RCA: General concept
“LSL”

Implementation Model for

Enhanced **L**evel 3

Supervision for all situations

flexible trackside / onboard **L**ocalization

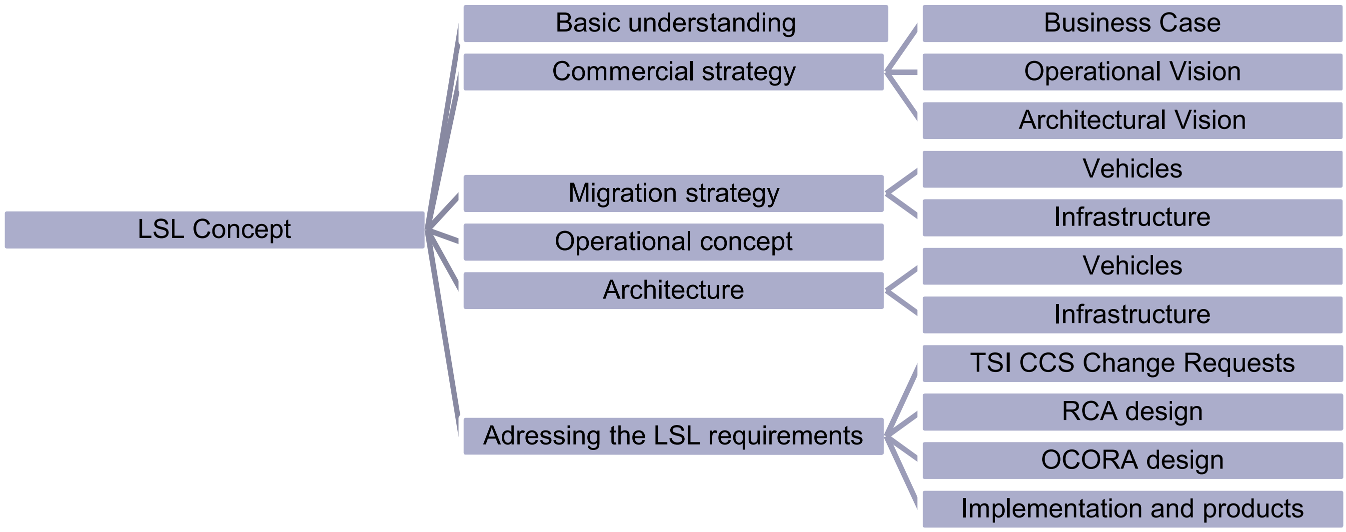
Flexible migration to an advanced ETCS Level 3 implementation. One implementation model for today and tomorrow.

Explanations and context for the RCA CRs for the TSI 2022.

RCA Group, Steffen Schmidt, 10th November 2019, Version 1.0

1. Content

The basic structure of the LSL concept



Index

Illustration Index

Change History

Version	Date	Author	Modifications
0.73 Draft	9.9.2019	Steffen Schmidt	First published draft
0.74 Draft	13.10.2019	Steffen Schmidt	1. Including some (not already all) review comments of Rob Dijkman, Maarten Bartholomeus, Urs Mosele and Joerg Liesche 2. Chapters new sorted (document flow) 3. New chapters about migration 4. Reworked summary about TSI impacts

0.75 Draft	3.11.2019	Steffen Schmidt	5. Included review comments from Stefan Bode, Stephane Kaloustian, Simon Müller, Janina Bonjour, Urs Guggisberg, Bernhard Rytz
0.76 Draft	10.11.2019	Steffen Schmidt	6. Draft for CCSA3. New input of RCA Core-group included. 7. Introduction rewritten

Textformats

1.1.1.1.1. A concept statement is written in this format.

1.1.1.1.2. A (basic high level) requirement is written in this format.

1.1.1.1.3. *An example for a possible solution is written in this format.*

Editorial remarks

1.1.1.1.4. The intention is to keep this document short enough for an overview and as a discussion basis. Not all concept details and only the high-level requirements are shown, and they are described in a compressed form using single key words. The safety aspects are shown in a compressed form to give an overview over the basic principles.

1.1.1.1.5. This document is not a “precise cab signalling and localization” specification. It just describes the context of related TSI CCS change requests for these game changers.

1.1.1.1.6. This document uses some new terms and avoids some ETCS terms by intention. The reason is to avoid misinterpretations caused by associations with existing well-defined terms. Nearly all of the new terms in this document can be described by the terms used in the TSI CCS.

2. Glossary, important terms used in this documentation

For the better understanding of this the terms in this document it is recommended to read the description of the RCA, see [1].

Title	Description
0P, 1P, 1PI and OTD locatable	0P locatable are MOB, that do not send localization information. 1P located are MOB, that can only send a TPR with one point information (distance to the reference point), that marks one boarder of the virtual track occupancy. 1PI located are 1P located MOB, that can also send integrity information. OTD located MOB send P1/P2/integrity, or one point with a reliable length and integrity.
APS	Advanced Protection System, part of the RCA
Localization	The function to retrieve the track occupancy data of a track bound moveable object on the track, including the full track occupancy information
"Completely localized"	The virtual track occupancy is known for a MOB at every necessary moment. The reliability of this information is high enough to fulfil the needs of the specific safety case.
Localization	"Localization" (**trackside and onboard!**) is the process to retrieve the needed information for these processes: - The VS (ETCS kernel) has to know i.a. positions for the speed calculation and for the driver information. - Other onboard units like for example ATO, C-DAS (driver assistance), passenger information, TCMS (onboard train control management system) or energy control need localization information for their specific functions - The trackside safety (e.g. APS) system has to assure, that a track section is free (no localized objects) when it grants a new movement authority or when it sets a track section to status free behind a moving train for example to move a point. - The trackside safety system has to detect MOBs moving without movement permission or which doesn't comply movement permission restrictions - Commercial applications and the traffic management system need train position information for disposition and traffic flow prognosis.
L3	Abbreviation for ETCS Level 3
LSL	LSL is not an ETCS Level, it is an implementation model. It is "Level 3 extended by some new CR (always connected, CAB anywhere), also allowing the punctual or wide spread use of TTD, with some new features possible because of OTD, and some new features needed by OTD.
Migration	The investment programs which change infrastructure and vehicles to an ETCS cab signalling environment.
MA	Movement Authority
MOB	Track bound moveable object (like a train, wagon, etc.). All types of trains, vehicles or elements that can occupy the track, that are "TTD or OTD locatable" and have to be supervised by the TSS. "MOB" is often used instead of "train" because there are MOB that have no leading engine, but can have OTD.
MP	Movement permission. An area (like a route in the interlocking) in which a vehicle is allowed to drive.

OTD	Onboard track occupancy detection is delivering the Train position, length and integrity
OTD Area	A part of the network, where OTD is mandatory
P0/P1/P2	P1/P2=The boarder positions of the virtual track occupancy relative to a reference point. P0=The position of cab of the leading engine relative to a reference point.
RCA	Reference CCS Architecture see [1]
SERA	Single European Railway Area
TCS	Train Control System. Main components: TSS, VS.
TPR	Train Position Report (sent from ERTMS onboard to TSS)
TSS	Trackside Safety System like for example APS or “electronic interlock-ing+RBC”
TTD	Trackside track occupancy detection aka trackside train detection
TTD Area	Area equipped with TTD
URA	Usage restriction area with special usage conditions (e.g. building site, damaged infrastructure, obstacle on track, temporary speed restriction, etc.)
VBS	Virtual balise service; onboard system that transfers a message packet (“virtual balise”) to VS (or other onboard system) at a predefined position, the VL reports. It is not a localization system, it just stores packages that are sent to VS at a certain position.
VL	Vehicle Locator (also known as enhanced odometer), onboard system that performs the OTD.
Virtual MOB ex-tent (VME)	The length of the MOB (e.g. train) prolonged by the tolerance of the local-ization systems. It is guaranteed that the real train is always in the VME.
Virtual Track Oc-cupancy (VTO)	The track section, where the VME is situated
VS	Vehicle supervisor, onboard system that supervises the safety of move-ment starts braking if necessary

3. Scope of the document

This document describes an implementation model "LSL" for various types of ETCS Level 3 implementations based on the RCA principles (including Hybrid Level 3). The intention is to make use of the full power of ETCS Level 3 ("L3") in the long run, but also to be able implement L3 with technologies and products, that are available today or in short term. It shall simplify the migration to ETCS cab signalling by introducing an advanced localization strategy, that allows a very efficient and effective production and the reduction of trackside assets.

L3 can be a very big business case (shown by the SBB example). In the end LSL allows to reduce a big amount of trackside assets (as shunting signals and axle counters). Capacity is maximized and operations will be simplified. It allows safety supervision for all types of movements in undegraded modes. But L3 means much more: It supports an important step - the stepwise architectural and operational standardisation – which is the core target of RCA.

The vision for the future railway CCS includes a high-performance train control system (ETCS) with homogeneous simplicity and precision, high grade of TCS-automation and low amount of necessary trackside assets. Precise continuous localization (trackside and/or onboard) is the key. This document summarizes missing capabilities to reach the vision.

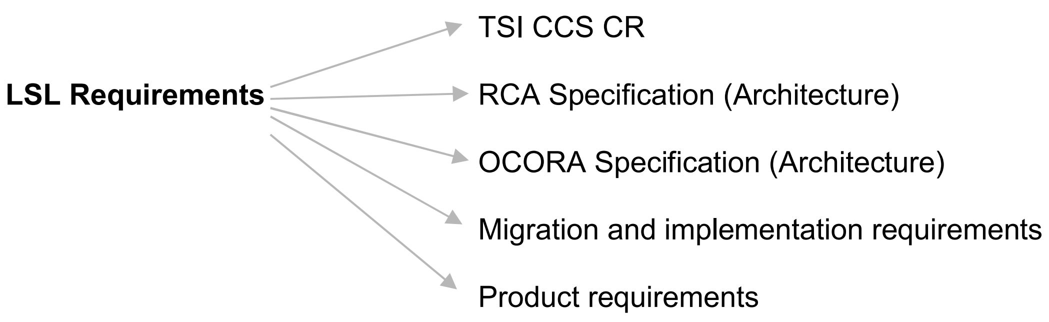
The LSL concept is used is to explain CRs for TSI CCS 2022 concerning ETCS cab signalling and localization. Requirements are described in their long-term context. This does not mean, that it takes long to implement all of them, or that they do not create short-term advantages.

The ETCS L2/L3 specification contains today several aspects and mitigations that exist only because of lacking technological capabilities of existing products. The idea behind LSL is to extend the TSI CCS specification for cab signalling concerning localization and supervision model to allow simple and powerful implementations also without those technological gaps.

The original ETCS concept of an "uninterrupted full supervision" of "all types of trains and track-bound objects" in "any type of movement process" for "all operational states" and "in always the same simple way" is renewed with LSL.

LSL introduces (compatible to RCA) a flexible concept for trackside and onboard localization (occupancy detection) that allows also hybrid level 3 or other cab signaling implementation models, especially to get a scalable cost/performance design and to support migration paths for different situations.

The LSL concept gives an overview about new implementation aspects. These may lead to TSI CCS CR, just to implementation requirements or to specifications inside of the RCA or OCORA.



4. Basic technical principle of LSL

LSL is an implementation form for today and tomorrow, designed to allow the following localization combinations (ERTMS OBU is mandatory) as alternatives “per point” on the track:

1. Only trackside train detection (TTD)
2. Only/mandatory onboard track occupancy detection (OTD, including safe length an integrity)
3. TTD + OTD (hybrid)

Important: These three alternatives can all be part of an LSL implementation on the same line. They are mixed. LSL does not have 3 different implementation forms, it is one implementation form. It can be understood as one trackside safety system / operational rule set, allowing different localisation configurations mixed on the track.

