RCA

Reference CCS Architecture

An initiative facilitated by the ERTMS Users Group and the EULYNX consortium

Cost–Benefit Analysis for the Track Occupancy Concept

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Disclaimer
The content of this document reflects the current ongoing specification work of the ERTMS Users Group Localisation Working Group (EUG LWG). The document is based on inputs from RCA. Requirements management and change management will be introduced in future iterations. The content may be unfinished, will likely contain errors and can be changed without prior notice.

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Executive Summary

This document is a cost-benefit analysis (CBA) for the track occupancy concept paper written as part of the RCA's vision for a digitalized and automated railway operation. It can be used for getting an overview of the different economic benefits and additional costs introduced by the RCA Track Occupancy (TO) Concept and, once consolidated, to drive possible choices for implementing the new TO concept.

It offers an overview of the track occupancy concept which varies from the reference scenario based on a trackside-centric approach for detecting elements on the tracks, to the target scenario based on a train-centric approach and then explains the methodological approach followed to derive the cost-benefit analysis. That represents an upgrade from an ERTMS/ETCS Level 2 stage to an ERTMS Level 3 GNSS. It also describes the calculation engine used for the cost-benefit analysis. Six business case applications originating from each EUG partner are detailed and a benchmark of those is presented including potential projection at European level.

This CBA study drives to the five following **main conclusions**:

- **N°1:** The implementation of the Track Occupancy Concept shows a positive Net Present Value tacking into account the evolution of the localisation items only (Group 1). The corresponding cost-benefit calculation provide a 12 K€/km gain in average all the 6 business cases included in the study.
- **N°2:** When considering all type of Train Detection system (Item Group 1 & 2 which includes Axel counter and track circuit), the NPV varies from 6 to 85 k€/km depending on the line, traffic configuration and initial density of track side assets.
- **N°3:** The benefit increases for global network transformation (i.e. massive deployment) towards the target scenario (ERTMS/ETCS Level 3) as the investment for rolling stock upgrade can be balanced with greater savings on trackside assets.
- **N°4:** The project total on-board additional cost is mitigated due to the study assumptions for the LOC-OBU unit:
  - Board CAPEX Mitigation: acceptable industrial target price, as defined in the OCORA group and replacement of the legacy odometry function.
  - Board reduced OPEX maintenance cost (5% of CAPEX) due to a standardize design.
- **N°5:** TDS assets CAPEX and OPEX savings have a high contribution on the CBA NPV and proves that it is worth reducing as much as possible the use of these assets on the tracks.

To strengthen the CBA methodology, to improve the modelling of the possible scenarios and to mitigate project risks, the following 8 **actions are recommended** to be implemented:

- **N°1:** The TDS reduction ratio is one of the key factors with high sensitivity to the CBA result. The hypothesis of 50% reduction ratio would need to be further studied as it may be very variable depending on the tracks and network types.
- **N°2:** Study the extension of the operation period from 20 to 30 years that will certainly improve the project NPV.
- **N°3:** Explore additional complexities (i.e. migration scenario, interrelations between assets and process of a infrastructure manager) and assess additional costs when applying concept to a national scenario on a global network.
- **N°4:** Address capacity increase from Track Occupancy project, promises to be one of the major benefits of the ERTMS Level 3 solutions, in further studies.
- **N°5:** Address the increase of punctuality and regularity of operations (increasing attractiveness of the rail service) from TO benefit in decision-making process.
- **N°6:** Benchmark cost assumptions with the industry and adjust the study assumptions, when necessary.
- **N°7:** The cost and benefits of TIMS function should be studied more precisely in further studies.
- **N°8:** Coordinate migration strategies and benefit sharing mechanism between IMs and Rus.

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1. Introduction

1.1. Purpose of the document

This document comprises a cost-benefit analysis (CBA) for the track occupancy concept paper written as part of the RCA's vision for a digitalized and automated railway operation. The document is designated to provide a top-down approach overview on how the concept of track occupancy, as pictured on the RCA framework, can show a beneficial business case.

1.2. Scope

This document aims at providing a short overview of the track occupancy principle, whose concept was developed in [RCA.Doc68] and continued in the ERJU System Pillar.

The scope of the present document is to present a cost-benefit analysis by comparing a reference scenario for determining the occupancy of the tracks to the RCA target scenario.

The final target is framed in the context of RCA. To reach this situation, a migration strategy needs to be defined. This transient scenario is not in the scope of this document nor the migration strategy.

The document will provide a qualitative and, where possible, quantitative analysis of the costs and benefits provided by the target track occupancy concept in comparison with the current systems in place.

The scope is to describe the CBA methodology to be applied to the TO concept and to perform the analysis by taking as examples different scenarios for different countries.

1.3. Use of the document

This document can be used for getting an overview of the different economic benefits and additional costs introduced by the RCA Track Occupancy Concept and, once consolidated, to drive possible choices for implementing the new TO concept.

This version 2.0.1 is a public version. The business case confidential data has been removed and is kept in the confidence of the operators.

1.4. Target group

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

1.5. Related documents

Document	Remarks	Version number
RCA – Track Occupancy Concept	RCA Doc.68	1.0
RCA – System Architecture	Poster	
RCA plateau migration approach	RCA.Doc.28	1.2
RCA Solution Concept MAP	RCA.Doc.54	0.3
CR1368	Economic Justification	
EUG-LWG Remit		
RCA mains concepts and goals		
Subset 026 ETCS SRS	SS026	3.6.0
LOC OB System Definition and Operational Context	22E126	1.0
OCORA Economic Model	OCORA-BWS06-010	Version: 2.01
X2RAIL-4 Cost benefit analysis	Deliverable D6.2	1.1
Economic Justification of Accurate Onboard Localisation	CR 1368	0.g

1.6. Terms and abbreviations

AC	Axle counter
ATO	Automatic train operation
CCS	Command, Control and Signalling
CAPEX	Capital expenditure
CBA	Cost-benefit analysis
GHG	Greenhouse gases
GNSS	Global navigation satellite system
LOC-OB	Localisation on-board
ERTMS	European Rail Traffic Management System
EUG LWG	ERTMS Users Group Localisation Working Group

NPV	Net present value
OBU	On-board unit
OPEX	Operational expenditure
RCA	Reference CCS architecture
TC	Track circuit
TDS	Train detection system
TIMS	Train integrity management system
TMS	Traffic management system
TO	Track occupancy

1.7. Structure of the document

The document is based on the Track Occupancy Concept [RCA.Doc68] and is structured as follows:

- Chapter 2 offers an overview of the track occupancy concept which varies from the reference scenario based on a trackside-centric approach for detecting elements on the tracks to the target scenario based on a train-centric approach.
- Chapter 3 explains the methodological approach followed to derive the cost-benefit analysis.
- Chapter 4 describes the calculation engine used for the cost-benefit analysis.
- Chapter 5 details six business case applications, that originated from each EUG partner.
- Chapter 6 presents the business case benchmark and potential projection at European level.
- Chapter 7 gives a conclusion and recommendations for project investment based on Track Occupancy Concept approach.

