CLUG DEMONSTRATION OF READINESS FOR RAIL - CLUG 2.0

D6.4 BUSINESS CASE FOR LOC-OB

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EXECUTIVE SUMMARY

This document is a deliverable of the "Work package 6 - Communication, Dissemination, Exploitation and Business Case" of the CLUG 2.0 project which stands for Certifiable Localisation Unit using Global Navigation Satellite System (GNSS) in the railway environment. The project is one more milestone in transforming the way of train localisation using technologies such as GNSS and European Geostationary Navigation Overlay Service (EGNOS) which are among the "game-changing" technologies for future digital and automated railway operations. This document, "D6.4: Business case for GNSS based absolute safe train positioning", provides a cost-benefit-analysis (CBA) that evaluates the economic feasibility of implementing GNSS-based onboard localisation technology (LOC-OB) as proposed in the CLUG 2.0 project. The aim is to assess the potential for LOC-OB to replace traditional localisation technology using Eurobalises and legacy odometry systems, and to provide recommendations for its adoption by infrastructure managers (IMs) and railway undertakings (RUs).

The document evaluates three business cases, one for each of the contributing infrastructure managers with national applications for DB and SNCF and a single-line application for SBB. Each business case considers two sub-scenarios focussing on the transition from legacy odometry to LOC-OB in the context of ETCS L2 and ETCS moving block hybrid respectively.

The core benefit considered within this analysis lies in the reduced need for Eurobalises, resulting in reduced investment and operation and maintenance costs when equipping lines with ETCS. In order to avoid fixed assumptions about the key parameter of Eurobalise reduction ratios, the analysis employs a sensitivity-based approach, identifying the minimum reduction ratio required to achieve a positive business case and evaluating scenarios ranging from 0% to 70% reduction. The methodology further incorporates local parameters specific to DB, SBB and SNCF, ensuring adaptability to varying conditions across the different railway networks, while also applying consistent principles to ensure comparability.

The cost-benefit analysis confirms that the implementation of LOC-OB technology delivers positive economic outcomes across all evaluated scenarios, despite quantifying only the most immediate benefit of LOC-OB, Eurobalise reduction. The results demonstrate that LOC-OB provides significant operational cost savings through Eurobalise reduction, driving the overall cost reduction on the infrastructure side which is fully able to offset required increased investments into onboard technology. The analysis highlights that the economic feasibility of LOC-OB is robust for different railway systems and under varying operational contexts. These findings underscore the potential of LOC-OB to deliver long-term financial benefits for railway systems.

The analysis sets clear targets in regard to the Eurobalise reduction ratio and time of availability for LOC-OB technology to be profitable in its implementation. Infrastructure managers (IMs) need to synchronise their ETCS and LOC-OB rollout, optimising the transition from legacy odometry to LOC-OB in order to maximise Eurobalise reduction benefits. Fleet homogenisation is advised to reduce engineering costs and improve outcomes for railway undertakings (RUs). Collaboration between IMs and RUs is essential to manage the cost transfer from trackside to onboard and ensure mutual benefits.

LIST OF ACRONYMS

ACRONYM	CONCEPTS
ATO	Automated Train Operation
CAPEX	Capital Expenditure
CBA	Cost Benefit Analysis
CCS	Control-Command and Signalling
ERA	European Railway Agency
ERJU	Europe's Rail Joint Undertaking
EUG TO	ERTMS User Group Track Occupancy
EUSPA	European Union Agency for the Space Programme
ETCS	European Train Control System
ETCS MB	ETCS moving block
ETCS-OBU	ETCS Onboard Unit
GNSS	Global Navigation Satellite System
IM	Infrastructure Manager
LOC-OB	Localisation Onboard Unit
MA	Movement authority
MBH	Moving block Hybrid or Hybrid moving block
maxSFE	Maximum Safe Front End
NIP	National Implementation Plan
NPV	Net Present value
OPEX	Operating Expenses

ACRONYM	CONCEPTS
QTY	Guantity
RBC	Radio Block Centre
RU	Railway Undertaking
TDS	Trackside Train Detection System
TIMS	Train Integrity Monitoring System
TMS	Traffic Management System
UNISIG	Union Industry of Signalling

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1 Introduction

1.1 Purpose of the document

This document provides a cost-benefit analysis (CBA) for the onboard localisation concept (LOC-OB) as part of the CLUG 2.0 project. In accordance with the CLUG 2.0 target architecture[1], the LOC-OB concept this document refers to is confined to GNSS-based onboard localisation technology. Accordingly, the LOC-OB acronym is being used to only refer to GNSS-based LOC-OB. The document intends to provide a top-down approach overview for which scenario(s) the implementation of safe onboard localisation technology shows a beneficial business case for Control-Command and Signalling (CCS) applications.

1.2 Scope of the document

The scope of the present document is to explicitly examine the advantages and disadvantages of implementing GNSS-based onboard localisation technology (LOC-OB) in accordance with the CLUG 2.0 target picture in a given system. Accordingly, the document only examines costs and benefits directly related to the transition in localisation technology itself, providing qualitative and, where possible, quantitative analyses. Building upon the item contribution classification undertaken in the cost-benefit analysis for the EUG Track Occupancy Concept [1], this document will only concern itself with items from Group 1 (Figure 1), namely the reduction of required Eurobalises by implementing LOC-OB. Since items in Group 2 do not directly relate to localisation technology and instead concern themselves with train integrity management, they are not considered within this document. Implementation of LOC-OB additionally contributes to additional items classified under Groups 3 and 4. However, since this document follows an approach of isolating costs and benefits directly and solely related to localisation, these additional related items are not being considered in the quantitative part of the CBA and will only be touched upon in a qualitative reflection.

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[1] The CLUG 2.0 functional architecture is displayed and further discussed in chapter 4.3.

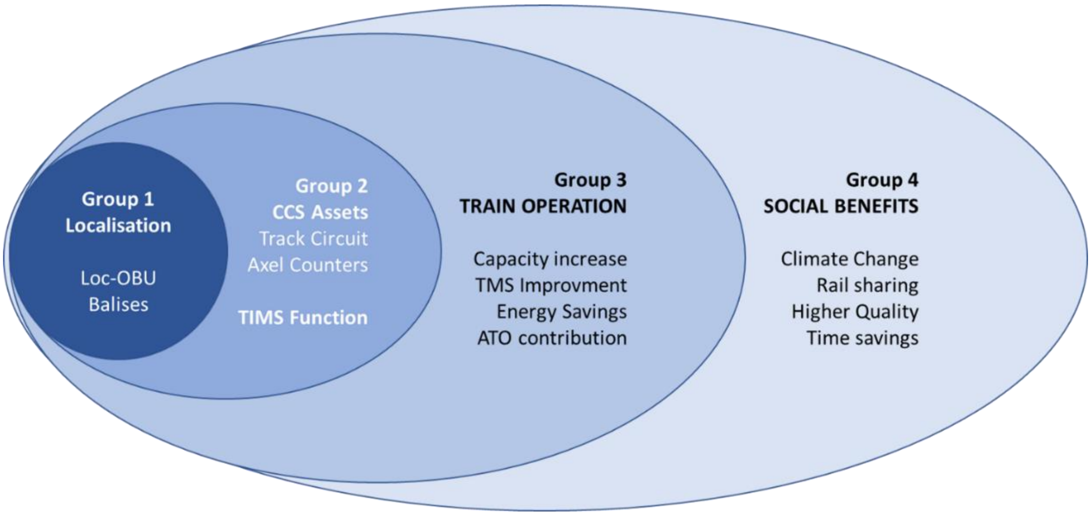

Figure 1: EUG TO CBA item contribution classification [1]

The CBA aims at identifying all sector-wide costs for the development and rollout of a LOC-OB technology and comparing them against the sector-wide benefits the implementation of LOC-OB holds. Corresponding with the infrastructure managers - DB, SBB & SNCF - contributing to the document, the CBA examines the railway systems for Germany, Switzerland and France with individual business cases while using a consistent CBA model. This approach allows for a differentiated assessment of the economic feasibility of LOC-OB implementation while ensuring comparability between the results for the national railway systems. Additionally, while this document builds upon the CBA model used in the EUG Track Occupancy concept, it goes beyond it by modelling a transition from existing odometry technology to LOC-OB, taking into account limitations of rolling out LOC-OB and enabling a more realistic estimation of costs and benefits.

1.3 Use of the document

This document can be used for getting an overview of the different economic costs and benefits introduced by implementing LOC-OB and, once consolidated, to drive possible decisions for implementing the LOC-OB concept.

1.4 Target group

This document is intended for the EUSPA members. Additionally, this document shall be used as an input for the ERJU System Pillar.

1.5 Related documents

Document	Issued by	Issue date	Version
Cost-Benefit Analysis for the Track Occupancy Concept	RCA	31/01/2023	2.0.1
CBA for E-GNSS-based Virtual Balise within ERTMS and progress monitoring of E-GNSS adoption in public transport	GSA	31/01/2018	1.1
D6.2 Cost-Benefit Analysis: Case studies	STARS	26/11/2018	0.8
Cost Benefit Analysis	GRAIL	08/08/2007	1.0

2 Scenario comparisons

A cost-benefit analysis (also called business case in this document) aims to compare the cost of an investment with the projected benefits as a basis for making investment decisions. The cost should cover all aspects of the capital expenses (CAPEX) and the operational expenses (OPEX) for the selected investigation period. The investigation period should be over a realistic time frame in line with the nature of the project so that the costs and benefits over the long term are considered.

For a balanced investment decision, it is recommended to compare two different scenarios: a reference scenario against a target scenario. This CBA will therefore perform a comparison of two main scenarios:

- Reference scenario: safe train localisation as implemented today in ETCS based on onboard odometry.
- Target scenario: safe train localisation relies on LOC-OB using GNSS.

The comparison of scenarios will be performed for different levels of ETCS operations of the target scenario. The first analysis focuses on ETCS level 2 (ETCS L2) operation using a fixed block approach where the extremities of the block sections are at fixed locations. A train is only able to move from one block into the next when the block ahead is clear [2]. On the other hand, the second analysis evaluates an operational scenario of ETCS L2 with TIMS using a moving block approach where the track occupancy is train-centric and can be dynamically defined by the maximum safe front end (maxSFE) of each train (Figure 2). In moving block, the track section occupied by the train is continuously being adjusted based on the train's safe length and maxSFE. The moving block scenario has been considered separately because of the need for additional balises - especially in large stations - needed to achieve the minimum operational performance expected from the technology as will be outlined in detail in chapter 2.2. However, since this CBA only focuses on assets from Group 1 as discussed in chapter 1.2, hybrid moving block operations which require trackside train integrity monitoring equipment such as axle counters or track circuits for trains which are not equipped for full moving block capability, will be considered. This implies that all trackside train detection systems (TDS) are excluded from consideration because no changes are made to the TDS between the reference and target scenario.

These two sub-comparisons aim to explicitly examine the economic advantages and disadvantages of implementing GNSS-based onboard localisation technology in a network which operates with any kind of system. The document examines both systems - ETCS L2 fixed block and moving block hybrid - in separate scenario comparisons in order to examine the economic effect of implementing LOC-OB when a network is equipped with only fixed block system, as well as on a network that is also equipped with moving block. The scenarios are further explained and visualised in the following sub-chapters.

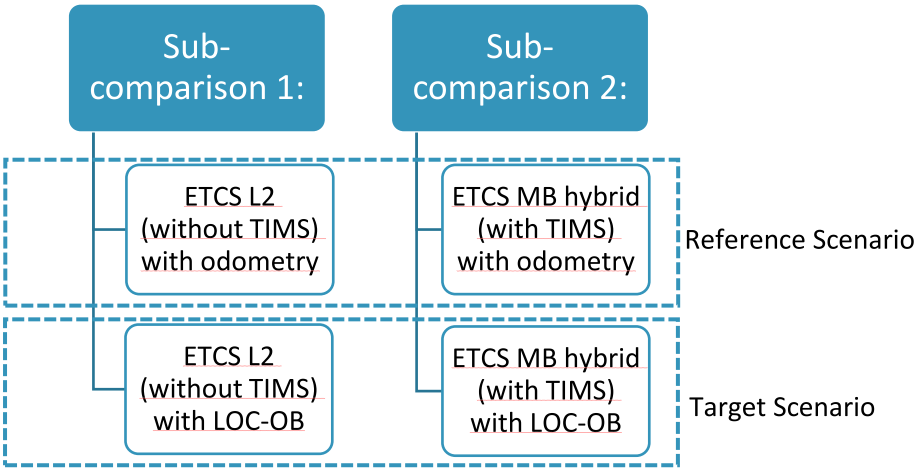

Figure 2: Overview of CBA scenario comparisons

2.1 Sub-comparison 1: ETCS L2 fixed block

Within this analysis, both the reference and target scenario comprise of a rail network and its associated rolling stock fully compliant with ETCS Level 2. In both scenarios, track occupation as the basis for train protection is determined by TDS. Most of the networks use track release installations such as track circuits or axle counters to determine track occupancy. Track circuits continuously prove that the section they are monitoring is not occupied, while axle counters determine if the same number of axles that entered a track section corresponds to the same number of axles that left. The interlocking safety logic then uses the information from either a track circuit or axle counter to determine when to block or release a route section.

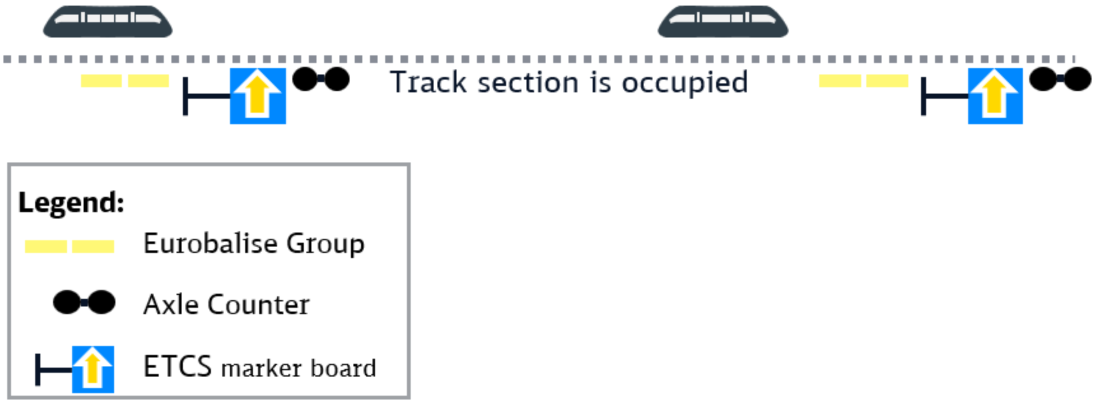

Figure 3: Schematic view ETCS L2 fixed block operation

Reference and target scenarios for the first comparison differ solely in the approach of determining the front-end localisation of the train (Figure 3). In the reference scenario, the location of the train is determined using Eurobalises on the track, and a Eurobalise reader and an odometry system on the train. In the target scenario, the train needs to be equipped with an onboard localisation unit (LOC-OB), enabling continuous and safe onboard localisation using GNSS. The LOC-OB, consisting of a GNSS and EGNOS unit and antennas, an Inertial Measurement Unit (IMU) and speed sensors for safe train localisation, completely replaces the existing odometry system. Besides the installation of a LOC-OB on the train, a digital map needs to be provided and maintained. This implies additional costs for infrastructure managers (IMs) and railway undertakings (RUs) but enables benefits such as the reduction of Eurobalises in the field and existing GNSS solutions for other applications on the train.

There are different types of messages transmitted by Eurobalises and not only localisation messages. Also, Eurobalises would still be needed in some track sections where the GNSS signals could be limited, e.g. in tunnel sections, and for backwards compatibility for trains without LOC-OB. Therefore, only a part of them can be removed. Consequently, rolling stock still needs to be equipped with Eurobalise readers. The reduction of Eurobalises on the track needed for safe and efficient ETCS operation constitutes the main benefit quantified within this CBA. Eurobalise reduction does not only reduce the CAPEX investment into the Eurobalises itself, but it also impacts the cost of other related processes such as its planning, installation and maintenance.

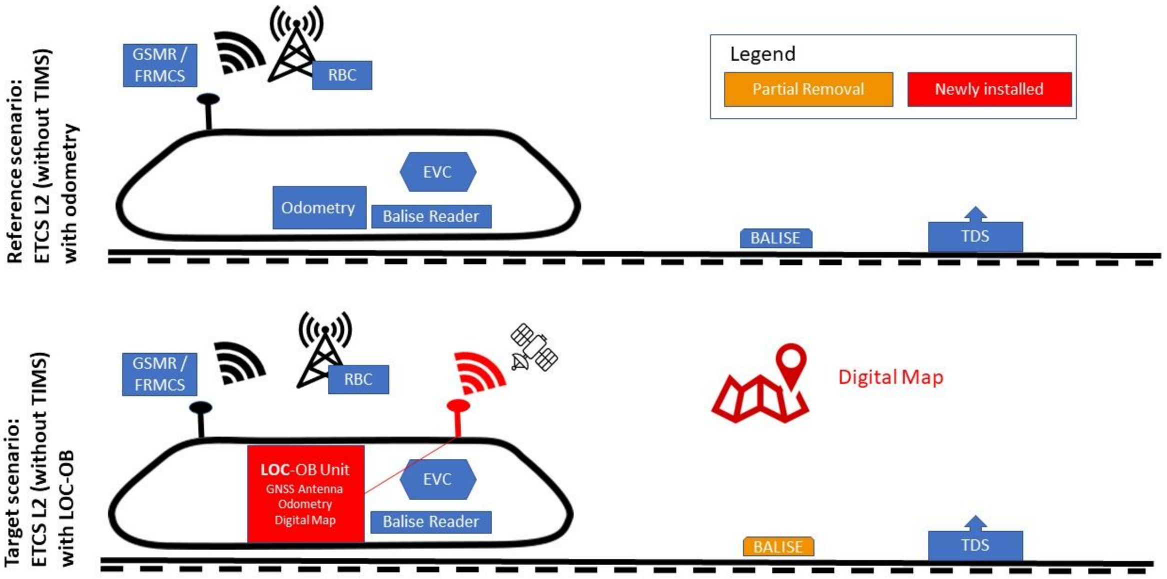

Figure 4: ETCS L2 fixed block: Reference scenario versus target Scenario

2.2 Sub-comparison 2: ETCS L2 moving block

Scenario comparison 2 focuses on ETCS Level 2 hybrid moving block, formerly ETCS hybrid Level 3, operation where train integrity and safe train length are managed within the scope of the onboard ERTMS system for moving block equipped trains, but trackside train detection devices (TDS) are still relevant for non-moving block trains (Figure 5).

Although this document assumes that the train integrity is being managed by the onboard Train Integrity Monitoring System (TIMS), the availability and implementation of such a system will not be evaluated in this CBA. This is because CLUG 2.0 is focused primarily on localisation and consequently, the analysis focuses solely on costs and benefits related directly to localisation. All costs and benefits arising from TDS and the likely reduction potential are not within the scope of this CBA.

The continuous reporting of localisation and train integrity data enables moving block operation, where instead of dividing the track into fixed blocks, track occupation is defined in real-time as safe zones around the train (Figure 5**Error! Reference source not found.**), based on the information on the integrity and localisation provided by the train.

