

E_ODO-TS is the entity in the track side, responsible for providing additional information to the E_ODO-OB. It is currently a separate entity from ETCS-TS but it could interface with ETCS-TS to re-use existing communication channels (see [2] for further details). The main duty of the E_ODO-TS is to provide the digital map to the E_ODO-OB which includes functions to perform version control, map updates and ensuring integrity in the exchanged information. Due to the complexity associated with the digital map update mechanism, E_ODO-OB has a dedicated entity named "Data Client Manager" to handle the protocol with the E_ODO-TS. Another optional duty that the E_ODO-TS may have is to be responsible to forward GNSS augmentation information to the E_ODO-OB if necessary. In addition, as E_ODO-TS is a separate entity, it is foreseen that E_ODO-OB should report its position periodically to E_ODO-TS.

On the right-hand side of Figure 6-1, the interaction of E_ODO-OB and ETCS-OB is illustrated. On one hand, as input to the E_ODO-OB, active cab and the train length is required by the SFA to provide the position of the train front end. In addition, there is information from ETCS-OB that may be helpful to the SFA. This information is mainly Cold Movement Detection (CMD) and Balise Data information. The former, allows the SFA to maximise its availability at first cold start-up, since the last known position can be valid even in harsh environment such as places with no GNSS coverage or strong signal distortion places such as stations. The latter offers the SFA the opportunity to compute track discriminative function as long as this balise information is also contained in the digital map. On the other hand, as output of the E_ODO-OB, the SFA offers absolute position referenced to a known global coordinate system such as WGS84 or position referenced to a reference point (e.g. a point from the digital map or the LRBG provided by the ETCS-OB) and speed information including confidence intervals for these values.

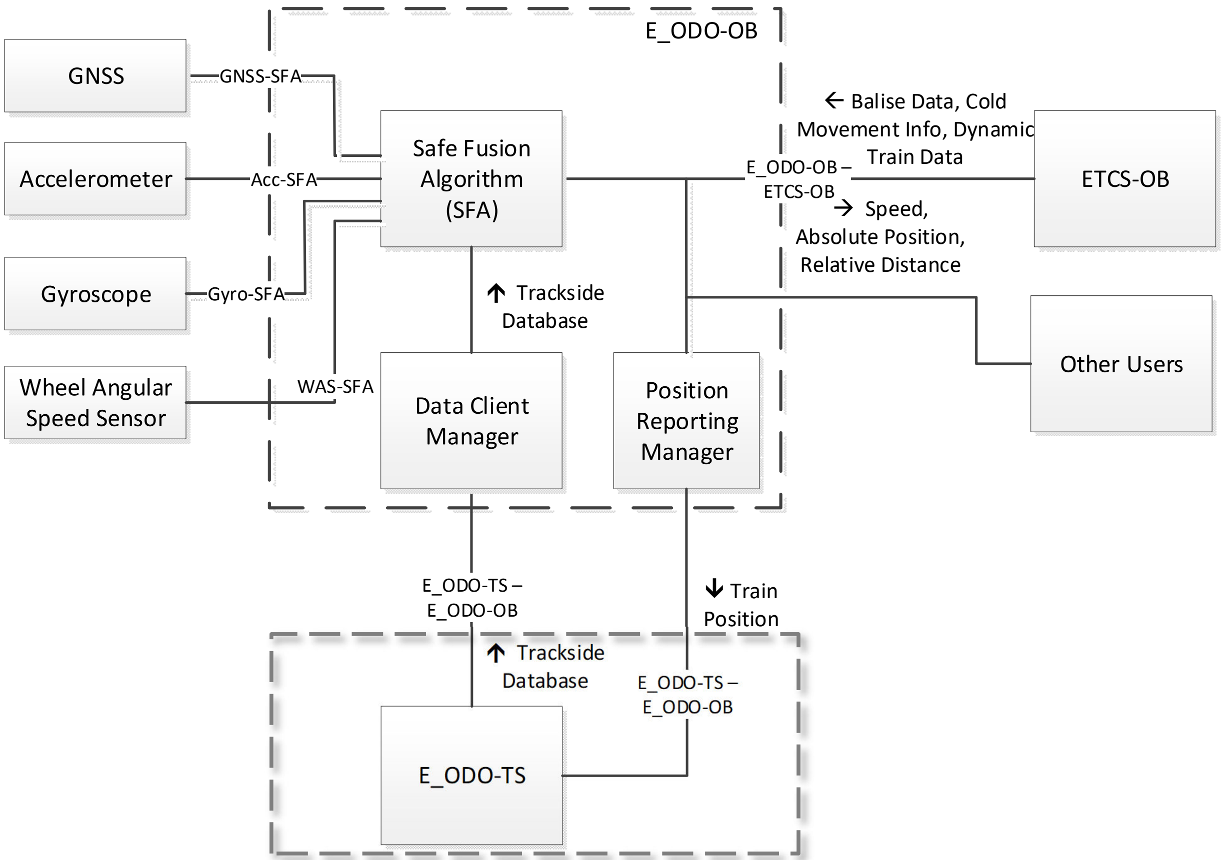

Figure 6-1 Functional Architecture of the FSTP

In the current ETCS-OB specification, the only information from E_ODO-OB that could be integrated without further modification are the travelled distance information, and/or distance from the LRBG of the train front end and the train speed. Any other information such as absolute position - if to be used by ETCS-OB will need a thorough investigation with regard to integration. Nevertheless, if the travelled distance error margin is below the current engineering rule of 5m +5% or it could be set to a constant value up to a certain speed it could potentially provide benefits to the existing subsystem.

This has been the target for STREAM2 as defined in its system requirement specification [1]. The two main requirements from that document are quoted here:

- *[1] SRS 7.1.7 –" Fail-safe train positioning shall calculate train's front position with a maximum confidence interval of +/-10 meters within speed intervals from zero to 40km/h, 40km/h included.*

For speeds greater than 40km/h and lower or equal to 500 km/h the confidence interval shall be equivalent to a distance run in one second"

- *[1] SRS 7.1.11 – "Fail-safe train positioning shall provide the confidence interval to the train's speed. Fail safe train positioning shall calculate train's speed with a maximum confidence interval of +/-2km/h for speed lower than 30km/h, and then increasing linearly up to 12km/h at 500km/h"*

By looking at the proposed architecture, the following functions are expected to be present in FSTP with a tolerable hazard rate equivalent to a SIL4 functionality:

- FN1: FSTP shall locate the train in the correct track, guaranteeing track discrimination.
- FN2: FSTP shall calculate the travelled distance from a reference point, with a confidence interval defined SRS 7.1.7 [1].
- FN3: FSTP shall calculate the speed along the track of the front of the active cab, with a confidence interval defined SRS 7.1.11 [1].

It is important to remark that WP7 is only targeting the demonstrator of the SFA functional block in order to study the feasibility of the provided solutions in real environment. As such, other functionalities expected from the FSTP are subject to further evolution.

6.1.2 Functional Inputs

To perform the FSTP Stream 2 function, the following inputs shall be provided. Some may be optional, which means if used, reliability and overall performance may be improved but they are not necessary to reach the required safety level. Mandatory interfaces are required by the system to reach the required safety level and to cover the requirements. Finally, it is important to note that this is an architecture for feasibility study and conclusion from the study may lead to a change on interface definition. This feature, optional or not, is addressed for each interface. Notice that the FSTP is based on E_ODO-OB and E_ODO-TS and the interfaces between them are of interest of the partners. As such the functional inputs for each of these entities are described separately.

6.1.2.1 Functional Inputs to the E_ODO-OB sorted by Interfaces:

- FI 1 GNSS-SFA [MANDATORY]: GNSS Raw data.
  - The source of this information is an integrated sensor.
- FI 2 Acc-SFA, Gyro-SFA [MANDATORY]: 6 DOF IMU sensor providing 3 accelerometers and 3 gyroscopes information
  - The source of this information is an integrated sensor.
- FI 3 WAS-SFA [MANDATORY]: Wheel angular speed sensor or tachometers.
  - The source of this information is an integrated sensor.
- FI 4 [OPTIONAL]: Other speed sensors based on Radars or Optical technology are additionally possible but not considered as primary options.

  - The source of this information is an integrated sensor.
- FI 5 [MANDATORY]: Track Side Database. The data base shall include absolute position profile. OPTIONALLY, it could contain curvature, gradient and cant profiles.
  - The source of this information is E_ODO-TS (see 6.1.2.2 for further details).
- FI 6 [OPTIONAL]: GNSS augmentation information including integrity parameters.
  - The source of this information is E_ODO-TS (see 6.1.2.2 for further details).
- FI 7 E_ODO-OB – ETCS-OB [MANDATORY]: Train Dynamic information including active cab and train length.
  - The source of this information is the current ETCS-OB.
- FI 8 [OPTIONAL]: Cold Movement Detection information.
  - The source of this information is the current ETCS-OB. If available, the FSTP availability could be increased.
- FI 9 [OPTIONAL]: Balise Data information.
  - The source of this information is the current ETCS-OB. The balise data itself is only valuable, if the digital map includes the balise information, so that track discrimination can be guaranteed.