2. Scenarios

A cost-benefit Analysis (CBA) refers to an economic study that compares two scenarios: a reference scenario versus a target scenario. Its purpose is to provide a basis for decision-making prior to large project investments, that will be based on:

- The costs including Capital Expenses (CAPEX) and Operational Expenses (OPEX) all over the selected project period.
- Any beneficial factors that can be justified in the target scenarios versus the reference scenario. Finally, the comparison of costs and benefits in the defined time horizon.

The two scenarios of our Track Occupancy Concept CBA study have been defined as described below:

- The reference scenario will be a rail network and its associated rolling stock fully compliant with ERTMS / ETCS Level 2 and with a completed equipment of FRMCS.
- The target scenario will be an evolution of the infrastructure from ERTMS / ETCS Level 2 status to ERTMS / ETCS Level 3 using continuous safe on-board localisation and thus transferring required CCS equipment from the infrastructure to the train, with rolling stock equipped with a LOC-OB unit to implement the Track Occupancy concept.

As a “starting point” (or “reference scenario”), the present study considers an ERTMS L2 architecture deployed on typical track layouts. This ERTMS L2 architecture basically consists in existing TDS, balises and Onboard LOC-OB devices. The related cost/benefit evaluation (covering a given lifespan of the system including its initial deployment) is named the “reference scenario”.

The study addresses the same deployment scenario but this time with an ERTMS L3 architecture based on GNSS Localization. This second scenario is named the “target scenario”.

The aim of these reference and target scenario is therefore to highlight the advantages and disadvantages in terms of investment of implementing GNSS based ETCS level 3 instead of ETCS level 2.

2.1. Reference Track Occupancy scenario

Track occupancy management is the cornerstone of the safety management of rail operation, which prevents two trains from collisions. Track occupancy determination is based nowadays on track detection devices which are reporting when they detect any kind of rolling stock in the area they are monitoring. These hardware elements physically detect if a track-bound object is occupying a certain area of the network they are monitoring. These elements, due to their technological principles, are reliable but do not provide a continuous and point-exact occupancy of the track. The “occupied” status is given for the whole length of the track segment, while effectively only a part of it is occupied by the train. This leads to space for optimizing the capacity of the rail network. On top of that loss of capacity, trackside elements constitute additional costs for infrastructure managers resulting from installation and maintenance works as well as costs for the hardware replacement and the interrelation between assets and processes such as the temporal removal of balises during tamping.

This document assumes in the reference scenario a situation where track occupation is only determined by these trackside detection devices and any other additional elements to determine train position under ETCS (European Train Control System). Most of the networks use track release installations such as track circuits or axle counters to determine track occupancy. Track circuits are continuously proving that the section they are monitoring is not occupied, while the interlocking machine logic uses information from axle counters to keep the section occupied when they determine that a certain number of axles have entered the block and not all of them have left it. The determination of the localization of the train is assumed to be managed using balises in the field and respective balise readers on the train.

Both technological approaches have their benefits and drawbacks, but both represent an investment cost for installing the devices and blocking the track during the installation time and later in operation resulting in maintenance costs to monitor their performance and fix any malfunction. The supervision of the safety of the system and the execution of the operational plan is done according to the information provided by these elements.

Within the scope of our CBA study, the main assumption of our reference scenario will be that the trackside equipment, ensuring the track occupancy monitoring, will be the ERTMS / ETCS Level 2 standard.