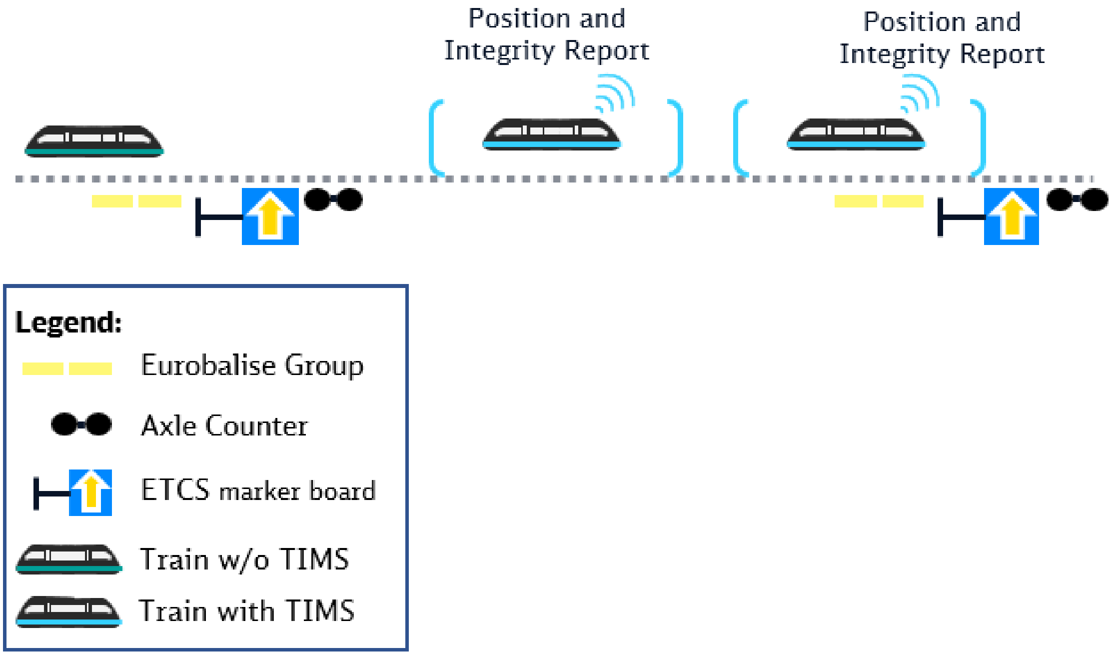

Figure 5: Schematic view ETCS L2 moving block hybrid operation

Sub-comparison 2 shares the same differences between the reference and target scenario as sub-comparison 1. In the reference scenario, the localisation of the train occurs trackside through Eurobalises that are being scanned by the onboard Eurobalise reader in interaction with an onboard odometry system. In the target scenario, localisation is being performed fully onboard, continuously and GNSS-based by the LOC-OB unit. For this, the same vehicle-side adaption as well as a suitable digital map is needed (Figure 6), incurring the same costs for Infrastructure Managers (IMs) and Railway Undertakings (Rus) as in sub-comparison 1.

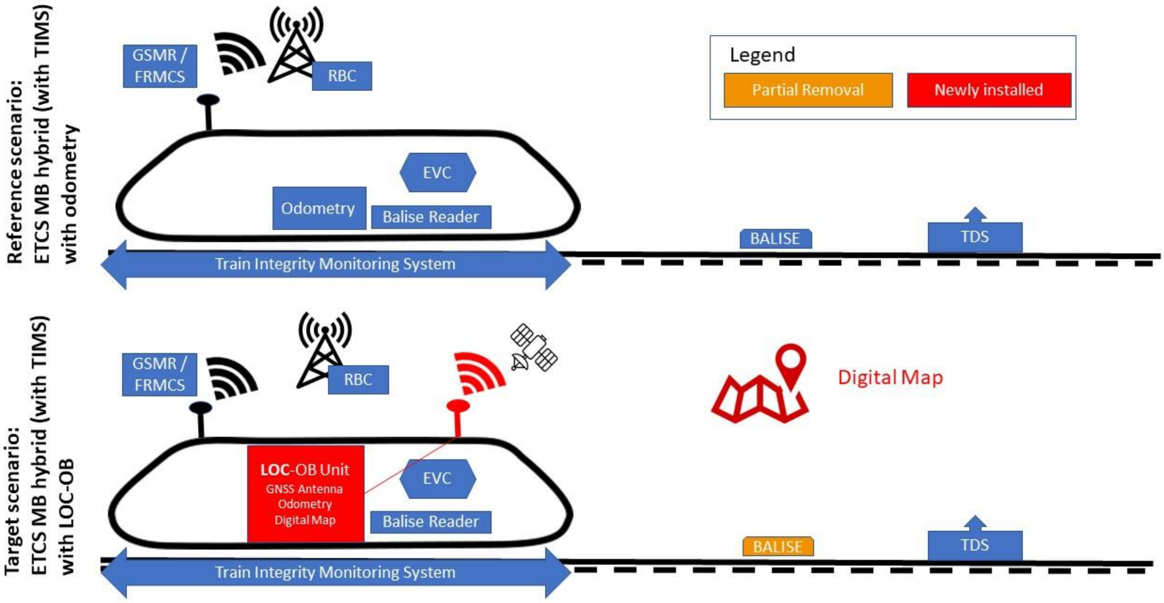

Figure 6: ETCS L2 moving block hybrid: Reference scenario versus target Scenario

In general, moving block operation enables vehicles on the track to travel in closer succession and IMs target higher operational performance with this technology. This necessitates the use of additional Eurobalises to reset the confidence interval, thereby shortening the headway times especially in station heads [3][3][3][3][3]. This document assumes that the continuous localisation data provided by LOC-OB leads to smaller confidence intervals regarding the position of the train when compared with legacy odometry localisation using Eurobalises (see Figure 7 as adapted from the ERTMS/ETCS System Requirements Specification [4]). This assumption is based on the LOC-OB system requirements which limits the confidence interval to a maximum of 20 meters close to stopping points, 10 meters each for the over estimation and under estimation [5].

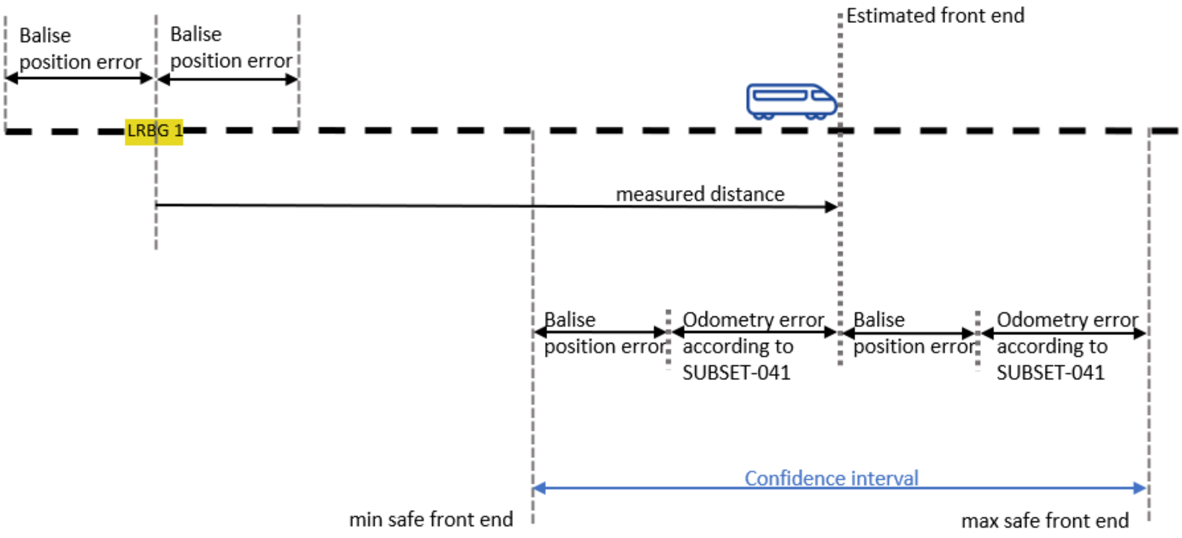

Figure 7: Mechanism for the determination of confidence interval using Eurobalises

The mechanisms and interaction between the confidence interval and its effect on operational performance are described in detail as follows:

- The target speed monitoring is based on the permitted curve. Therefore, if the confidence interval is high, it will negatively affect the running time in areas of speed change because the train has to reduce its speed earlier/ increase speed later than necessary, leading to an impact on the infrastructure blocking time (see Figure 8).
- The confidence interval also plays a role in determining the indication point. A large confidence interval would mean an earlier indication point (leading to premature braking of the train).
- If the routes are released by means of train position reports and train integrity reports as is the case in moving block operations, the minimum safe rear end will also affect the occupation time (due to the clearance time component of the blocking time) and thus the infrastructure usage.

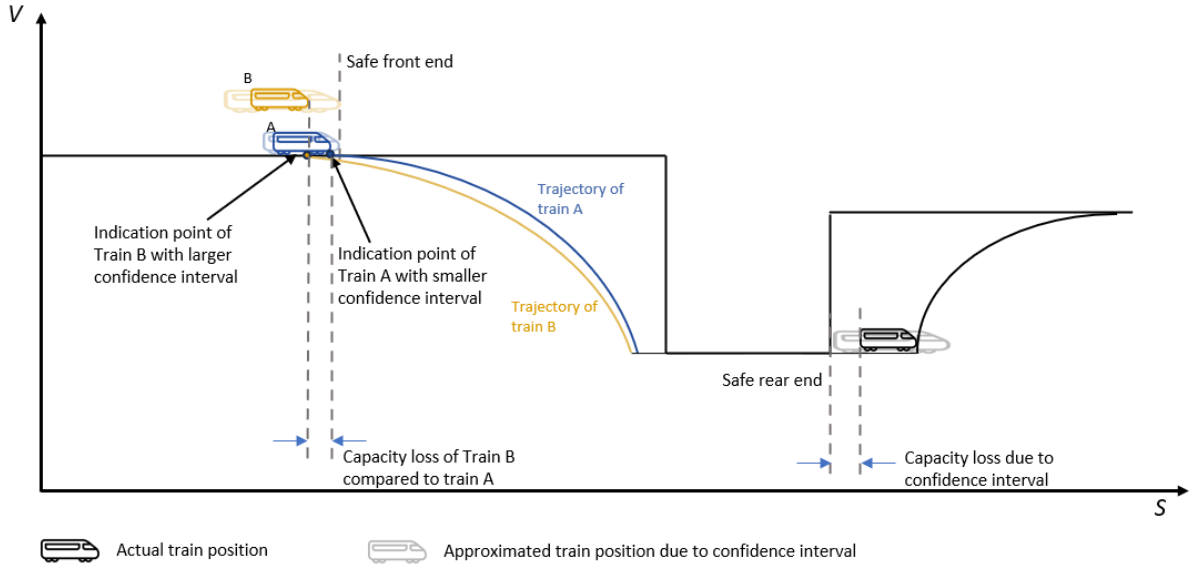

Figure 8: Effect of confidence interval on operational performance

The increased Eurobalise density needed for the reference scenario with moving block, consequently implies that there is more potential for the total number of Eurobalises that can be saved in the target scenario.

2.3 Transition between scenarios

In the target scenarios analysed in this CBA, a migration strategy mostly based on the national implementation plan of each country is considered. This means that a full reference scenario is not compared against a full target scenario, rather a more realistic target scenario which considers a transition from reference to target scenario is analysed (see Figure 9). When considering the reduction potential for Eurobalises through the implementation of LOC-OB, it is assumed that as soon as a part of the network is equipped with trackside elements for ETCS L2 operation, the already installed Eurobalises will not be decommissioned. This is because the additional cost incurred by the replanning of the track section, the physical removal of Eurobalises and all related opportunity costs arising from the necessary trackwork would likely exceed the costs saved by reduced Eurobalise investment and maintenance. It is also assumed that not all vehicles need to be equipped with a LOC-OB unit when transitioning to the target scenario, but only the vehicles required to run on tracks that still need to be equipped with ETCS when LOC-OB is available.

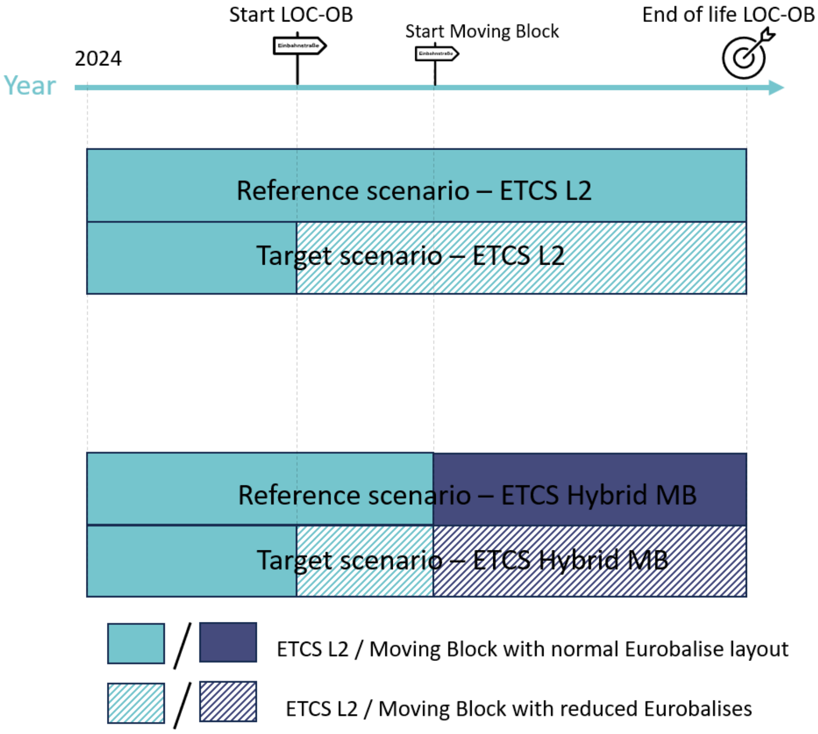

Figure 9: Modelled transition between scenarios

For a network-wide business case analysis, the year in which LOC-OB becomes available for implementation is therefore very relevant for the possible benefit that can be achieved. The later LOC-OB gets rolled out, the smaller the absolute potential for Eurobalise reduction becomes, and the less the number of vehicles that also need to be equipped. The CBA model therefore considers the ETCS rollout plan – defined by the track kilometres being equipped with ETCS trackside elements per year – as well as the LOC-OB rollout on the vehicles once available – approximated by the progress of ETCS rollout – in order to estimate the potential benefits from transitioning from reference to target scenario (see **Error! Reference source not found.**).

3 CBA Methodology

This chapter describes the methodology used to derive the CBA model and presents the results for the implementation of LOC-OB.

3.1 Cost-Benefit Analysis Principles in Rail Projects

Railway projects are usually capital-intensive and often require trade-offs. Several solutions could be applied to solve a particular problem or to optimise existing aspects of the railway system. Hence it is necessary to apply CBA methods and models that consider the peculiarities of the railway sector such as:

- High volume of transport for both passenger and freight;
- Cleaner mode of transport compared to road and air transport;
- Long-term projects as well as longer average life span of products compared to road transport;
- Capital-intensive projects with high operation and maintenance costs compared to road transport.

A cost and benefit assessment of the various possible solutions is necessary in the railway sector in order to guide decision-makers in choosing the most optimum solution to meet the short and long-term needs of the railway customers, while also considering the economic aspect. The main quantitative indicator for the CBA will be the net present value (NPV), which shows whether the anticipated earnings (or savings) exceed the costs. In this CBA, the NPV will be calculated as the difference between the costs of the reference and target scenario after factoring in the inflation and discount rate which represents the avoided investment costs. A negative NPV signifies that the costs of the target scenario are higher than the costs of the reference scenario and therefore not economically beneficial, while a positive NPV means that the economic benefit of implementing the target scenario is greater than that of the reference scenario.

3.2 CLUG 2.0 CBA Phases

In order to take all aspects impacting the examined costs and benefits into account and to be able to create a realistic but sufficiently abstract model for the calculation of results, this CBA uses a methodology workflow consisting of five main phases (Figure 10), similar to the EUG Track Occupancy CBA [1]. Each phase is described in detail in the following subchapters.

Figure 10: CBA methodology workflow

3.2.1 Phase 1: Scope & Item Specification

For the first step in the methodology workflow, five items with a quantitative impact on the CBA have been identified as presented in Table 1:

TYPE	ITEM	STAKEHOLDER	IMPACT	NATURE
Board	LOC-OB unit	RU	Cost	CAPEX / OPEX
Board	Odometry function	RU	Benefits	CAPEX / OPEX
Board	Current GNSS onboard solutions for non-safe applications	RU	Benefits	CAPEX / OPEX
Track (Data)	Digital Mapping	IM	Cost	CAPEX / OPEX
Track	Eurobalise	IM	Benefits	CAPEX / OPEX

Table 1: Key items considered in the CBA

Each item can be classified based on the following features:

- Type: describes if the item is hardware situated on the train (onboard), on the track (trackside) or a data requirement.
- Stakeholder: reflects who has to take responsibility for the implementation and therefore likely bears the cost or receives the benefits. It is classified for this analysis as either the railway undertaking (RU) or the infrastructure manager (IM).
- Impact: classifies the item based on costs or benefits. The item could be either a source of additional cost (costs) or beneficial (benefits) to the stakeholder(s) involved.
- Nature: shows if the cost or benefit is a one-time capital expenditure (CAPEX) or a continuous yearly operating expenditure (OPEX) across the life cycle of the item. As can be seen in Table 1, all of the items have both CAPEX and OPEX, meaning all aspects of the cost of purchase and installation and costs incurred or saved during operation of the item will be considered.

An additional cost item with high relevancy for the technical functionality of LOC-OB that has not been considered within this CBA are costs for the transmission of EGNOS data to rolling stock vehicles. It is assumed that in order for transmitting EGNOS data to rolling stock, terrestrial transmission stations will need to be constructed. As these stations would serve further stakeholders outside of the railway sectors, these construction costs have not been considered, assuming that the investment would be undertaken by the space sector. It is furthermore assumed that the transfer of EGNOS data from the transmission stations to the vehicles will be covered by FRMCS infrastructure. Accordingly, the only remaining cost factor pertaining to the EGNOS transmission would be the usage fee railway undertakings would have to pay to the operators of the beforementioned terrestrial transmission stations for using their infrastructure. During the development of this CBA, an estimation for these usage fees could not have been obtained. Accordingly, this cost factor could not have been included in the model. The omission of costs pertaining to EGNOS transmission is further discussed in the limitations of this CBA in chapter 4.6.