6.1.2.2 Functional Inputs to the E_ODO-TS:

- FI 10 [MANDATORY]: Track Side Database. The data base shall include absolute position profile and shall ensure a safety integrity level.
  Optionally, it could contain curvature, gradient and cant profiles.
  - The source of this information is an external entity to be defined. It is not clarified whether E_ODO-TS is responsible to provide the safe digital map or this is given by this external entity.
- FI 11 [OPTIONAL]: GNSS augmentation information including integrity parameters.
  - The source of this information is to be defined. On one hand, there is an option where an external entity such as the ESSP (EGNOS Satellite Service Provider) is able to forward the GNSS augmentation information either as it is today or with a dedicated railway implementation. On the other hand, augmentation information may be generated by the E_ODO-TS itself as specified in proposals [3] and [4].
- FI 12 [OPTIONAL]: Train position report. The on-board unit could directly report its position to track side, this could either be done by existing ETCS interface to track side or optionally using the same communication link as the one used to download the data base.

6.1.3 Functional Outputs

6.1.3.1 Functional Outputs of the E_ODO-OB:

- FO1 [MANDATORY]: Train absolute position: The absolute position of the front of the train along the track together with its confidence interval. This value can either be given with a global reference system (2D or 3D) or by referring to a given reference point (e.g. a point from the digital map or the LRBG provided by the ETCS-OB) plus the travelled distance along this reference point (1D).

- FO2 [MANDATORY]: Longitudinal Train Speed: The 1D train speed of the front of the train including its confidence interval.
- FO3 [MANDATORY]: Relative Distance: train travelled distance and its confidence interval since switch on (unknown absolute starting point).

6.1.3.2 Functional Outputs of the E_ODO-TS:

- FO 4 [MANDATORY]: Track Side Database. The data base shall include absolute position profile. Optionally, it could contain curvature, gradient and cant profiles.
- FO 5 [OPTIONAL]: GNSS augmentation information including integrity parameters
    - (see FI11 in 6.1.2.2 for further details).

6.1.4 Assumptions

The list of assumptions related to the FSTP have been divided into two main lists. The former is referred as the list of assumptions to implement the proposed FSTP for Stream2. The second one, is the list of assumptions made for the performance requirements by the FSTP mission.

6.1.4.1 Assumptions to implement Stream2:

The following list of preliminary assumptions is collected from a top-down approach. Whenever the demonstrators are finished, further assumptions may need to be considered:

- ASS1: The line under which the FSTP shall run, needs to have GNSS coverage. The limitation of the GNSS coverage is not defined and the impact at which stages this coverage needs to be present, during Start of Mission for instance, is to be defined too.
- ASS2: All inputs and outputs are expected to be timestamped to avoid inaccuracies.
- ASS3: The line needs to be digitised and frequently updated. It is assumed that the digital map is always up to date and correct at E_ODO-OB. It is expected that the digital map represents the current track with high resolution and completeness. If balises are present, they need to be located too in the digital map.
- ASS4: The communication between the E_ODO-TS and E_ODO-OB is expected to be as safe as required by the FSTP safety analysis.

6.1.4.2 Assumptions of the performance requirements

- PERF1: It is assumed that the FSTP needs to be available under large periods of absence of GNSS signal.
- PERF2: It is assumed that the FSTP needs to perform adequately under harsh environmental situations including heavy snow, rain, leaves, dust or fog.

- PERF3: It is assumed that the FSTP needs to perform adequately under harsh electromagnetic interferences for RF signal with strong multipath, spoofing and jamming scenarios (for GNSS and TS communication frequency bands).
- PERF4: It is assumed that the FSTP is able to perform safe track discrimination.
- PERF5: It is assumed that the FSTP is able to perform position a train, once the track discrimination function determines the track in which the train is at.
- PERF5: It is assumed that if the FSTP is powered from cold start on a track, is able to keep track continuously of its position unless the system is powered off and the train is moved while switched off.

7 Description of the Demonstrators

7.1 Introduction

In the context of WP7, there are four demonstrators carried out by CAF, SMO, SNCF-R and TD. Although all demonstrators have in mind the SRS definition, all have its own particularities and details to solve the problem. This section is intended to describe all these demonstrators in a readable manner without entering specific details.

7.2 Common view on all demonstrators

All WP7 demonstrators focus on the on-board functions of the Stand-Alone Fail-Safe Train Positioning System (FSTP). In Figure 7-1 the functions to be demonstrated in separate projects are highlighted in blue. At this high-level description, it is only one box representing the Safe Fusion Algorithm. The demonstrators may prefer different sensor sets as input for the SFA. Figure 7-1 shows a collection of suitable sensors on the left part of the figure.

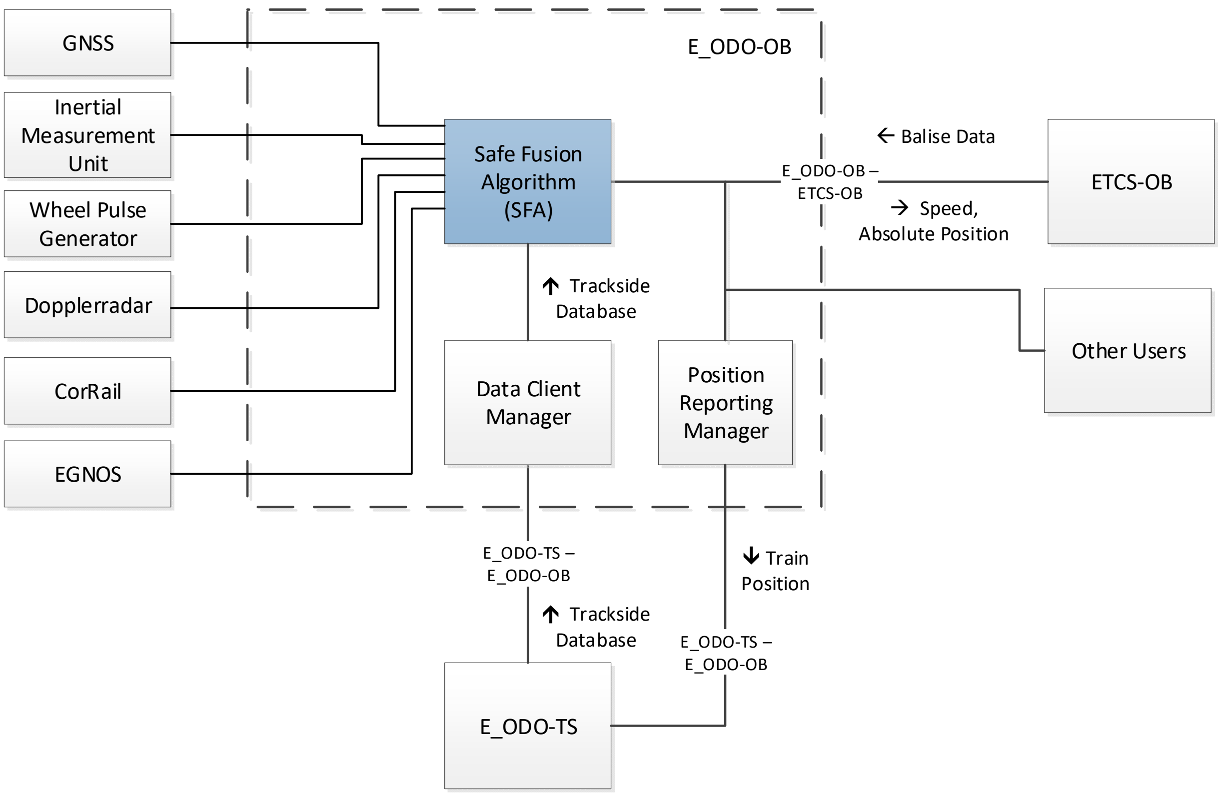

Figure 7-1 Demonstrator Scope within On-Board Architecture for E_ODO-OB

The Inertial Measurement Unit (IMU) can include accelerometer and gyroscope in one to 3 spatial axes. A minimum IMU is just one accelerometer in the longitudinal body axis of the train.

7.2.1 Overview of the sensors usage in the demonstrators

The following table lists the sensors according to their measured physical value and their contribution in each of the demonstrators identified by responsible company short name (CAF, SMO, SNCF, Thales Deutschland).