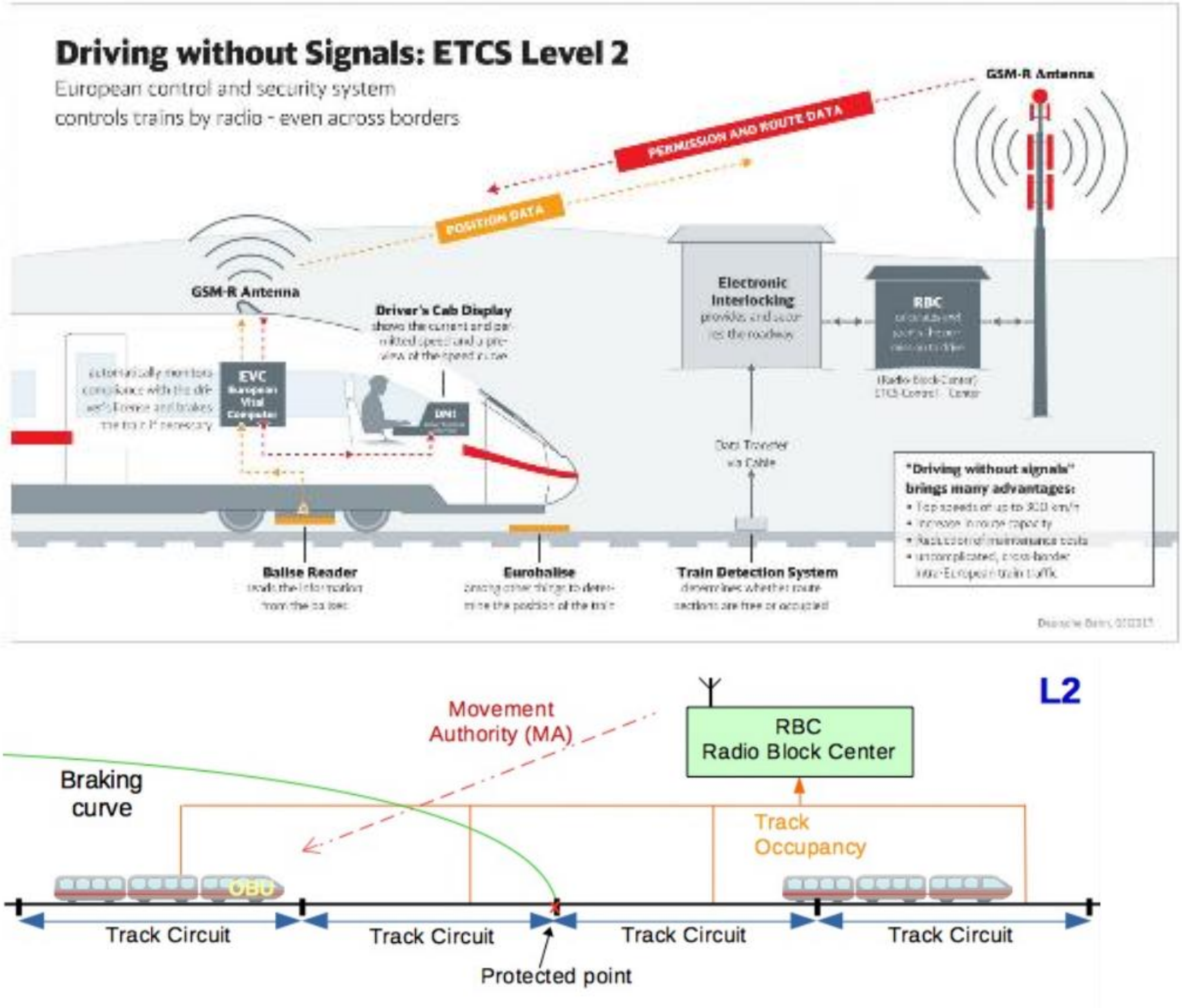

Figure 1 - Reference Scenario ETCS Level 2

2.2. Target Track Occupancy scenario

In radio-based train supervision, the train reports its own position by means of the train position report (TPR) message. The ETCS train position report in the target scenario contains at least the following data:

1. Reference location (LRBG)
2. Confidence interval of the train
3. Safe train length and train integrity information
4. Further train data (e.g., speed, ETCS mode, ETCS level).

Please refer to [SS026] chapter 7 for a complete list of ETCS parameters contained in an ETCS train position report.

In order to increase the capacity of the networks, and decrease associated costs to determine track occupancy, the use of new technologies such as GNSS and digital map (among others) need to be included in an interoperable way.

Providing the actual occupation of the tracks, in an accurate and reliable way will allow the trackside to have a complete picture of the situation of the occupancy of the tracks, and the use of trackside TDS could be minimised. Additionally, other related processes such as planning, installation, maintenance, etc. of TDS will be positively impacted, as well as the service level for customers.

With this idea in mind, track occupation determination could move from the current trackside-centric approach, where track occupancy is determined by TDS, to a train-centric approach, where the track occupancy is given by relying on train position information.

However, relying on train position information has some constraints that depend on configuration factors:

1. Frequency of TPRs
2. Latency of the communication
3. Frequency of train integrity determination
4. Confidence intervals and inaccuracy

New ETCS functions such as “cab always connected” will facilitate the implementation of the target scenario.

All these factors may lead to keeping some TDS in certain areas where accuracy plays a more key role to guarantee capacity during rail operation (e.g. stations, level crossings, etc.).

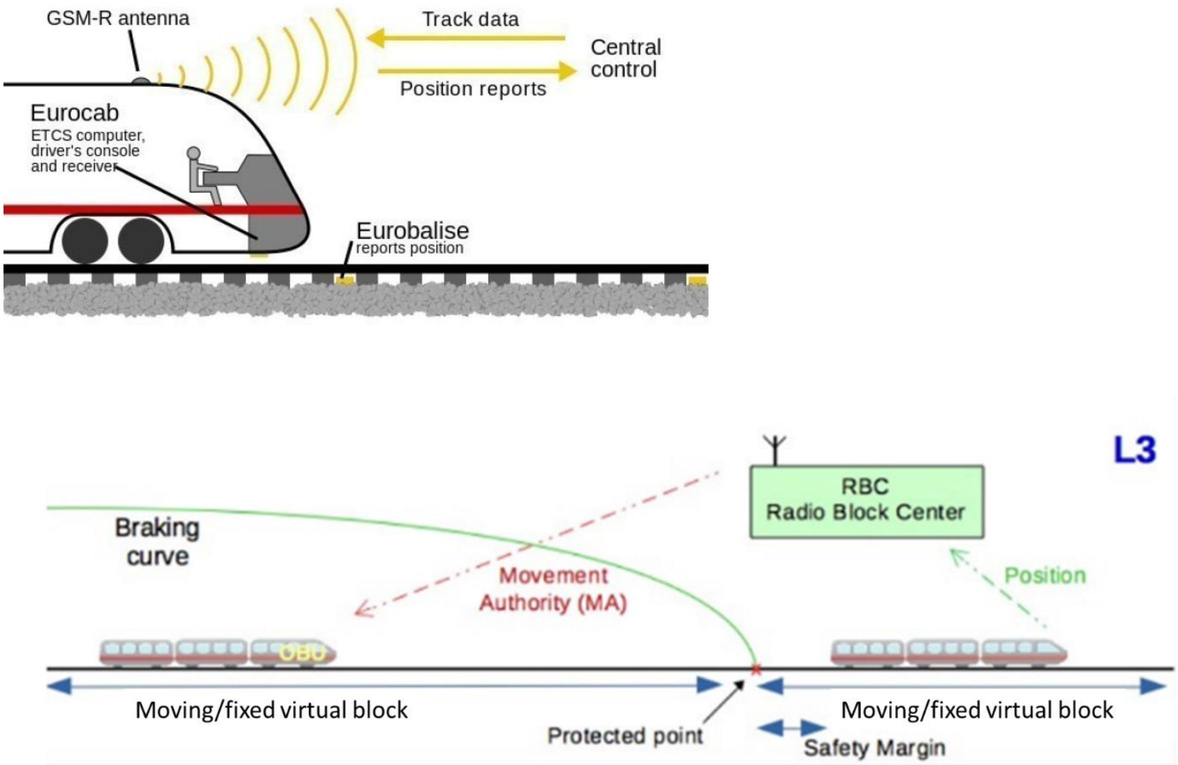

Figure 2 – Target Scenario ERTMS Level 3 GNSS [transport.ec.europa.eu/transport-modes/rail/ertms_en]

Following this, a combined track occupancy model is needed to determine which parts of the network are occupied, with the main goal of reducing the number of TDS, improving the capacity of the network, and keeping the operations safe.