The "impact" of each previously discussed item included in the model is further explained in the Table 2 (onboard), Table 3 (data) and Table 4 (track) below:

ONBOARD	Description
Rolling stock onboard localisation system equipment (LOC-OB), development, engineering, installation	To enable continuous safe onboard localisation based on GNSS, a major upgrade of the onboard CCS unit and further required transformations such as digital mapping processor, multi-source GNSS receiver and processor etc. need to be developed. Besides the LOC-OB hardware unit needed for each vehicle, each fleet (also called vehicle class) will also need to be engineered and retrofitted for the new onboard unit and obsolescence costs of the unit and its sensors need to be accounted for.
Odometry function	Train localisation under ETCS is currently achieved with an onboard odometry system, which is part of the ETCS-OBU. Retrofitting vehicles with LOC-OB enables the replacement of the current odometry system.
Current GNSS onboard solutions	Many trains already have at least one GNSS systems onboard, e.g., to provide information to passengers on the train's location or for fleet asset management. Retrofitting vehicles with LOC-OB enables the replacement of these GNSS antennas, unifying all localisation functions using LOC-OB as the sole source of information.[2]

Table 2: Description of onboard-related elements

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[2] This replacement underlies limitations, further discussed in chapter 4.6

DATA	Description
Digital Mapping	LOC-OB will require a safety integrity level (SIL) 4 digital representation of the rail network along which it will operate. This means that an initial data collection campaign and regular updates of this data will be necessary. As infrastructure elements continue to be added, removed or repositioned, the digital map data will also need to be updated. It is therefore necessary to consider the CAPEX and OPEX for collecting, processing, preparing, storing, homologating and transmitting a digital map in a form suitable for LOC-OB. It is important to note that, as explained further in chapter 4, a digital map is also required for ETCS level 2 operations using current odometry systems. Because for a digital map for LOC-OB as assumed in the frame of CLUG 2.0, there are no specific layers relating to specific sensors and only track centre line and curvature is considered, a similar data collection procedure and therefore similar costs as for an ETCS L2 digital map have been assumed. However, the processing and preparation of such data could vary for LOC-OB and odometry functionality, usually requiring additional cost for LOC-OB. Only this additional cost compared to a regular ETCS Level 2 map will be considered for the CBA. Since map data can be used by other digital systems such as ATO, CTMS or perception systems, digital mapping costs are assumed on the lower end, assuming costs could be shared across the implementation of these systems. However, it is important to note that the estimation of digital mapping costs remains one of the major uncertainties of this CBA.

Table 3: Description of data-related elements

TRACK	Description
Eurobalise CAPEX and OPEX	With LOC-OB, Eurobalises which handle only localisation function (i.e. resetting the confidence interval) can be avoided. Hence, the potential number of Eurobalises that can be reduced is dependent on which functionalities and messages that can be taken over and transmitted by the LOC-OB and digital map which are presently being transmitted by Eurobalises. Similar to the EUG TO analysis [1] referenced in chapter 3.1, the following cost components will be considered for Eurobalises: CAPEX: 1. System and installation studies: which covers the positioning design for the Eurobalises, Eurobalise content determination and installation support for the sleepers or rail mountings etc. 2. Hardware cost: which covers the cost for purchasing the Eurobalise and its mounting support. 3. Installation: which includes the cost of programming the Eurobalise, setting the Eurobalise and then installing on the rail or sleeper. Also post-installation cost such as testing which comprises of reading and checking the Eurobalise message(s) are included. 4. Opportunity cost for Eurobalise installation: which includes the costs for interrupting operations and track access/protection. 5. Inspection and approval: which comprises of costs for the installations to be validated by the IM and updated in the infrastructure plan. OPEX: 1. Failure detection and replacement: refers to costs for monitoring and identification of Eurobalise failures as well as cost for repairs including hardware purchases. 2. Opportunity cost for regular Eurobalise maintenance: refers to cost of lost operations due to interruption for repair or diagnostic work, track access/protection and personnel cost. 3. De-installation and re-installation: might be necessary in some case where a Eurobalise needs to be re-programmed, dismounted or remounted. The associated re-testing costs are also inclusive. 4. Re-inspection and approval: might be necessary depending on the extent of the maintenance work that has been carried out. 5. Routine track maintenance works such as rail renewal/repair, ballast tamping, sleeper renewal etc. may also trigger removal and re-installation costs.

Table 4: Description of trackside-related elements

Since this CBA does not consider newly purchased vehicles, standard onboard communication devices – which are nevertheless required for ETCS Level 2 operations with legacy odometry systems – are assumed to have been installed on the vehicles prior to the implementation of the target scenario.

3.2.2 Phase 2: Business case definition

A good CBA for a project in the railway sector should reflect all benefits and costs associated with the project. Focus should cover both the direct impacts such as impacts on the direct users like the passengers, freight transport companies, railway undertakings, infrastructure managers, etc. and the indirect impacts such as impacts on the society and environment. Likewise, the initial capital investment, operational costs, maintenance costs and obsolescence costs should be considered, to ensure that all costs and benefits along the lifecycle of the product are considered.

It is therefore necessary that a systematic approach is followed in identifying all factors necessary to be considered for each scenario analysed. In some cases, it is helpful to also define the scenarios and boundary conditions systematically, so that they reflect the most important aspects relevant in guiding the decision makers in taking cost-efficient investment decisions.

This subchapter is dedicated to describing the characteristics of the business cases to be analysed and the specific items necessary for the model development. The model should be able to cope with the varying business case applications for each partner, therefore all available (or unavailable) input parameters to be considered in the model are pre-defined.

The key parameters which will impact the overall results of the business case and different from all partners include:

1. The track length to be equipped for LOC-OB
2. The number of fleet and vehicles to be equipped with LOC-OB
3. The Eurobalise density i.e. the average number of Eurobalise per track kilometre
4. Time frame considered for the analysis

The first three parameters are provided individually by each IM and/or RU for each business case. This implies that each partner selects informed and realistic track lengths to be considered in the CBA and then derives the number of vehicles needed for operations on the selected tracks. The track selection can be done based on the NIP or for particular lines or traffic types based on national strategic decisions.

The selection of the vehicles to be equipped with LOC-OB is split between high-speed, regional and cargo trains in order to cope with any possible variation in selection requirements, such as the average age of the fleet and the remaining lifespan of the vehicle, which could be different for cargo and passenger trains. However, for simplicity, the costs for the hardware and engineering will not be differentiated based on these vehicle types, rather a single aligned value will apply to all. A relevant aspect of vehicle numbers is the homogeneity of fleets - a homogenous fleet means that the total engineering cost (discussed further in chapter 4) will be less and therefore advantageous for the vehicle costs - by reducing the CAPEX - compared to a more inhomogeneous fleet.

The Eurobalise density determines the total number of Eurobalises that need to be installed on the investigated track section. The higher this is, the higher the absolute number of Eurobalises that can be potentially reduced which also translates to high impact on CAPEX and OPEX for the duration of the investigation period.

The time frame for the CBA should be consistent with the economic lifetime of the main assets that will be invested into. The results of the analysis at the end of this time frame will be presented in one single value – the NPV - which reflects costs and benefits over time as well as the time effect of its occurrence. Although the investment period for a project is often indefinite, it is necessary in the project analysis to define an appropriate time in the future when all the required assets are fully set up and exploited, and then examine whether the investment was economically successful.

3.2.3 Phase 3: CBA model setup

In this phase, a model which can analyse all the input parameters and presents the total CAPEX and OPEX costs for the items in the reference and target scenarios for each examined case is set up. The model then derives the NPV as the final key output by calculating the difference in total costs (sum of CAPEX and OPEX) between the reference and target scenario. The main and only benefit considered in the CBA are the costs avoided if the target scenario is implemented instead of the reference scenario. An inflation and actualisation rate[3] will be applied starting from the base year. The model also gives room for adapting each input parameter, including the overall time frame for the analysis.

As there is no fixed Eurobalise reduction ratio assumed by each partner for the CBA, the model will conduct a sensitivity analysis in order to show the minimum Eurobalise reduction ratio that is needed to achieve a positive NPV, while also showing detailed NPV results from 30% Eurobalise reduction up to 50% Eurobalise reduction. This is intended to serve as a guide in determining the target Eurobalise reduction ratio for a positive business case for LOC-OB for each partner. Whether this target is achievable or not, is out of scope for this CBA.

3.2.4 Phase 4: Country application

The CBA will be carried out for the IMs involved in CLUG 2.0. This necessitated the use of local input parameters specific to each partner's network and strategy. Although the CBA is done for each partner using local parameters, some parameters will be the same across each business case/country application calculated as described in chapter 4.3. Following this methodology means that the results will not be directly comparable, nevertheless, some trends and similarities or differences could be extracted. Differentiating between each partner application, also allows for a more specific interpretation of the results, making it a useful and reliable reference for the decision makers.

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[3] Applying an actualisation rate enables discounting the cashflow to allow for consideration of the time value of investments.

3.2.5 Phase 5: CBA conclusion & recommendations

In the end, some conclusions are made based on the results and some recommendations suggested, such as:

- Possible estimation of the minimum required Eurobalise reduction ratio in order to achieve a positive business case result.
- Effect of applied migration strategy and other assumptions on the overall business case.
- Main conclusions on the results of the financial appraisal of migrating towards LOC-OB when it is available.
- Recommendations on possible improvements for future similar CBAs.

4 CBA Model

4.1 Model principle

The principle applied by the model to determine the benefits considers the avoided cost if the reference scenario was continuously implemented instead of the target scenario as the benefits of migrating to the target scenario once LOC-OB is available. The model will consider a gradual system replacement with a transition phase whose duration depends on the number of vehicles needing to be equipped with LOC-OB and the speed at which this retrofitting occurs. To reduce complexity, it is assumed that the equipment and retrofitting rate for the vehicle follows the rate of ETCS trackside rollout. For the specified investigation period of the model timeframe, the yearly CAPEX investment for the onboard and trackside is being accrued. This is then nominalised with a given inflation rate, and then actualised by considering the discount rate, before calculating the NPV delta CAPEX over the entire years of investigation. Therefore, the delta CAPEX is the difference of all the relevant costs considered in both scenarios and takes into account when on the timeline these investments take place and what that value means today. Since the yearly CAPEX is directly dependent on the number of track kilometres being equipped with ETCS and the number of vehicles being equipped with LOC-OB, as soon as the rollout of each is complete, the CAPEX automatically equals zero for the remaining years considered.

$$\Delta\mathrm{CAPEX}_{NPV} = \sum_{t=1}^{p} \mathrm{CAPEX}_{Reference} * \frac{(1+i)^t}{(1+d)^t} - \sum_{t=1}^{p} \mathrm{CAPEX}_{Target} * \frac{(1+i)^t}{(1+d)^t}$$

$$(p = years\ of\ investigation, i = inflation\ rate, d = discount\ rate)$$

For the OPEX, the same calculation is being applied with the only difference that OPEX continues to accrue yearly even after the migration from reference to target scenario is complete.

$$\Delta\mathrm{OPEX}_{NPV} = \sum_{t=1}^{p} \mathrm{OPEX}_{Reference} * \frac{(1+i)^t}{(1+d)^t} - \sum_{t=1}^{p} \mathrm{OPEX}_{Target} * \frac{(1+i)^t}{(1+d)^t}$$

$$(p = years\ of\ investigation, i = inflation\ rate, d = discount\ rate)$$

In order to evaluate the overall benefit of the investment into LOC-OB, the NPV of the project as a whole will be calculated based on the following formula:

$$NPV_{CBA} = \Delta\mathrm{CAPEX}_{NPV} + \Delta\mathrm{OPEX}_{NPV}$$

4.2 Business case parameters

Depending on the nature of the business case, different parameters could be considered. In the railway sector, possible business cases could focus on:

- Type of line: high-speed or regional,

- Nature of service: passenger or freight,
- Specific part of network: e.g. for modernisation or new construction,
- National network,
- European corridors.

For this CBA, some of the parameters considered in the EUG TO CBA have been used [1]. In addition, further parameters have also been included to enhance the quality of the CBA.

4.2.1 Business case identification

To differentiate the individual business cases for DB, SBB and SNCF from each other, simple identification parameters have been defined (Table 5).

Business case identification	BC N°	
	VERSION	
	HOLDER	DB / SBB / SNCF
Business case type	USAGE	Passengers Only / Mixed (passengers & Freight)

Table 5: Business case identification parameters

4.2.2 Business case sizing

There are four main parameters that will size the business case. These are the track length, its associated rolling stock, the number of fleets the rolling stock is comprised of, as well as the number of Eurobalises installed per KM.

Track	TRACK LENGTH	KM
Rolling stock general	REFERENCE YEAR	YEAR
	YEARLY FLEET GROWTH	%
Rolling stock long distance	ROLLING STOCK LONG DISTANCE TRAINS	QTY
	TRAIN MODELS LONG DISTANE TRAINS	QTY
	LIFESPAN LONG DISTANCE TRAINS	YEARS
Rolling stock regional	ROLLING STOCK REGIONAL TRAINS	QTY
	TRAIN MODELS REGIONAL TRAINS	QTY
	LIFESPAN REGIONAL TRAINS	YEARS

Rolling stock cargo	ROLLING STOCK CARGO TRAINS	QTY
	TRAIN MODELS CARGO TRAINS	QTY
	LIFESPAN CARGO TRAINS	YEARS
Eurobalise	EUROBALISE / KM ETCS FIXED BLOCK	QTY/KM
	EUROBALISE REDUCTION ETCS FIXED BLOCK	Sensitivity analysis
	EUROBALISE / KM ETCS MOVING BLOCK	QTY/KM
	EUROBALISE REDUCTION ETCS MOVING BLOCK	Sensitivity analysis

Table 6: Business case sizing parameters

The track length is a major input parameter which is easily derived from the IM's ERTMS ETCS L2 rollout plan. The track length as an input parameter does not distinguish between single or multi-track lines. Each partner estimates the length of the network area or line to be considered in track kilometres, when this is not directly known.

The percentage of fleets and rolling stock to be considered for the CBA is an important aspect of the analysis because of the high impact this parameter has on the CAPEX and overall results. As the CBA does not only consider the cost of retrofitting vehicles but also the cost of engineering first-of-class vehicles of a train model, the number of vehicles as well as train models need to be considered. Due to the high CAPEX, it is additionally recommended to consider the remaining lifespan of rolling stock and the average age of all rolling stock that make up a fleet in the selection process.

The upper limit of the number of trains engineered and retrofitted for LOC-OB and the rate of equipment of the trains correspond with the percentage of track not yet equipped with ETCS and the planned rollout rate on these tracks from the time when LOC-OB becomes available respectively. Alternatively, an estimation derived from the number of trains running per day in the considered network area could be used.

Lastly, when considering the number of Eurobalises being installed per track kilometre and the share of Eurobalises that can be avoided after implementing LOC-OB, the CBA distinguishes between ETCS Level 2 fixed block and ETCS Level 2 hybrid moving block to account for the two scenario comparisons, then conducts a sensitivity analysis in order to determine this minimum Eurobalise reduction percentage for a positive NPV for each scenario.

4.2.3 Rollout & transition modelling

The considered rollout model for ETCS and LOC-OB does not only have an impact on when CAPEX investments need to take place and to what extent yearly OPEX occurs, but also influences how big the overall benefit through Eurobalise reduction is. This CBA does not separately model the rollout sequence for LOC-OB on the rolling stock and ETCS Eurobalises on the track, but rather assumes a schematic approach where the number of track KM equipped with ETCS, taken from the National Implementation Plans (NIP), also corresponds to the rollout progress of the LOC-OB. This simplifies the rollout modelling and serves as an approximation for the fact that only trains which travel on the area of the network to be equipped with ETCS after LOC-OB is available are actually considered in the analysis. Tracks already equipped with ETCS and therefore already equipped with Eurobalises will not be considered in the percentage of Eurobalise that can be saved, because it is assumed that no existing Eurobalise will be removed even after LOC-OB is available due to removal costs likely exceeding the benefits of removing Eurobalises.

Since ETCS moving block likely becomes available later than ETCS fixed block, a different starting year is assumed and reflected in the respective scenario comparisons.

ETCS rollout	START ROLLOUT ETCS L2 FIXED BLOCK	YEAR
	START ROLLOUT ETCS L2 MOVING BLOCK	YEAR
	YEARLY ROLLED OUT ETCS KM	KM
LOC-OB rollout	AVAILABILITY OF LOC-OB	YEAR
	% OF EXISTING FLEET TO BE EQUIPPED	%

Table 7: Scenario transition parameters

4.2.4 Cost parameters

Lastly, the cost parameters which directly impact the CAPEX & OPEX costs and benefits calculations need to be defined.

LOC-OB	CAPEX ENGINEERING	€ / TRAIN MODEL
	LIFESPAN UNIT	YEARS
	LIFESPAN SENSORS	YEAR
	REOCCURING ENGINEERING CAPEX	%
	CAPEX HARDWARE	€ / UNIT
	QTY PER TRAIN	QTY / TRAIN
	OPEX OPERATION & MAINTENANCE	€ / TRAIN / YEAR
Odometry	CAPEX ENGINEERING	€ / TRAIN MODEL
	LIFESPAN UNIT	YEARS
	LIFESPAN SENSORS	YEAR
	REOCCURING ENGINEERING CAPEX	%
	CAPEX HARDWARE	€ / UNIT
	QTY PER TRAIN	QTY / TRAIN

	OPEX OPERATION & MAINTENANCE	€ / TRAIN / YEAR
Current GNSS onboard solutions	CAPEX ENGINEERING	€ / TRAIN MODEL
	CAPEX	€ / UNIT
	OPEX	€ / UNIT / YEAR
Digital mapping	CAPEX	€ / KM
	OPEX	€ / KM / YEAR
Eurobalise	CAPEX	€/ UNIT
	OPEX	€/ UNIT / YEAR

Table 8: Cost factor parameters

The differences between the CBA's reference and target scenarios can be summarized as follows:

- Introduction of the LOC-OB for the continuous train localisation function instead of the classical trackside Eurobalise and onboard odometry solution;
- Replacement of any installed GNSS onboard solutions;
- Augmentation of the digital map data.

For the LOC-OB and the current odometry solutions, three main cost types are being considered: engineering costs (including costs for certification studies and first-of-class equipment), hardware costs and costs for operation and maintenance. However, to account for the higher obsolescence of the LOC-OB in comparison with the current odometry systems, the lifespan of the unit and its sensors is considered for a fourth cost - re-occurring engineering cost - for both onboard systems. The CBA assumes the re-occurring engineering costs occur at:

- the end of the sensor lifespan, and
- the half-life of the unit

and is applied per train model.

The CAPEX and OPEX cost parameters each are a conglomeration of all relevant individual cost factors. For *CAPEX engineering*, this includes costs for FoC engineering and equipment as well as the homologation and certification of the system for the respective train model. If the engineering and homologation process has to be repeated later into the life cycle of the unit or component, these costs are covered by the *CAPEX reoccurring engineering costs* parameter. *CAPEX hardware* includes the hardware cost for the respective system as well as costs incurred for installing the system onto the vehicle. For the hardware costs of legacy odometry systems, an objective cost evaluation is not possible as these systems are currently part of the European Vital Computer (EVC). Accordingly, these hardware costs were only estimated based on the cost of individual hardware components and expert opinion. Lastly, *OPEX operation and maintenance* includes the recalibration of the system, replacement of (computing) parts with spares in case of failure as well as replacement of sensors or the entire unit at the end of life.

Regarding the augmentation of the digital map, a CAPEX investment per KM is being assumed that covers the preparation, homologation and implementation of a digital map suitable for LOC-OB positioning. This price per KM indirectly contains the one-time up-front cost of setting up the process for automatised map generation. Additionally, an OPEX per year and KM is also assumed to account for the regular updates needed to be carried out before and after trackwork and changes in track layout.

4.2.5 General inputs

To set the boundary conditions and to ensure results from all business cases are partially comparable, some general values need to be pre-defined. The following are the general parameters used for the CBA:

General inputs		
	NOMINALISATION RATE	%
	ACTUALISATION RATE	%
	START YEAR OF NOMINALISATION	YEAR
	START YEAR OF ACTUALISATION	YEAR
	INVESTIGATION PERIOD	YEARS

Table 9: General input parameters

Nominalisation and actualisation rates reflect the time value of money. Nominalisation rate factors in inflation, thereby forecasting the likely rise in the cost of an item in the year it is to be bought or sold, based on the historical increase in the price of such assets. Although this rate is usually different yearly, an average value is applied for simplification of the model. In contrast, the actualisation rate factors in interest (or in this case discount) rate to determine the present value of future cash flows. In order to cover for costs at a certain time in the future, a lesser principal could be invested today which yields enough interest to cover for the future costs. The start year for applying the inflation and discount rate is preferred to be consistent and should typically be the year in which the analysis is made. The investigation period refers to the number of years being considered in the analysis and should also be chosen in such a way that long term costs and benefits are captured as much as possible.