Sensor classification	physical measurement principle	Product / Manufacturer	CAF,SMO,SNCF,TD
absolute position			
	GNSS Ranging	GNSS Receiver Septentrio / uBlox	CAF, SMO, SNCF, TD
	GNSS Ranging with RTK		--, SMO, --, --
	Dual Frequency GNSS Receiver	Septentrio / uBlox	CAF, SMO, SNCF, TD
	Eurobalise (RF beacon) with location in Map database		CAF*, SMO, --, TD
Augmentation information	network of Reference Stations generates differential corrections		
	EGNOS SiS	EGNOS SiS	CAF, SMO, --, TD
	EDAS web service via mobile radio	EGNOS radio	--, SMO, --, --
	EGNOS v3 DFMC emulation offline processing	Airbus Défense and Space	-- , -- , SNCF, --
Distance			
	Wheel (im)pulse Generator, Tachometer, OPG, wheel speed sensor	Hasler, Optek, Lenord&Bauer	CAF, SMO, SNCF, TD
Speed			
	Doppler radar	Deuta	--, SMO, --, TD
	optical correlation	CorRail	--, SMO, --, --

Sensor classification	physical measurement principle	Product / Manufacturer	CAF,SMO,SNCF,TD
	Wheel impulse Generator (WIG, OPG, wheel odometer, tachometer)	Optek,Faiveley, Lenord&Bauer	CAF, SMO, SNCF, TD
Heading			
	Yaw rate integrated, digital map	IMU: Analog Devices , SBG Ekinox, iXblue Atlans, TDK,	CAF, SMO, SNCF, TD
	magnetic field	IMU, compass	--, --, --, TD
	Dual Antenna GNSS heading (v=0)	uBlox ZED_F9	--, SMO, --, --
Driving direction	nominal / reverse by pulse phase relation of WIG, OPG outputs, radar, orientation / active cab, direction	Lenord&Bauer, Hasler	CAF, SMO, --, TD
Acceleration			
	along track acceleration	1D-accelerometer	--, --, --, --
	3 axes MEMS integrated in IMU	IMU	CAF, SMO, SNCF, TD
turn rate	gyroscope MEMS	IMU	CAF, SMO, SNCF, TD
cold movement supervision	wheel turning detector, changed position in CMD	CMD	CAF, --, SNCF, --
Antennas	radio frequency reception		
GNSS	L1, L5 circular polarisation	Antonics, Trimble, Huber&Suhner	CAF, SMO, SNCF, TD
(Euro) Radio	GSM-R, LTE	Huber&Suhner	CAF, SMO, SNCF, TD

***CAF may use Eurobalise or equivalent balises for first reference point with track discrimination.**

Table 7-1 Sensor Classification

A description of the dedicated sensor equipment can be read (if authorised to the reader) in the following document references:

CAF;	[10] (CO)	chapter 6.2
SMO:	[8] (PU)	chapter 6.2
SNCF:	[7] (PU)	chapter 6.1.2
TD:	[9] (CO)	chapter 6.2

7.2.2 Highlights of the Demonstrator's features:

SNCF	uses 4 different GNSS receivers.
SMO	provides Dual Antenna GNSS Heading at zero-speed
CAF	track curves are used as reference points
TD	has an own train and test track with GNSS critical environment: wooden curvy valley track

7.2.3 Digital Map of the test tracks used in the demonstrators

To achieve a valid accurate 1D position determination, the FSTP requires a track map on-board the train. This information is structured into track segments and nodes, connecting different segments. The train position is expressed as a distance on a segment. Therefore the segment has a start and a length. Since a track consists of concatenated segments, an orientation of a segment is also required (defined by a parameter).

The demonstrators all use this principle for their track map. Specialities of the properties are depicted here.

7.2.3.1 CAF's map used in the demonstrator

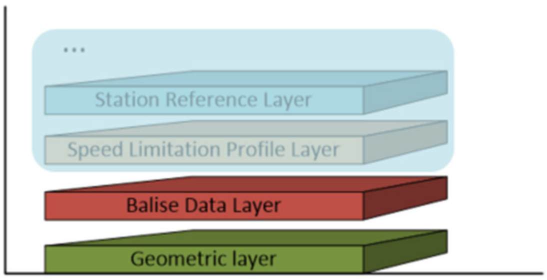

Figure 7-2 CAF's Digital Map Layers

For the demonstrator of the fail-safe train positioning, the 2 lower layers are considered only: Geometric Layer and the Balise Data Layer. The digital map is provided in a hierarchical structure of files defined in the digital map main file referring to a structure of routes and a structure of segments.

Geometric Layer

It represents the track centre line by 3 types of sections within a plane:

a) straight line b) curve c) clothoid

The characteristics of these 3 section types are:

a) The straight line has a constant heading (named orientation east = 0).
b) The curve is described by its constant radius R
c) The clothoid (Euler spiral or Cornu spiral) is a plane curve whose curvature (1/R) at any point is proportional to the distance along it.

The nodes of a section are defined as points represented by 3D geo-coordinates with ellipsoidal or geoid height. In addition, for each node cant angle (roll) of the track section is defined, while a gradient has to be derived from the 3D coordinates of the points along the section.

A segment is a concatenation of sections each described by one of these section types, having a parameter set with a starting point and an arc length of the section.

Balise Data Layer

A balise represents a unique point on a segment with an identifier and its distance from the segment starting point.

7.2.3.2 SMO map applied in the demonstrator

The SMO demonstrator is deployed on SBB tracks in Switzerland. SBB maintains a very accurate, geo-referenced database of its assets, including track centre lines in cm accuracy, locations of signals, points, Eurobalises and also tunnels, bridges, buildings, platforms.

Track data is maintained as a node and spoke model. The demonstrator uses a track map extracted as a subset from the database contents. The data is geo-referenced to the Swiss Gridd but swisstopo provides a conversion algorithm to WGS84 [16].

Figure 7-3 Digital Map Representation on an Open Street Map (OSM) Layer

Blue lines are the spokes, the coloured dots are nodes (e.g. Balises are yellow). The spokes have geo coordinates about every 10m along the centre line of a track.

7.2.3.3 SNCF uses a simple map in the demonstrator consisting of 3 layers:

1. **base layer** with a pool of track segments called TrackEdges having a direction

2. **centreline layer** collects the 3D coordinates of sequenced points along the track centre line

3. **curvature layer** contains radius of the track horizontal curvature at the 3D points of the centreline

The along-track **distance reference** is defined by the start track node on each TrackEdge

7.2.3.4 TD uses a layer structured safe HD map

The digital map used in TD's demonstrator as on-board embedded map is based on static safe high definition (HD) map data, generated from a LIDAR supported survey within a safety checked process chain.

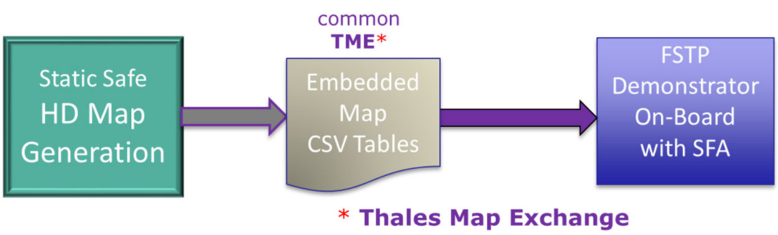

Figure 7-4 Digital Map transfer to the On-Board of the Demonstrator

Map information is provided in 4 layers. For the demonstrator the following layers are used:

Layer 1 defines the track centre line split into segments between junctions (switch points) by an equation including curvature parameters. Layer 4 is derived from layer 1 and contains the centreline of a track sub-segment as sequence of 3D geo-coordinated equidistant points every 4 m or less. Layer 2 is reserved for modelling the masking angles of the open sky along the track. Balises with their 3D coordinates and ID are contained in the POI layer (Layer 3).

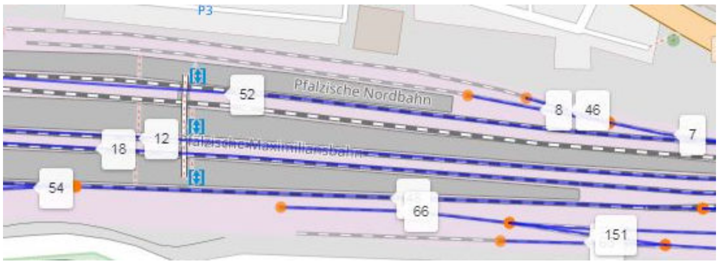

Figure 7-5 Embedded Track Map with segment and vertex representation as OSM overlay

A vertex is shown as orange round separator between segments carrying a label with their ID.