3. TO CBA Methodology

This chapter describes the methodology that has been implemented to build the presented CBA Model dedicated to the Track Occupancy Concept.

3.1. Cost-Benefit Analysis Principles in Rail Projects

The economic assessment of rail investment projects relies on cost-benefit analysis (CBA) principles that can cope with:

- the technical and economic peculiarities of the rail sector which are defined by its capacity to provide fast and regular services to a large number of passengers and freight volumes in a safer way than other modes of transportation (road, air and maritime)
- its capital-intensive construction costs together with significant operation and maintenance costs.

Rail transport is characterized by long-term capital-intensive projects. CBA studies also intend to optimize costs induced by such projects. In general, the cost-benefit analysis assesses the economic impact of projects, using a single value (NPV) that provides the main indication of the project's economic performance. The analysis includes some of the following items:

- Economic: Differences of CAPEX and OPEX over a defined time horizon compared between reference and target scenario
- Capacity changes: Impact of increase of capacity on the current network and of avoidance of network extension (CAPEX) resulting in higher network utilisation.
- Indirect effects such as environmental impacts or social benefits.

In a nutshell, the Track Occupancy Concept drives evolutions on track, on-board and system management that can be described in the following figure:

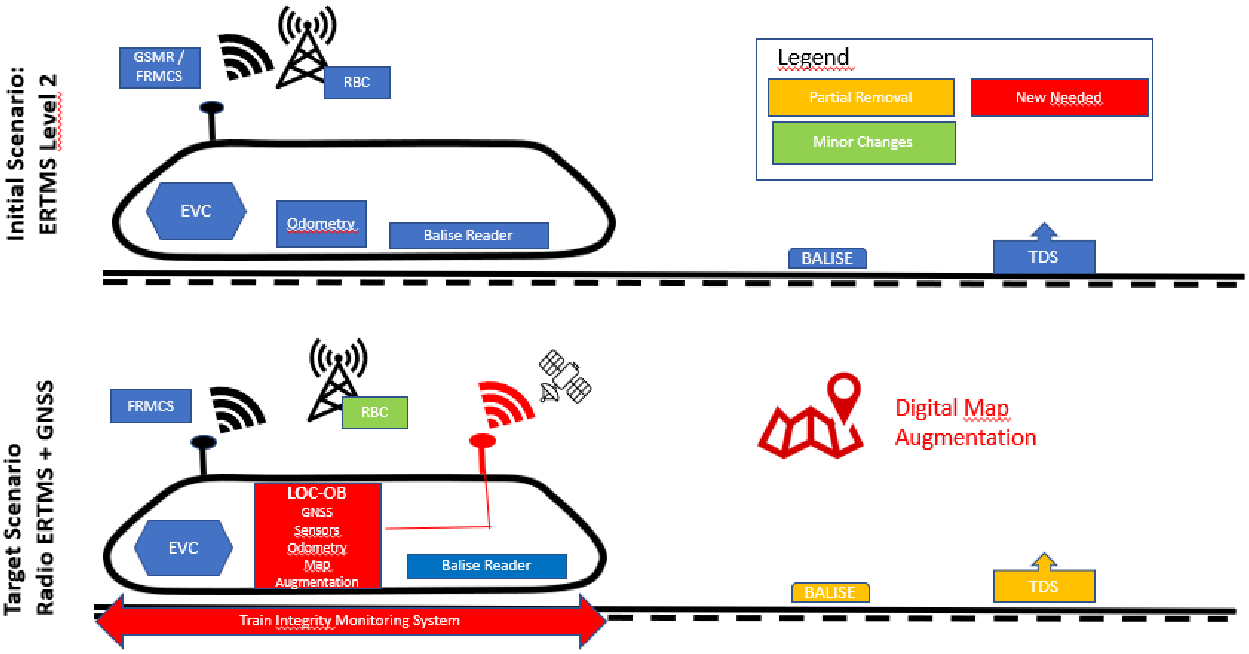

Figure 3 - Reference scenario versus Target Scenario

As depicted in the previous figure, in order to achieve the train-centric approach, the train needs to be equipped with additional devices using sensors to get a reliable and accurate position. The specific identified functions of the LOC-OB are described in [22E126]. This additional equipment represents an additional cost to the rolling stock but allows the removal of trackside equipment.

As a preliminary action, the European Guidelines for cost-benefit analysis of investment project (EC 2015), the Railway Project Appraisal Guidelines from the European Investment Bank, which respond to the need for EU-harmonised procedures for the socio-economic and financial appraisal of rail projects following the latest developments in the sector were analysed. We also considered the Return of Experience of many projects or initiatives assessing Rail & GNSS (based on public publications) in Europe.

CBA case	Holders	Program	Date	Document in reference
SR 4.0	SBB – ERTMS User Group – EULYNX consortium	SBB	2020	RCA Business Case for IMs
STARS	UNIFE	H2020	2018	D6.2 Cost Benefit Analysis
Hitachi	Consortium – coordinator	GSA	2020	D1.4 – CBA for Virtual Balise Concept
X2Rail 2	Consortium – coordinator: Alstom France	H2020	2020	D4.5 Cost Benefit Analysis
HPMV	SNCF	SNCF	2017	Rapport d'étude Socio économique
OCORA	DB – SBB – SNCF	Europe's Rail JU	2020	Open CCS On-board Architecture

Table 1 - Related CBA Documents

Those initiatives represented in Table 1 - Related CBA Documents, are very heterogeneous but target a similar objective. Such comprehensive approaches remain very challenging due to the variety of the starting point of scenarios, the processing of transition phases and the lack of data for quantitative and qualitative markers allowing for refined global assessment of projects. Furthermore, due to the closed railway market and the cartel law, the interchange of prices between industrial vendors is prohibited.