The trackside implementation has an algorithm that retrieves the available localisation information from trackside and onboard to “aggregate” the occupancy information. This aggregated geometrical occupancy information can be used in block-based interlockings (conversion of geometric data to fixed virtual blocks necessary) or in “geometric” interlockings (like RCA APS, see [1] and 9.3.1.1.3.2). TTD is not only used to determine a block occupancy. The geometric positions of the TTD boundaries are known in the trackside safety system (TSS) and help to determine the safe length of a train. For movements or occupancies of track-bound objects without known safe length TTD is of course mandatory. Example line:

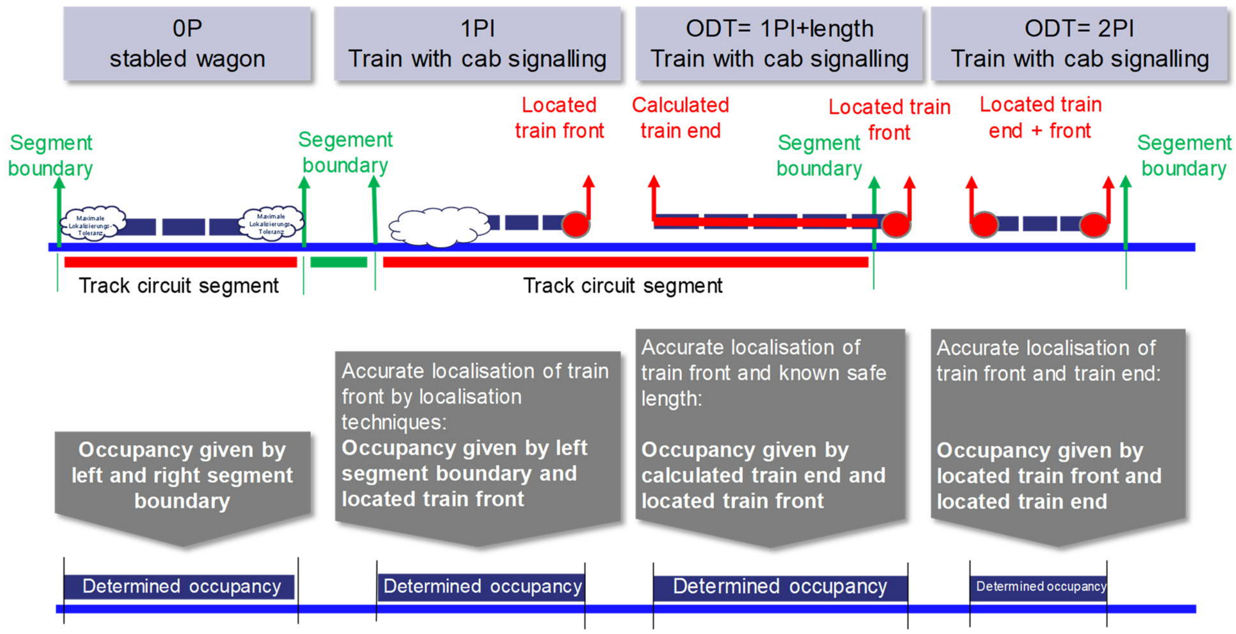
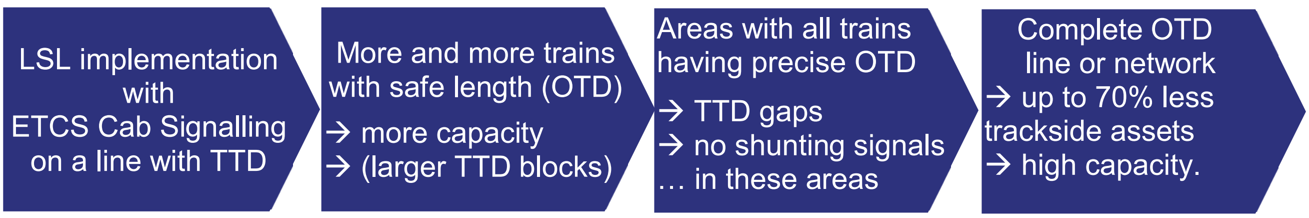


Figure 1: LSL allows “localization mixtures” on the same line

The “mixed” LSL implementation model allows to make use directly (capacity, train ahead time) of the better localisation equipment of newer trains, but also allows older localisation constellations on the same line (when still having TTD). This flexibility allows the following “LSL migration path” without changing the trackside safety system between the steps (and operational rules):



5. Necessary enhancements

To follow this migration path in small or big steps, certain challenges have to be overcome step by step.

1. Precise onboard localisation (the better it becomes, the less TTD)

2. Precise onboard determination of safe length and integrity

3. In areas without TTD every train has to be registered and continuously supervised without disruption (also in standby, e.g. cold movement detection or battery powered localization).

4. To get rid of TTD and shunting signals all shunting and other manoeuvre movements have to be supervised (e.g. cab signalling for propelling).

5. TTD today protects the areas around building sites and allows special vehicles and yellow fleet to move to the building site. So special vehicles and yellow fleet (means all vehicles) have to be equipped with an ERTMS OBU.

6. TTD is necessary for stabling wagons and coaches inside of the supervised area, until they a) can be localized as single mobile units or b) they can be “trapped” between mobile and localized sensors that were put on the track.

7. In areas without TTD the failures of the ERTMS onboard lead to an inefficient degraded mode. A fallback TCS or at minimum a self-sufficient fallback localization system is necessary to maintain degraded operations.

6. Commercial Strategy

6.1. Business Case potential

6.1.1.1.1. Business case potential and advantages

1. Getting rid of main signals
   → cost reduction and less disruptions
2. Getting rid of shunting signals and dwarf signals
   → cost reduction and less disruptions
3. Getting rid of trackside train detection (for many parts of the network)
   → cost reduction and less disruptions
4. Full utilization of infrastructure by using precise train localization and a real time train control
   → capacity and operational improvements
5. Precise adaptive train flow control in stations and bigger nodes
   → capacity and operational performance
6. All movements supervised
   → safety

6.1.1.1.2. *Example: In the case of SBB/smartrail4.0 the implementation of the long term LSL concept would*
- reduce the amount of trackside assets by up to 65%
- reduce the amount of CCS-related disturbances by >40%
- reduce the minimal (technical) train ahead time by up to 20% in the dense swiss traffic
- reduce the collision risk generated by shunting and manoeuvres by up to 90%
- reduce the amount of network extensions for capacity: Study is still running.
→ With all CCS optimization projects in smartrail4.0 (TMS, APS, ATO, COAT/OCORA, etc.) SBB will reduce the yearly cost by more than 400m swiss francs.
→ The reduction of trackside assets with LSL will reduce yearly cost by up to 250m swiss francs.
→ The detailed buisiness case description is available at smartrail4.0.

6.2. Business Vision

6.2.1. Targets

6.2.1.1.1. A TCS allows, assures safety and supervises all trackbound movements.

6.2.1.1.2. A TCS shall have a **high grade of automation,** which means, that only a necessary minimum of manual operations is necessary.

6.2.1.1.3. A TCS shall have **a high performance and precision,** which means, that it does not slow down the production or waste capacity.

6.2.1.1.4. A TCS shall have **low life cycle cost,** which means it uses simple (necessary skills), robust, maintainable and long living systems and architectures, for which the asset life cycle processes have a high grade of automation, and which need a low amount of systems onboard and trackside.

6.2.1.1.5. A TCS shall be **interoperable** concerning the interfaces especially for “train<>trackside” or “component product<>component product” in general.

6.2.1.1.6. A TCS shall generate **operational simplicity,** which means, that from the perspective of a human user (driver, operator) or a system there are a minimum of possible scenarios that need different processes in the SERA.

6.2.1.1.7. A TCS shall allow a **scalable** implementation, which means that different levels of supervision/safety/automation/cost can be implemented with the same operational model and architecture.

6.2.1.1.8. A TCS shall allow a **rolling change of technology** without change of the whole architecture (modularity, “soft” migration).

6.3. Operational Vision

6.3.1.1.1. Driver / ATO, undegraded situation[1]: **Always full supervision.**

- Always in Full Supervision Mode for every type of situation, movement or vehicle.
- Every vehicle is always trapped[2] in an MA.
- Safe data is always available concerning if, how fast and how far a track-bound object actually can drive.
- There is no situation, where a driver or operator has to compensate technological/functional gaps concerning localisation in the TCS process/system with manual/substituting operations or communication with operators.

6.3.1.1.2. Operator/trackside safety system, undegraded situation: **Production Transparency**

- Sees/has safe data and controls every track-bound object at any time with all of its movement-related attributes (speed, track occupancy, etc.).

6.3.1.1.3. Safety: **Simple generic safety rules, especially**

- All track-bound objects are “trapped” by movement permission areas (MP), that usually do not overlap (except near-range operations).

[1] Except situations, where the needed control precision is higher than the technically available control precision
[2] A train cannot leave the area given by an MA.

- Changes to these boundaries (MP) are only allowed if the localization status of all surrounding registered track-bound objects is "completely available" and the points and level crossings are locked for the MP.
- Localization is "completely available" if by combining every available sensor information the track occupancy of a track-bound object can be calculated.

6.3.1.1.4. Degraded situations: **Redundancy instead of operational workarounds**

- The productivity of degraded modes is mainly achieved by cheap system redundancy, not by operational workarounds. This can be architectural redundancy or self-sufficient fallback systems, that can establish an autonomous fallback TCS.

6.4. Architectural Vision

6.4.1.1.1. LSL is based on the RCA strategy, which means in this context:

- **Scalability**
    - Free mixture of trackside or onboard localization technologies on a line/in a fleet
    - Performance and cost of localisation technologies can be freely chosen as long as the performance fits to operational needs and safety targets
- **Exchangeability and lifecycle assurance**: Standard FFFiS product interfaces
- **Upgradeability**
    - Safe platform systems for virtualized safe applications
- **Modularity and the right component split**
    - Functional components are split (functional isolation) if this makes sense because of
        - **Different functional safety integration levels**
        - **Modular Safety** design and implementation pattern to strongly reduce SIL4 functionality and integration workload (impact reduction)
        - **Component Size**: No "too large" component (creates too much dependencies, does not allow smaller companies to provide products) and no "too small" component (creates overhead and too much inflexibility)
        - **Reduced Change impact**: Functionality, that changes very often vice versa very seldom, shall be isolated in a component
        - **Lifespan**: Functionality, that has different lifespans, shall be isolated
        - **Expert Skills:** Special functionality, that can only be provided by special experts, shall be isolated
        - **Customization level:** Functionality, that usually is very much / very less customized (additional plugins/features) shall be isolated

7. Migration Strategy to LSL

7.1. There will be no pure level, it will be a continuous migration for ever

7.1.1. Safe investments

7.1.1.1.1. The most economic migration is, when infrastructures and fleets can change step by step “at the perfect moment”. This moment normally comes “at end of life of assets” or “when needed for capacity changes” or for example when a corridor line has to changed completely while not all vehicles are already “perfectly equipped” with ERTMS and all necessary localization systems.

7.1.1.1.2. So a continuous growth of maturity of vehicles equipment shall be allowed by LSL.

7.1.1.1.3. “Green field” approaches with ETCS Level 3 do not provide a migratable solution that saves old investments.

7.1.2. Scalability

7.1.2.1.1. If there is only one train per hour on a long line, axle counters are a cheap and good solution, also in the future, since a very long block section can be chosen. If there is a shunting area with high and complex dynamics and single wagons, it may make sense to use track circuits plus redundant onboard localization to get maximum productivity and safety. The onboard localization will get cheaper and more precise over the years, but it does not always make sense to rip out all existing axle counters 20 years before their EOL.

7.1.3. Early benefits

7.1.3.1.1. When a railway owns 70% of passenger trains and 30% of freight train, the following situation may occure: For 70% of the trains the measurement of position, length and integrity may be simple and cheap. For 30% it will take many years, a lot of investments and needs new products. It brings already a lot of capacity when the train ahead time to passenger train can be shortened already behind 70% of the trains.

7.1.3.1.2. The implementation of LSL shall allow to make use of every single trains individual capabiltites.

7.1.4. Architectural consequence

7.1.4.1.1. So the localization configuration for cab signalling seems to be a continuous changing mix of technologies. The success of a TCS will be decided by the ability to handle the mix by providing standard interfaces between the TSS and any type of localization system (trackside or onboard).

7.1.4.1.2. LSL is implementing ETCS Level 3 but is also allowing TTD (like axle counters, fibre optic sensing or track circuits). So LSL in real implements a mixed situation for Level 3 and Level 2 – it is an “open cab signalling implementation”.

7.2. General migration principle for LSL

7.2.1. The usual path: Vehicles first

7.2.1.1.1. The economical migration path for cab signaling is to equip vehicles first (perhaps supported by a step in between for example with ETCS L1LS to allow single cabs).