7.2.3.5 Clear definition of track segment borders

Segments have a unique unambiguous driving path from start to end point. At switch points a segment has to end, meaning, a segment never contains any switches. Each segment has linkage attributes which define the connections at both ends of this segment. A track segment shall have a unique number and shall be linked to a track, which is linked to a railway line. If numbering or labeling of rail infrastructure organisations are available, they should be used.

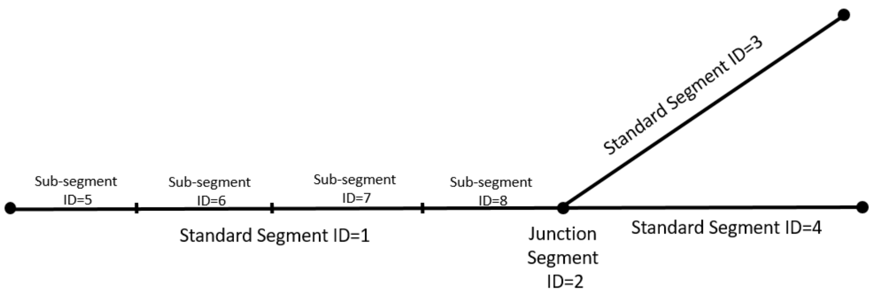

Figure 7-6 Segment borders at a junction (switch point)

The Standard Segments can consist of sections or sub-segments, see Figure 7-6.

The origin of a track segment shall be fixed at rail construction points or relevant topological nodes (e.g. switch point, station, buffer).

Each segment has a defined along track orientation: s = 0 at starting point, s = L at ending point, noting L as the arc length of the segment, with L > 0.

This orientation defines also what is a predecessor segment (= the segment connected to this segment at s = 0), and what is a successor segment (= a segment connected to this segment at s = L). Orientation of the segment is a static definition independent of the moving train. If the train travels along a segment against the track orientation, it enters the segment at s = L.

7.2.4 Augmentation Information processing

7.2.4.1 Differential corrections

They are necessary to enhance absolute positioning accuracy to reach the performance requirements. These corrections could be applied to the PVT solution by adding a correction vector to the position calculated from the GNSS receiver.

But to have the correct vector for the on-board receiver, the reference station should generate it from the same set of satellites used by the receiver on-board (which is dynamically changing). If a different set of satellites is used, an incorrectly shifted position estimate on-board could be the result. A more precise solution is to get and apply differential corrections for the ranging data obtained from each satellite whose signal is used in the position calculation.

7.2.4.2 Integrity information about satellites

This information provides the healthy state of the satellite ranging function and alerts the user, if accuracy, availability and transmitted messages are out of the specified performance.

European standardisation promotes to use EGNOS Service to enhance the GNSS performance of the train: improving the accuracy and the integrity of the positioning function. The current EGNOS v2 services are optimised for aviation to support landing (vertical position accuracy), but railway operation requires horizontal accuracy and integrity along track orientation. If this can be implemented in v3 is not clear yet.

At least the supervision of satellite healthiness, with a defined time to alarm, increases integrity already for railway domain using EGNOS v2.

7.2.4.3 Application of the EGNOS data for the demonstrators

CAF uses SiS by means of the GNSS receiver, if the geostationary satellites are in view.

SMO uses EGNOS SiS or EDAS via internet.

SNCF emulates EGNOS V3 DFMC for the demonstrator, see [1] in chapter 6.2.1. The input of the emulator uses IGS products (external interface to IGS server) for the time span of the corresponding data collection period (RINEX NAV, SP3).

TD uses EGNOS SiS directly within the GNSS receiver to correct the pseudo ranges of the received satellites.

7.2.5 Safe Fusion Algorithm comparison

The Safe Fusion Algorithm function (see Figure 7-1) is responsible for calculating the train's position and speed. It works in 2 phases: Starting at train power up until the first safe position output and in the 2nd phase, the SFA performs continuously updates of the position during train movement along the railway network.

In the **first phase** of train locating the initial position with track determination and train orientation in relation to the digital map, the track has to be determined safely. This is the most challenging procedure, and help from a Cold Movement Detector can speed up the process in most operational cases.

If the 1st safe position is known to the SFA, the **second phase** of train localisation is entered. Here the SFA needs to follow the movement of the train along the path of the railway. The SFA is updating the current position output with time tagging the values of travelled distance and speed, based on the sensor inputs and the track geometry provided by the digital map.

A continuous verification function supervises the SFA function increasing integrity by revealing errors and keeping the train positioning output in a safe state.

This supervision is common to all demonstrators but can be performed by different methods to reach the required integrity of the SFA output.

Method 1: Since a filter uses input measurements from sensors in a weighted manner during a period of time, an erroneous measurement sample should be detected and excluded from entering the filter. This can be done by comparing the value against the expected value calculated by extrapolation of the previously generated outputs. If the variance is too big, the new measurement will be rejected. This helps to ensure that underlying assumptions of the filter algorithm input are met.

It enables calculating confidence intervals from the standard deviations estimated by the filter.

Method 2: Another method is to use complementary filtering of independent sensor sets and comparing the filter outputs. If the outputs are consistent, integrity of the solution is increased. If the results diverge, the generated output should be provided with an increased protection limit.

The performance of this method depends on the selection of the sensors for each filter. Each filter chain should provide continuous output and comparable availability. Each output should have appropriate accuracy and performance also in challenging environmental conditions.

Even a combination of both methods is helpful to increase the reliability of the safe position function.

7.2.5.1 Comparison of the 4 demonstrator algorithms against the generic description

The **SMO** demonstrator applies method 1 to increase integrity, while TD's demonstrator follows method 2 with two filter chains and a consolidation stage behind them. TD's demonstrator also uses method 1 to eliminate outliers from the sensor specific SFA inputs.

The demonstrator of **CAF** uses a kind of a dual chain approach according to method 2, where the second chain is a supervisor function called diagnostic. It uses different inputs than the main filter and its aim is to ensure the main algorithm is performing with coherence. If the positions do not match, the train's position is not considered verified and therefore availability of the system is diminished. Speed is supervised against thresholds using GNSS speed values compared with the read ones from the wheel speed sensors.

The **SNCF** demonstrator provides its SFA with a concept to process a sensor data stream independently from the other sensors. Therefore, each time a new measurement is available from a certain sensor, the sensor specific update function is launched and executed.

In this way, the sensor fusion system can deal with asynchronous input data streams. Integrity is increased using a tightly coupled filter by combining sensor inputs rather than generating full PVT solutions on each sensor and combining these PVT results to one output solution.

On top of that, method 1 is implemented. As a fault detection and exclusion mechanism a bank of pre-filters is used to remove faulty measurements from being used in the Kalman filter.

A characteristic of the SNCF demonstrator is to have speed sensors only as optional. They want to use IMU, GNSS and track map as localisation means only.

7.2.6 Configurability of the Demonstrator for different Test Scenarios

Parameters of the SFA and the verification function can be optimised for different test scenarios, e.g. straight lines with high speed in contrast to shunting operations.

7.3 Agreed file formatting for data analysis

7.3.1 Common Ground Truth (GT) File format

This section is based on the experience of former research projects. The extension to multi-sensor safe positioning requires additional information like lever arms of sensors in relation to the coordinate system origin on the train and a more common time stamp than from GPS.

The train body coordinate system is defined to practically access the coordinate origin at the track axis in the rail heads plane at the front of the active cab. The lever arms of the sensors with reference to the train front coordinate system have to be known, if the optional IMU values for attitude changes shall be useful. With the train length information, the body frame coordinate system origin can be transferred to the other train end, if the active cab is switched to there.