4.3 Aligned parameter values

This analysis compares the individual business case results with each other, while also trying to individualise the input parameters where necessary. This ensures that results reflect the individual peculiarities of the individual railways systems as well as allows for some level of comparison with other partners' results. In this section, only the parameter values which have been aligned by all contributing CLUG 2.0 partners (DB, SBB & SNCF) and therefore, the same for all business cases calculated will be presented.

ITEM CATEGORY	PARAMETERS	CONSTANT	UNIT
General inputs	NOMINALISATION RATE	2%	%
	ACTUALISATION RATE	3,5%	%
	START YEAR NOMINALISATION & ACTUALISATION	2024	YEAR
	INVESTIGATION PERIOD	20	YEARS
LOC-OB	CAPEX ENGINEERING	300.000	€ / TRAIN MODEL
	LIFESPAN UNIT	20	YEARS
	LIFESPAN SENSORS	7	YEARS
	REOCCURING ENGINEERING CAPEX	5%	%
	CAPEX HARDWARE	40.000	€ / UNIT
	QTY PER TRAIN	2	QTY / TRAIN
	OPEX OPERATION & MAINTENANCE	2.000	€ / TRAIN / YEAR
Odometry	CAPEX ENGINEERING	400.000 / 200.000	€ / TRAIN MODEL
	LIFESPAN UNIT	20	YEARS
	LIFESPAN SENSORS	10	YEAR
	REOCCURING ENGINEERING CAPEX	5%	%
	CAPEX HARDWARE	25.000	€ / UNIT
	QTY PER TRAIN	2	QTY / TRAIN
	OPEX OPERATION & MAINTENANCE	2.500	€ / TRAIN / YEAR
Current GNSS onboard solutions	CAPEX ENGINEERING COST	10.000	€ / UNIT
	CAPEX	1.000	€ / TRAIN
	OPEX	150	€ / UNIT / YEAR

Table 10: Aligned parameter values

A nominalisation rate of 2% has been aligned based on the average inflation rate in Europe over the past ten years. The discount or actualisation rate has been fixed at 3,5% in line with the “Guide to cost-benefit analysis of investment projects” of the Directorate General for Regional Policy of the European Commission [5]. Because European interest rates have increased significantly since the release of the document mentioned in 2014, the actualisation rate has been exemplarily verified by calculating the capital costs for DB InfraGO using the WACC approach and financial figures from 2023 and 2024. The calculated capital costs were lower than 3,5%, verifying the value to be a conservative assumption even in the current financial landscape. The start of the nominalisation and actualisation has been set at 2024, reflecting the year in which the analysis began. The time frame for the analysis is set at 20 years, reflecting the lifespan of the LOC-OB unit, so that all possible costs and benefits would have been captured. This 20-year analysis period may be considered short for such a study, as lifespans of vehicles and trackside assets largely exceed 20 years.[4] However, as the scope of the CBA lies solely in the transition from legacy odometry systems to LOC-OB and the costs for replacement of the system are therefore not considered, the shorter time frame of 20 years has been chosen as it covers the technological transition fully. Costs that occur during this time frame for maintaining and updating the LOC-OB system are covered in *CAPEX reoccurring engineering* and *OPEX operation and maintenance* respectively.

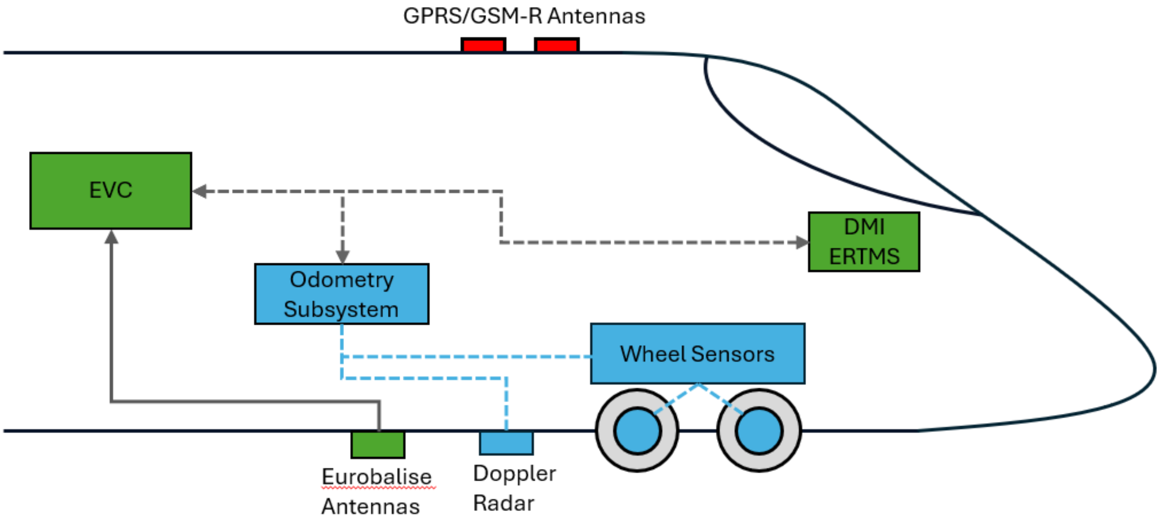

Figure 11: Sensor layout for legacy odometry systems

For legacy odometry systems, an expert estimate for the CAPEX engineering cost of 400 k€ has been provided by the SNCF engineering department and used for the analysis. This cost estimation is based on the overall 1 M€ engineering costs required for the European Vital Computer (EVC) of which the odometry system is a part. Based on this estimation, the CAPEX engineering costs for LOC-OB have been estimated by members of the CLUG 2.0 consortium at 300 k€, assuming the engineering of this new system to be less complex and therefore less costly than for legacy odometry systems. This assumption has been taken because legacy SIL 4 odometry systems are exposed to more environmental and mechanical stress than LOC_OB would be, as all of its sensors, usually consisting of two speed sensors and a radar sensor, are installed on the un-sprung mass of the rolling stock bogie or the underside of the train respectively. According to the current hypothesis of the LOC-OB architecture[6], LOC-OB also contains a speed sensor which has to be situated outside of the train in close proximity to the rolling stock bogie and wheels. However, the remaining components will be installed inside the train with the exception of the antennas being installed on the train roof. Accordingly, the components of the LOC-OB system would overall be subjected to less mechanical stress, enabling lower engineering costs compared to legacy odometry systems. Nevertheless, there is the possibility that the engineering costs for legacy odometry systems are less than those of the LOC-OB because less effort is needed for the installation and certification of the existing system

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[4] Accordingly, the Directorate General for Regional Policy of the European Commission recommends a timeframe of 30 years for Cost Benefit Analyses. [5]

compared to a new LOC-OB system. Hence, a second sub-business case with a CAPEX engineering cost of 200 k€ for the odometry is calculated for all business case application as discussed in the result presentation.

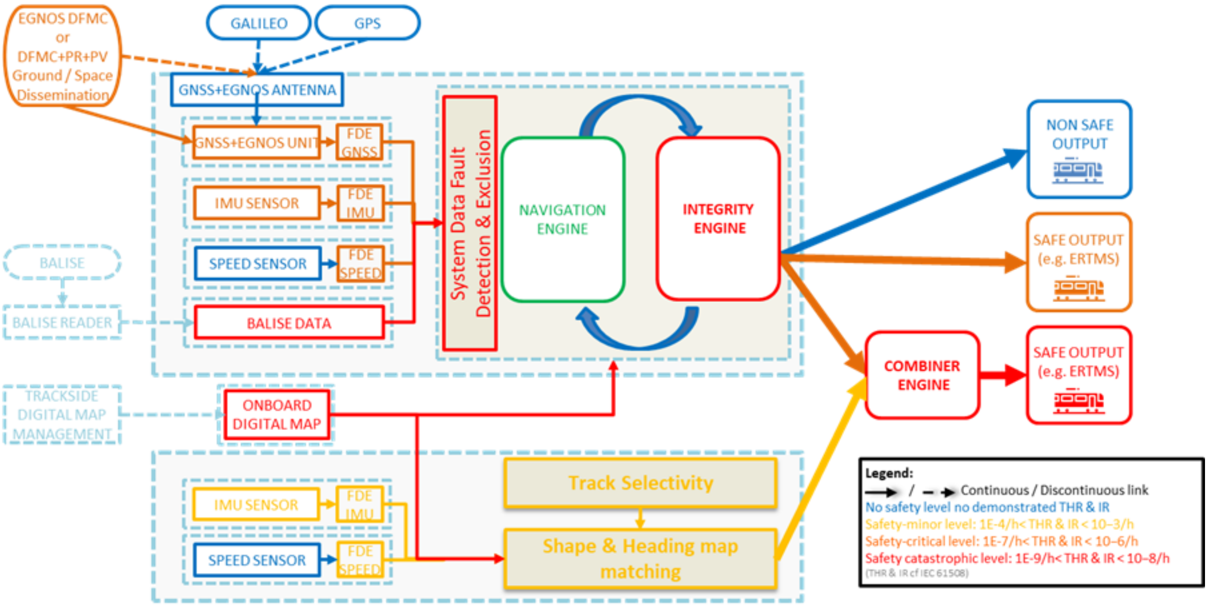

Figure 12: CLUG 2.0 LOC-OB high level functional architecture [6]

The CAPEX hardware costs for the legacy odometry systems of 25 k€ have been directly provided by engineering experts and are based on the overall hardware costs for the EVC. For the OPEX for maintenance and operation, 10% of the CAPEX has been assumed, as is standard for these odometry systems. The CAPEX hardware for LOC-OB of 40 k€ is based on a cost estimation carried out jointly by members of the Localisation Working Group (LWG). This estimation had already been executed for the EUG TO CBA and has been reaffirmed within this analysis. It is based on the assumption that component costs will stay at similar levels as for the current onboard technology and adds up the hardware costs for all required components, amounting to around 30 k€. On top of that, a 33% markup for the development of the system has been added. The OPEX for maintenance and operation has been assumed at only 5% of the CAPEX hardware because LOC-OB is exposed to less environmental influences than legacy odometry systems, as described in the discussion on engineering costs, and also because less maintenance work is needed for such a modular system once the unit and the antenna have been installed. It is also assumed that each rolling stock will have two units of LOC-OB, one for each locomotive at the front and rear end of the train. The same was assumed for the number of odometry units per train, since the majority EMUs and loco-hauled trains naturally consist of two locomotives with one odometry unit each. The few modern EMUs having only one EVC and odometry unit have been considered as negligible.

The re-occurring engineering cost for both odometry and LOC-OB have been assumed to be same and aligned to be 5% of the CAPEX engineering cost. This assumption is based on an estimation of the re-occurring engineering costs for legacy odometry systems at 20 k€, provided by the SNCF engineering department and based on re-occurring engineering activities carried out on TGV models. As there is no data on re-occurring engineering costs available for LOC-OB, the assumption for legacy odometry was put into relation to the CAPEX engineering and reused accordingly. Based on the same expert opinion, the unit lifespans were estimated at 20 years for both legacy odometry and LOC-OB respectively, whereas the sensor lifespan for legacy odometry and LOC-OB have been aligned to be 10 and 7 years respectively. 10 k€ is assumed as the cost for engineering all current GNSS onboard solutions. The hardware cost is set at 1 k€ per rolling stock while the OPEX is assumed to be 150 € per vehicle per year. Again, to reduce complexity, these values have been chosen to represent an average estimate cost for all GNSS onboard solutions and do not consider how many GNSS devices are used per train model because this information widely varies between train models and sometimes even between trains of the same model.

Other mostly non-confidential values which are not aligned - such as the number of vehicles and number of Eurobalises per km - will be introduced while calculating each business case.

4.4 Model calculation process

Due to legal reasons, each business case has to be calculated separately by each partner using the same model, and then only relevant aspects of the results are shared. The model therefore consists of an input sheet where all input parameters are given. The parameters are then used for the calculation and presentation of results in 5 main steps:

1. CAPEX and OPEX calculation for the vehicle side: The yearly CAPEX and OPEX costs for each item related to the vehicle are calculated for the reference and target scenario in a first step. These calculated values do not yet consider the nominalisation and actualisation rates. Since there is no difference in the vehicle in terms of localisation for ETCS L2 or moving block, the same CAPEX and OPEX value is used.
2. CAPEX and OPEX calculation for the trackside: Similar to step 1, the yearly CAPEX and OPEX is calculated for the trackside in second step. In this stage, the calculation is made separately for both ETCS L2 trackside and ETCS hybrid moving block, because the Eurobalise reduction potential is different in both cases.
3. NPV CAPEX and OPEX: The nominalisation and actualisation rate are then applied to all values as the third step, both for the vehicle and trackside.
4. NPV for each sub-business case: The reference and target scenario for each sub-business case are then compared with each other to determine the NPV since the avoided investment of the reference scenario is considered as the benefit. This is calculated by subtracting the sum of NPV for the vehicle and track in the target scenario from the NPV sum of vehicle and track in reference scenario. A positive value translates to cost savings (benefits) of implementing the target scenario.
5. Sensitivity analysis: In the last step, a sensitivity analysis is conducted to determine the conditions (in terms of Eurobalise reduction ratio) necessary to achieve a positive business case for each partner. This is done by calculating the NPV for each even percentage of Eurobalise reduction ratio beginning from 0% to a maximum of 70%.

4.5 Result presentation

The following results will be presented for each sub-business case where a positive value signifies benefits or cost savings arising from implementing the target scenario instead of the reference scenario (see Table 11):

- Minimum Eurobalise reduction required: this will be the minimum even value required to achieve a positive NPV for the target scenario. Three selected exemplary values (30%, 40% and 50%) will be presented in detail. The values were chosen based on the Eurobalise reduction ratio assumed in the EUG TO CBA [1]. As this analysis is based on the general methodological approach of the EUG TO CBA but aims to use more realistic and conservative assumptions, 50% was chosen as the maximum highlighted value, complementing the result presentation with results from more conservative balise reduction assumptions of 30% and 40%.
- NPV CAPEX: this will be calculated for each sub-business case when the target and reference scenario are compared. This shows the additional (negative value) investment capital necessary for the target scenario.
- NPV OPEX: this shows the additional maintenance cost (negative value) or potential savings in maintenance and operations cost (positive value) for the target scenario.
- NPV Vehicle (onboard): this shows the additional cost (negative value) or benefit (positive value) on the side of the RU if the target scenario is implemented.
- NPV Trackside: this shows the additional cost (negative value) or benefit (positive value) on the side of the infrastructure manager if the target scenario is implemented.
- NPV Onboard per vehicle: this shows the additional cost (negative value) or benefit (positive value) per vehicle when the target scenario is implemented. This value is important for the RU in evaluating the financial impact of LOC-OB per vehicle.
- NPV Trackside per kilometre: this shows the additional cost (negative value) or benefit (positive value) per track kilometre when the target scenario is implemented. This value is important for the IM in evaluating the financial impact of LOC-OB per track kilometre.
- NPV: This shows the overall benefit of implementing the target scenario. The presented value will be positive.

BC IDENTIFICATION	HOLDER	SCOPE	ENGINEERING COST ODOMETRY

Key Figure	Unit	ETCS L2	ETCS MBH	ETCS L2	ETCS MBH	ETCS L2	ETCS MBH
Eurobalise reduction	%	30 %		40 %		50 %	
NPV CAPEX	k€						
NPV OPEX	k€						
NPV Onboard	k€						
NPV Trackside	k€						
NPV Onboard p. vehicle	k€/ veh						
NPV Trackside p. km	k€/ km						
NPV	**k€**						

Table 11: Format of CBA result presentation

4.6 CBA limitations and assumptions

Although the model is designed to cover the scope for which the CBA is made, several assumptions lead to some limitations:

- Rollout plan: The model uses the ETCS rollout strategy provided from the respective IM which is a reflection of the NIP, the plausibility of this strategy was not considered. The length of track considered for ETCS within the investigation period strongly influences the NPV. It is also assumed that once a track is equipped for ETCS L2, no additional Eurobalise will be planned and installed even when moving block technology is available.
- Eurobalise reduction ratio: No Eurobalise installed on the track will be decommissioned even when LOC-OB is available. In other words, savings potential is only considered for the planned ETCS tracks not yet equipped with Eurobalises when LOC-OB is available.
- Hybrid moving block scenario: The model makes an assumption on the additional number of Eurobalise in moving block operations needed for a target operational performance. This number is described for each business case calculated.

- Vehicle equipment scope: Only the existing fleets are considered in the model. The engineering costs and hardware costs for new fleets and vehicles are assumed to be part of the cost of the vehicle itself and therefore out of scope for the analysis. The coupling of the vehicles considered with the ETCS rollout strategy (as described in 4.2.2) is also a limitation because more vehicles might need to be equipped with LOC-OB to allow for flexibility in operations. The latter limitation constitutes a key question regarding the modelling of LOC-OB implementation. While it is clear that not all vehicles would have to be equipped with LOC-OB if the technology is only rolled out on part of the network, an accurate model of how many and which vehicles to equip would have to take into account vehicle rotation, traffic density, as well as the ETCS rollout sequence. To model vehicle equipment to that granularity requires further analysis with a more focussed scope.
- Obsolescence cost: This cost is not directly considered but has been indirectly considered through the lifespan of the sensors and unit and the associated re-engineering cost.
- EGNOS costs: Due to no existing information or assumption regarding the costs for transmitting EGNOS data from terrestrial transmission stations to rolling stock vehicles, this cost factor has not been considered in the CBA. As discussed in chapter 3.2.1, the only relevant cost factor regarding EGNOS data transmission would only be usage fees for terrestrial transmission stations receiving EGNOS satellite signals and transmitting them to FRMCS infrastructure. While EGNOS is an important technological aspect for full LOC-OB functionality withing the CLUG 2.0 target architecture, these usage fees are likely not a significant cost factor for RUs if there is sufficient LOC-OB rollout scope because the costs do not scale with vehicle numbers. Subsequently, the more RUs invest into LOC-OB, the more distributed and therefore manageable the usage fees would become. As this CBA assumes a national LOC-OB rollout for the majority of the business cases considered, the omission of EGNOS costs is considerably justified.
- Existing GNSS solutions: It is assumed that all existing GNSS solutions can be avoided with LOC-OB. However, the associated cost of adaptations to the existing interfaces are not considered in this analysis. However, these costs would be negligible in relation to all other onboard costs considered and further would be offset by not requiring any further costs for the setup of the original interface. It is also difficult to accurately model the number and cost of GNSS solutions for each rolling stock, therefore reasonable assumptions were aligned.
- Development phase: All the costs during the development phase of both reference and target scenario are only implicitly considered within the cost assumptions for hardware and engineering. Through this approach, the sector-wide costs for developing and implementing LOC-OB can be analysed without explicitly considering the development phase.
- CAPEX and OPEX values: The values from each partner’s accounting system are used for the analysis.