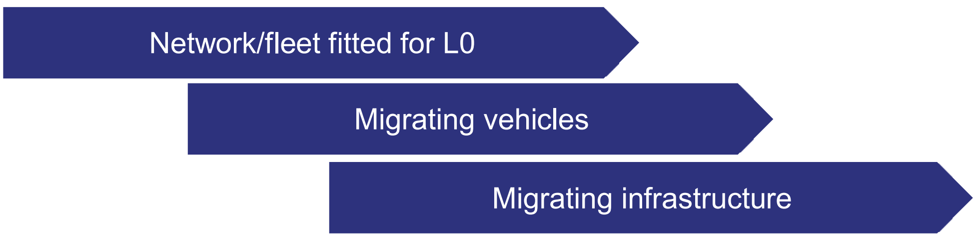


Figure 2: Migrate vehicles first

The only constraint when designing a migration route is the interoperability:

Figure 3: Example for LSL interoperability

7.3. Evolution of localization: Parallel developments and early standards

7.3.1.1.1. LSL (and TSI, RCA, OCORA) shall be prepared and shall allow the integration of new products directly when they are ready.

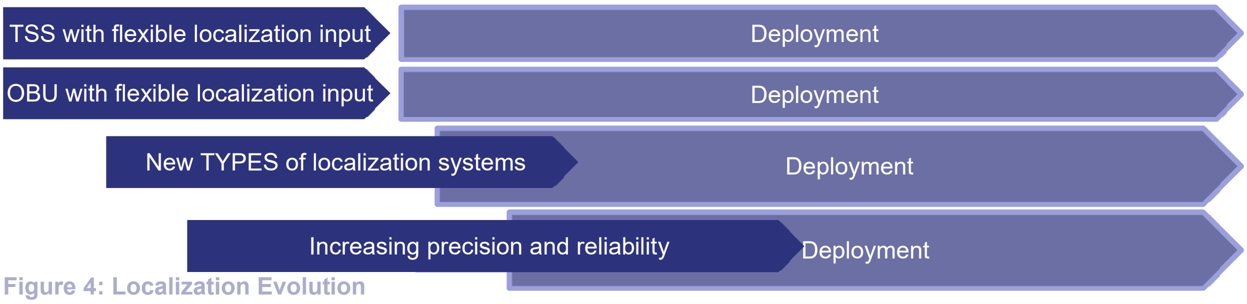


Figure 4: Localization Evolution

7.3.1.1.2. This leads to the following requirements for the migration path:

1. RCA: The TSS shall be developed in a way, that allows the connection of various localization systems in the future (abstract system definition)
2. OCORA: The onboard architecture shall allow the connection to various localization systems (including length and integrity measurement)
3. The TSI CCS shall include as early as possible interface definitions (air gap interface), that are needed to integrate new onboard localisation technologies
4. The TSI CCS shall include interface definitions (air gap interface), that allow in all undegraded situations the “full supervision modes” for all types of movements and vehicles

7.4. Migration for vehicles

7.4.1. Compatibility to Baseline 3

7.4.1.1.1. ERTMS Vehicles with BL3 shall be able to run on LSL lines, if they are able to send the train position report (TPR) including integrity and length information to the TSS with high reliability – or if they are able to send a TPR and the trackside below every part of the vehicle is equipped with TTD. Vehicles need to have cold movement detection or the TPR must be sent in all modes (also in standby).

7.4.1.1.2. A BL3 line today has to have balises to allow a train to localize itself with sufficient quality. And future localization systems (especially their MVP) will need absolute referencing points like balises. This means, that fixed balises will be used on LSL lines (minimal necessary amount) as long as BL3 vehicles are running on them (and possibly longer, to support the vehicle locator (VL)).

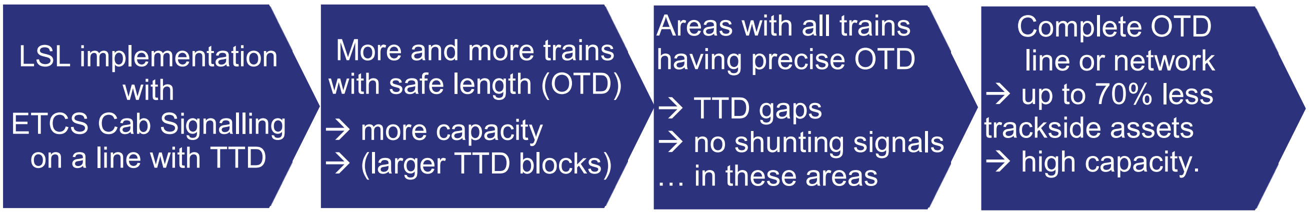
7.4.1.1.3. Compared to a train, that is equipped with an ERTMS OBU today, the additional installation process for LSL is (if done by systems and not by operational processes):
1. Install a system (TIMS), that informs the VL about the train integrity status
2. Install a system, that informs the VL about the actual train length

7.4.1.1.4. The mix of class A and B systems is excluded on LSL lines (can be a migration step before implementing LSL).

7.5. Migration for trackside

7.5.1.1.1. The LSL concept is designed as a pure ETCS cab signalling implementation without Class B / other overlayed train control systems on trackside. This means that all verhicles have to be equipped with an ERTMS OBU (>= BL3) for an LSL line.

7.5.1.1.2. The typical migration path for a new LSL line is the following



7.6. Save todays investments.

7.6.1.1.1. To follow this migration path the following principles are important:

7.6.1.1.1.1. When implementing ERTMS cab signalling an LSL-capable trackside safety system should be installed from the beginning. This especially means that it is able to combine mixed localization information and to connect to modern localization technologies (standardized RCA interfaces).

7.6.1.1.1.2. The trackside assets will be reduced in small or large steps, but rather not completely from the beginning. This especially means, that a trackside safety system (safety logic) should be used, that is able to allow a simple reduction process without expensive safety cases or engineering processes.

7.6.1.1.1.3. Because there is a high probability of new localization technologies for the coming years the vehicle and the trackside architecture should allow simple software upgrades and the connection of new systems on standardized interfaces (RCA).

7.6.1.1.2. To save todays investments in actual architectures for cab signalling, investors should be upwards compatible to LSL. Important measures are for example:

7.6.1.1.2.1. Contracts in bigger programs: Arrange the later change of architecture.

7.6.1.1.2.2. Platform systems (vehicle and trackside): Prepare the upgrade to other software and use a generic method for application-level communication

7.6.1.1.2.3. Interfaces: Use as much as possible RCA interfaces, especially to with trackside interfaces using EULYNX

7.6.1.1.2.4. Object aggregation (RCA component): Prepare the TSS for the trackside combination of different localization inputs for the trackside safety system

7.6.1.1.2.5. Modularity: Use a modular approach for your architecture and be sure to own the IPR for interfaces and the necessary documentations for integration safety cases.

7.7. Less workarounds to close technological gaps

7.7.1.1.1. The LSL concept does not define the new technologies, it defines TSI changes and RCA/OCORA requirements to make them connectable and compatible.

7.7.1.1.2. TCS automates a control and safety function based on sensors and actuators onboard and trackside. The grade of automation and simplicity of a TCS depends on sensoric capabilities and the control capabilities. The lower they are, the more the human actors in the process have to do. Complex or unsafe processes are the consequence of these **technological gaps**.

7.7.1.1.3. *Example 1: Release speed. The more precise localization or prediction of braking behaviour is, the less "releasing" (no automatic braking) is necessary.*
Example 2: If the localization precision is 50m and the train has to stop with 10m precision the process of stopping cannot be automatically and completely supervised.

7.7.1.1.4. Most of the todays inhomogeneous workarounds (operational, functional) for ETCS cab signalling are the result of those technological gaps.

7.7.1.1.5. The LSL concept defines requirements for necessary TSI CCS change requests to close the technological gaps. The target is, to allow the usage of new localization systems and trackside safety systems able to close the gaps.

7.8. Virtualizing trackside assets

7.8.1.1.1. Trackside assets can be divided into two categories: Assets that are physically necessary (points, level crossings) for the railway system and assets that just have the functionality of information exchange (signals, track sensors, boards, etc.).

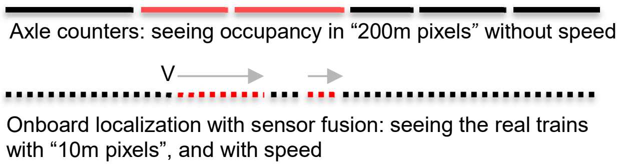
7.8.1.1.2. The second category could theoretically be reduced to zero when trains are able to handle the full information exchange with highly available systems. Shifting such functions from trackside to onboard reduces the amount of these systems by around factor >1:20, single onboard systems can implement many trackside functions, without getting expensive.

7.8.1.1.3. *Example: SBB hast 115.000 trackside assets over all. But only 14.000 points and 900 level crossings.*

8. Operational target situation for LSL

8.1. Full moving block is not a completely new operational philosophy, it is just simpler

8.1.1.1.1. Every sensor or control system has a resolution and produces "blocks". When the operator or the trackside safety system "sees" the train with different types of sensors, at minimum they see in every type of TCS the track occupancy, which shows the virtual train/MOB extent including the resolution of the sensor. The occupancy is moving ("jumping") when the train moves – in every TCS with every type of sensor. In general, there is nothing new except the resolution, characteristics and exchange method of sensor information. It does not create a completely new process, except that the operational communication works more often with positions instead with blocks marked with boards.



Safety processes always follow the same basic rules, and this does not change with full moving block:

- Reserve space for a movement permission only for free areas
- Lock trackside assets in the reserved area
- Allow the movement, supervise the movement
- Free the space again, when the area is not occupied anymore.

8.1.1.1.2. The operational idea behind LSL can be described with the phrase "every movement is just a movement with the same (ETCS) (full) supervision and the same operational process". Together with an "always" available localization no distinction is necessary for undegraded modes. The situation for the driver is always simply the same in all operational scenarios: He sees if he is allowed to move the train, how far (in both directions), and how fast (the "movement authority", full supervision). The harmonisation of operational processes will be simpler because of less process scenarios.

8.1.1.1.3. Even if the OTD has a low precision this LSL principle could be used. The train just gets virtually longer.

8.1.1.1.4. In the existing definition of ETCS the number of movement scenarios can be high. Problems start when the localization system generates a too long virtual train extent, or when the localization is not available. In this case the grade of supervision decreases, and local safety actors (e.g. safety guard on building site) start to carry more responsibility. Communication with the operator gets necessary. The safety level and the efficiency decrease.

8.1.1.1.5. To handle these types of problems the actual ETCS specification (which is 99% identical for L2 and L3) contains a lot of "**operational workarounds"** like the staff responsible mode. These will be necessary until OTD is mature (precise/available) enough for a certain traffic environment.

8.1.1.1.6. The maturity of the localization technologies increases actually (running product developments) and a pure and simple operational world of LSL will become applicable in the next years in more and more cases. Even a normal ETCS fitted train of today with high odometric sensor quality and guaranteed length and integrity information offers enough OTD performance to be used in an LSL scenario.

8.1.1.1.7. The operational processes for degraded modes of LSL are nearly the same as they are today for L2 (explained later).

8.1.1.1.8. The advantage of onboard track occupancy detection (OTD) is that a stronger redundancy for the TCS process (fallback systems with OTD for low speed manoeuvres) becomes possible and affordable, so that completely degraded modes happen more rarely. This means also a simplification for the operational concept of an IM, because it would allow a reduction in the amount of fallback processes.

8.2. TTD and OTD Areas

8.2.1.1.1. OTD Areas are typically surrounded by TTD areas. Trains coming from outside have to be registered before they enter an area without TTD

During the migration (depends on maturity of onboard localization) typically points, level crossings, shunting areas and stabling areas are still equipped with TTD.

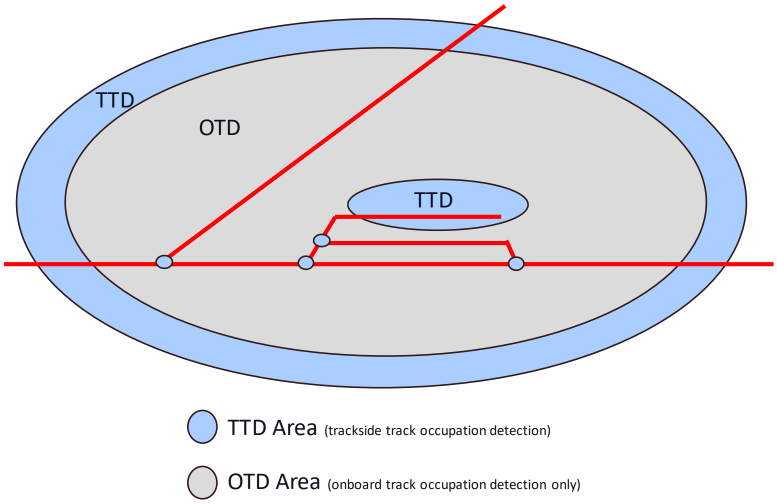


Figure 7: Example for TTD and OTD areas

8.3. Geometric representation of Movement Permission (trackside reservation)

8.3.1.1.1. "Movement Permission" (MP) = Is the track part reserved by the TSS for (usually one) a movement. This is for example the "route" in traditional electronic interlockings or a geometrically defined part of the track inside of the APS.