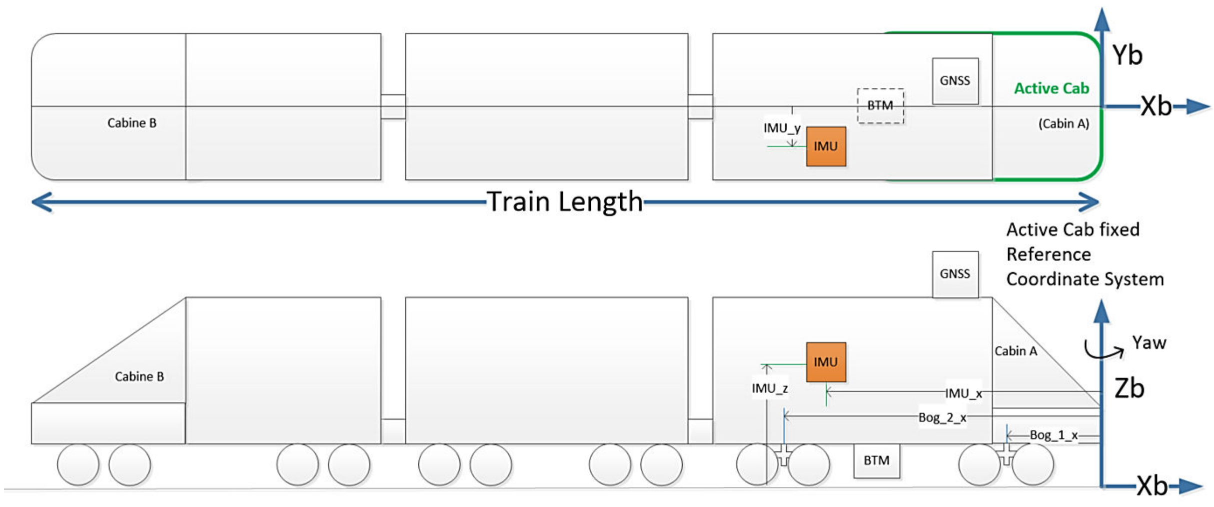

Figure 7-7 Reference Coordinate System of the train at the active cab

Disclaimer: use the Excel sheet from COOP Tool for the most updated version.

The values below have been extracted from the edition of the definition file defined in [14].

The extract is divided into a table of mandatory and a table of optional values:

7.3.1.1 Mandatory values within the GT file:

POS	NAME	Description
1	day_reference	Date from the GT recording
2	day_time	24h day time of the GT recording (without local offset)
3	utc_time	UTC seconds as float starting from 1970-01-01.
4	position_type	Type of the position: - Absolute (i.e. balise based) - Relative (i.e. interpolated) - Other (i.e. based on GNSS/INS)
5	latitude	Latitude of the vehicle position at the front of the train on top of the rails in WGS84 range [-90 , 90], see Figure 7-7 Reference Coordinate System
6	longitude	Longitude of the vehicle position at the front of the train on top of the rails in WGS84 range [-180 , 180], see Figure 7-7 Reference Coordinate System
7	height	Distance above the WGS84 ellipsoid (not sea level)*.
21	relative_travel_dist	Travelled distance since switch on
23	velocity_absolute	Absolute velocity of the vehicle (norm of the 3D velocity vector)

24	velocity_orientation	Velocity orientation nominal: where the active cab is running forward. Standstill value has a threshold (0.1m/s) where absolute speed is set to zero..
26	train_heading_north	Orientation value with respect to the true north of the front of the train. Positive values clockwise, range [0,360]. If the train is running reversing the heading should still match the heading of the map.

Table 7-2 Table of mandatory GT values

* Height shall refer to a reference available easily in all train locations over the world. Thus referring to the WGS84 ellipsoid is more general and appropriate, than determining a common geoidal model for that location.

Rationale:

1) Even though it's a model, a Geoid comes from a kind of earth gravitational field mapping for the purpose of giving a 3D shape of the 0 meters surface (it is not a regular geometrical shape). It inherently implies having a bitmap stored somewhere or a complex math model to be processed for the purpose of computing heights against it.(Ref: https://en.wikipedia.org/wiki/World_Geodetic_System, https://en.wikipedia.org/wiki/Geoid)

2) On the other hands, an ellipsoid comes the same from a kind of earth surface mapping. But an ellipsoid implies a more regular structure and computing heights against it is mathematically pretty and straightforward.

7.3.1.2 Optional values could be within the GT file as additional columns:

POS	NAME	Description
8	latitude_unc	Uncertainty of the given latitude. If not valid put a value equal to 1'000'000.0
9	longitude_unc	Uncertainty of the given longitude. If not valid put a value equal to 1'000'000.0
10	height_unc	Uncertainty of the given height. If not valid put a value equal to 1'000'000.0
11	ECEF_X	ECEF coordinates in ITRF frame
12	ECEF_Y	ECEF coordinates in ITRF frame
13	ECEF_Z	ECEF coordinates in ITRF frame
14	ECEF_X_unc	Uncertainty of the given ECEF value. If not valid put a value equal to 1'000'000.0
15	ECEF_Y_unc	Uncertainty of the given ECEF value. If not valid put a value equal to 1'000'000.0

POS	NAME	Description
16	ECEF_Z_unc	Uncertainty of the given ECEF value. If not valid put a value equal to 1’000’000.0
17	segment_ID	Reference Segment Id at which the train is located. The orientation information is defined in segment_id_direction. In CLUG also referred as TrackEdgeId.
18	segment_ID_direction	In case the segmentID does not include the orientation value, this information shall allow to distinguish the direction of the train. The "unkown" value defines segment_ID and segment_travel_dist shall be considered invalid.
19	segment_travel_dist	Travelled distance since segment_ID value. Always an increasing value considering 0m the start of the segment_ID (the reference of segment_ID shall be combined with the segment direction).
20	segment_travel_dist_unc	Travelled distance uncertainty. If not valid put a value equal to 1’000’000.0.
22	relative_travel_dist_unc	Travelled distance since switch on uncertainty
24	velocity_unc	Uncertainty of the given speed value. If not valid put a value equal to 1’000’000.0
26		
27	yaw	Yaw angle at the IMU reference coordinate system, range [-pi, pi]. see Figure 7-7. Positive values for counter-clockwise.
28	roll	Roll angle at the IMU reference coordinate system, range [-pi, pi]. see Figure 7-7. Positive values for a right handed turn.
29	pitch	Pitch angle at the IMU reference coordinate system, range [-pi, pi]. see Figure 7-7. Positive values when the train is going downhill.
30	yaw_unc	Uncertainty of the yaw angle, range [0, pi]
31	roll_unc	Uncertainty of the roll angle, range [0, pi]
32	pitch_unc	Uncertainty of the pitch angle, range [0, pi]
33	yaw_rate	Yaw angle rate at the IMU reference coordinate system, range [-10,+10] /(rad/s). see Figure 7-7. Positive values for counter-clockwise.
34	roll_rate	Roll angle rate at the IMU reference coordinate system, range [-10,+10]. See Fig. Reference Coordinate System. Positive values for a right handed turn.
35	pitch_rate	Pitch angle rate at the IMU reference coordinate system, range [-10,+10]. see Figure 7-7.

POS	NAME	Description
36	yaw_rate_unc	Uncertainty of the yaw angle rate, range [0,10]
37	roll_rate_unc	Uncertainty of the roll angle rate, range [0,10]
38	pitch_rate_unc	Uncertainty of the pitch angle rate, range [0,10]

Table 7-3 Table of optional GT values

The maximum values should not be exceeded but can be clipped to clearly indicate erroneous values. E.g.: An erroneous value of an angular speed of 12.34 rad/s will be clipped to 10.00 rad/s.

7.3.2 Safe Fusion Algorithm Output (SFA-Out) values

Extract from the Excel file defined in [15] which further contains value ranges:

POS	NAME	Description
1	day_reference	Date of the GT recording
2	day_time	24h day time of the GT recording (without local offset)
3	utc_time	UTC seconds as float starting from 1970-01-01.
4	algorithm_status	Status of the algorithm, possible values are OK,NOT_OK values.
5	latitude	Latitude of the vehicle position at the front of the train on top of the rails in WGS84 range [-90, 90], see Figure 7-7
6	longitude	Longitude of the vehicle position at the front of the train on top of the rails in WGS84 range [-180 , 180], see Figure 7-7
7	height	Distance above the WGS84 ellipsoid (not sea level)*.
8	latitude_unc_meters	Uncertainty of the given latitude, at one sigma. If not valid put a value equal to 1’000’000.0
9	longitude_unc_meters	Uncertainty of the given longitude, at one sigma. If not valid put a value equal to 1’000’000.0
10	height_unc	Uncertainty of the given height, at one sigma . If not valid put a value equal to 1’000’000.0
15	relative_travel_dist	Travelled distance since switch on (may be different than GT)
16	relative_travel_dist_unc	Travelled distance since switch on uncertainty
17	velocity_absolute	Norm of the 3D velocity vector of the vehicle
18	velocity_unc	Uncertainty of the given speed value. If not valid put a value equal to 1000000.0
19	velocity_orientation	Velocity orientation nominal: where the active cab is running forward. Standstill value has a threshold (0.1m/s) where absolute speed is set to zero. See 8.2.2.1.