With all this in mind, a dedicated methodology for the "Track Occupancy CBA" was created, which focuses on the analysis of the TO implementation costs and benefits while transferring the track occupation determination from a trackside-centric to a train-centric scenario. A diversity of different input parameters and specifics of different countries as well as the availability of data during the exercise were considered when developing the model and the strategy to follow. This methodology is presented in the next chapter.

3.2. Track Occupancy: methodology of Cost-Benefit-Analysis

The Track Occupancy Concept opens several possibilities from which the railway stakeholders' benefit:

- Contribute to major savings by reducing the need for most of the trackside TDS.
- Increase of network capacity.
- Improve availability and quality of service based on precise train localisation.
- Facilitate and accelerate the digitalisation of rail, providing scalable solutions for accurate railway positioning, which is essential for safety and better user experience.

To better assess those benefits, the "TO CBA" Methodology falls into 6 main phases:

Figure 4 - Methodology Workflow

Each phase is described in detail in the following chapters.

3.2.1. Phase 1: Scope & Item Specification

Due to the expected development of the on-board localisation systems in the context of RCA to provide reliable localisation information with the focus set on the target scenario, the economic impact on the trackside needed to be considered. Inputs from several countries have been challenged during the development of this CBA and previous CBA have been benchmarked.

Eleven items with a direct quantitative or qualitative impact on the CBA have been selected from the list and have been classified into 4 groups in order to facilitate the decision-making process and the analysis itself.

TYPE	ITEMS	STAKEHOLDERS	IMPACT	NATURE	CONTRIBU-TION GROUP
Board	LOC-OBU	RU	Cost	CAPEX / OPEX	1
Board	Odometry function	RU	Benefits	CAPEX / OPEX	1
Board	TO Extended Digital Mapping	IM	Cost	CAPEX / OPEX	1
Board	On-board TIMS Function	RU	Cost	CAPEX / OPEX	2
Track	Balise	IM	Benefits	CAPEX / OPEX	1
Track	Axle Counters	IM	Benefits	CAPEX / OPEX	2
Track	Track Circuit	IM	Benefits	CAPEX / OPEX	2
TMS	Capacity Increase	IM + RU	Benefits	CAPEX / OPEX	3
TMS	Train Operation Energy Sav-ings	IM + RU	Benefits	OPEX	3
TMS	Improved Track and Fleet Management Services	IM	Benefits	CAPEX / OPEX	3
Social	Punctuality	All	Benefits	OPEX	4
Social	New Passengers Services	All	Benefits	OPEX	4
Social	GHZ transportation savings	All	Benefits	OPEX	4

Table 2 - Items considered in the CBA

The item description refers to the following characteristics:

- Type: Trackside, on-board or system depending on the asset usage
- Stakeholders: IM (infrastructure manager), RU (Railway Undertaker), depending on who will carry the cost or collect the benefit.
- Impact: Cost and/or benefits depending on the impact of the items in the CBA calculation. Both are possible if it entails a cost during a period and a benefit for another period.
- Type of cost: CAPEX means an impact on investment and OPEX means a recurrent annual impact on profit and loss.
- Contribution: Representative of the part of the impact directly linked to the Track Occupancy Concept and the part of the impact shared with others initiative.

Items are classified into 4 groups:

- Group 1 is dedicated to the on-bboard localisation function with enhanced LOC-OB and balises. Items that are directly linked to the change in train localisation processes within the TO concept. 100% of the costs/benefits can be linked to Train Localisation technological choices. The CBA will make a special focus on this category.
- Group 2 encompasses CCS-assets ensuring the other TDS functions, such as track circuit, axle counter, related software and the TIMS function. They are closely linked to train localisation, safe train separation that benefits from train localisation developments. The Track Occupancy Concept generates savings on TDS assets, which could vary from 30% to up to 90% depending on the business cases. The TIMS function is a dedicated Software device that will report the train integrity function. Our CBA model considers 100% of the costs/benefits of TDS changes linked to train localisation technological choices.
- Group 3 refers to train operation and traffic management-related items that benefit from train localisation technological advancements (e.g., capacity increase, ATO accuracy, traffic regulation, energy savings, ...). Those benefits depend on business cases (type of traffic, density of traffic, traffic growth, reference scenario projection, target scenario projection) and their simulation is limited in the use of justifying in a preliminary study. Our CBA calculation will take none of its benefits. The presented business case will focus on reporting the qualitative impact of the track occupancy concept. Thus, these benefits represent a significant upside potential and should be further studied in other studies.
- Group 4 social benefits: all other items that benefit indirectly (social impact of a better transportation offer) from the TO Concept are not explicitly studied and are excluded from this analysis.
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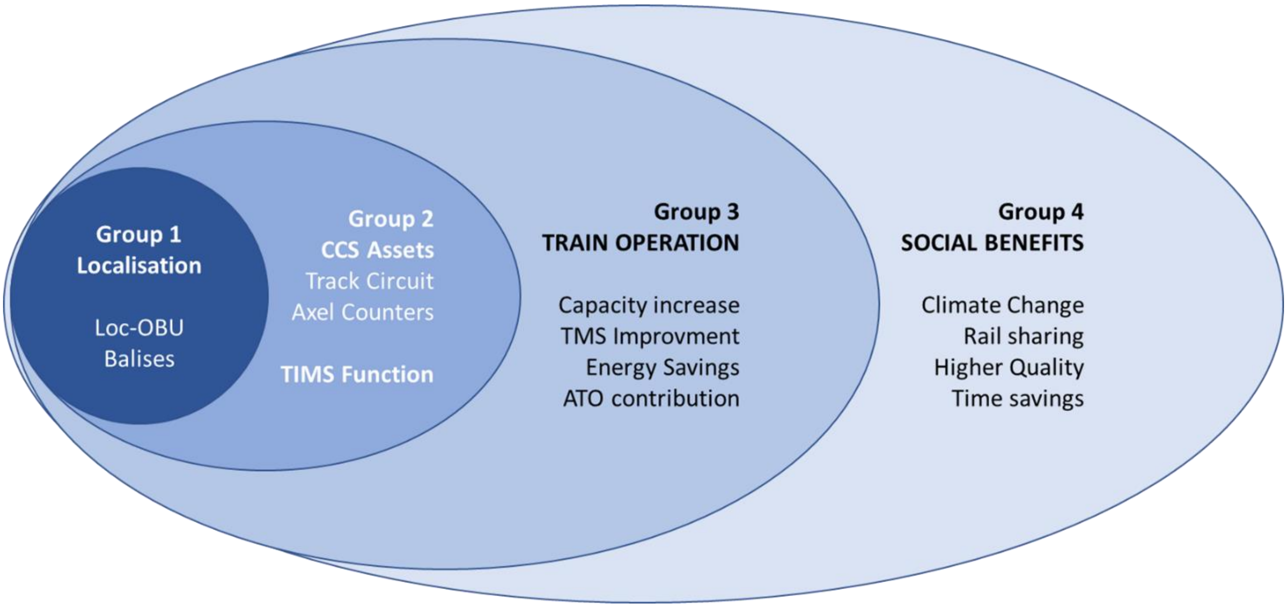