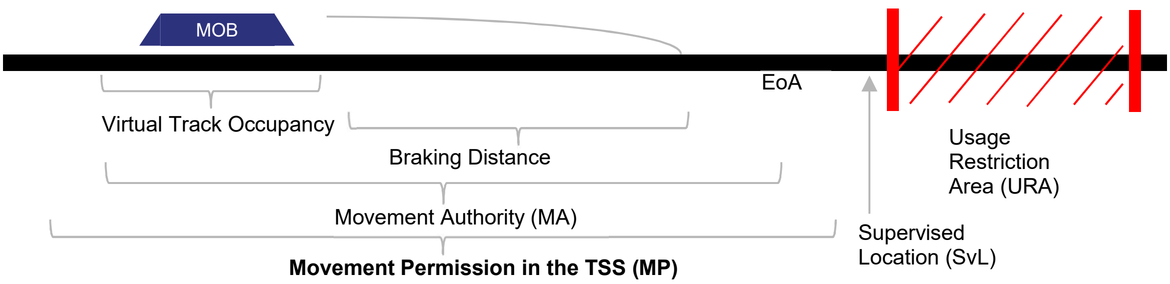


Figure 8: Virtual track Occupancy, MP, MA and URA

8.4. All type of MOB always completely localized and supervised

8.4.1.1.1. As explained in **Fehler! Verweisquelle konnte nicht gefunden werden.**. on the long run all types of track-bound objects have to be localized. This can for example mean, that the leading engine is "in the middle" (yellow fleet on lines without TTD).

8.4.1.1.2. *Examples:*

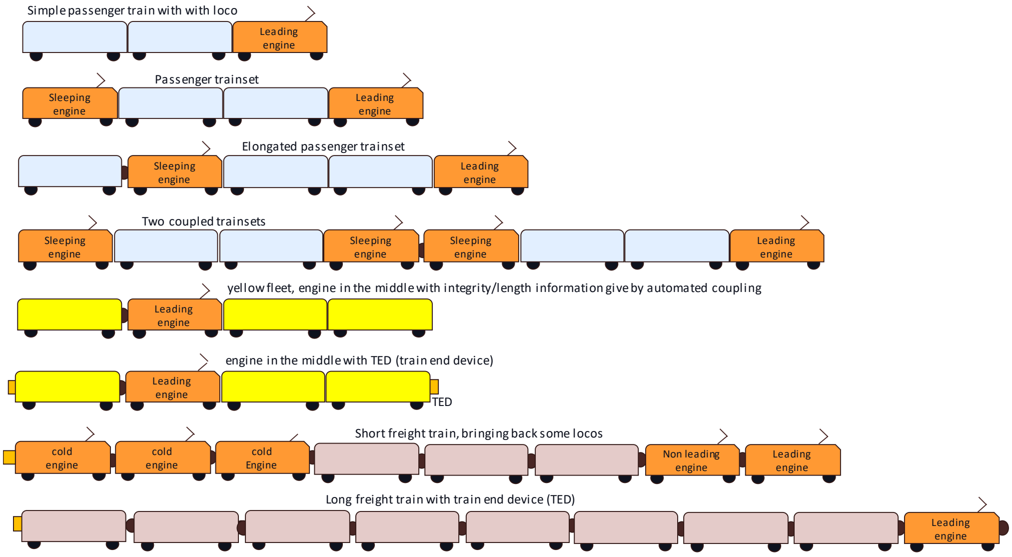


Figure 9: Supervised train configurations

8.4.1.1.3. All track bound MOB (self-propelling or not) shall be always located (mandatory in undegraded mode) and supervised in Level 3 concerning their movements, speed and their track occupancy. Supervised MOB are also wagons, coaches, and train-parts without leading engine.

8.4.2. Supervision of all types of movements

8.4.2.1.1. All movement types supervised

a. Leading Engine can be (in driving direction) at front, in the middle or at the end
b. The "orientation" of the cab can be forwards or backwards
Combining a. and b. there are 6 types of movements, that shall be supervised:
1. „Forwards": Cab forwards, leading engine in front position
2. "Dragging": Cab backwards, leading engine in front position
3. „Middle-Engine forwards ": Cab forwards with leading engine in the middle
4. „Middle-Engine backwards ": Cab forwards with leading engine in the middle
5. "Propelling": Cab forwards, leading engine in end position
6. „Backwards": Cab backwards, leading engine in end position

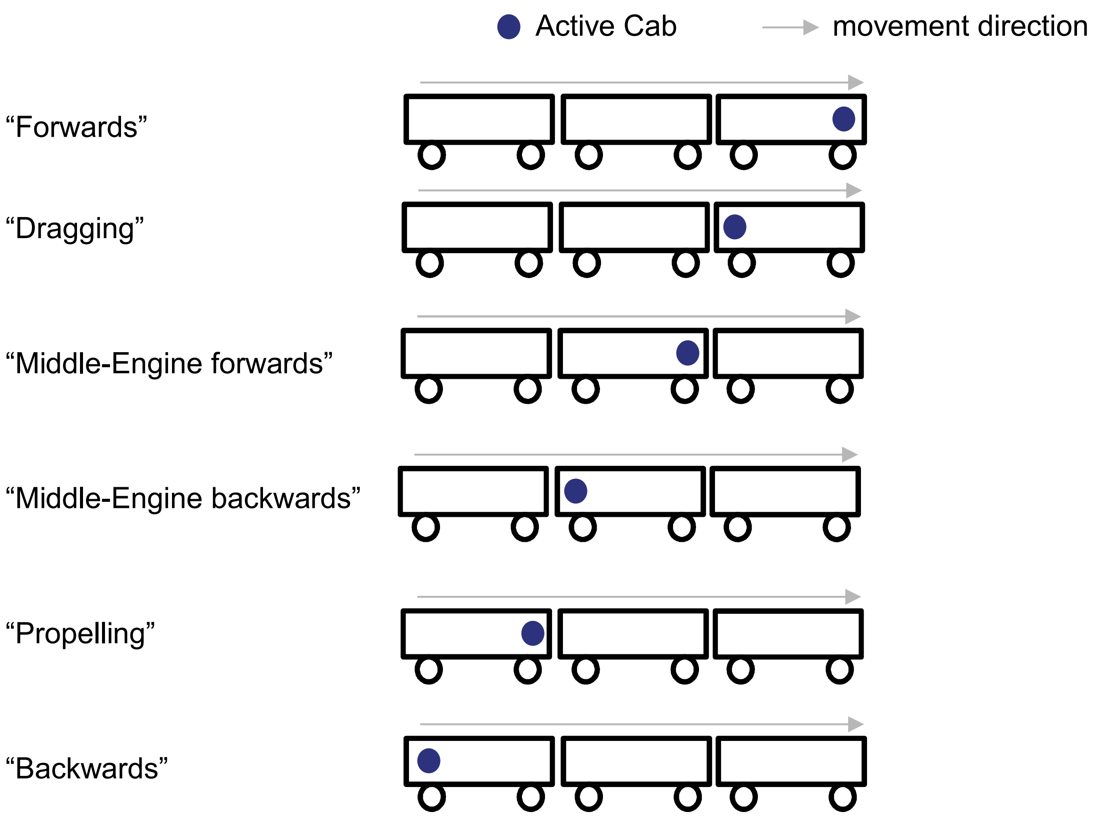


Figure 11: Cab in any position and orientation

8.4.2.1.2. When a train is completely located (VME), the ETCS kernel can calculate the braking curve within its MA whatever train configuration is used or movement type is happening.

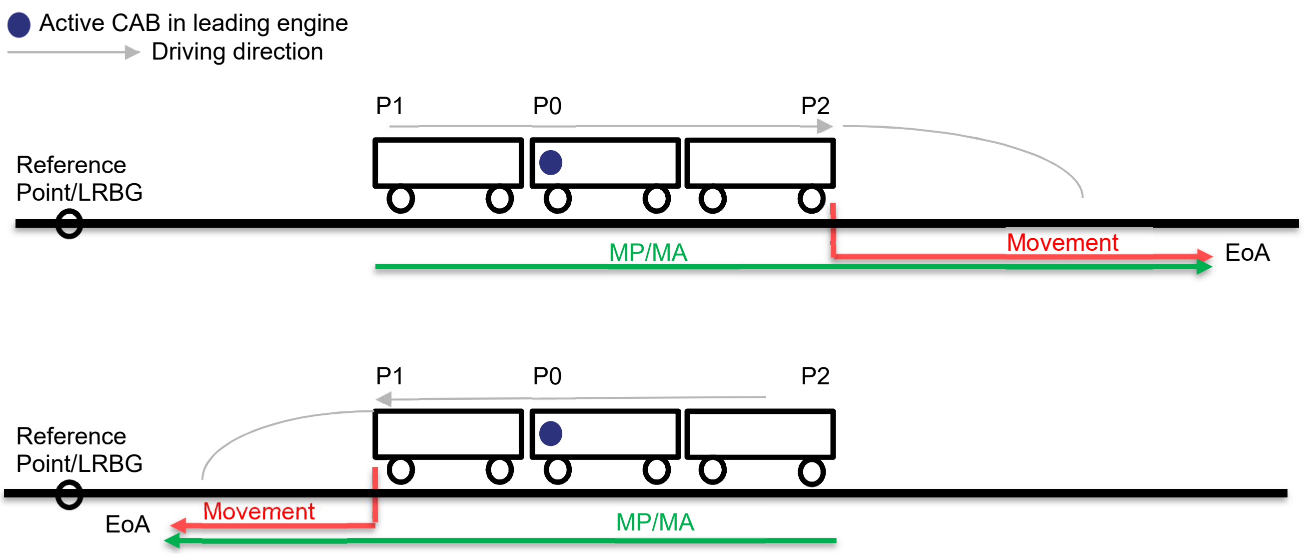
8.4.2.1.3. But because of these new setups the calculation and representation of the MA might be slightly different (TSI impact analysis necessary).

8.4.2.1.4. The ETCS onboard shall supervise movements for all (6) movement types.

8.4.2.1.5. The DMI shall provide information and functionality for all (6) movement types.

8.4.2.1.6. For small vehicles a low cost solution for the ERTMS onboard shall be designed.

8.4.2.1.7. *Example: Leading engine “in the middle”:*



8.5. Operational model

8.5.1. Differences of LSL to traditional ETCS L2

8.5.1.1.1. Instead of listing again all operational scenarios, the main operational differences of LSL to existing ETCS L2 implementations are discussed in this chapter.
The basic differences are (explained in the following chapters):

8.5.1.1.1.1. Safety in OTD areas: “Positive supervision” (see following chapter).

8.5.1.1.1.2. Onboard OTD process and information flow

8.5.1.1.1.3. No fixed positions configured in TSS

8.5.1.1.1.4. New localization technologies

8.5.1.1.1.5. New types of supervised movements (e.g. propelling / shunting manoeuvres) and train configurations

8.5.1.1.1.6. No L2 like today – operation model in TTD areas.

8.5.2. Safety in OTD areas: “Positive supervision”

8.5.2.1. Basic safety concept for OTD areas (without TTD)

8.5.2.1.1. The safety in OTD areas is based on an “active surveillance” a.k.a as “positive train detection/supervision“. The basic principle:

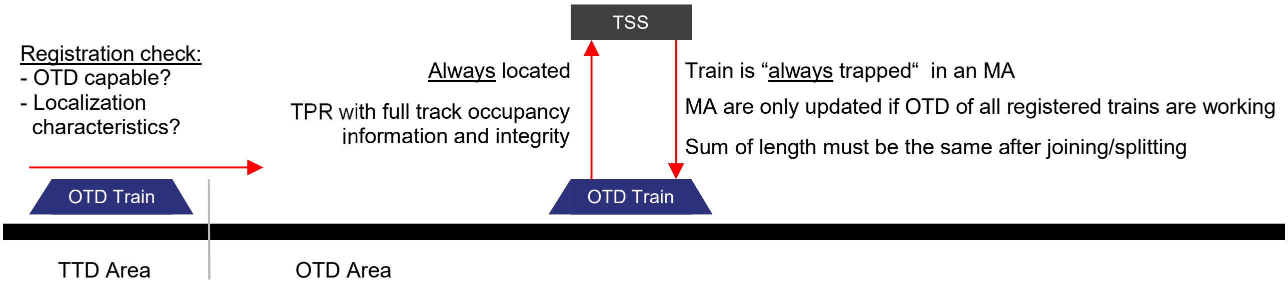


Figure 4: Basic Safety concept for OTD areas: Positive supervision

8.5.2.1.2. Every MOB inside of the OTD area and outside of a usage restriction area (URA) is known/connected to the TSS at all times (no degraded mode) and is completely localized only because of its own active position reports (even in stand-by), including integrity information.