5 Business Case Application

5.1 Business case presentation

One business case, each comparing reference and target scenario for ETCS L2 and MB hybrid has been analysed for each CLUG 2.0 partner – DB, SBB and SNCF. However, for each business case, sub-business cases for high and low engineering costs in the reference scenario have been calculated. In doing so, the most possible and realistic scenarios are covered. Table 12 below summarises the identified business cases:

Business CASE IDENTIFICATION	BC N°	BC1		BC2		BC3	
	HOLDER	DB		SBB		SNCF	
	SCOPE	National		Line		National	
Business CASE TYPE	TYPE	Mixed		Mixed		Mixed	
	USAGE	Passenger & freight		Passenger & freight		Passenger	
Odometry engineering cost	CAPEX	High	Low	High	Low	High	Low

Table 12: Overview of individually considered business cases

5.2 BC 1 – DB – National

This sub-chapter applies the DB specific parameters to the model and presents the results.

5.2.1 Business case description – DB

In addition to the aligned parameters described in 4.3, the following individual parameters in Table 13 were used.

ITEM	PARAMETER	UNIT	VALUE
Business case identification	BC n°	-	BC 1
	Holder	-	DB
	Scope	-	National
Business case type	Track type	-	Mixed
	Track usage	-	Passengers & freight
ETCS rollout	Start Rollout ETCS L2	Year	< 2024
	Start Rollout ETCS moving block	Year	2037
	ETCS km rolled out per year	km/ Year	According to NIP

ITEM	PARAMETER	UNIT	VALUE
Track	Total track length	km	According to NIP
Rolling stock	High-speed vehicles qualifying for LOC-OB equipment	Trains	321
	High-speed fleet qualifying for LOC-OB engineering	Train models	14
	Regional train vehicles qualifying for LOC-OB equipment	Trains	3164
	Regional fleet qualifying for LOC-OB engineering	Train models	59
	Cargo vehicles qualifying for LOC-OB equipment	Trains	1900
	Cargo fleet qualifying for LOC-OB engineering	Train models	33
Digital mapping	CAPEX	€ / KM	500
	OPEX	€ / KM / YEAR	100
Eurobalise	CAPEX	€/ unit	confidential
	OPEX	€/ unit/ year	confidential
	Eurobalise per km ETCS L2	qty / km	6,5
	Additional required Eurobalise per km for ETCS moving block	qty / km	0,182
	Eurobalise reduction ratio	% reduction ratio	Sensitivity analysis

Table 13: BC 1 (DB) – Individual parameter values

For this analysis, the whole DB network has been taken into account. The rail network is made up of approximately 33.000 km of lines. This translates to about 60.000 km of track length when lines with dual (or multi) tracks as well as tracks on train stations, passing sidings etc. are considered. The majority of the German railway network is a mixed traffic usage with only small parts separated into passenger and freight usage. Hence, the reason why no differentiation in the scenario is made for the track usage, rather one single application is analysed.

In Germany, the rollout of ETCS L2 is currently ongoing and about 1.004 km of tracks have already been equipped as of 2024. According to the present ETCS rollout strategy, it is planned that all tracks will have been equipped with ETCS by 2040, with the moving block technology planned to be available in 2037.

The rolling stock used in the German railway network stands at more than 13.000 trains but only 5.386 trains (comprising of 106 fleets) will be equipped and engineered respectively for LOC-OB. For the purpose of this business case, it is assumed that the same percentage of tracks needing to be equipped with ETCS when LOC-OB is available, directly corresponds to the same percentage of vehicles needing to be equipped with LOC-OB. However, the selected vehicles need to fulfil the following criteria:

- Only fleets with more than 10 vehicles will be engineered and equipped,
- The average age of the fleet should be at least 30 years for passenger trains and 40 years for freight trains,
- The train should have a minimum remaining life span of 15 years.

By 2035, 41% of the German rail network still needs to be equipped with ETCS which is less than the number of rolling stocks that fulfil the three criteria mentioned above. Therefore, the equipment of only 41% of eligible vehicles with LOC-OB has been modelled.

Since there are not yet concrete information about mapping costs available on DB side, the costs for the digital map have been generically and conservatively estimated with a CAPEX of 500 €/km and an OPEX of 100 €/km. The cost estimation is based on the already established processes for generating a digital map for ETCS L2 with odometry currently in use by SNCF (see chapter 5.4.1). Because the process of map creation is not as established as for SNCF, a 200% markup on the required workdays per 100 km and upfront investment for setting up the process for automatised map generation has been assumed. Additionally, a further 1,2 M€ upfront investment for the establishment of the map creation process has been assumed. Regarding the OPEX, five required maintenance operations per year and 100 km were assumed. The OPEX value covers the cost for frequent updates required for example, due to track closures, adaptations to the position of elements on the infrastructure etc. Most updates will not require re-measuring of the infrastructure and therefore do not trigger a new collection of data and preparation of the map data.

The CAPEX and OPEX costs for the Eurobalise are confidential to Deutsche Bahn. About 6,5 Eurobalises are needed per kilometre to fulfil safety and operational requirements with ETCS L2. Based on the results of a previous study (see 2.3), in moving block technology without LOC-OB an average of about 0,182 additional Eurobalise per kilometre will be needed to achieve an improved operational performance. A sensitivity analysis is conducted for the optimum percentage of Eurobalise reduction ratio to obtain a positive NPV for both scenarios.

5.2.2 Business case results and analysis – DB

The result presentation is divided along the two sub-business cases considering high and low engineering costs for the odometry system (based on the distinction described in chapter 4.3).

5.2.2.1 High odometry costs

The results for the sub-business case when analysed with a higher engineering cost for the reference scenario in comparison to the target scenario are as follows:

BC IDENTIFICATION	HOLDER	SCOPE	ENGINEERING COST ODOMETRY
BC 1	DB	National	**High** – 400 k€

Key Figure	Unit	ETCS L2	ETCS MBH	ETCS L2	ETCS MBH	ETCS L2	ETCS MBH
Eurobalise reduction	%	30 %		40 %		50 %	
NPV CAPEX	k€	-42.149	-40.579	-13.120	-11.026	15.910	18.577
NPV OPEX	k€	142.409	144.613	185.430	188.369	228.451	232.124
NPV Onboard	k€	-74.271	-74.271	-74.271	-74.271	-74.271	-74.271
NPV Trackside	k€	174.531	178.305	246.581	251.614	318.632	324.923
NPV Onboard p. vehicle	k€/ veh	-13,8	-13,8	-13,8	-13,8	-13,8	-13,8
NPV Trackside p. km	k€/ km	7,1	7,3	10,0	10,2	13,0	13,2
NPV	**k€**	**100.260**	**104.034**	**172.310**	**177.343**	**244.361**	**250.652**

Table 14: BC 1 (DB) – Results for high odometry engineering costs sub-business case

For DB, in the sub-business case for high odometry engineering costs, an overall positive NPV result of 100 – 250 M€ could be achieved for the three selected Eurobalise reduction ratio values. Calculating the internal rate of return (IRR), equivalent to the discount rate at which the NPV equals zero, provides a return on investment between 30% and 142%. As expected, the sub-scenario for ETCS MB hybrid generally has a slightly better NPV result compared to ETCS L2. This is due to the increased number of Eurobalises required for ETCS MB hybrid which subsequently means that a higher amount of Eurobalises can be saved when implementing LOC-OB (as described in chapter 2.2). It can also be seen that the NPV Onboard is negative for all sub-scenarios considered. This is because the onboard invest into vehicle engineering and equipment stays constant, irrespective of the ETCS mode of operation or the Eurobalise reduction ratio that is being considered. The NPV for the onboard is highly influenced by the homogeneity of the fleet. As engineering costs are incurred per train model and, in this sub-business case, the engineering costs for legacy odometry exceed the ones for LOC-OB, the more inhomogeneous a fleet is – meaning there are more train models for the same number of vehicles – the more extreme the overall difference in engineering costs between legacy odometry and LOC-OB will be. These cost savings for the vehicle engineering, however, are offset by higher vehicle equipment costs for LOC-OB. In this sub-business case, as the fleet is relatively homogeneous with a large number of vehicles per train model, the higher costs for LOC-OB vehicle equipment exceed the lower costs for LOC-OB vehicle engineering, when compared with legacy odometry systems, resulting in a negative NPV for the onboard side.

It can be seen that the overall positive NPV result is generally driven by the NPV OPEX, indicating that the saved maintenance and operation costs for Eurobalises not required under LOC-OB is the main benefit driver. This is because, while the CAPEX investment is only saved once, the OPEX is saved continuously for every year considered in the analysis. Accordingly, the costs savings for the OPEX are around double than for the CAPEX, when not accounting for nominalisation and cashflow discount. For the sub-scenarios considering 30% and 40% Eurobalise reduction ratio, it can also be seen that the CAPEX investment of LOC-OB on the onboard side still exceeds the CAPEX savings from the avoided Eurobalise installation on the trackside, resulting in an overall negative NPV CAPEX. However, this negative NPV CAPEX can still be offset by the NPV OPEX, resulting in an overall positive NPV.

Looking at the sensitivity analysis in Figure 13 and Figure 14, the minimum Eurobalise reduction ratio required to achieve a positive result for the ETCS L2 sub-scenario is 18 %, corresponding with a NPV of around 14 M€. For the ETCS MB hybrid sub-scenario, only a 16% reduction is needed for a positive NPV result of around 1,4 M€. Overall, the analysis shows the same linear increase in the NPV and NPV Trackside with an increment of 14,4 M€ in the ETCS L2 case and 14,6 M€ in the ETCS MBH case for every additional 2 % reduction. For each sub-scenario, the graph for the NPV Trackside runs in parallel to the graph for the overall NPV, exhibiting the same liner increase since the general relationship of both values with the Eurobalise reduction ratio is the same. The only difference is that the overall NPV also takes into account the NPV Onboard, whereas the NPV Trackside does not.

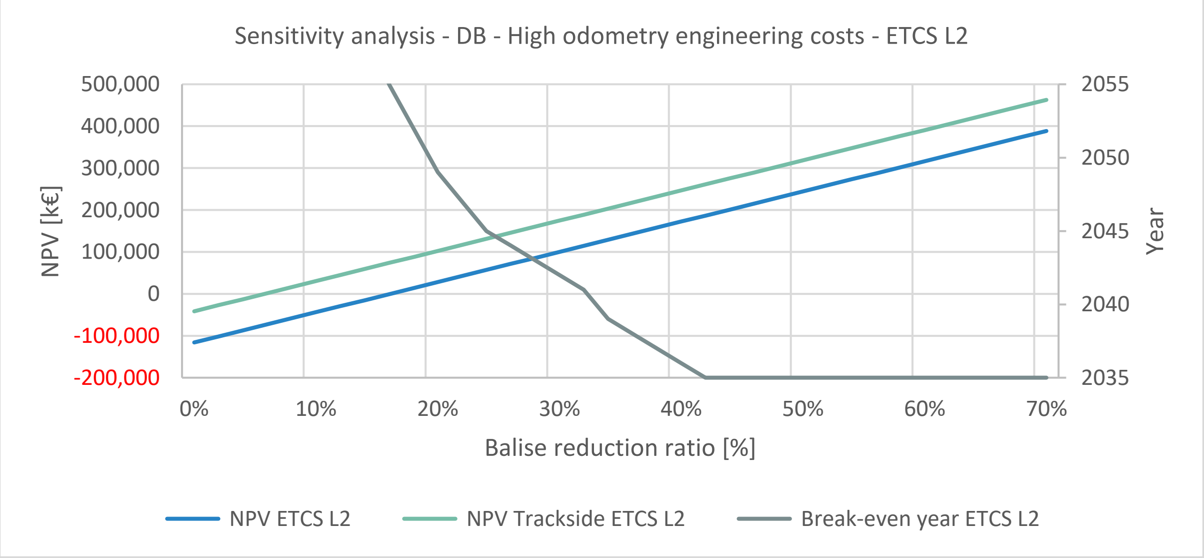

Figure 13: BC 1 (DB) – Sensitivity analysis ETCS L2 (high odometry engineering cost)

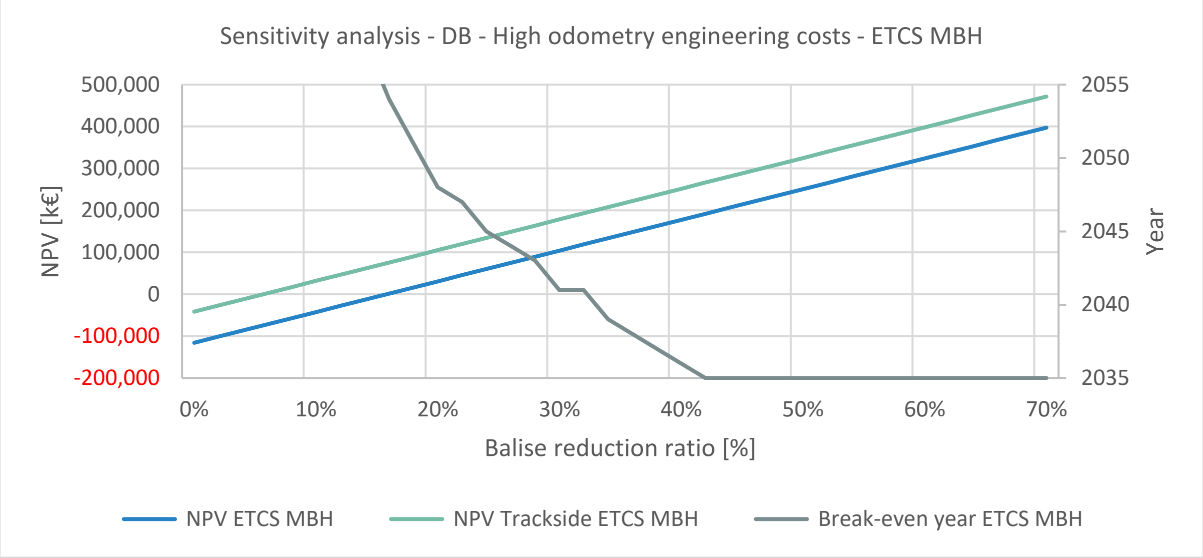

Figure 14: BC 1 (DB) – Sensitivity analysis ETCS MBH (high odometry engineering cost)

When examining the break-even year, 42 % Eurobalise reduction ratio marks threshold value where a break-even is achieved within the first year of LOC-OB rollout. That means that the reduced costs from installing less Eurobalises on the part of ETCS track that is being rolled out in 2035 alone is enough to offset the entire LOC-OB investment required into vehicles and the digital map. The maximum break-even year is 2055 as the CBA only considers a time frame of 20 years after start of LOC-OB rollout. Accordingly, the Eurobalise reduction ratio for which the break-even can only be achieved in 2055 corresponds with the minimum reduction ratio required for a positive NPV result (18 % and 16 % respectively for ETCS L2 and MBH).

5.2.2.2 Low odometry costs

The results for the sub-business case when analysed with a lower engineering cost for the reference scenario in comparison to the target scenario are as follows:

BC IDENTIFICATION	HOLDER	SCOPE	ENGINEERING COST ODOMETRY
BC 1	DB	National	**Low** – 200 k€

Key Figure	Unit	ETCS L2	ETCS MBH	ETCS L2	ETCS MBH	ETCS L2	ETCS MBH
Eurobalise reduction	%	30 %		40 %		50 %	
NPV CAPEX	k€	-61.130	-59.560	-32.101	-30.007	-3.071	-453

BC IDENTIFICATION	HOLDER	SCOPE	ENGINEERING COST ODOMETRY
BC 1	DB	National	**Low** – 200 k€

Key Figure	Unit	ETCS L2	ETCS MBH	ETCS L2	ETCS MBH	ETCS L2	ETCS MBH
Eurobalise reduction	%	30 %		40 %		50 %	
NPV OPEX	k€	142.409	144.613	185.430	188.369	228.451	232.124
NPV Onboard	k€	-93.252	-93.252	-93.252	-93.252	-93.252	-93.252
NPV Trackside	k€	174.531	178.305	246.581	251.614	318.632	324.923
NPV Onboard p. vehicle	k€/ veh	-17,3	-17,3	-17,3	-17,3	-17,3	-17,3
NPV Trackside p. km	k€/ km	7,1	7,3	10,0	10,2	13,0	13,2
NPV	**k€**	**81.279**	**85.053**	**153.329**	**158.362**	**225.380**	**231.671**

Table 15: BC 1 (DB) – Results for low odometry engineering costs sub-business case

The results for the analysis considering lower engineering cost for the reference scenario follow the same trend as for the higher odometry engineering costs but differ slightly in magnitude. The overall NPV results range from 81 M€ to 231 M€, representing an IRR between 19% and 107%. Again, the NPV Onboard exhibits the same negative result for both ETCS sub-scenarios across all Eurobalise reduction ratios considered. However, the result is almost 20 M€ lower than for the sub-business case considering higher odometry engineering costs. This means that this relative increase of LOC-OB engineering costs results in around 25 % higher overall costs for the Onboard side. Similarly, it can also be observed that the overall NPV result for all exemplary Eurobalise reduction ratio values considered is positive, solely driven by a positive NPV OPEX. In contrast to the sub-business case considering higher odometry engineering costs, even at 50 % Eurobalise reduction ratio, a positive NPV CAPEX cannot be achieved this time. The overall NPV results are consistently around 20 M€ lower than for the high odometry engineering costs sub-business case, matching with the increased Onboard costs explained above.

The minimum Eurobalise reduction ratio required to achieve a positive business case within the investigation period is 20 % for the ETCS L2 sub-scenario, which corresponds to a NPV of about 9 M€. Moreso, the same Eurobalise reduction percentage of 20 % is also needed for the hybrid moving block scenario to break even with a higher NPV of 11,7 M€. The sensitivity analysis in Figure 15 and Figure

16 also show the same linear increases for the overall NPV and NPV Trackside as in the sub-business case for the higher odometry engineering costs, as this increase is independent of any costs on the onboard side.

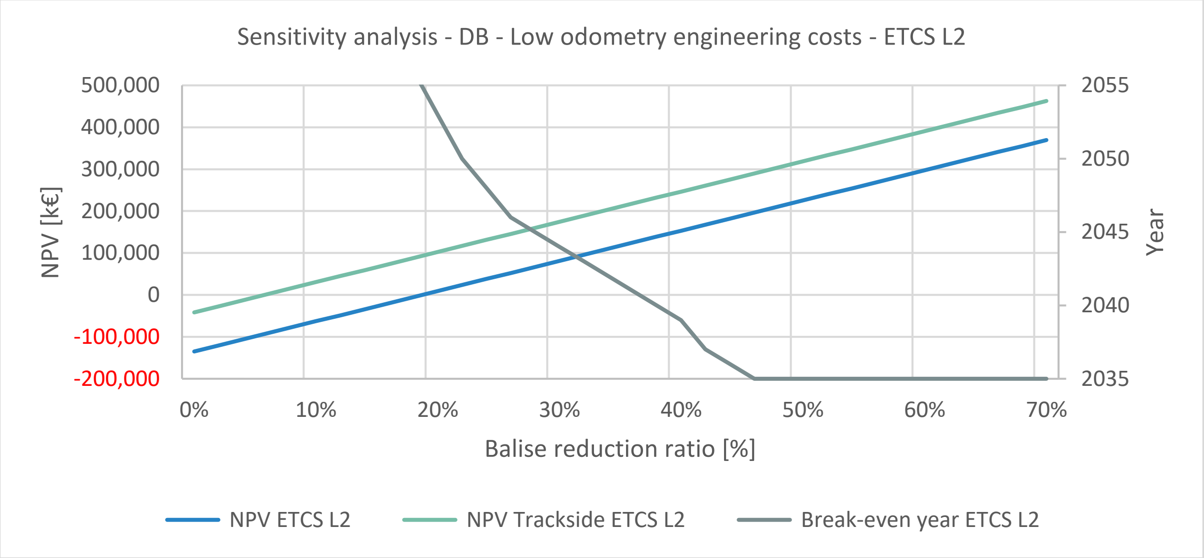

Figure 15: BC 1 (DB) – Sensitivity analysis ETCS L2 (low odometry engineering costs)

Lastly, considering the break-even year, it can be observed that the threshold value to achieve a positive business case in the same year LOC-OB rollout starts is at 46 % Eurobalise reduction and therefore expectedly higher than for the sub-business case considering high odometry engineering costs. If only 42 % Eurobalise reduction ratio, the previously discussed threshold value, is achieved, the CBA breaks even in 2037. While this discrepancy is not tremendous, it highlights once more how the assumption regarding the odometry engineering costs influences the overall NPV result as much as the time it takes for the investment to pay off.