20	heading_north	Orientation value with respect to the true north of the front of the train at the active cab. Positive values clockwise, from true north, range [0,360]

Table 7-4 Table of mandatory SFA-Out values

POS	NAME	Description
11	segment_ID	Segment_ID at which the train is located. In CLUG also referred to as TrackEdgeId.The orientation information is defined in segment_id_direction.
12	segment_id_direction	In case the segment_ID does not include the orientation value, this information shall allow to distinguish the direction of the train. The "unkown" value defines segment_ID and segment_travel_dist shall be considered invalid.
13	segment_travel_dist	Travelled distance since the beginning of the segment_ID. Always an increasing value considering 0m the beginning of the segment_ID (the begin reference point of the segment_ID defines the segment direction).
14	segment_travel_dist_unc	Travelled distance uncertainty. If not valid put a value equal to 1’000’000.0.
21	yaw	Yaw angle at the IMU reference coordinate system, range [-pi,pi].,. See Figure 7-7
22	roll	Roll angle at the IMU reference coordinate system, range [-pi,pi].
23	pitch	Roll angle at the IMU reference coordinate system, range [-pi,pi].
24	yaw_unc	Uncertainty of the yaw angle, range [0, pi]
25	roll_unc	Uncertainty of the roll angle, range [0, pi]
26	pitch_unc	Uncertainty of the pitch angle, range [0, pi]
27	yaw_rate	Yaw angle rate in the IMU reference coordinate system, range [-pi,pi].
28	roll_rate	Roll angle rate in the IMU reference coordinate system, range [-pi,pi].
29	pitch_rate	Pitch angle rate in the IMU reference coordinate system, range [-pi,pi].
30	yaw_rate_unc	Uncertainty of the yaw angle rate, range [0,pi]
31	roll_rate_unc	Uncertainty of the roll angle rate, range [0,pi]
32	pitch_rate_unc	Uncertainty of the pitch angle rate, range [0,pi]

Table 7-5 Table of optional columns in the SFA-Out file

8 Description of the Operational Test Scenarios

8.1 Introduction

This section introduces a description of test scenarios in the framework of X2RAIL5:WP7 based on the work carried out in [5] . As for the next section, three concepts need to be clearly understood.

- A Test Scenario defines the train operations, track section type and train movement types which essentially are test features controllable by the demonstrators
- Test Scenario Conditions are the conditions upon which the test scenario is carried out in a test run which may differ from run to run, i.e., for instance rainy weather. They are documented, but cannot be modified.
- Test Run: It is a test carried out from a train which may combine several test scenarios and multiple test scenario conditions.

In the following section further description of these concepts and candidate test scenarios are presented within the context of WP7.

8.2 Description of the Test Scenarios

The spatial definition of the test scenario depends on several local environmental conditions which can have an adverse impact on the performance of the train localisation system. Where applicable, a parameterisation has been defined as proposal for the derivation of test cases depending on environmental conditions. Proposed parameters are generic assumptions estimated by expert and domain knowledge and not based on official regulations, which shall be applicable to all European railways and networks. Parameters for conditions stated as “n/a” cannot be defined quantitatively. Thus, the following sections will be introduced:

- Definition of the Test scenario.
- Test Scenario Conditions that could impact sensor performances.
- Example of Test Scenario

Definition of the test scenario is the foundation of the present work and will lead to define a common benchmark. Here is proposed a harmonisation in scenario definition. In addition to the scenario, an overview of test scenario conditions that could impact sensor performances is done. Recall from section 7 that the train sensor set-up is composed from a combination of at least the following 6 sensors:

1. GNSS Receiver
2. IMU
3. Wheel Encoder
4. Doppler Radar (optional)
5. Optical Encoder (optional)

6. Balise Reader (optional)

Each sensor has its own force and weakness, which lead to definition of operational conditions whose target is to test the algorithm performance at different sensor performance levels. In the following sections first a test scenario definition is presented, then different test scenario conditions are described, and the section is concluded by test scenario examples.

8.2.1 Test Scenario Definition

In this section it is described how a scenario is defined based on the following three parameters described hereafter in detail.

8.2.1.1 Train operations

Train operations define the different identified ways in which a driver could use the train consist. A train movement is split into the following concatenated phases:

N°	Definition of the operation	Short Description
1	Initialising	Train is powered on.
2	Start Rolling	Train consist is unbraked
3	Acceleration	Train speed increases.
4	Normal running	Train runs at constant speed.
5	Deceleration	Train slows down.
6	Target Stop	Train speed aimed very low speed nearly 0.
7	Stop/Standstill	Train doesn’t move and is braked.

Table 8-1 Extract of Operations from [6], page Operations Overview column F to M.

This table defines all basic Train consist possible operations.

8.2.1.2 Track section

Track section is an indicative information about type of tracks used within the test run. Two parameters are used to describe this concept:

Reference	Definition

A	Within Station
B	Open Track section

Table 8-2 Extract of Operations [6], page Operations Overview, column B.

Track section is an import information about train mobility, it can provide some traffic restrictions data and train dynamic limits.

8.2.1.3 Movement types

Movement types is an indicative of the type of movement the train is undergoing:

Reference	Movement	Description
A1	Shunting movements	Slow speed movements in a controlled area (shunting yard) and multiple parallel lines. Limitation on movements shall be considered as well as safety limitations.
A2	Train movements other than that in shunting mode.	These movements can be conducted in any track section at any speed.

Table 8-3 Definition of elementary train movements, [6], page Operations Overview, column C.

8.2.2 Test Scenario Conditions

Several conditions could be reduced for sensor performances. Here is a proposal of these conditions in 7 categories:

1. Driving Conditions
2. Train Features.
3. Trackside conditions.
4. Topology and Track Layout.
5. Topography and Wayside Elements.
6. Geographical and Surrounding conditions.
7. Environmental and weather conditions.
8. Traffic conditions.

8.2.2.1 Driving conditions

Driving conditions refer to the dynamic speed profile change of the test run. Hereafter it can be found the possibilities considered and their potential impact on sensors:

N°	Definition		Min	Max	Unit	Impacted Sensors
N	Standstill		0	3	Km/h	IMU
O	Acceleration	weak	0.02	0.1	m/s²	IMU, Wheel Encoder
P		strong	0.1	0.7	m/s²	IMU, Wheel Encoder
Q	Speed	slow	0	25	Km/h	Wheel Encoder, Doppler Radar, Optical Encoder
R		normal	25	160	Km/h	Wheel Encoder, Doppler Radar, Optical Encoder
S		fast	160	500	Km/h	Wheel Encoder, Doppler Radar, Optical Encoder
T	Deceleration	Service braking	0	0.8	m/s²	IMU, Wheel Encoder
U		Full braking	0.8	1.2	m/s²	IMU, Wheel Encoder
V		Emergency braking	*1.2*	*NA*	*m/s²*	IMU, Wheel Encoder

Table 8-4 Driving behaviour: Extract of Operations [6], page Operations Overview, column N to V.

8.2.2.2 Train Features conditions

In the next table the train features are described.

N°	Definition		Description	Impacted Sensors
W	**Traction power applied**		up to ≈550kN for freight trains with screw couplers or respective maximal starting tractive effort for other trains	IMU, Wheel Encoder
X	**Train Weight**	Light train or locomotive only	n/a	IMU,

				Wheel Encoder
Y		Heavy train	n/a	IMU, Wheel Encoder
Z	**Power distribution**	Loco hauled	n/a	IMU, Wheel Encoder
AA		Multiple unit	n/a	IMU, Wheel Encoder
AB	**Brake distribution**	Unbraked vehicles	n/a	IMU, Wheel Encoder
AC		All braked vehicles	n/a	IMU, Wheel Encoder

Table 8-5 Extract of Train Features [6], page Operations Overview, column *W to AC*.

8.2.2.3 Trackside conditions

The following trackside conditions are defined:

N°	Description		Definition	Impacted Sensors
AD	Track type	Slab track	n/a	IMU, Doppler Radar
AE		Ballasted track	n/a	none
AF	Electrification	Overhead line	n/a	GNSS
AG		Conductor rail	n/a	none
AH		None	n/a	none

Table 8-6 Extract of Operations [6], page Operations Overview, column *AD to AH*.

8.2.2.4 Topology/Track layout

The following topology/track layout can be expected:

<table>
<tr><th>N°</th><th>Definition</th><th>Description</th><th>Impacted Sensors</th></tr>
<tr><td>AI</td><td>Straight section</td><td>n/a</td><td>none</td></tr>
<tr><td>AJ</td><td>Curve and curve transition</td><td rowspan="2">depending on track,
speed and superelevation:
Radius⩾300m main lines (⩾180m for branches/secondary lines)
at speed ⩽40km/h till radius ≈ 4000m with speed ≈300km/h at 160mm superelevation</td><td>IMU,
Wheel Encoder</td></tr>
<tr><td>AK</td><td>Switch non and moveable</td><td>IMU,
Doppler Radar,
Optical Encoder</td></tr>
<tr><td>AL</td><td>Railway crossing</td><td>n/a</td><td>Doppler Radar</td></tr>
<tr><td>AM</td><td>Rail joints</td><td>n/a</td><td>IMU</td></tr>
</table>

Table 8-7 Extract of Operations [6], page Operations Overview, column *AI to AM*.