Figure 5 - Item Contribution Classification

The main costs and benefits are detailed below:

ON-BOARD	
Rolling stock on-board localisation system equipment (LOC-OB), installation and development	TO Concept implies a major upgrade of the OBU and further required transformations (digital mapping processor, multi-source GNSS receiver and processor, augmentation information, possibly other future technologies) that need to be developed within a modular CCS architecture
Odometry function	The TO scenario, in reference, enables the replacement of the odometry function with the LOC-OB – enhanced on-board train positioning function.

TIMS (train integrity and length)	On-board system providing train integrity data and potentially train length in a safe way. Train integrity provided by the on-board is necessary to determine the safe train length and hence implementing ERTMS / ETCS Level 3 application, which is in the target TO scenario. [RCA.Doc68].

Table 3 – On-board-related description

SYSTEM / DATA	
Trackside digitalisation	TO concept requires a digital representation of the entire rail network with an initial collection campaign and regular updates. Updates will also be requested upon track evolution. This will generate CAPEX and OPEX costs for such a digital map generation, storage, and transmission to trains. Nevertheless, this digitalisation is already needed to support other functions and ERTMS ETCS Level 2 scenario [RCA.Doc.59]. Thus, our CBA will consider only the additional data required for the ERTMS – ETCS GNSS Level 3 evolution, meaning only a percentage of the total cost of the digital representation. This percentage will be frozen during the CBA setup, based on conclusions of the RCA group dealing with the standardisation of the digital map.

Table 4 - System-related description

TRACK	
Balise deployment costs (CAPEX) and associated OPEX savings	The proportion of balises dedicated to train localisation that can be decommissioned or even not installed by using TO Concept. The following components shall be considered for balises: CAPEX 1. System studies: balise positioning design (schematic plans for installation), balise content determination 2. Installation studies: the balises and their support (for rail or sleepers mounting) 3. Hardware Cost: purchase of balise and its mounting support 4. Intervention: interruption of operation, track access/track protection, staff 5. Installation: programming the balise and setting the support, 6. Post-installation checking and testing (balise reading and checking of balise content) 7. Inspection and approval: acquisition, validation and update of schematic plans OPEX 1. Failure detection: possible analysis to identify the balise failures 2. Replacement after failure: purchase of balise and its mounting parts and possible individual components such as cabling 3. Intervention: interruption of operation, track access/track protection, staff (applies to 4 to 6 below). 4. Re-installation (in case it is needed): programming and dismounting/re-mounting of balise. 5. Repeated Post-installation checking and testing (balise reading and checking of balise content). 6. Removal and reinstallation of balises due to other track works (eg Rail renewal, ballast tamping ….) with potentially reprogramming

TRACK	
Deployment costs (CAPEX) and associated OPEX savings for other CCS track assets	The proportion of trackside CCS (track release infrastructure such as track circuits and axle counters) used for block occupancy supervision that can be decommissioned or even not installed by using TO Concept. The following components shall be considered for track circuits (TC) and axle counters (AC): CAPEX 1. System studies: TC/AC positioning design (schematic plans for installation) 2. Installation studies: survey prior to studies e.g., for checking possible constraints on track 3. Procurement: purchase of TC/AC devices (for TC: emitter/receiver, cables, power supply; for AC: counter, mounting device, cables, power supply) 4. Intervention: interruption of operation, track access/track protection, staff 5. Installation: mounting of devices 6. Post-installation checking and testing 7. Inspection and approval: acquisition, validation and update of schematic plans OPEX 1. Failure detection: possible analysis to identify TC/AC failures 2. Replacement after failure: purchase of TC/AC devices (emitter/receiver, cables, power supply) 3. Intervention: interruption of operation, track access/track protection, staff 4. Re-installation (in case it is needed): dismounting/re-mounting of devices 5. Repeated Post-installation checking and testing
Deployment costs (CAPEX) and associated OPEX savings for track assets connection	For some business cases, the total removal of trackside assets will also reduce the need for connectivity and power supply along the track, providing further savings.

Table 5 - Track-related elements description

Traffic Management System	Qualitative impact Only
Capacity increase	ERTMS / ETCS Level 3 will improve traffic capacities for a given track line without the need for an expensive, complex, and time-consuming infrastructure extension and then generate revenue when this capacity can be commercialised.
Train operation energy savings	The TO will have a positive impact on train energy consumption, having real-time movement authority messages based on moving/fixed virtual blocks concepts and reducing breaking or acceleration instruction frequency. Furthermore, the TO concept will enable a system-wide optimisation of the railway operation.
Improved track and fleet management services	Track digitalisation will also improve track maintenance operation as well as rolling stock availability, potentially leading to savings in new train CAPEX engagement and maintenance OPEX.