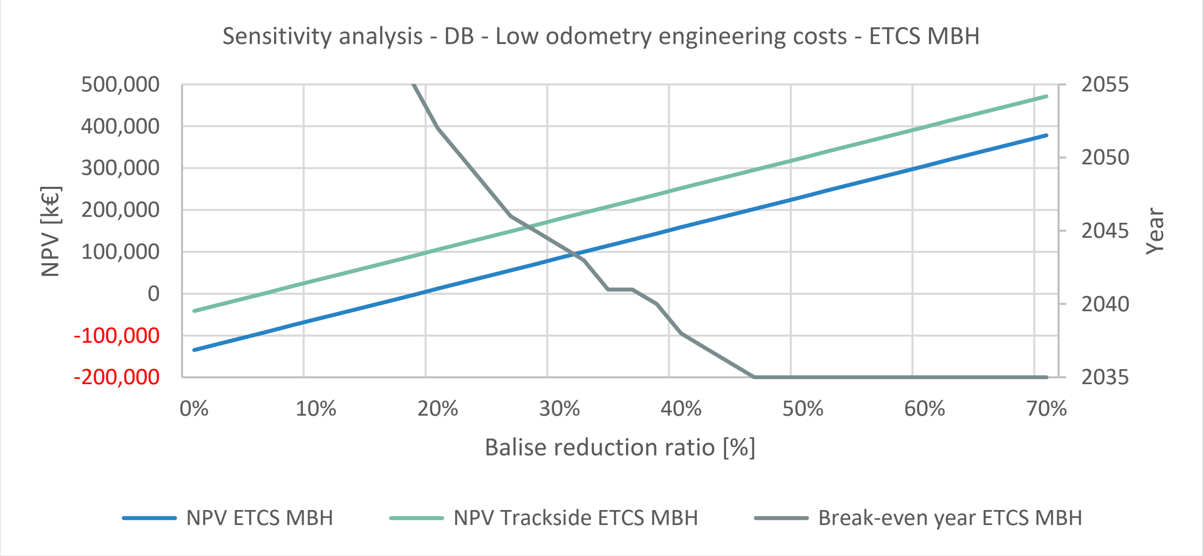

Figure 16: BC 1 (DB) – Sensitivity analysis ETCS MBH (low odometry engineering costs)

5.3 BC 2 – SBB – Line

This sub-chapter applies the SBB-specific parameters to the model and presents the results.

5.3.1 Business case description – SBB

In addition to the aligned parameters described in 4.3, the following individual parameters in Table 16 were used.

ITEM	PARAMETER	UNIT	VALUE
Business case identification	BC n°	-	BC 2
	Holder	-	SBB
	Scope	-	Line
Business case type	Track type	-	Mixed
	Track usage	-	Passengers & freight
ETCS rollout	Start Rollout ETCS L2	Year	2030
	Start Rollout ETCS moving block	Year	2035
	ETCS km rolled out per year	km/ Year	120
Track	Total track length	km	120
Rolling stock	High-speed vehicles qualifying for LOC-OB equipment	Trains	8
	High-speed fleet qualifying for LOC-OB engineering	Train models	2
	Regional train vehicles qualifying for LOC-OB equipment	Trains	8
	Regional fleet qualifying for LOC-OB engineering	Train models	2
	Cargo vehicles qualifying for LOC-OB equipment	Trains	8
	Cargo fleet qualifying for LOC-OB engineering	Train models	2

ITEM	PARAMETER	UNIT	VALUE
Digital mapping	CAPEX	€ / KM	500
	OPEX	€ / KM / YEAR	100
Eurobalise	CAPEX	€/ unit	confidential
	OPEX	€/ unit/ year	confidential
	Eurobalise per km ETCS L2	qty / km	5
	Additional required Eurobalise per km for ETCS moving block	qty / km	1
	Eurobalise reduction ratio	% reduction ratio	Sensitivity analysis

Table 16: BC 2 (SBB) – Individual parameter values

The investigated line of SBB is currently planned to be equipped with ETCS Level 2 due to a foreseen interlocking replacement. SBB follows a line-based approach with the target to solely rely on ETCS Level 2 cab signalling for renewal projects and new lines. The described line connects two larger stations with a medium station in the middle. Between them, 13 smaller stations are uniformly distributed across the line. The current timetable consists of 2 intercity trains per hour, 1 regional express, 2 regional trains from one larger station to the one in the middle and 2 regional trains from the other larger station to the one in the middle per hour, and a capacity of 2 freight train paths per hour. All connections are operated bi-directional. The scenario is of interest due to its actuality. Additionally, it adequately represents the main characteristics of a typical line in Switzerland. The network in Switzerland is completely equipped with ETCS Level 1 Limited Supervision and partially with Level 2. The network is designed for mixed traffic, is interoperable, and is based on a node principle operated using synchronised timetable. Nevertheless, some assumptions were taken which are explained below.

As stated above, the line is operated with mixed traffic - passenger and freight trains use the same tracks. The rollout of ETCS Level 2 on this line is planned for 2030. It is assumed that within one year, the complete line will be transitioned from current ETCS Level 1 Limited Supervision to Level 2 with cab signalling (i.e. no line side signals necessary). Eventually, ETCS moving block will be available by 2035. However, to ascertain the effect of moving block on the investigated line, it is assumed that the line will be equipped with ETCS Level 2 or ETCS hybrid moving block in the year 2036. The business case result therefore does not consider a migration scenario, but the results represent the NPV with full ETCS Level 2 or full ETCS moving block on the investigated line. The line is approximately 50 km long and completely dual-tracked. An additional 20 km of track for shunting yards, sidings for passenger trains, and private sidings for industry freight distributed along the line has also been considered.

Regarding the rolling stock, the needed fleet to serve all connections explained in the timetable above is assumed. Compositions with double-decker wagons pulled by a locomotive and double-decker long-distance trainset are used for the interregional line. Similarly, a double-decker regional trainset and a standard regional train serve the regional connections including the express service. The freight transport is assumed to be served by standard freight locomotives of two different types. Respecting the timetable requirements and substitute vehicles (maintenance, replacement, etc.) for all types, the fleet side is estimated to eight long-distance, eight regional, and eight freight vehicles and two different fleet types for each category.

Analogous to the estimation in the DB business case, due to unavailability of concrete cost information, the CAPEX for the digital map has been set at 500 €/km while the OPEX is set at 100 €/km. The cost estimation is based on the already established processes for generating a digital map for ETCS L2 with odometry currently in use by SNCF (see chapter 5.4.1). Because the process of map creation is not as established as for SNCF, a 200% markup on the required workdays per 100 km and upfront investment for setting up the process for automatised map generation has been assumed. Regarding the OPEX, five required maintenance operations per year and 100 km were assumed. The OPEX value covers the cost for frequent updates required for example, due to track closures, adaptations to the position of elements on the infrastructure etc. Most updates will not require re-measuring of the infrastructure and therefore do not trigger a new collection of data and preparation of the map data.

The CAPEX and OPEX of the Eurobalise of SBB are confidential and not shared with the public. The assumed density of 5 Eurobalises (not groups) per km is based on a regional line that has already been equipped with ETCS Level 2 in Switzerland. If the fundamentals of the engineering rules do not change, this number is realistic. It is also assumed that a single additional Eurobalise per km – 6 Eurobalises per km in total - is required to achieve the same headway times with moving block and today's odometry accuracy compared to moving block in the target scenario with better localisation accuracy. The Eurobalise reduction ratio will be used for the sensitivity analysis, however, SBB generally targets a 30% reduction of Eurobalises with LOC-OB.

5.3.2 Business case results and analysis – SBB

The result presentation is divided along the two sub-business cases considering high and low engineering costs for the odometry system (based on the distinction described in chapter 4.3).

5.3.2.1 High odometry costs

The results for the sub-business case when analysed with a higher engineering cost for the reference scenario in comparison to the target scenario are as follows:

BC IDENTIFICATION	HOLDER	SCOPE	ENGINEERING COST ODOMETRY
BC 2	SBB	Line	**High** – 400 k€

Key Figure	Unit	ETCS L2	ETCS MBH	ETCS L2	ETCS MBH	ETCS L2	ETCS MBH
Eurobalise reduction	%	30 %		40 %		50 %	
NPV CAPEX	k€	729	895	1.006	1.227	1.283	1.560
NPV OPEX	k€	316	367	400	468	485	569
NPV Onboard	k€	180	180	180	180	180	180
NPV Trackside	k€	864	1.081	1.226	1.515	1.587	1.948
NPV Onboard p. vehicle	k€/veh	7,5	7,5	7,5	7,5	7,5	7,5
NPV Trackside p. km	k€/km	7,2	9,0	10,2	12,6	13,2	16,2
NPV	**k€**	**1.045**	**1.262**	**1.406**	**1.695**	**1.767**	**2.218**

Table 17: BC 2 (SBB) – Results for high odometry engineering costs sub-business case

For SBB, in the sub-business cases for high odometry engineering costs and for the exemplary values of Eurobalise reduction ratio highlighted, LOC-OB implementation achieves positive NPV results overall, for trackside and onboard as well as for CAPEX and OPEX. Since the SBB business case only considers one line, the results only range in the hundred thousands to low millions. Again, as seen in the previous business cases, the sub-scenario for ETCS MB hybrid generally delivers a better NPV result when compared to ETCS L2. However, for the SBB business case this difference in results is more significant with the ETCS MB hybrid result exceeding the ETCS L2 result by around 25 %. This more pronounced difference is driven by the significant number of additional Eurobalises required for ETCS MB hybrid – assumed at one per kilometre of track – while in the DB business case only less than 0,2 additional Eurobalises per kilometre of track were assumed.

The most noteworthy NPV result for the high odometry engineering costs sub-business case is the NPV onboard which, unlike all other sub-business cases considered in this CBA, remains positive. The reason for this result lies in the composition of the assumed fleet. For the line modelled, there are two train models per type of transport (high-speed, regional & cargo) with four vehicles each. This ratio between train models and vehicles is much lower than it would be for the SBB national railway system as a whole and is rather a caveat of the sample selection. In the sub-business case assuming high odometry engineering costs, the engineering costs for legacy odometry systems are higher than for LOC-OB. Normally, these lower engineering costs for LOC-OB are offset by significantly higher costs for equipping the vehicles. However, this offset only comes into effect if there is a sufficient number of vehicles per fleet. If there is a very small number of vehicles per fleet, the lower engineering costs for LOC-OB outweigh its higher retrofitting costs, leading to a positive business case for the onboard side alone. It is important to note that this relationship would not hold up in a business case with national scope, because vehicles of the same train models also operate on other lines. As SBB is striving for an increased homogenisation of its fleet, the offset of low engineering costs by high retrofitting costs would even increase in the future.

While for this sub-business case, the NPV CAPEX result remains positive for all exemplary Eurobalise reduction ratios considered, it can still be seen that the NPV OPEX remains the main driver for the overall NPV result. This once again indicates that the saved maintenance and operation costs for Eurobalises not required under LOC-OB are the main benefit driver in this analysis for the same reason explained in chapter 5.2.2.1.

Looking at the sensitivity analysis in Figure 17 and Figure 18, the minimum Eurobalise reduction ratio required to achieve a positive result within the investigation period for the ETCS L2 as well as the hybrid moving block sub-business case is 2 %, which corresponds to a NPV of 34 k€ and 48 k€ respectively. The reason for this sub-business case being able to achieve a positive result at such a low Eurobalise reduction ratio is the same as for the positive Onboard NPV. As the costs for equipping vehicles with LOC-OB are lower than for equipping them with legacy odometry systems in this specific sub-business case, no significant Eurobalise reduction is required to offset any additional onboard costs. However, at 0 % Eurobalise reduction, the overall NPV is still negative, because the trackside CAPEX and OPEX required for digital map implementation and maintenance of 288 k€ exceeds the cost savings on the onboard side of 180 k€. Accordingly, the 2 % Eurobalise reduction is still required for an overall positive NPV result.

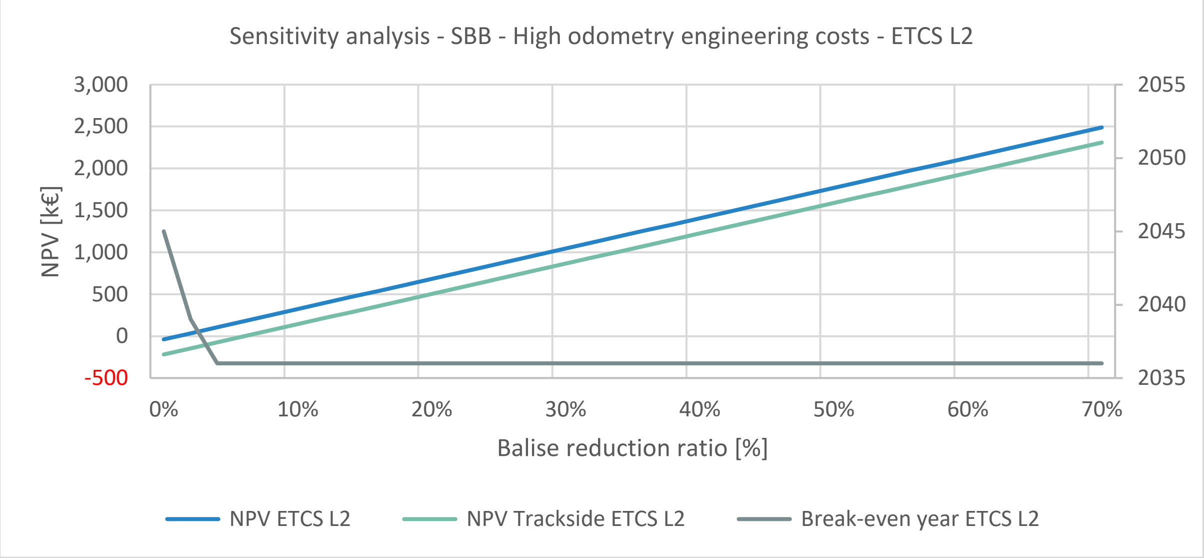

Figure 17: BC 2 (SBB) – Sensitivity analysis ETCS L2 (high odometry engineering costs)

Overall, the sensitivity analysis shows a linear increase in the NPV depending on the Eurobalise reduction ratio achieved with an increment of 72 k€ in the ETCS L2 case and 87 k€ in the hybrid moving block case for every additional 2 % reduction. In contrast to all other sub-business cases considered, the lines showing the NPV Trackside runs lower than the overall NPV line. This is once again caused by the positive NPV Onboard boosting the overall NPV result in this case, while it reduced the NPV in all other sub-business cases.

Lastly, it can be seen that the minimum break-even year of 2036 is already being achieved at 4 % and 2 % for the ETCS L2 and moving block hybrid sub-scenarios respectively. The minimum break-even year is 2036 for the SBB business case, in contrast to 2035 for DB and SNCF, because for SBB it is assumed that the ETCS equipment of the considered line occurs in 2036. Accordingly, the benefit of reducing Eurobalise costs can only be achieved in 2036.

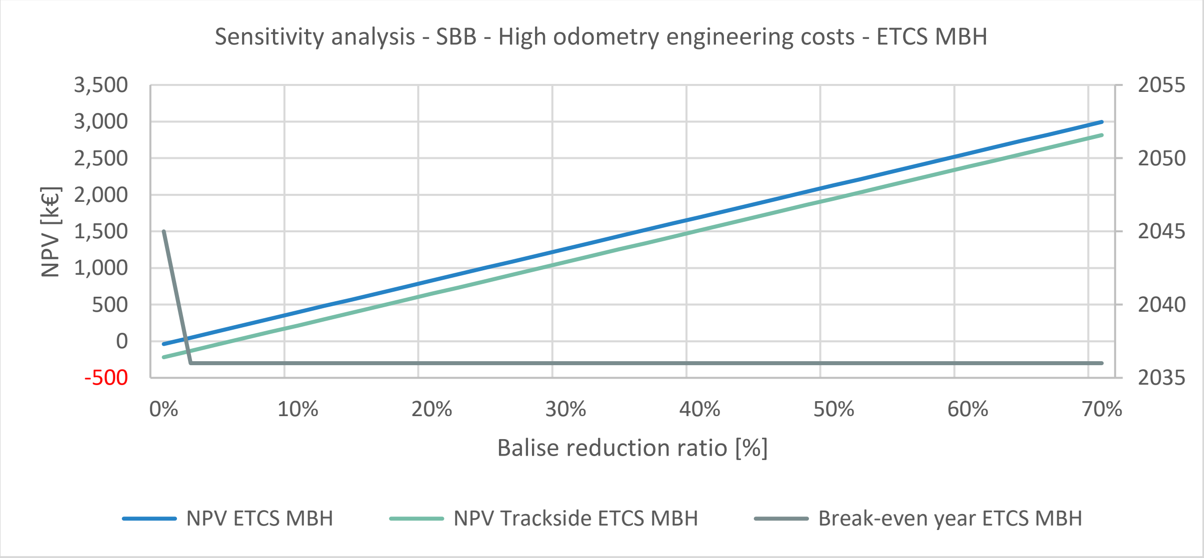

Figure 18: BC 2 (SBB) – Sensitivity analysis ETCS MBH (high odometry engineering costs)

5.3.2.2 Low odometry costs

The results for the sub-business case when analysed with a lower engineering cost for the reference scenario in comparison to the target scenario are as follows:

BC IDENTIFICATION	**HOLDER**	**SCOPE**	**ENGINEERING COST ODOMETRY**
BC 2	SBB	Line	**Low** – 200 k€

Key Figure	**Unit**	**ETCS L2**	**ETCS MBH**	**ETCS L2**	**ETCS MBH**	**ETCS L2**	**ETCS MBH**
Eurobalise reduction	%	30 %		40 %		50 %	
NPV CAPEX	k€	-382	-216	-105	117	172	449
NPV OPEX	k€	316	367	400	468	485	569
NPV Onboard	k€	-930	-930	-930	-930	-930	-930
NPV Trackside	k€	865	1.081	1.226	1.515	1.587	1.948
NPV Onboard p. vehicle	k€/ veh	-38,8	-38,8	-38,8	-38,8	-38,8	-38,8
NPV Trackside p. km	k€/ km	7,2	9,0	10,2	12,6	13,2	16,2
NPV	**k€**	**-65**	**151**	**296**	**585**	**657**	**1.018**

Table 18: BC 2 (SBB) – Results for low odometry engineering costs sub-business case

The results for the SBB sub-business case considering low odometry engineering costs differ greatly in magnitude when compared with the results from the sub-business case considering high odometry engineering costs. This significant difference is solely driven by the fact that the previously discussed relationship of lower onboard costs for LOC-OB if compared with legacy odometry does not hold anymore, as in this sub-business case the engineering costs for LOC-OB exceed the engineering costs for the legacy odometry system by 100 k€ per fleet. As a result, and as seen in all the DB and SNCF sub-business cases the NPV Onboard is greatly negative and can only be offset by the NPV Trackside driven by the Eurobalise reduction. The overall NPV result still remains positive for almost all sub-scenarios considered except for the ETCS L2 30 % Eurobalise reduction ratio, where no positive business case can be achieved. This shows that the odometry engineering costs has a high impact for the SBB business case. The reason for this lies again in the assumption of only eight vehicles per fleet which gives the assumed engineering costs a larger weight in relation to e.g., assumptions regarding vehicle equipment costs.