8.2.2.5 Topography/Wayside Elements

The following topography is defined:

<table>
<tr><th>N°</th><th>Definition</th><th>Description</th><th>Impacted Sensors</th></tr>
<tr><td>AN</td><td>Flat section</td><td>n/a</td><td>none</td></tr>
<tr><td>AO</td><td>Inclination Upwards slope</td><td rowspan="2">max. 12,5 ‰ main lines (40 ‰ for secondary lines) - step routes up to ≈60-70 ‰ (GER)</td><td>IMU,
Wheel Encoder</td></tr>
<tr><td>AP</td><td>Inclination Downwards slope</td><td>IMU,
Wheel Encoder</td></tr>
<tr><td>AQ</td><td>Tunnel</td><td>≈10km (DE) to max. 57km (CH),
underground railway lines and underground stations (e.g. Berlin North to South)</td><td>GNSS</td></tr>
</table>

		up to ≈6 - 10km	
AR	Bridges	max. ≈6,5km (DE), viaducts possibly longer (e.g. Berlin Stadtbahn ≈11km)	GNSS
AS	Super-elevation	up to 180mm (DE), transition up to 1:400	IMU, Wheel Encoder
AT	Overcrossing and undercrossing	n/a, height and width at least limited by clearance gauge	GNSS
AU	Noise Barriers	possibly higher than 4m (up to ≈6m), distance to rail centreline min. 3,60m to 3,80m	GNSS
AV	Railroad cuts and retaining walls	n/a, limited by clearance gauge	GNSS
AW	Railroad embankment	n/a	none
AX	Platforms and Roofs	up to 432m length (Berlin Spandau), especially terminus stations up to ≈400m	GNSS
AY	Vegetation between rails/encrustation	n/a	Doppler Radar

Table 8-8 Extract of Operations [6], page Operations Overview, column *AN to AY*.

8.2.2.6 Geographical and Surrounding conditions

The following geographical and surrounding conditions are defined:

N°	Definition	Description	Impacted Sensors
AZ	Open Sky	n/a	none

BA	Forest and vegetation	n/a	GNSS
BB	Mountains	n/a	GNSS
BC	Canyons	n/a	GNSS
BD	Urban area and Large Structures	n/a	GNSS
BE	Metal structures and masses	n/a	GNSS

Table 8-9 Extract of Operations [6], page Operations Overview, column *AZ to BE*

8.2.2.7 Environmental and weather conditions

The following environmental weather conditions are expected:

N°	Definition	Description	Impacted Sensors
BF	Snow and Closed snow cover	n/a	Wheel Encoder, Doppler Radar, Optical Encoder
BG	Ice and icing	n/a	GNSS, Wheel Encoder, Optical Encoder
BH	Leaves and plants	n/a	Wheel Encoder, Optical Encoder
BI	Rain	n/a	GNSS, Wheel Encoder, Doppler Radar, Optical Encode
BJ	Fog and Humidity	n/a	GNSS, Wheel Encoder
BK	Dust and Dirt	n/a	Wheel Encoder, Optical Encoder

Table 8-10 Extract of Operations [6], page Operations Overview, column *BF to BK*

8.2.2.8 Traffic conditions

The following traffic conditions are defined:

N°	Definition	Description	Impacted Sensors

BL	Parked	up to 740m/835m	GNSS
BM	Oncoming	up to 740m every ≈90s to ≈120s on every rail	GNSS, IMU
BN	Passing trains	up to 740m every ≈90s to ≈120s on every rail	GNSS, IMU

Table 8-11 Extract of Operations [6], page Operations Overview, column *BL to BN*.

8.2.3 Test Scenario Examples description

The current section introduces several scenario examples within the same train campaign. During this run, 5 different scenarios are exposed.

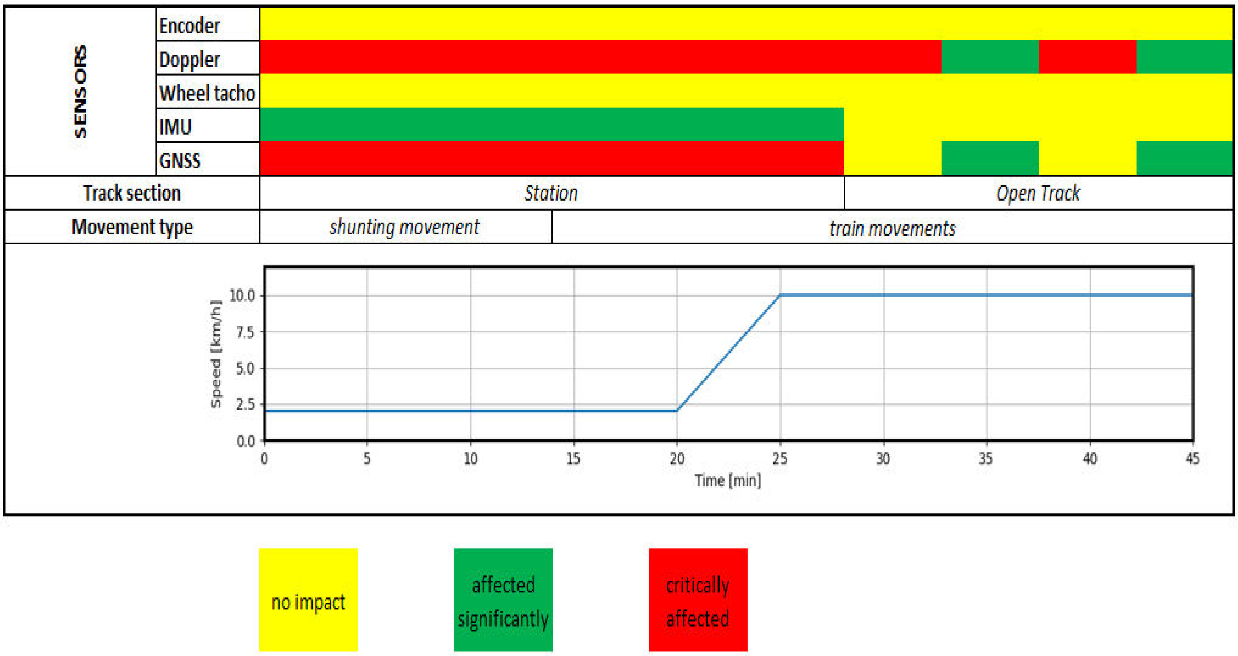

Figure 8-1 Example of a test run evolution depending on time (during one train run)

The current section introduces several scenario examples within the same train campaign. During this run, 5 different scenarios are exposed.

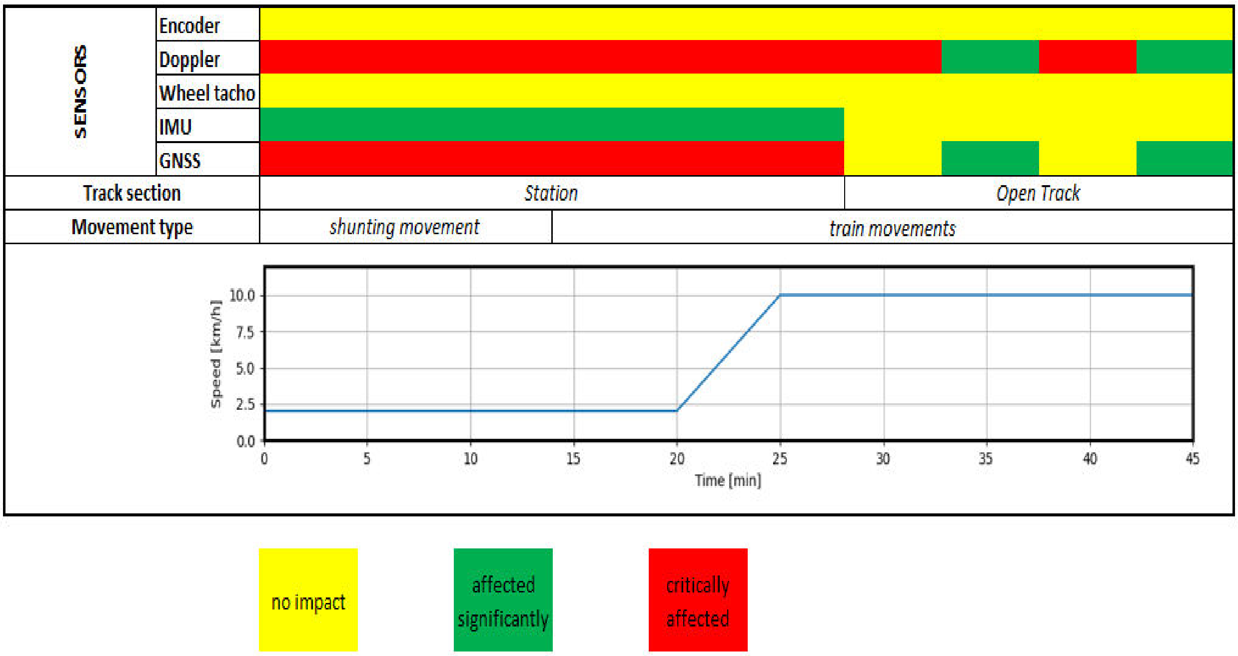

Figure 8-1 presents an example of scenario depending on time. No details about environmental conditions are introduced but only their repercussions on sensor performances.