8.5.2.1.3. The borders of URA and TTD areas, that cannot be protected physically (e.g. point) shall be protected by TTD devices (e.g. fixed or mobile train detection) that can detect a MOB moving without OTD.

8.5.2.1.4. The complete localization (VME) information is known by the train (braking) AND the TSS.

8.5.2.1.5. The sum of length of registered involved trains stay constant while joining and splitting

8.5.2.1.6. OTD is mandatory in an OTD area. Only trains shall enter (from an TTD area or an URA), that are equipped for OTD and OTD is working.

8.5.2.1.7. This normally means, that OTD areas are surrounded by TTD areas to protect the OTD area.

8.5.2.1.8. The basic safety rules to handle traffic in an OTD area are for the TSS:

8.5.2.1.9. **Isolated track usage:** A movement on a track shall occur inside of a defined MP or an URA. MP usually do not overlap. MP can overlap URA if the TSS or a local safety responsible system/person assures the safety of movements.

8.5.2.1.10. **Compliant track usage**: In the MP the track usage conditions are defined, which give the limitations for all MA, that are operated inside of the MP, to guarantee safe movements.

8.5.2.1.11. **Locked usage conditions**: While granting an MP, the trackside assets are set and locked. Inside of an MP the physical status of points and level crossings cannot be changed.

8.5.2.2. Degraded modes

8.5.2.2.1. If the VL is not able to send a valid VME, the train stops immediately inside of his MA and the TSS sends no new MA.

8.5.2.2.2. It is necessary in OTD areas, that a train is always operationally or functionally "trapped" in an MP or into an URA by the TSS. Because of this the availability or frequency of train position reports or the time lag of the localization do not influence the safety process per se. Changes to MP, MA, URA or trackside assets are only done by the TSS, when the necessary localization information for the relevant surrounding trains is available and actual. In degraded modes, it might be a line specific condition, that moving with an overwrite is forbidden when the vehicle is not locatable.

8.5.2.2.3. All movements of the train can be technically blocked by TSS in all modes if no localization is available, also in degraded situations (optional line specific condition).

8.5.2.2.4. The TSS does not update or grant movement authorities for trains, if no complete localization is given by the train or by the surrounding registered MOB.

8.5.2.2.5. If the OTD cannot be fixed, fallback localization and authorization processes shall be used like "radio and boards", "secondary fallback TCS" or "second loco is coming" (all like today).

8.5.2.2.6. If the connection gets lost, the MA cannot be updated and the train is "trapped" in his actual MA (MP), until the connection is established again, or fallback localization and authorization processes shall be used.

8.5.2.2.7. A loss of integrity of a train in an OTD area results in a safety reaction of the TSS for the following trains.

8.5.2.2.8. The operational reaction to a fault of the OTD system in an OTD area is the stop of the train, since the ERTMS onboard cannot supervise the speed and distance anymore.

8.5.2.2.9. Differences between TTD faults and OTD faults:

8.5.2.2.9.1. An OTD fault happens always in a track segment, that is already reserved by the MP/MA the train has, that carries the broken OTD system. So an OTD fault never generates an emergency reaction for other trains.

8.5.2.2.9.2. But a TTD fault can happen inside, outside or overlapping to an MP/MA. Because of this it can generate more types of scenarios.

8.5.2.2.9.3. But after stopping the trains (if necessary) the situation is in both cases the same: A track segment has an unclear occupancy status. Trains may be unlocatable. Systems have to be repaired or trains have to be rescued by fallback localization (onboard) and authorization processes (e.g. radio).

8.5.2.2.9.4. Not relevant for safety but for the duration of recovery: TTD normally have a fault only for one block section. The train can reach the next working TTD block section and can move on faster. Together with the surrounding two TTD block sections a defect block can be compensated by seeing the three TTD (broken block in the middle) as one block section.
A defect in an OTD system can lead to longer recovery durations, but on the other hand it is much cheaper to install fallback OTD systems onboard than investing into redundant TTD.

8.5.2.2.10. *Example: A simple fallback OTD could base on long distances between trains, simple GNSS/IMU localization, track path historisation and public radio.*

8.5.3. Onboard OTD process and information flow

8.5.3.1.1. In an OTD area the OTD system ("Vehicle Locator") has to report a virtual train extent (position+length) and the integrity status to the ETCS onboard supervision functionality and to the TSS (in the TPR) (and to other onboard systems like ATO).

8.5.3.1.2. The VTO is the complete "safe shadow" of the train on the track including localization tolerances.

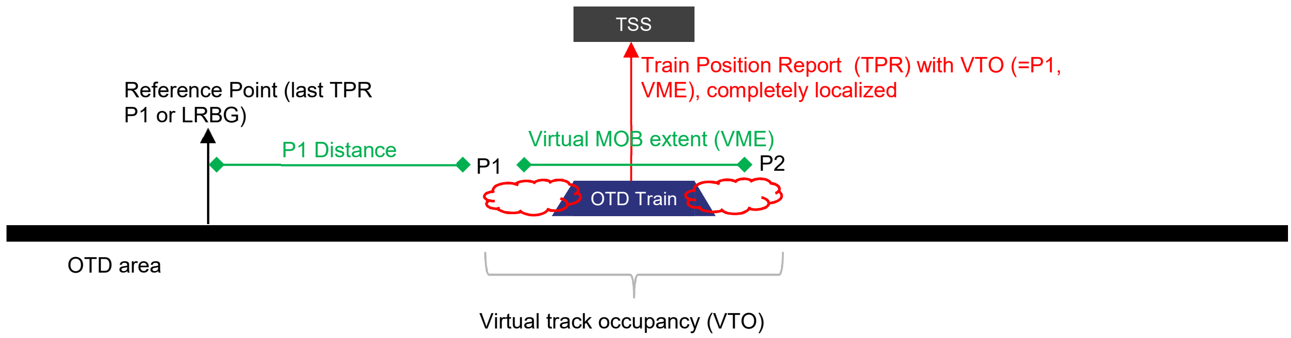


Figure 5: TPR with virtual track occupancy

8.5.3.1.3. The TPR of an OTD system (VL) shall contain the virtual MOB extent (VME).

8.5.3.1.4. *Example: This TPR can have the form of two points P1/P2 or P1+Length, like it is defined in TSI CCS today. Points are expressed as a distance to a reference point. The refence point can be the LRBG or to the position of the last TPR that was sent.*

8.5.3.1.5. Before granting an MP/MA for a train with certain onboard sensor capabilities, the trackside and onboard equipment has to be checked, if it is sufficient for the calculation of the virtual track occupancy.

8.5.3.1.6. Looking at different railway scenarios there will be different technical solutions to solve this requirement.

8.5.3.1.7. A passenger train can retrieve P1 from the odometry in the leading engine and the length from the TCMS.

8.5.3.1.8. A leading engine of a train can retrieve P1 and P2 from the two ERTMS onboards (via cable or radio) on both sides and calculates the VME. This simple feature allows a faster migration: This is typically possible for all trainsets or passenger trains and allows to use shorter train ahead times for following trains already in early migration steps. Or lines only with passenger traffic can then be OTD areas.

8.5.3.1.9. The leading engine should be able to receive positions from all engines and train end devices to calculate integrity and length.

8.5.3.1.10. A freight train will retrieve P1 from the odometry in the leading engine and the length from a length measurement system or from the automatic coupling system.

8.5.3.1.11. So the OTD system (VL) of the leading engine (or wagon) has to "collect" several pieces of information before it can send a TPR with VME to the TSS.

8.5.3.1.12. For a stable migration and upgradeability of the onboard architecture the interfaces from the OTD system to secondary sensor systems shall be standardized. This includes also:

8.5.3.1.12.1. TPR or odometry information from the ERTMS cab at the other side of the train (onboard connection or via radio)

8.5.3.1.12.2. Length information (e.g. from the TCMS)

8.5.3.1.12.3. BTM information

8.5.3.1.12.4. Odometry information (wheel sensors, radars)

8.5.3.1.12.5. Geoposition from absolute sensors

8.5.3.1.13. *Example: Simple GNSS/IMU sensors in freight wagons*

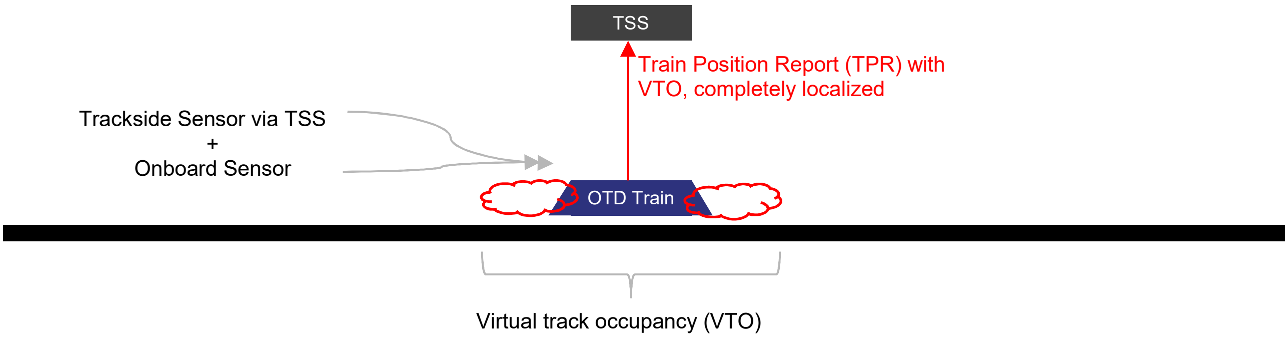
8.5.3.1.13.1. P1, P2, speed, geoposition or train length from secondary/redundant OTD systems

8.5.3.1.14. The train is always responsible to deliver the safe VME to the TSS in Level 3.

8.5.3.1.15. But cheap and precise sensors may be installed at the trackside on a national basis. If the VL acquires this sensor information to temporarily get a higher precision, it does not change his responsibility. The VL has to be interoperable in every country the same way. If less trackside localisation support and data is available, the precision of the VL may be reduced but the VL should still be working safe.

8.5.3.1.16. The VL shall be able to retrieve sensor information from trackside (OCORA/RCA requirement, optional)

8.5.3.1.17. The VL shall work independently from trackside localisation support but can use such data to improve its precision temporarily, if it is available.



8.5.3.1.18. *Example: An BL3 train with onboard integrity detection and without length information wants to drive through an OTD area. The safe length can be measured once by a trackside system (e.g. axle counter + speed monitoring), which can be retrieved by the VL. This could be a good migration solution to come faster to LSL.*

8.5.3.1.19. *Example: Different types of hybrid localization (=trackside+onboard sensors) are possible to make use of traditional block-based interlockings in the migration phase. Typically, P1 is determined onboard while P2 or the virtual MOB length is determined trackside with block based sensors like axle counters.*

8.5.3.1.20. The following combinations of sensors allow the calculation of the virtual track occupancy:

8.5.3.1.20.1. Onboard sensors determine P1 and P2

8.5.3.1.20.2. Onboard sensors determine P1 or P2 to calculate the virtual MOB extent (VME)

8.5.3.1.20.3. Trackside sensors determine P1 and P2

8.5.3.1.20.4. Trackside sensors determine P1 or P2 to calculates the VME

8.5.3.1.20.5. Onboard sensors determine P1 and trackside sensors determine P2.

8.5.4. New sensor technologies

8.5.4.1.1. Hardware abstraction: Localization technologies shall not be described by hardware type in a standard, they shall be described and handled by their characteristics

8.5.4.1.2. Concerning localization component product types there are characteristics like

8.5.4.1.2.1. Frequency of acquisition

8.5.4.1.2.2. Coordinates/Reference System

8.5.4.1.2.3. Need of supporting reference data (like logical or GIS track map)

8.5.4.1.2.4. Calibration/Referencing requirements

8.5.4.1.2.5. Need of augmentation data (like DGPS/EGNOS for GNSS)
8.5.4.1.2.6. “positioning performance model” (variance of the precision)
8.5.4.1.2.7. Timing function for error revelation
8.5.4.1.2.8. Reliability and availability
8.5.4.1.2.9. Immunity and robustness, security
8.5.4.1.2.10. Self sufficiency
8.5.4.1.2.11. Reset requirements (time, process)
8.5.4.1.2.12. Mobility (form, fit, weight, power consumption)

8.5.4.1.3. There are some of these aspects of new localization technologies, that lead to new requirements for TSI CCS CR

8.5.4.1.4. Open Point: It has to be considered, which quantitative capability parameters of localisation technologies shall be uniquely defined in the TSI, and which can be network or vehicle type specific. This trade off – cost of onboard localization technologies versus network capacity and robustness – will need an compromise. But the cheaper the localization technologies get, the smaller this problem will be. But today there should also exist cost efficient solutions for regional lines with low density traffic, not only solutions for dense traffic. Special vehicles that are moving very seldom over a line (e.g. for mowing) shall not be equipped with expensive technologies. The compromise could perhaps be done by defining capability requirements by “vehicle type”.