As in all previously discussed sub-business cases, the overall results once again are driven by the NPV OPEX. However, in contrast to SBB sub-business case considering high odometry engineering costs, this sub-business case does not achieve a positive NPV CAPEX result for several sub-scenarios.

Considering the results from the sensitivity analysis in Figure 19 and Figure 20, the minimum Eurobalise reduction ratio required to achieve a positive business case within the investigation period for the ETCS L2 sub-scenario increases sharply from 2 % to 32 %, corresponding to a NPV of 7 k€. Moreover, 28 % Eurobalise reduction is now needed for the hybrid moving block scenario with a NPV of 238 k€. The sensitivity analysis also shows the same linear increase in the NPV as in the sub-business case considering low odometry engineering costs of about 72 k€ in the ETCS L2 sub-scenario and about 87 k€ in the hybrid moving block sub-scenario for every additional 2 % Eurobalise reduction. Lastly, the minimum break-even year of 2036 is being achieved at 40 % Eurobalise reduction for the ETCS L2 sub-scenario and at 34 % Eurobalise reduction for the ETCS MBH sub-scenario.

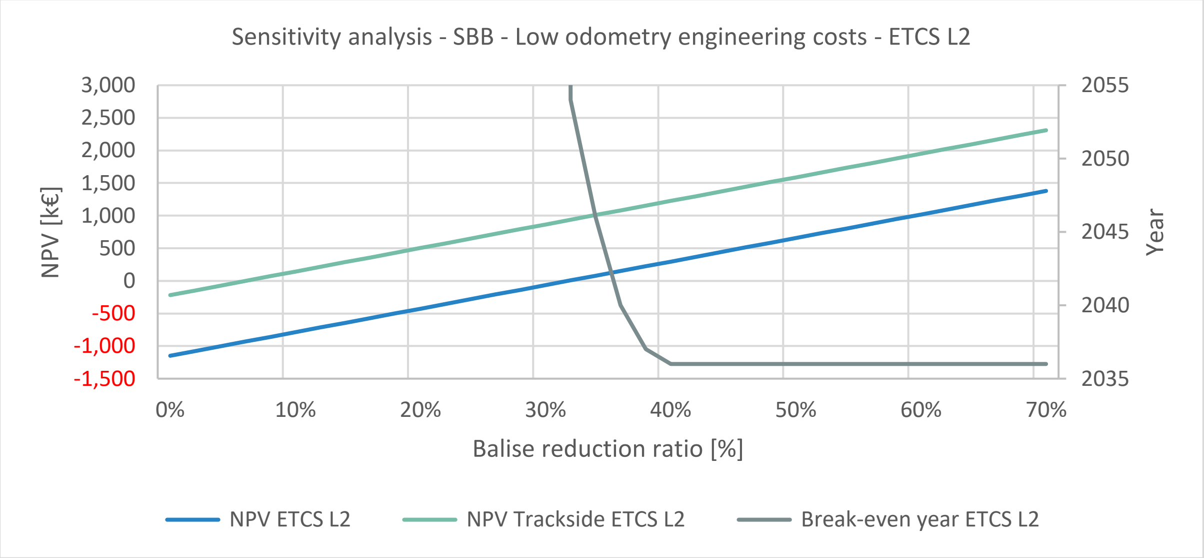

Figure 19: BC 2 (SBB) – Sensitivity analysis ETCS L2 (low odometry engineering costs)

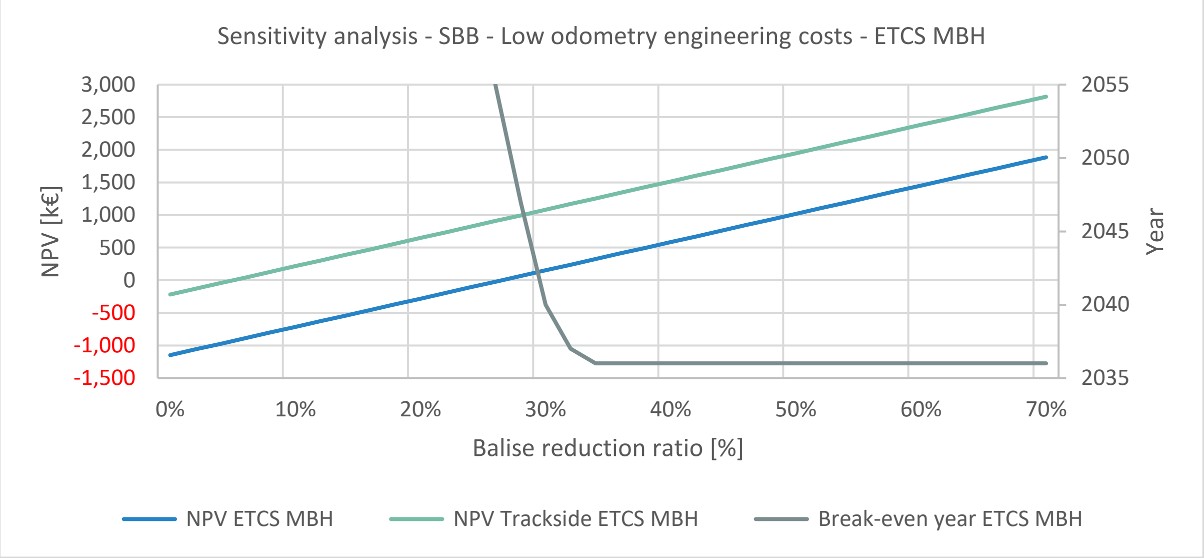

Figure 20: BC 2 (SBB) – Sensitivity analysis ETCS MBH (low odometry engineering costs)

5.4 BC 3 – SNCF – National

This sub-chapter applies the SNCF specific parameters to the model and presents the results.

5.4.1 Business case description – SNCF

In addition to the aligned parameters described in 4.3, the following individual parameters in Table 19 were used.

ITEM	PARAMETER	UNIT	VALUE
Business case identification	BC n°	-	BC 2
	Holder	-	SNCF
	Scope	-	National
Business case type	Track type	-	Mixed
	Track usage	-	Passengers only
ETCS rollout	Start Rollout ETCS L2	Year	< 2024
	Start Rollout ETCS moving block	Year	2037
	ETCS km rolled out per year	km/ Year	confidential
Track	Total track length	km	confidential

ITEM	PARAMETER	UNIT	VALUE
Rolling stock	High-speed vehicles qualifying for LOC-OB equipment	Trains	298
	High-speed fleet qualifying for LOC-OB engineering	Train models	3
	Regional train vehicles qualifying for LOC-OB equipment	Trains	788
	Regional fleet qualifying for LOC-OB engineering	Train models	4
	Cargo vehicles qualifying for LOC-OB equipment	Trains	0
	Cargo fleet qualifying for LOC-OB engineering	Train models	0
Digital mapping	CAPEX	€ / KM	100
	OPEX	€ / KM / YEAR	40
Eurobalise	CAPEX	€/ unit	confidential
	OPEX	€/ unit/ year	confidential
	Eurobalise per km ETCS L2	qty / km	5
	Additional required Eurobalise per km for ETCS moving block	qty / km	0,182
	Eurobalise reduction ratio	% reduction ratio	Sensitivity analysis

Table 19: BC 3 (SNCF) – Individual parameter values

This description is based on the document “support manual of the ERTMS National Input Plan for the French network”. This document sets out the guidelines, assumptions, constraints and strategic choices that have been made in drawing up a national ERTMS deployment plan. It is important to note that the plan consulted is not definitive and does not necessarily reflect the NIP that will be presented to the European Commission. In addition, at the stage of writing this deliverable, it should be pointed out that this document is confidential. Some of the input data used to build this business case will therefore not be made explicit.

- Number of kilometre of lines in the perimeter of this CBA: Up until 2024, there are more than 1000 km of tracks already equipped with ERTMS. In the NIP scenario, only a part of the French network will be migrated in ERTMS. The choice of lines considered is based on strategic considerations relating to the overall performance of the network and the medium-term industrial vision. The scenario developed in the NIP starts from 2024 and covers a period of 20 years. For this study, the date of availability of the LOC OB has been set in 2035 and for a lifespan of 20 years, which is also used as the investigation period. So, an extrapolation of the data given in the NIP was necessary to cover the period from 2044 to 2054. In it, the average number of track km per year to be equipped with ERTMS has been calculated on the basis of NIP data and applied for the period 2044-2054.
- Rolling stock in the perimeter of this CBA: For the purpose of this business case, it is assumed that the same percentage of tracks needed to be equipped with ETCS when LOC-OB is available, directly corresponds to the same percentage of vehicles needed to be equipped with LOC-OB. Furthermore, given that only one line specifically dedicated to freight is mentioned in the NIP and that this line is already equipped (or in the process of being equipped) with ETCS level 1, it has been decided not to consider freight trains for this study.

  The following parameters have also been taken into account:

  - The train should have a minimum remaining life span of 15 years to be equipped with ETCS (and therefore considered in this analysis).
  - As for the trackside part, for the period between 2044 and 2054, an extrapolation was made using the same method as detailed above for track km.
  - An annual growth of 1% of the total fleet was assumed.
- Digital mapping costs: Based on already established processes for generating a digital map required for ETCS L2 with odometry, a more concrete cost estimation for the digital map has been made for the SNCF business case. The steps of the SIL 4 process in place at SNCF to generate the current railML data, already cover most of the work to be done to generate the Digital Map for LOC-OB. The supplementary cost is related to the last step of the process, specific to the Digital Map required for LOC-OB. The department in charge of map generation for ETCS estimated the last cross validation step for LOC-OB map generation equal to two workdays per 100 km of track, therefore the CAPEX for the digital map has been set at 100 €/km. These costs include one-time upfront costs of around 600 k€ for setting up the process for automatised map generation. The OPEX for the digital map has been set at 40 €/km, assuming two required maintenance operations per year and 100 km of track.
- Parameters for the Eurobalises: The average CAPEX and OPEX costs for the Eurobalise remain confidential. It is assumed that about 5 Eurobalises per kilometre fulfil the safety and operational requirements in ETCS level 2. Based on the results of a previous study (see chapter 3), in moving block technology without LOC-OB an average of about 0,182 additional Eurobalise per kilometre will be needed to achieve the required localisation accuracy for a good operational.

A sensitivity analysis is conducted for the optimum percentage of Eurobalise reduction ratio to obtain a positive NPV for all scenarios.

5.4.2 Business case results and analysis – SNCF

The result presentation is divided along the two sub-business cases considering high and low engineering costs for the odometry system (based on the distinction described in chapter 4.3).

5.4.2.1 High odometry costs

The results for the sub-business case when analysed with a higher engineering cost for the reference scenario in comparison to the target scenario are as follows:

BC IDENTIFICATION	HOLDER	SCOPE	ENGINEERING COST ODOMETRY
BC 3	SNCF	National	**High** – 400 k€

Key Figure	Unit	ETCS L2	ETCS MBH	ETCS L2	ETCS MBH	ETCS L2	ETCS MBH
Eurobalise reduction	%	30 %		40 %		50 %	
NPV CAPEX	k€	6.475	7.388	16.571	17.788	26.667	28.188
NPV OPEX	k€	34.517	35.348	45.105	46.215	55.694	57.081
NPV Onboard	k€	-17.410	-17.410	-17.410	-17.410	-17.410	-17.410
NPV Trackside	k€	58.401	60.146	79.086	81.412	99.771	102.678
NPV Onboard p. vehicle	k€/ veh	-16,0	-16,0	-16,0	-16,0	-16,0	-16,0
NPV Trackside p. km	k€/ km	6,2	6,4	8,5	8,7	10,7	11,0
NPV	**k€**	**40.992**	**42.736**	**61.677**	**64.002**	**82.362**	**85.269**

Table 20: BC 3 (SNCF) – Results for high odometry engineering costs sub-business case

The SNCF sub-business case considering high odometry engineering costs achieves positive overall NPV results for all sub-scenarios and exemplary Eurobalise reduction rates considered, ranging from 41 M€ to 85 M€. Calculating the internal rate of return (IRR), equivalent to the discount rate at which the NPV equals zero, provides a return on investment between 117% and 201%. Again, the sub-scenario for ETCS MB hybrid generally delivers a slightly better NPV result as for ETCS L2, driven by the additional Eurobalises required for operational performance under ETCS MB hybrid that can be saved when implementing LOC-OB (as described in chapter 2.2). Once again, it can also be seen that the NPV Onboard is negative for all sub-scenarios considered, driven by the fact that the lower engineering costs for LOC-OB are being offset by the vehicles costs, as discussed for the DB sub-business case considering high odometry engineering costs in chapter 5.2.2.1.

Similar to the previously discussed sub-business cases, the overall NPV result is being driven by the NPV OPEX which is driven by the reoccurring benefit of reduced Eurobalise OPEX. However, in contrast to the DB sub-business case considering high odometry engineering costs, the NPV CAPEX here is positive for all sub-scenarios and exemplary Eurobalise reduction ratios considered. This is likely driven by a smaller number of vehicles in relation to the length of ETCS track where the benefit of Eurobalise reduction is being realised.

Considering the sensitivity analysis in Figure 21 and Figure 22, the minimum Eurobalise reduction ratio required to achieve a positive business case within the investigation period for the ETCS L2 sub-scenario is 12 %, which corresponds to a NPV of over 3,7 M€. In the hybrid moving block scenario, a Eurobalise reduction ratio of only 10 % is required to achieve a positive NPV of 204 k€. A linear increase in the NPV with an increment of about 4,1 M€ for the ETCS L2 sub-scenario and about 4,3 M€ for the hybrid moving block sub-scenario for every additional 2 % Eurobalise reduction can be observed. The graph for the NPV trackside runs in parallel with the same slope, consistently showing 17,4 M€ higher values, driven by the fact that this result is not being offset by the NPV Onboard.

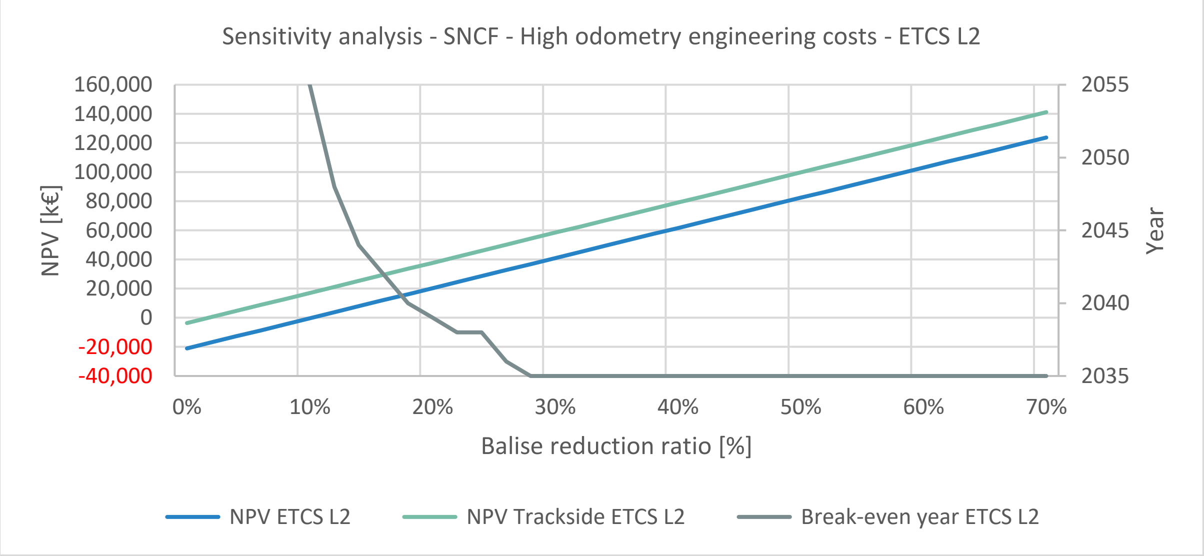

Figure 21: BC 3 (SNCF) – Sensitivity analysis ETCS L2 (high odometry engineering costs)

When examining the break-even year, 28 % Eurobalise reduction ratio marks threshold value where a break-even is achieved within the first year of LOC-OB rollout, both for the ETCS L2 and MBH sub-scenarios. Again, as in all other business cases considered in this analysis, the maximum break-even year is 2055 as the CBA only considers a time frame of 20 years after start of LOC-OB rollout in 2035. Accordingly, the Eurobalise reduction ratio for which the break-even can only be achieved in 2055 corresponds with the minimum reduction ratio required for a positive NPV result (12 % and 10 % respectively for ETCS L2 and MBH).