Table 6 - TMS-related description

SOCIAL	Qualitative impact Only
Punctuality	Making railways a more efficient, punctual and reliable transportation system will have an impact on passengers' satisfaction.
New passengers' services	Precise GNSS localisation and on-board communication will provide passengers with more valuable information on traffic updates.
GHG transportation savings	TO concept will contribute of transferring people and industries from road transportation to rail transportation in a wider way, migrating to a greener and more efficient way of transport, leading to CO2 savings.

Table 7 - Social-related description

Any other items necessary for train operation are considered as being stable between the reference scenario and the target scenario, meaning already necessary for the ERTMS / ETCS Level 2 implementation. As an example, the rolling stock on-board communication equipment costs are supposed to have been already invested prior to the target scenario implementation.
Given the scope of the group developing this CBA, some other simplifications have been made, such as no consideration of potential GNSS augmentation investments.

3.2.2. Phase 2: Business case definition

A CBA looks at project benefits that accrue to both direct users (e.g., rail passengers or freight rail shippers) and non-users (e.g., society at large), as well as the costs required to achieve a project's expected outcomes. Benefits could also include societal and environmental factors, while costs should include the capital, operating, and maintenance expenses necessary to deliver the project benefits.

The systematic process of identifying, quantifying, and comparing expected benefits and costs helps decision-makers to organise information about and evaluate trade-offs among alternative transportation investments. A CBA compares the anticipated benefits that accrue from a target scenario to the anticipated costs of a reference scenario over a specified period of time.

In this section, the business cases, in which the model will process the above items, are characterised. Within the framework of track occupancy, the business cases can be very diverse including high-speed lines, regional lines, local lines, and passengers and/or freight traffic, starting from very different modernisation statuses. A flexible approach is required to include various cost-benefit analyses, depending on the different partner networks, organisations, and the availability of data.

The business case scope needs both stakeholders, infrastructure manager and railway undertaker, prospective reporting the length and type of tracks, and the associated rolling stock sizing linked to the project. These later parameters might be difficult to weigh and will be directly linked with the transition policy implemented by IM and RU.

Other reference scenarios (i.e., with no ETCS standard) are considered out-of-scope of this study as the CBA focuses on the contribution of the TO concept and assesses the benefits of the installation of ERTMS with LOC-OB to ERTMS without LOC-OB. Also, no migration scenario has been evaluated.

The ERTMS / ETCS Level 3 project time frame must be consistent with the economic lifetime of the main assets that will be invested. The results of the analysis will be represented in one single value, which reflects costs and benefits over time as well as the time effect of the occurrence: the NPV. Although the investment horizon is often indefinite, in a project analysis it is convenient to assume reaching a point in the future when all the assets are in place. At this point, it will be possible to judge whether the investment was a success. A 20-year reference time horizon is applied, being in the average of the upper limit of equipment life span.

3.2.3. Phase 3: CBA model setup

This economic calculation will point out differences between the reference scenario and the target scenario within the project timeframe. For the proposed model, the following considerations apply:

- The Track Occupancy Concept CAPEX differences, meaning the additional CAPEX required by on-board and the CCS track CAPEX savings for the completion of the system migration.
- The exploitation phase of OPEX differences during 20 years of network operation between the two scenarios
- No costs/savings during the migration time have been considered since no migration scenario has been modelled. Only the final stages of each scenario have been compared. Implementing country-specific migration scenarios would require a dedicated CBA.

For each item, the CBA will specify the unit CAPEX, the annual expenses per unit and per year and the quantified differences between both scenarios. As explained earlier, the model has been designed to isolate the contribution of Item Group 1, to highlight the direct contribution of localisation items.

3.2.4. Phase 4: Country application

The CBA is intended to be applied to different input parameters provided by EUG LWG members. Since the input data for individual items comprise a different scope for each country (see list of items and individual components in 3.2.1), a comparison between the different outcomes is difficult. The results rather provide a certain trend or direction of the outcome instead of a precise CBA result. For the application of the presented CBA to a specific partner's case, a detailed revision of the input data with the relevant experts has to be undertaken. This will lead to an improvement and enrichment of the CBA and with this, it will be an improved basis for decision-makers.

3.2.5. Phase 5: CBA model convergence

Phase 5 will have 2 objectives:

- **Objective N°1**: Compare common values such as CAPEX & OPEX on the different items
- **Objective N°2**: Compare Net Present Values of the CBA, reported in a K€/Km scale.
- **Objective N°3:** Make a specific focus on localisation Items (Group 1)

3.2.6. Phase 6: CBA conclusion & recommendations

The last phase of the process consists of formalising the conclusions and recommendations of the TO CBA application, such as:

- The average value for items considered that could be described as reference values
- Possible estimation of the CAPEX/OPEX for the LOC-OB and TIMS devices in order to achieve a positive business case (target price analysis as the actual price of described components can currently not be precisely estimated)
- Main conclusion on the financial appraisal of the Track Occupancy Concept for the various potential business cases
- Main recommendations for decision markers for the optimisation of the deployment of the Track Occupancy Concept

4. TO CBA Model

4.1. Model principle

The model considers an instant system replacement without any migration or transition phases. The delta CAPEX will be considered spent during the first year after which it considers the OPEX for an exploitation period of 20 years. Each cash flow is weighted by the group contribution as defined in 3.2.1.

The delta CAPEX sums all the costs associated to equipment and their installation in both scenarios (both are negative because represent spending). To simplify the inputs, our model considers that the value of decommissioned equipment is fully recovered. That's why the whole reference scenario is then subtracted to the actual one.

$$\sum_{t=1}^{20} \Delta\text{CAPEX} = \text{CAPEX}_{Target} - \text{CAPEX}_{Initial}$$

An OPEX value is calculated for each item based on actual prices given as inputs. The model then considers the relative OPEX: a device that needs less maintenance brings in a positive OPEX whereas new items to maintain bring negative OPEX. All of those are summed up to obtain the global reference OPEX. This reference is then updated each year with an inflation rate given as input, which is considered as a constant for the 20-year exploitation period. This parameter might have to be revisited due to the economic situation.

Finally, the net present value is calculated based on the following formula:

CBA formula = Net present Value Delta CAPEX (Transition period) + Net Present Value of Delta OPEX (Operational period) or

NPV=Today's value of the expected cash flows−Today's value of invested cash

4.2. Business Case Parameters

There is a large variety of business cases that can be considered:

- High-speed or regional lines
- Passengers and/or freight services
- Studies for a specific part of the network under modernization
- Globalized national business case
- Projection at the European level.