8.5.4.2. Conversion between different coordinate/reference systems

8.5.4.2.1. The TSS and the OTD system have to share a TPR incl. VME.

8.5.4.2.2. Sensors deliver their information referring to different types of reference systems. (linear/relative, Track No/km, Track No KM-to-KM, Geopos./Geo track atlas in 3D).

8.5.4.2.3. *Example for delivered point positions of sensors:*
- 1424 m distance from last report or from LRBG (relative linear)
- 47.585392,7.5577477, 15.4 (absolute 3D)
- Track 14, km 24.4445
- Block 447 (lies between defined absolute pos like Track XXX from KM….to KM….)

8.5.4.2.4. For interoperability reasons a design decision has to be taken which coordinate and reference systems are used and how they are converted to each other. This decision limits the usability of sensor types.

8.5.4.2.5. The description for TPR is done with the linear relative reference system, that is used in ETCS BL3 today (backwards compatibility).

8.5.4.2.6. Sensors that deliver linear relative distances, km positions on defined tracks, km-ranges on defined tracks and geopositions shall be usable, as long as a bijective conversion to/from the linear relative reference system of ETCS is possible in the TSS and in the OTD system (VL).

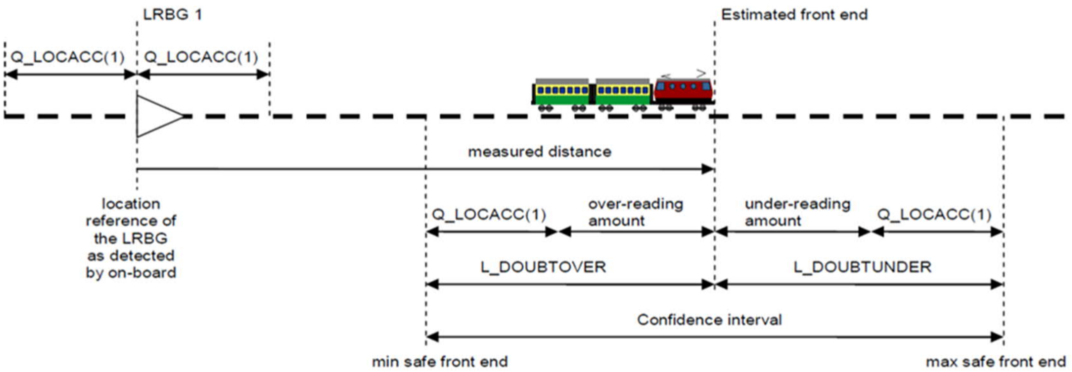


Figure 6: The linear reference system defined by ERTMS subset 026

8.5.4.2.7. Reference points in the linear ETCS positioning are today only LRBG. To make it possible for example to move forwards and backwards between balises (shunting) or reduce the amount of balises additional reference principles shall be implemented that use virtual reference points (for example P1 of the last TPR, only possible with absolute positioning systems onboard).

8.5.4.2.8. The onboard trackmap fulfills several needs coming up with the game changers and the open onboard architecture and should be an optional onboard service. It allows conversions between several sensor coordinate system; it is used in sensor fusion algorythms (higher precision, lower cost); it can store track conditions and available communication connections, track services per point, information for customer information or virtual balise information; it is needed for an self-sufficient fallback TCS.

8.5.4.2.9. To allow conversions between different representations and for the sensor fusion process of onboard localization systems a track map (logical and geopositioned node-edge model) should be available as an onboard service (used by different onboard functions like OTD), that is online synchronized with the TSS.

8.5.4.3. Positioning performance model (PPM)

8.5.4.3.1. The concept of an "increasing confidence interval" is already existing in ERTMS. With new sensor types the variability of sensors may change and may have new factors (depending on their quality and type).

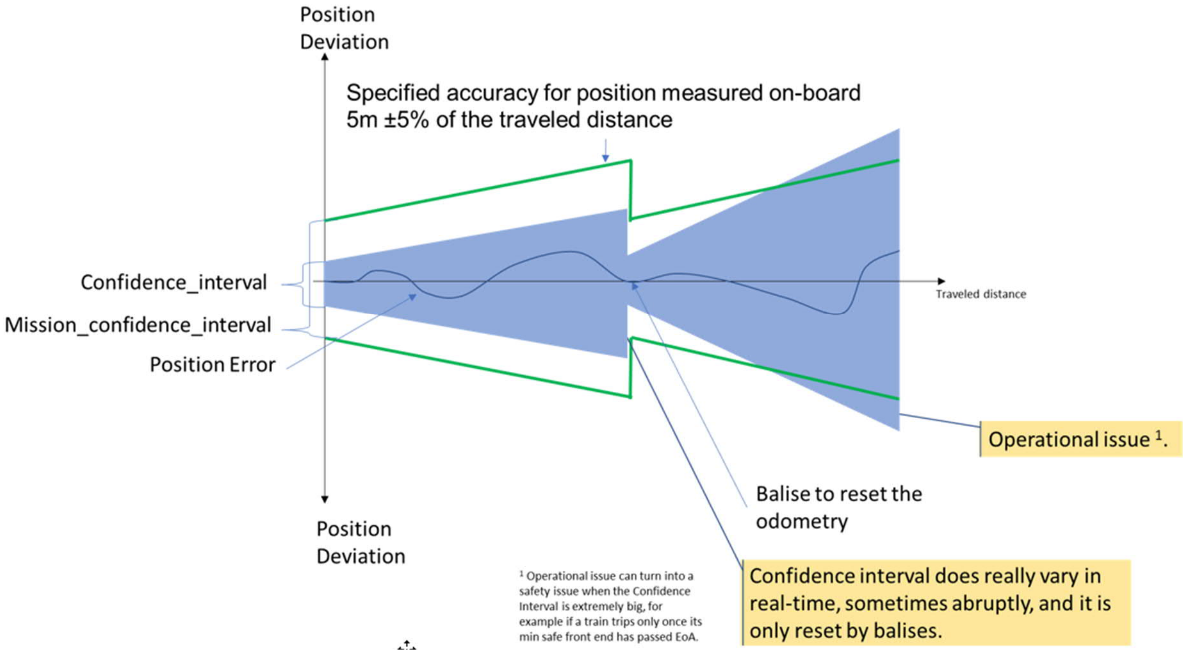


Figure 7: Todays positioning performance model

8.5.4.3.2. The "positioning performance model" (PPM) expresses the precision under certain circumstances. This can be for example:
- The precision is a function of the driven distance from the last referencing point (like in ETCS today) or
- The precision is a function of speed (like for GNSS)
- The precision is a function of time since the last referencing/calibration (like for IMU / inertial sensors)
- The precision is a function of environment parameters (like temperature, rain, DGPS augmentation, etc.)

8.5.4.3.3. Normally sensor fusion algorithms are used for onboard localization, that use different types of sensors. The “positioning performance model” of this sensor fusion is an aggregation (better) than in the single sensor.

8.5.4.3.4. Since new sensor types are added to existing odometry technologies it is expected, that the future variance of precision can be smaller than today.

8.5.4.3.5. The VL (OTD system) shall send the actual positioning performance model (time, speed, distance, environment) to the trackside (TMS), that allows a more precise prediction of the VME.

8.5.4.3.6. Because of the following reasons:

8.5.4.3.6.1. If the PPM includes too much reserves, capacity is wasted. If it has not enough reserves (compared to reality), unwanted or unsafe effects may occur. The optimal PPM should be used at a certain moment (including degraded modes). If it is only defined as a static rule or is not fitting to the actual situation, capacity may be wasted by wrong MA calculations.

8.5.4.3.7. *Example for an unsafe or inefficient CIF: If the precision gets unexpectedly and unpredicted low with a too small “positioning performance model” calculation the virtual track occupancy may jump “backwards” against driving direction. This means, that it reaches out of its MP area and produces perhaps a braking process in the following train.*

8.5.4.3.7.1. For a standing train the precision could be much better than for a moving train.

8.5.4.3.7.2. The TSS has to know a reliable confidence interval, that may occur while the train is driving along an MA, because the MP area must be large enough to include all occurring precisions (confidence intervals).

8.5.4.3.7.3. The OTD has to know its guaranteed general PPM, and its actual precision. Low cost OTD solutions (or cheap fallback systems in degraded modes) may prolong the virtual MOB extent of the train (or standing wagon). This is not per se forbidden and a commercial discussion. Trains can have different length physically. Or they can have different virtual length because of the quality of their OTD system.

8.5.4.4. Acquisition timing function and error revelation (revelation time, fault rate)

8.5.4.4.1. Localization systems have varying acquisition durations and delays, that depend on the circumstances. This can be for example:
- Varying time of data integration (collection) in the sensor fusion because of sensor data quality
- Varying times of sensoric acquisition (e.g. repetition because of faults)
- Delays because of necessary referencing/calibration cycles

8.5.4.4.2. Since OTD and ETCS Kernel (Vehicle Supervisor) are different functional units in the future onboard architecture, the timing of the interface has to follow defined performance parameters

8.5.4.4.3. The average and tolerated maximum time between new TPR shall be defined and exchanged between OTD and ETCS kernel (like today).

8.5.4.5. Efficient shunting movements and manoeuvres

8.5.4.5.1. This efficiency depends on additional features necessary for these scenarios:

8.5.4.5.1.1. A sequence of forward and backwards movements with no time for long start of mission procedures

8.5.4.5.1.2. Unclear braking status (not all “FS” conditions fullfilled)

8.5.4.5.1.3. Remote control (driver beside the train, using ATO GoA2 interface)

8.5.4.5.1.4. Remote emergency stop procedures

8.5.4.5.2. The following requirements shall be implemented (implementation requirements)

8.5.4.5.2.1. Fast start of mission without long train data entry (e.g. just choosing a generic profil with “generic parameters” or technical solutions)

8.5.4.5.2.2. Efiicient MA management
- Granting MA for multiple start/stop/forward/backward movements
- DMI Information about direction of driving

8.5.4.5.2.3. – Remote emergency stops and updates of MA shall be possible at any time

8.5.4.5.3. For non self-propelling MOB (wagons, coaches, etc.) it is assumed, that the following types of solutions are applied in OTD areas (alternatives):

8.5.4.5.3.1. The MOB is localized by the TSS

8.5.4.5.3.2. The MOB cannot move (physically) and is located in an URA

8.5.4.5.3.3. The MOB is located in an URA which borders are protected by fixed or mobile train detection devices

8.5.4.6. Remote ETCS Cab with ATO GoA 2

8.5.4.6.1. In combination with ATO GoA 2-4, especially LSM (or any movement type) may be operated by a remote control system, without using an expensive proprietary remote control system. The minimal requirements for this remote mode are on the air gap:

8.5.4.6.2. Safe transfer of the DMI information/control to a trackside or mobile system

8.5.4.6.3. Automatic stop in case of lost connection to the remote control system

8.5.4.7. High availability of the VL in OTD areas

8.5.4.7.1. For higher operational availability redundant OTD systems shall be usable for the supervision process.

8.5.4.7.2. Switching between two redundant OTD systems (perhaps with lower quality) shall happen seamless (implementation requirement).

8.5.5. Need of augmentation data (like DGPS/EGNOS for GNSS)

8.5.5.1.1. Augmentation data contains additional information for a localization system, which allows to calculate positions with higher precisions.