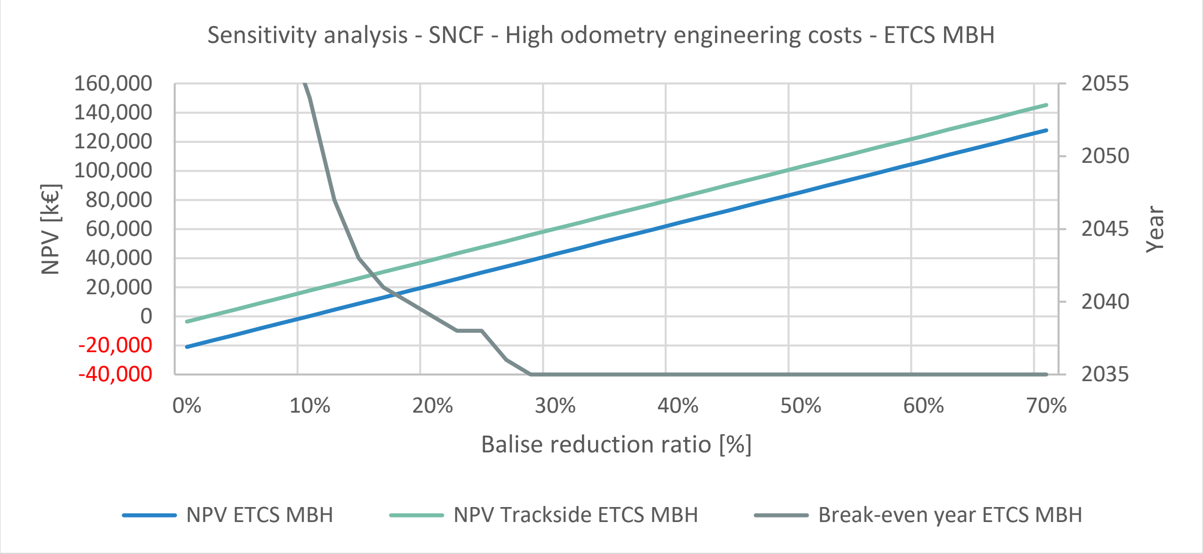

Figure 22: BC 3 (SNCF) – Sensitivity analysis ETCS MBH (high odometry engineering costs)

5.4.2.2 Low odometry costs

The results for the sub-business case when analysed with a lower engineering cost for the reference scenario in comparison to the target scenario are as follows:

BC IDENTIFICATION	HOLDER	SCOPE	ENGINEERING COST ODOMETRY
BC 3	SNCF	National	**Low** – 200 k€

Key Figure	Unit	ETCS L2	ETCS MBH	ETCS L2	ETCS MBH	ETCS L2	ETCS MBH
Eurobalise reduction	%	30 %		40 %		50 %	
NPV CAPEX	k€	5.289	6.201	15.385	16.601	25.481	27.002
NPV OPEX	k€	34.517	35.348	45.105	46.215	55.694	57.081
NPV Onboard	k€	-18.596	-18.596	-18.596	-18.596	-18.596	-18.596
NPV Trackside	k€	58.401	60.146	79.086	81.412	99.771	102.678
NPV Onboard p. vehicle	k€/veh	-17,1	-17,1	-17,1	-17,1	-17,1	-17,1

BC IDENTIFICATION	**HOLDER**	**SCOPE**	**ENGINEERING COST ODOMETRY**
BC 3	SNCF	National	**Low** – 200 k€

Key Figure	**Unit**	**ETCS L2**	**ETCS MBH**	**ETCS L2**	**ETCS MBH**	**ETCS L2**	**ETCS MBH**
Eurobalise reduction	%	30 %		40 %		50 %	
NPV Trackside p. km	k€/ km	6,2	6,4	8,5	8,7	10,7	11,0
NPV	**k€**	**39.806**	**41.550**	**60.491**	**62.816**	**81.175**	**84.082**

Table 21: BC 3 (SNCF) – Results for low odometry engineering costs sub-business case

The results for the analysis considering low odometry engineering costs follow the same trend as for the higher odometry engineering costs but differ slightly in magnitude. The overall NPV results range from 39 M€ to 84 M€, representing an IRR between 88% and 156%. Although these results are slightly worse than for the sub-business case considering high odometry engineering costs, the difference is almost negligible, indicating that the assumption regarding odometry engineering costs does not have a significant impact on the SNCF business case results. This can also be seen in the NPV Onboard exhibiting a very similar negative result for both ETCS sub-scenarios across all exemplary Eurobalise reduction ratios considered as in the SNCF sub-business case considering high odometry engineering costs. The difference in NPV Onboard is also minimal because in the SNCF business case, only a very small number of three high-speed and four regional train fleets has been considered. As the engineering costs scale with the number of fleets, the impact of this parameter is therefore rather small in this case. As there is only a small difference in NPV Onboard, also the overall NPV results are very similar between both sub-business cases.

As for all other sub-business cases, it can once again be seen that the overall results are being driven by the NPV OPEX and as in the SNCF sub-business case considering high odometry engineering costs, and in contrast to the DB sub-business cases, the NPV CAPEX once again exhibits only positive results, likely again driven by a favourable relation of vehicle equipment numbers and the length of ETCS track where the benefit of Eurobalise reduction can be achieved.

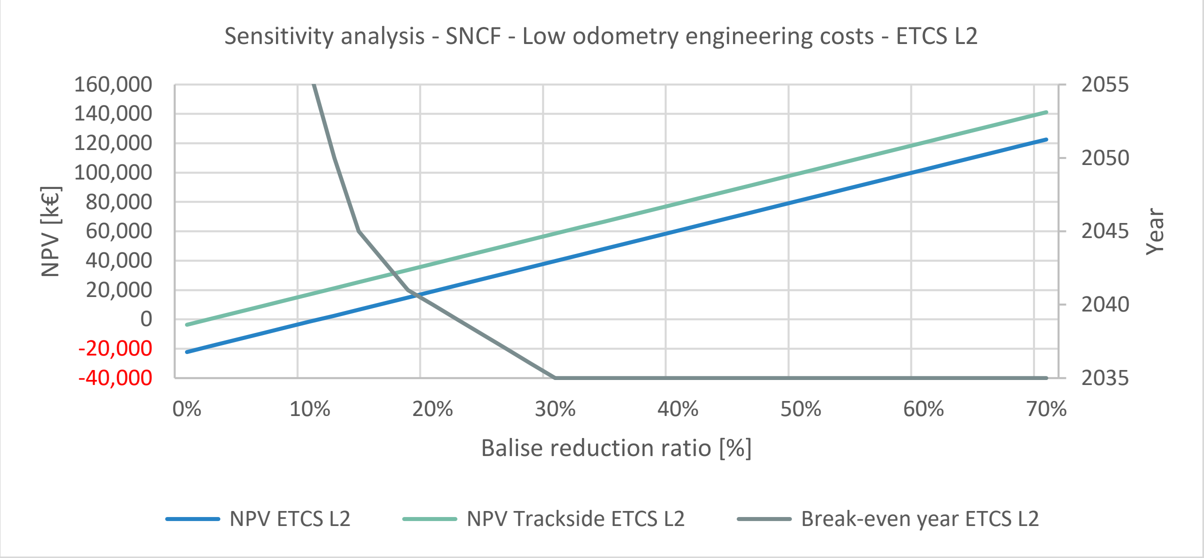

Figure 23: BC 3 (SNCF) – Sensitivity analysis ETCS L2 (low odometry engineering costs)

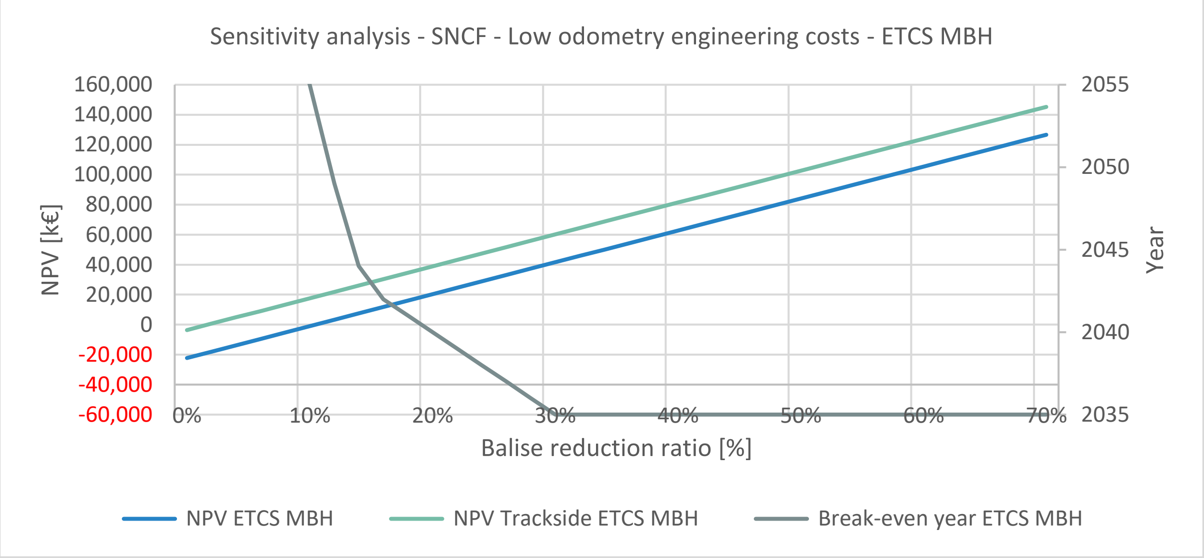

Figure 24: BC 3 (SNCF) – Sensitivity analysis ETCS MBH (low odometry engineering costs)

Considering the sensitivity analysis in Figure 23 and Figure 24, the minimum Eurobalise reduction ratio required to achieve a positive business case within the investigation period for the ETCS L2 as well as the ETCS MBH sub-scenario is 12 %, corresponding to a NPV of about 2,6 M€ and 3,3 M€ respectively. These results are once again very similar to the ones from the sub-business case considering high odometry engineering costs. The sensitivity analysis also displays the same linear increase in the NPV with an increment of about 4,1 M€ and 4,3M€ for the ETCS L2 and ETCS MBH sub-scenarios respectively for every additional 2 % Eurobalise reduction as in the SNCF sub-business case considering high odometry engineering costs. When examining the break-even year, 30 % Eurobalise reduction ratio marks threshold value where a break-even is achieved within the first year of LOC-OB rollout, both for the ETCS L2 and MBH sub-scenarios.

6 Discussion, conclusion and recommendation

6.1 Discussion of quantitative results

The CBA results presented in this document make a case for LOC-OB being a profitable investment for railway operators, even if its costs and benefits are being considered in isolation. The overall positive results were able to be established within the analysis despite only considering the most immediate benefit of LOC-OB, Eurobalise reduction, and without quantifying any further benefits the technology contributes to. If these additional effects, discussed in the following sub-chapter, are taken into consideration, the indicated positive impact of LOC-OB is even more pronounced.

The CBA shows a positive NPV for the implementation of the technology even for moderate rates of Eurobalise reduction. Comparing the results for the different country cases, it is evident that the more widespread LOC-OB implementation is, the better the overall NPV for the investment becomes. On one extreme, the assumption of implementing LOC-OB for use on the parts of the 60.000 km long DB network that have not yet been equipped with ETCS L2, leads to an NPV in the hundred-million Euros. On the other, equipping only trains from one line with LOC-OB, as assumed in BC2 for the SBB network, the resulting NPV does not exceed 500k Euros. The latter result barely exceeds the investment necessary to equip two vehicles with an ETCS OBU, illustrating how the net benefit for equipping only one line with LOC-OB is almost negligible in comparison with investments required for ETCS rollout. While this relation between rollout scope and the CBA result is not surprising, it makes an argument that after LOC-OB get developed, IMs and RUs need to jointly push for a widespread rollout of the technology to maximise its benefits and return on investment.

However, it is important to note that the profitability of LOC-OB implementation hinges on a couple of key parameters. One of them obviously lies in the rate of Eurobalise reduction, as discussed in detail throughout this document. If only around 5 – 10 % of Eurobalises become redundant when implementing LOC-OB, the technology simply is not profitable anymore. In contrast, if more Eurobalises become redundant, then the technology becomes more profitable, especially when ETCS moving block becomes available. Therefore, IMs should set a realistic target for the reduction ratio.

Besides that, the year of availability of LOC-OB technology greatly impacts whether its implementation is worthwhile. The later the technology becomes available, the more the ETCS rollout will have already advanced, diminishing the opportunity of reducing the number of installed Eurobalises. While current hypotheses of ETCS NIPs might not hold true and the installation of ETCS trackside assets could get delayed, LOC-OB implementation will always remain a race against the clock. Accordingly, the key take-away from this CBA lies in clear expectations towards how quickly LOC-OB has to become available and to what degree it has to prevent Eurobalises having to be rolled out.

Lastly, a key implication of this CBA lies in LOC-OB implementation leading to a transfer of costs from trackside to onboard systems. On the onboard side, RUs would have to bear significantly increased onboard costs, driven by the assumption of LOC-OB onboard unit costs of 40 k€ exceeding estimated costs for current odometry onboard technology by 60 %. Accordingly, if the onboard side is being evaluated in isolation, LOC-OB implementation leads to extra investments that are not directly being offset, represented by the generally negative NPV Onboard. While these required extra investments are being offset by cost savings on the trackside, the structure of separating infrastructure managers and railway undertakings into different enterprises means that this transfer of costs from trackside to onboard is not easily manageable. Any cost savings for the infrastructure manager would be relayed to the railway undertakings over time through reduced track fees. However, both entities need to cooperate with each other and political decision-makers throughout the development and implementation process to enable railway undertakings managing the significant upfront investments for the required vehicle equipment.

Ideally, in the long run, cooperation between IMs and RUs ensures cheaper and easier implementation and a reduced maintenance effort for LOC-OB if compared to legacy odometry, and therefore, enables a net-positive business case to be achieved for the RUs by itself. Homogenising fleets would further improve business case results for the RUs, as was discussed in Chapter 5.3.2.1. As these factors are still uncertain and could not have easily been assumed for the CBA model, the results of this analysis remain unfavourable for RUs if considered in isolation. Considering this transfer of costs from trackside to onboard, in order for LOC-OB to be implemented successfully, IMs and RUs need to work closely together, ensuring adequate financing of investments into LOC-OB technology in order to be able to guarantee that LOC-OB actually gets installed onto rolling stock. While LOC-OB does bring additional benefits besides the cost reduction for trackside assets, as discussed in the following chapter, these additional benefits need to be communicated properly to RUs, in order to garner their support for the implementation of LOC-OB technology.

6.2 Discussion of qualitative benefits

The implementation of GNSS-based onboard localisation technology (LOC-OB) offers numerous additional benefits beyond the immediate cost savings identified in the quantitative part of this CBA. These benefits contribute to the overall efficiency, safety, and competitiveness of railway operations and make a more compelling case for the widespread implementation of LOC-OB technology. The following chapter aims at giving a qualitative discussion of some key benefits that were identified along the item contribution classification discussed in Chapter 1.2.

6.2.1 Effects on train operation

Continuous train localisation, for which LOC-OB serves as a technical solution, forms a foundation for several digital technologies, all improving the efficiency of train operations. While not being a prerequisite for the implementation of moving block technology, LOC-OB enables better operational performance for networks operating under (hybrid) moving block as discussed in Chapter 2.2. Besides improving capacity for moving block operations, continuous localisation also benefits the implementation of advanced, digital traffic management systems. Continuous and accurate train localisation is a requirement for advanced TMS to optimally steer train dispatching. An advanced TMS, in tandem with ATO, ensures not only smooth operations but is also able to reduce headway times and by that, increase the capacity of the network. LOC-OB therefore, contributes to capacity gains generated by multiple digital technologies. While increased network capacity is difficult to estimate and assign monetary value to due to the heterogeneity of fleets, varying network topology and timetable dependence, it forms one of the more powerful benefits of digital rail technologies as they benefit IMs through increased track usage fees as well as RUs through increased fare income by being able to offer more frequent connections. Additionally, TMS and ATO increase punctuality and reduce operation costs by enabling more time- and energy-efficient operations. By reducing the workload for dispatchers, TMS also increases the demographic resiliency of a key workforce for managing train operations. In that sense, LOC-OB can be seen as the first step for a far-reaching modernisation of onboard CCS assets, enabling the implementation of several key digital technologies (ETCS MB, ATO & TMS) that benefit railway operations significantly. Additionally, as LOC-OB is being developed jointly by multiple European IMs in cooperation with industry partners and with the aim of introducing the technology into the TSI 2035, it contributes to the standardization of European rail networks, ensuring further interoperability between them. This in turn again leads to more efficient rail operations for cross-border traffic, benefiting the national rail operations as a whole.

6.2.2 Additional benefits

Besides direct operational benefits, LOC-OB also contributes to secondary social benefits as well as benefiting IM's and RU's image and reputation. Implementing LOC-OB positions railway operators as leaders in innovation and technology adoption, enhancing their brand image and appeal. This, in tandem with improved reliability and punctuality ensured by the previously mentioned digital technologies LOC-OB enables, can further attract new customers for freight and passenger services, boosting revenue. Subsequently, as RUs and IMs are able to increase their revenue, they will have more funds available to invest more into infrastructure, rolling stock and digital technologies, which in turn contributes to further benefits, creating a positive reaction chain. Additionally, the implementation of LOC-OB on low-density lines, which constitute areas with high potential for Eurobalise reduction due to often better GNSS connectivity and accuracy than in in urban areas, and the subsequent reduced operation and maintenance costs could be an enabler for keeping these lines profitable and – in turn – operational. Accordingly, LOC-OB would contribute to rail services continuing to be provided in areas under threat of losing their railway connection.

Lastly, as much of railway operations in European countries have been largely electrified and railway transport produces less climate emissions than road transport, the capacity increases through ETCS MB and advanced TMS have a beneficial impact on overall emissions, contributing to a transformation towards a future of climate-neutral transportation systems. This, besides increased economic efficiency as a secondary effect of more efficient railway operations, forms the main social benefit of digital rail technologies for which LOC-OB forms a foundation, its perceived sustainability further boosting the reputation of railway operators.

6.3 Conclusion and recommendations

This analysis has used mostly conservative values from industry experts for the cost of each item considered when this is not directly known from historical records, agreed target values or existing accounting systems. In contrast to previously conducted CBAs, a transition between scenarios has also been examined based on the present migration strategy of each CLUG 2.0 partner.

Based on the results of the CBA, it can be concluded that implementing LOC-OB comes with significant cost savings when compared with the traditional localisation method of using odometry systems and Eurobalises. These cost savings are nevertheless mainly from the OPEX rather than CAPEX. In addition, there is likely a significant increase in the onboard/vehicle costs. However, the possibility to reduce the number of Eurobalises required means that the trackside becomes cheaper and can fully compensate for the additional costs from the vehicle side, depending on the achieved Eurobalise reduction of the IM. The magnitude of the economic benefit is dependent among several factors on:

- how soon LOC-OB becomes available,
- how widespread it is deployed, and
- the achieved Eurobalise reduction percentage.

LOC-OB also provides the opportunity for several additional social benefits, as well as allows for improvement in train operations by supporting other digital technologies, which have not been quantitatively evaluated in this CBA.

With this analysis, RUs, IMs and other stakeholders can have a better economic viewpoint on LOC-OB's development, as the CBA comprehensively covers all relevant and quantifiable costs and benefits relating to LOC-OB implementation. Costs that are not directly part of the model, e.g., LOC-OB development costs on the supplier side, have been indirectly accounted for, in this case by assuming the development costs to be covered by the LOC-OB onboard unit costs of 40 k€. If costs were otherwise omitted, as done for costs relating to EGNOS, it was argued why these costs are out of scope and not as significant for the analysis (see Chapters 3.2.1 and 4.6). The results also suggest that when implementing LOC-OB, adequate attention should be given to the migration strategy, especially in determining which vehicles to equip so as to optimally manage the additional vehicle investment costs. In that same regard, RUs should ensure to homogenise their fleets as much as possible which significantly reduces engineering costs. Efforts should also be invested by the IM to reduce as many Eurobalises as possible in order to get the best return on investment. A Target Eurobalise reduction ratio of over 30% shows mostly positive results across all scenarios; achieving such a reduction ratio implies that some of the messages presently being transmitted by Eurobalises will be transmitted through the digital map or other solutions.

Finally, it will be meaningful to validate some of the assumptions used for this analysis when conducting future CBA, especially for the digital map and engineering costs. A consensus on a realistic target Eurobalise reduction ratio for future analysis can also be validated through studies.

7 References

REF	Document/Source	Title/WEBSITE	Version	Date
[1]	EUG/RCA	Cost–Benefit Analysis for the Track Occupancy Concept	2.0.1	31/01/2023
[2]	ERTMS/ETCS SUBSET-023	Glossary of Terms and Abbreviations	4.0.0	05/07/2023
[3]	DB & VIA-Con study published in ETR	Auswirkungen des Vertrauensintervalls auf Kapazität und Pünktlichkeit des Bahnsystems		11/2022
[4]	ERTMS/ETCS SUBSET-026-3	System Requirements Specification Chapter 3 - Principles	4.0.0	05/07/2023
[5]	D2.4 (LOC-OB System requirements)	D2.4 Localisation Onboard System Requirements	2.0.0	05/03/2024
[6]	EUROPEAN COMMISSION Directorate-General for Regional and Urban policy	Guide to Cost-Benefit Analysis of Investment Projects		12/2014
[7]	CLUG 2.0 D4.1	LOC-OB Functional Architecture	0.4	30/09/2024

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