The matrix analysis defines which and how impacted is the sensor. Its defined three degrees color-coded of impact: Yellow (*no sensor impacted or slight impact by condition*), Green (*sensors affected to a significant degree*), and Red (*sensors affected critically or unavailable*).

From 0 to 14 minutes, we identify one scenario: **Scenario 1**.

From 14 to 20, we identify one scenario: **Scenario 2**.

From 20 to 25 minutes, we identify one scenario: **Scenario 3**.

From 25 to 28 minutes, we identify another scenario: **Scenario 4**.

From 28 to 45 minutes, we identify another scenario: **Scenario 5**.

Scenario 1: Operator is doing shunting movements within a station. Train consist is in running at constant speed (2.5 km/h).

Scenario 2: Train is in normal movements within a station. Train consist is in running at constant speed (2.5 km/h).

Scenario 3: Train is in normal movements within a station. Train consist is accelerating until speed of 10 km/h.

Scenario 4: Train consist is in normal movements within a station. Running at constant normal speed (10 km/h) and is leaving station area.

Scenario 5: Train is in normal movements on an open track, running at constant speed (10 km/h)

During all those phases, sensors are impacted differently in terms of performances. As such, during the analysis phase it should be considered to run the same physical scenario more than once to be able to compare the impact of the same scenario but with different sensor performance values.

8.3 Candidates for test scenarios

To be able to produce an equivalent and comparable dataset from a company to another, here is defined a common scenario. This common scenario will allow to rate each solution performances on a similar level. In [6] each company has defined its test scenario candidate based on the expected train run, track availability and train sensor set-up. Nevertheless the following section provide a summary of these definitions.

8.3.1 Demonstrator Test Scenario Candidates

This part will be a short recall of demonstrator description document of each company.

8.3.1.1 CAF

This table summarise CAF capability in terms of test scenarios.

Scenario	Train operation	Track section	Movement types
CAF1	Initialisation	Open track/station	Train movements
CAF2	Start rolling from standstill	Open track/ Station	Train movements
CAF3	Acceleration	Open track/Station	Train movements
CAF4	Normal running	Open track/Station	Train movements
CAF5	Start rolling from	Station	Shunting movements
CAF6	Acceleration	Station	Shunting movements
CAF7	Normal running	Station	Shunting movements

Table 8-12 CAF test scenarios capabilities

8.3.1.2 SMO

This table summarises SMO capabilities in terms of test scenarios.

Scenario	Train operation	Track section	Movement types
SMO1	Initialisation	Open track/ Station	Train movements
SMO2	Start rolling from standstill	Open track/ Station	Train movements
SMO3	Acceleration	Open track/ Station	Train movements
SMO4	Normal running	Open track/ Station	Train movements

Table 8-13 SMO test scenarios capabilities

8.3.1.3 SNCF

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This table summarise CAF capability in terms of test scenarios.

Scenario	Train operation	Track section	Movement types
SNCF1	Initialisation	Open track/ Station	Train movements
SNCF2	Start rolling from standstill	Open track/ Station	Train movements
SNCF3	Acceleration	Open track/Station	Train movements
SNCF4	Normal running	Open track/ Station	Train movements
SNCF5	Start rolling from	Station	Shunting movements
SNCF6	Acceleration	Station	Shunting movements

SNCF7	Normal running	Station	Shunting movements

Table 8-14 SNCF test scenarios capabilities

8.3.1.4 Thales

This table summarise Thales capabilities in terms of test scenarios.

Scenario	Train operation	Track section	Movement types
TD1	Standstill	Open track / Station	Train movements
TD2	Normal running	Open track / Station	Train movements
TD3	Initialising	Station	Shunting movements
TD4	Normal running	Station	Shunting movements
TD5	Deceleration	Station	Shunting movements

Table 8-15 Thales Test scenarios capabilities

8.3.2 Identified Common Test Scenarios

Reference scenario will be use as a benchmark for the data analysis part. It should prepare future data analysis and performances comparison between demonstrators.

Based on each company feedback, here are defined 2 common test scenarios. These 2 scenario definitions relay on Train Operations table, Track Section and Movement types defined previously:

Scenario 1:

In this scenario, it is expected that the Train consist will run at constant speed (slowly) through a station as a normal operation.

The station could be on open or closed platform.

Scenario 2:

In this scenario, it is expected that the Train consist will run at constant speed (from low to top speed) on an open track as a normal operation.

9 Conclusions

The work presented in this document is the necessary pre-liminary work towards the final demonstrator design and evaluation process. The document first presented an overview of the SRS and the expected inputs and outputs functions and some of the necessary assumptions taken by the solution, see section 6. In the following section 7, the description of the common parts of the demonstrators is described. Notice that for standardisation purposes this list of inputs and outputs are very important definitions as they define the boundaries for inter-operability. In line with this work, a section for the common agreed file formatting for both the ground truth (GT) and the algorithm output (AO) has been defined which is the very first step to understand performance and evaluation of each of the demonstrators. One important aspect is that the reference position agreed by all demonstrators is to define the front-end position of the train as a position for both GT and AO.

Once the sensor types are defined, the operational scenarios that impact on the overall performance can be defined. This is exactly what it is developed in section 8. This section has taken a broad view of the operational scenarios, thinking on them as a general aspect to be tackled by the demonstrators. Authors are aware that not all of them are going to be tested due to the limitations on the demonstrators' time, budgets and environmental conditions. However, a list of candidate scenarios to be followed have been identified.

All in all, the document presents the pillars required to start with the design, development of the algorithms, ground truth and the data evaluation tools with a clear reference to the desired operational scenarios.

10 References

[1] X2R2 D3.8 Stand Alone System Requirements Specification for Fail-Safe Train Positioning V 06

[2] X2R2 D3.9 System Architecture Specification and System Functional Hazard Analysis for Stand Alone Fail-Safe Train Positioning V 05

[3] X2R5-JWG-I-HRI-008-01_-_ESSP-TN-26038_01 - 00_SBAS_L1_Guidelines_Rx_Rail_trackside.pdf

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[5] CLUG D2.2_operational_scenarios_v2.4

[6] X2R5-T7_3-M-SNR-009-01_-_Operational_Scenarios_X2RAIL5.xlsx

[7] X2R5-T7_3-T-SNR-004-03_-_SNCF_Demonstrator_Description.docx

[8] X2R5-WP07-I-DBA-001-01_-_X2R5_Demonstrator_SMO_ADS_DB_2022013.docx

[9] X2R5-T7_3-T-THD-003-01_-_DemonstratorDescription_TD_v5.docx

[10] X2R5-T7_3-T-CAF-002-02_-_CAF_Demonstrator_description.docx

[11] ERA, Report ERTMS Longer Term Perspective, 18/12/2015.

[12] STARS project. D5.1 - State of the art of EGNSS projects for the rail application, STR-WP5-D-IFS-033 (IFSTTAR - 21/03/17)

[13] X2R2-TSK3.10-D-CAI-001-02 - Architecture Specification for Stand-Alone Fail Safe Train Positioning, Version 03

[14] X2R5-T7_3-T-CAF-006-03 GT file format

[15] X2R5-T7_3-T-CAF-007-02 Algorithm Output Format

[16] https://www.swisstopo.admin.ch

[17] NGTC: Next Generation of Train Control Systems (https://cordis.europa.eu/project/id/605402)

[18] STARS: Satellite Technology For Advanced Railway Signalling (https://www.stars-rail.eu/)

Appendix A: Ownership of results

The following Table 10-1 lists the ownership of results for this deliverable.

Ownership of results			
Company	Percentage	Short Description of share/ of delivered input	Concrete Result (where applicable)
CAF	31		
TD	30		
SNCF	30		
DB	9		

Table 10-1 Ownership of results