8.5.5.1.2. A standardized protocol shall be designed to receive different types of augmentation data by the OTD system from the TSS.

8.5.5.1.3. OTD systems should not be completely dependent on augmentation data (interoperability). Augmentation data shall only improve its precision.

8.5.5.1.4. The OTD shall have access to an onboard track map for augmentation reasons.

8.5.6. Joining and splitting

8.5.6.1.1. With every precision OTD has there exists a “last meters” range, where technical supervision needs local safety actors (driver, shunting remote operator, automatic coupling system), because the precision is not high enough. These operations are typically identical between todays L2 operations and L3 or LSL.

8.5.6.1.2. But it is recommended to standardize these operational processes for LSL to harmonize them.

8.5.6.1.3. The general principle for the TCS process is like today. Vehicles can drive to each other with reduced supervision, when speed limit is low and a local responsible system or person has the responsibility for safe movements.

8.5.6.1.4. In areas without TTD, safety considerations about joining and splitting lead to the requirement, that no engine can move undetected (unregistered) by TSS.

8.5.6.1.5. All engines on track shall report a TPR in all modes.

9. Architectural considerations

9.1. Design rules and architectural mindset

9.1.1. LSL and RCA

9.1.1.1.1. This document does not focus on intermediate architectural compromises. This document focuses on a future target solution and a migration path to it.

9.1.1.1.2. RCA (under construction) is a set of FFFiS between standardized functional component product scopes (FRS) in the CCS area.

9.1.1.1.3. RCA can be used partially, especially because of migration reasons. So it allows different types of cab signalling implementations like L2 of today or HL3 with traditional interlockings and RBC.

9.1.1.1.4. LSL is the most advanced cab signalling configuration compatible to RCA, which uses all of its specifications.

9.1.2. Strict design for LSL, minimal design choices

9.1.2.1.1. In LSL, trackside design choices for product developers and investors are minimized and are only defined, if there is an economic reason for scalability because of different application (e.g. high/low traffic density lines).

9.1.2.1.2. Design flexibility is only given in two areas: The quality of localization products, and the density and mix of localization systems onboard and trackside.

9.1.2.1.3. Transactions between systems on the application level are defined for a realistic long term scope even if products are not available today, to reduce the amount of updates and improvements.

9.1.2.1.4. LSL shall be developed in pilot projects until it is mature, and afterwards the standardization of the interfaces (FFFiS) and components (FRS) shall be specified on the basis of their precise technical implementation description (openly available).

9.1.2.1.5. As described in RCA (under construction) all interfaces shall be designed along the strict design rules for "modular safety" (mininized integration safety case workload) and for modular capability based protocols (runtime negotiation of transaction model, mechanisms for upwards- and downwards compatibility and modular protocols).

9.1.3. Mixed technologies

9.1.3.1.1. New types of localization and train integrity systems will enter the market in the next years, with different safety integrity, reliability, availability and precision. They could include components for the following functions

- Mobile geo localization (loco, wagon/coach or train end)
- Mobile linear localization (absolute or relative with driven length)
- Mobile length and/or integrity measurement
- Mobile speed sensors with higher accuracy/reliability
- Linear trackside train localization (like fibre optic sensoring)
- Trackside length measurement
- Low cost trackside block-based localization….etc.

9.1.3.1.2. LSL shall not be built only for one certain localization technology. LSL shall be able to integrate them with standardized interfaces, that transfer abstracted information.

9.1.3.1.3. The RCA can be used already with the onboard locaslization, that is used today, for example to implement a Hybrid Level 3 installation. The quality and performance of new localization systems will increase with the years. LSL shall be able to use them with their actual abilities even in a mixed situation.

9.2. Onboard architecture recommended for LSL

9.2.1.1.1. It is assumed that a modular service (application) architecture will be established onboard. This architecture contains different services/applications and a “Universal vital Control and Command Bus”.

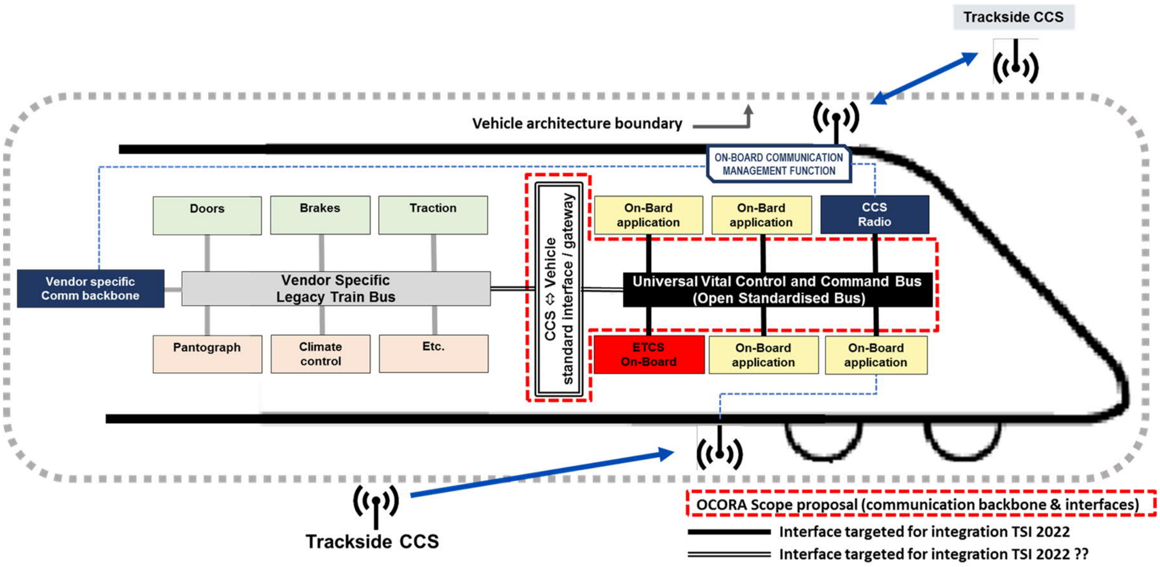


Figure 13: OCORA Perspective TSI 2022

9.2.1.1.2. It is assumed that concerning the LSL scope especially the following functional services are available on the CCS onboard bus on application level with standardized interfaces: ETCS onboard, Vehicle Locator Service, Odometer Service, BTM Service, Virtual Balise Service, TIMS, Track Map Service, Length Service, TED

9.2.1.1.2.1. **ETCS onboard** (called “Vehicle Supervisor” (VS) in RCA)

9.2.1.1.2.2. **Vehicle locator service** (aka “Enhanced Odometer” or OTD System): Delivers continuously the virtual track occupancy to the ETCS onboard and to other location-based services

9.2.1.1.2.3. **Odometer service**: reporting driven distance and speed

9.2.1.1.2.4. **BTM service:** Reads fixed balises and provides their information to the CCS onboard bus

9.2.1.1.2.5. **Virtual Balise service**: Provides stored (received by radio) location-specific data

9.2.1.1.2.6. **TIMS**: Provides train integrity information

9.2.1.1.2.7. **Track map service**: Logical node/edge+length, and 3D representation

9.2.1.1.2.8. **Length Service**: Provides a reliable train length

9.2.1.1.2.9. **TED**: Train Ende Devices, which absolute or relative report train end positions (connected by radio or cable)

9.2.1.1.3. The interaction of the services can be based on push or pull mechanisms.

9.2.1.1.4. The applications/service could run virtualized on the same runtime environment.

9.3. Trackside architecture (TSS)

9.3.1. Type of interlocking/RBC configuration

9.3.1.1.1. To understand the limitations and requirements the localization precision (could also be seen as block length in the TSS) again plays a central role. But also the type of the TSS is important for an LSL trackside architecture.

9.3.1.1.2. LSL is only possible when the OTD precision fulfils the operational needs in all scenarios.

9.3.1.1.3. For the TSS two general types shall be distinguished here:

9.3.1.1.3.1. "**Block-occupancy based TSS**" (BO-TSS, "traditional IXL") with typically larger blocks, that are manually configured in the TSS. The BO-TSS do not work with the block length or virtual train extent. The topology is just a chain of block IDs. The fixed blocks occupancy may be detected by one sensor (like axle counter) or by a mixed sensor configuration (hybrid). The BO-TSS have fixed configured and location specific rules, which block ID is trafficable under which block IDs occupancy constellation. Trafficable routes made of blocks are converted (in the RBC) to a geometric representation to before sending an MA to a vehicle.

9.3.1.1.3.2. "**Occupancy-location based TSS**" (OL-TSS, aka "geometric interlocking", "L3 interlocking", "Advanced protection system" (APS in RCA), "ETCS interlocking"). The OL-TSS retrieve out of every type of sensor information directly the geometric reference on the track map. They combine different types of sensors (TPR from onboard, trackside) to calculate the geometric extent of an occupancy. No fixed configuration about blocks is stored.

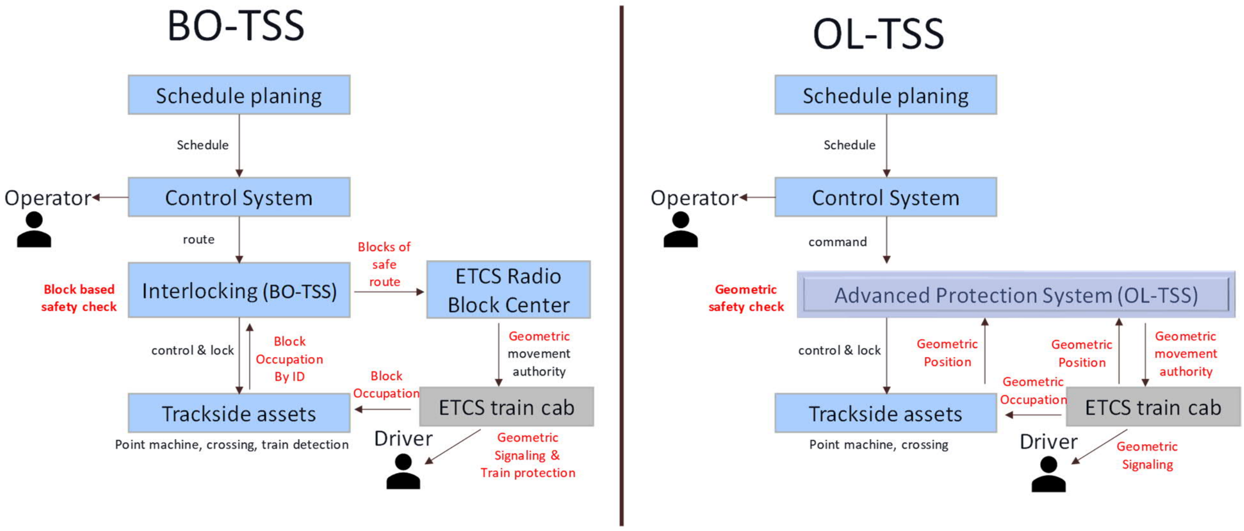


Figure 8: Block-occupancy versus occupancy-location based TSS

9.3.2. Using existing interlockings (BO-TSS) for LSL

9.3.2.1.1. LSL generates the requirement, that the occupancy information for the safety logic can also be calculated only by the OTD information in the TPR from the vehicle, which is geometric (relative distances to a reference point).

9.3.2.1.2. Safeguarding LSL with an BO-TSS is possible, by converting geometric occupancy information into block IDs which are needed inside of the BO-TSS safety logic.

9.3.2.1.3. Because of the "always located", "no operational workarounds" and "no double occupancy" rules of LSL the predefined blocks in the BO-TSS will get small in this case to reach operational efficiency.

9.3.2.1.4. Because of the short blocks the data preparation and management for the block configuration is a high workload for an BO-TSS.

9.3.2.1.5. So it is assumed and recommended, that OL-TSS (like APS) are used for LSL.

9.3.2.1.6. Upgrading existing interlockings (BO-TSS) to an OL-TSS is a very large software change and normally needs an exchange of the complete IXL logic (but not of the trackside assets) and a completely new safety case. But it is possible in general with interlockings, that have an upgradeable architecture concerning their software.

9.3.2.1.7. The architectural scheme for the OL-TSS has one very important new logical function, called "object aggregation" in the RCA. It allows to connect different sensor mixes and a sensor redundancy with seamless transition between the aggregation modes.

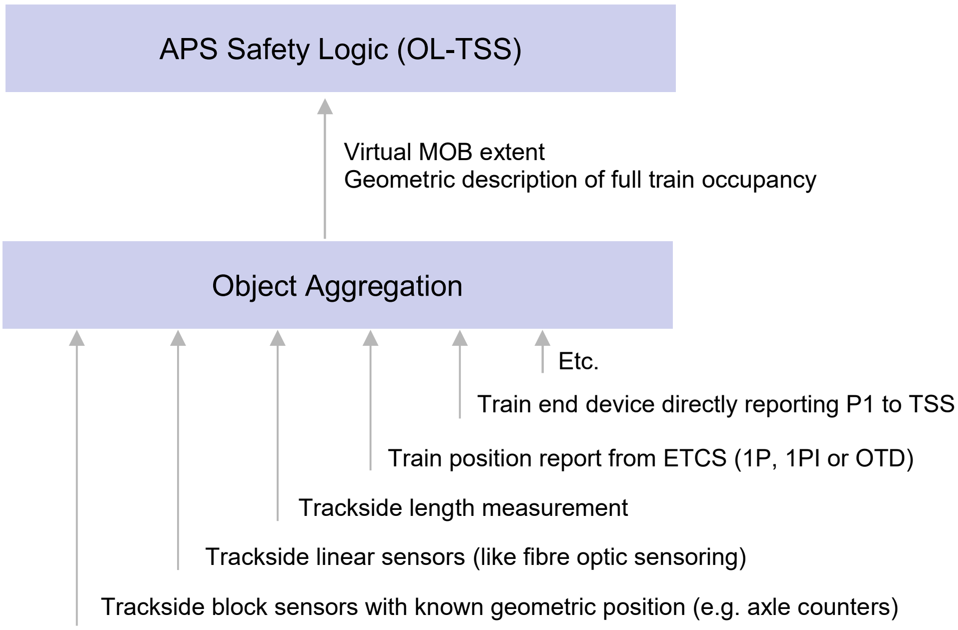


Figure 9: Object aggregation as a new trackside function in the TSS

9.4. Requirements concerning low life cycle cost: Scalable architecture

9.4.1.1.1. The different line and traffic types lead to different safety targets, performance targets and affordability's.

9.4.1.1.2. Different targets lead to different product qualities and abilities and different asset densities or product combinations for the localization

9.4.1.1.3. The lifecycle and age structure of the CCS equipment on tracks and vehicle may lead to the economic strategy to mix old equipment with new equipment.

9.4.1.1.4. The component products, that implement LSL requirements shall be used in many different railway environments, like for example high density mainlines, regional lines, urban lines, etc.. without change of interface.

9.4.1.1.5. The concept shall describe a scalable design concerning safety, availability, performance and cost. The scalability has to be assured by defining open ranges for the ODT system characteristics and by allowing combination of different localization products.

9.4.1.1.6. Existing TTD like axle counters and track circuits shall be integratable into the implementation architecture of LSL.

10. TSI CCS standardization and and change requests

10.1. Roadmap and standardization process

10.1.1. Operational CR with impact on the interoperability

10.1.1.1.1. The operational CR with impact on the interoperability will be ready for the TSI CCS 2022 in time.

10.1.2. Architectural CR with impact on the interoperability

10.1.2.1.1. The full architectural specification for LSL (for TSI CCS, RCA, OCORA) shall be developed and defined with FRS up to 2021. Interfaces (Draft FFFiS) and (Draft) architecture shall be defined openly (no IPR or patents). These Drafts (specification candidates) could perhaps be validated in a technical opinion from ERA.

10.1.2.1.2. Complete pilot projects or prototypes (compliant to the drafts, with real operation) for LSL shall be used to create a precise specification without ambiguities or too much design choices. They shall become reference implementations.

10.1.2.1.3. The pilots shall be implemented by voluntary partners. Their result can only be used for the standardization process, if the projects are compliant to certain rules, which are for example: Open documentation (human/system/environment interfaces FFFiS, components FRS); Rules for the requirement decision process and for the funding of developments and pilot cost; openness for participants that can bring in component products as black boxes for PiL testing (product in the loop testing); rules for public available specifications; exceptions concerning the TSI compliance; investment assurance for the pilot investors; etc..

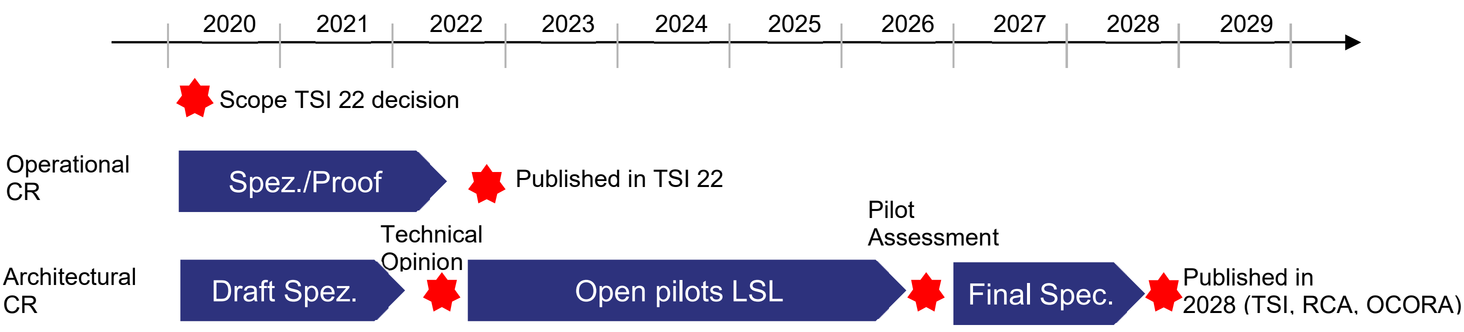
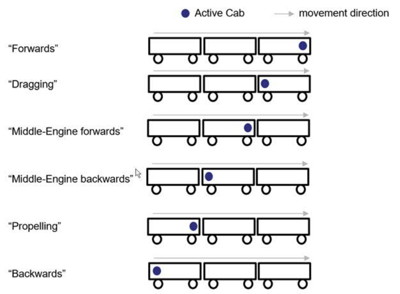


Figure 12: Roadmap

10.2. Operational CR with impact on TSI CCS and interoperability

LSL Requirement	CR Name (s)	Comments
8.4.2.1.1 All movement types supervised a. Leading Engine can be (in driving direction) at front, in the middle or at the end b. The "orientation" of the cab can be forwards or backwards Combining a. and b. there are 6 types of movements, that shall be supervised: 1. „Forwards": Cab forwards, leading engine in front position 2. "Dragging": Cab backwards, leading engine in front position 3. „Middle-Engine forwards ": Cab forwards with leading engine in the middle 4. „Middle-Engine backwards ": Cab forwards with leading engine in the middle 5. "Propelling": Cab forwards, leading engine in end position 6. „Backwards": Cab backwards, leading engine in end position  Figure 11: Cab in any position and orientation	Cab anywhere supervision	
8.4.1.1.3 All track bound MOB (self-propelling or not) shall be always located (mandatory in undegraded mode) and supervised in Level 3 concerning their movements, speed and their track occupancy. Supervised MOB are also wagons, coaches, and trainparts without leading engine.	Radio Session and Position reports in all modes / state (CR1350)	Includes "always located"
8.5.2.2.3 All movements of the train can be technically blocked by TSS in all modes if no localization is available, also in degraded situations (optional line specific condition).	Radio Session and Position reports in all modes / state (CR1350)	Necessary because of high risk in L3: "undetected movements" outside of the allowed areas.
8.5.6.1.5 All engines on track shall report a TPR in all modes.	Radio Session and Position reports in all modes / state (CR1350)	Improves safety case in OTD areas, especially for joining and splitting

10.3. Architectural CR with impact on interoperability

LSL Requirement	CR Name	Comments
8.5.4.2.7 Reference points in the linear ETCS positioning are today only LRBG. To make it possible for example to move forwards and backwards between balises (shunting) or reduce the amount of balises additional reference principles shall be implemented that use virtual reference points (for example P1 of the last TPR, only possible with absolute positioning systems onboard).	Enhanced onboard localisation	To make it possible to move forwards and backwards between balises or to reduce the amount of fixed balises
8.5.4.2.9 To allow conversions between different representations and for the sensor fusion process of onboard localization systems a track map (logical and geopositioned node-edge model) should be available as an onboard service (used by different onboard functions like OTD), that is online synchronized with the TSS. Condition (interoperability): If the TSS cannot provide the (fault free) track map or the train is not able to use it, the VL must still be able to send a VME (perhaps with lower precision).	Enhanced onboard localisation	Track maps reduce the cost for the VL / increase the precision and reliability / are necessary for some used technologies. Track maps are helpful when optional trackside services are introduced. The map should for example store the virtual balise data or alternative connection addresses, which are available also in disconnected situations.
8.5.4.3.5 The VL (OTD system) shall send the actual positioning performance model (time, speed, distance, environment) to the trackside (TMS), that allows a more precise prediction of the VME.	Enhanced onboard localisation	Necessary to mix trains with different localization performance on a track, or for degraded localization systems
8.5.5.1.2 A standardized protocol shall be designed to receive different types of augmentation data by the OTD system from the TSS.	Enhanced onboard localisation	
8.5.5.1.3 OTD systems should not be completely dependent on augmentation data (interoperability). Augmentation data shall only improve its precision.	Enhanced onboard localisation	

10.4. Architectural Requirements for RCA and OCORA (no TSI impact)

LSL Requirement	Comments
8.5.2.1.2 Every MOB inside of the OTD area and outside of a usage restriction area (URA) is known/connected to the TSS at all times (no degraded mode) and is completely localized only because of its own active position reports (even in stand-by), including integrity information.	

8.5.2.1.3 The borders of URA and TTD areas, that cannot be protected physically (e.g. point) shall be protected by TTD devices (e.g. fixed or mobile train detection) that can detect a MOB moving without OTD.	
8.5.2.2.1 If the VL is not able to send a valid VME, the train stops immediately inside of his MA and the TSS sends no new MA.	
8.5.2.2.6 If the connection gets lost, the MA cannot be updated and the train is “trapped” in his actual MA (MP), until the connection is established again, or fall-back localization and authorization processes shall be used.	
8.5.2.2.7 A loss of integrity of a train in an OTD area results in a safety reaction of the TSS for the following trains.	
8.5.2.2.8 The operational reaction to a fault of the OTD system in an OTD area is the stop of the train, since the ERTMS onboard cannot supervise the speed and distance anymore.	
8.5.3.1.12 For a stable migration and upgradeability of the onboard architecture the interfaces from the OTD system to secondary sensor systems shall be standardized.	
8.5.4.2.6 Sensors that deliver linear relative distances, km positions on defined tracks, km-ranges on defined tracks and geopositions shall be usable, as long as a bijective conversion to/from the linear relative reference system of ETCS is possible in the TSS and in the OTD system (VL).	
8.5.4.6.2 Safe transfer of the DMI information/control to a trackside or mobile system	For remote ETCS CAB, for example in combination with ATO GoA2
8.5.4.6.3 Automatic stop in case of lost connection to the remote control system	For remote ETCS CAB, for example in in combination with ATO GoA2
8.5.4.7.1 For higher operational availability redundant OTD systems shall be usable for the supervision process.	
8.5.4.7.2 Switching between two redundant OTD systems (perhaps with lower quality) shall happen seamless (implementation requirement).	
9.2.1.1.2 It is assumed that concerning the LSL scope especially the following functional services are available on the CCS onboard bus on application level with standardized interfaces: ETCS onboard, Vehicle Locator Service, Odometer Service, BTM Service, Virtual Balise Service, TIMS, Track Map Service, Length Service, TED	
8.5.3.1.9 The leading engine should be able to receive positions from all engines and train end devices to calculate integrity and length.	

10.5. Deeper analysis necessary (and impact analysis)

LSL Requirement	Comments
Low Cost ERTMS onboard for low cost vehicles	Necessary for special vehicles, other-wise TTD is needed or processes are very inefficient
Fast start of mission for shunting movements and ma-noeuvres	Necessary for efficient shunting move-ments in FS mode

10.6. Requirements for migration and implementation

LSL Requirement	Comments
7.4.1.1.1 ERTMS Vehicles with BL3 shall be able to run on LSL lines, if they are able to send the train position report (TPR) including integrity and length information to the TSS with high reliability – or if they are able to send a TPR and the trackside below every part of the vehicle is equipped with TTD.	

11. References

Ref-ID	Owner, Doc Number, Doc Title	Version	Release Date
[1]	Reference CCS Architecture, https://ertms.be/workgroups/ccs_architecture	Beta	5.9.2019