A standard parameter list has been issued to support the CBA calculation, whatever the heterogeneity of the Business Case.

4.2.1. Business Case identification

Business CASE IDENTIFICATION	BC N°	
	VERSION	
	HOLDER	
	NAME	
Business CASE TYPE	TYPE	High Speed / Regional / National …
	USAGE	Passengers Only / Mixt passengers & Freight

Table 8 - Business Case Identification

4.2.2. Business Case sizing

The two main parameters that will size the business case are the combination of the concerned track length and its associated rolling stock.

BUSINESS CASE SPEC	SINGLE TRACK	KM
	DUAL TRACK	KM
	ROLLING STOCK	QTY

Table 9 - Business case sizing

The identification of the track length seems straightforward. It remains a major factor, resulting from the global IM ERTMS / ETCS Level 3 deployment strategy. Furthermore, a dual-track can be a multi-track line in reality. In our study, we will have several configurations (High-speed, regional, national) that will illustrate the vast variety of the situations.

The identification of the rolling stock to be considered in the CBA seems more complex. It is very much dependent on the common IM & RU assets management policy and economic assessments. It remains decisive in the CBA results because it carries a significant part of the additional CAPEX. The CBA results will certainly influence the mutation strategy for track and board assets.

For the business cases not addressing the entire network, the size of the involved fleet has been determined by using a rate corresponding to the portion of the considered track against the entire equivalent network or by an estimation derived from the number of trains running per day.

4.2.3. Business Case parameters – Item Group 1: Localisation function

Group 1 gathers all item directly linked with the track occupancy concept and its on-board localisation function. The CBA calculation dealing with the NPV of Group 1 is a very important output of the study, as it shows the direct comparison with today's localisation function and the new track occupancy standard localisation function.

For the on-board subsystems, the differences between the reference and the target scenario, within the scope of the ERTMS / ETCS Level 3, can be summarized as follows:

- Introduction of the on-board unit conducting the Track Occupancy function, which will also cover a new simplified odometry function.
- Replacement of the legacy odometry function.
- Retention of the euro-balise reader function (unchanged in the 2 scenario).
- Use of digital mapping data.

		ITEM GROUP 1			
TYPE	**ITEMS**	**CAPEX**	**OPEX**	REFERENCE SCENARIO	PROJECT SCENARIO
Board	LOC-OBU	€/unit	€/unit/year		2 / TRAIN
Board	Odometry function	€/unit	€/unit/year	2 / TRAIN	
Board	Balise Reader	€/unit	€/unit/year	2 / TRAIN	2 / TRAIN
System Data	Digital Mapping	€/KM	€/KM		€ / KM
Track	Balise	€/unit	€/unit/year	QTY / KM	% of reduction

Table 10 - Item Group 1

As described in chapter 5.2. Track Occupancy Concept [RCA.Doc.68 / v1.0 36/41], the localisation function is central in the radio-based ETCS strategy.

- The localisation function for ERTMS / ETCS Level 2 system consists of a euro-balise transmission module (BTM) and an odometry system which measures the distance travelled since the last relevant balise group. Localisation accuracy can be specified by the infrastructure manager by adjusting the euro-balise density. Today's odometry shows performance issues due to slip and slide or other effects that result in degraded accuracy.
- The localisation function for ERTMS / ETCS Level 3 will be upgraded for matching the new localisation methods and technologies used for the TO concept, using new types of sensors such as GNSS and inertial navigation, resulting in additional CAPEX and OPEX. It will require an updated digital map that will increase accuracy and availability by means of the use of when using 3D positioning.

This will enable two major benefits:

- The reduction of balises along the track
- The replacement of the legacy Odometry function as this function is currently very exposed during operation and requires significant maintenance measures.

4.2.4. Business Case parameters – Item Group 2: CCS

Trackside detection devices are currently used for the CCS system. They fall into two types of assets: track circuits and axle counters. One of the main benefits of the target scenario will be to reduce those track CCS assets, enabling significant savings in CAPEX and OPEX. The CBA will consider the CAPEX and OPEX saving, calculated from the unit cost by the reduction of assets between the two scenarios.

The reduction ratio has a high impact and contribution to the CBA results. These percentages are likely to vary depending on the type of traffic, on the station density along the network and on general redundancy in safety policy.

		ITEM GROUP 2			
TYPE	**ITEMS**	**CAPEX**	**OPEX**	INITIAL SCENARIO	TARGET SCENARIO
Board	On-board TIMS Function	€/unit	€/unit/year		1 / TRAIN
Track	Axle Counters	€/unit	€/unit/year	QTY / KM	% OF SAVINGS
Track	Track Circuit	€/unit	€/unit/year	QTY / KM	% OF SAVINGS

Table 11 - Item Group 2

Nevertheless, such CCS assets reduction will imply the development of an on-board train integrity monitoring system (TIMS function). It refers to the level of belief in the train being complete and not having left coaches or wagons behind. The knowledge of the safe rear end location of a train is needed to free the travelled track part for enabling moving or virtual blocks distancing. The TIMS function has to be seen combined with the calculation of the safe train length.

While TIMS is seen as an essential, external input building block for LOC-OB, the presented business case model assumes TIMS function is provided by using two LOC-OB on each end of a train. At a later stage, TIMS will deliver its data to LOC-OB and one LOC-OB per train will be sufficient. However it is assumed that the expenses for the TIMS functionality are in the same order of magnitude as the ones for an additional LOC-OB.

In [X2RAIL-4 Cost benefit analysis D6.2] document, an analysis on the transfer of the TIMS function on-board was performed and concluded that the corresponding global savings were between 37 K€/km to 41 K€/km-track. The savings considered in this study mainly come from a reduction of trackside assets. It is very likely that the on-board TIMS function will enable further trackside reduction, in addition to the ratio that has been adopted in the presented CBA and improve the CBA results (see section 4.3.5). But this requires a specific study.

In the case of a ERTMS / ETCS Level 3 high-speed line, the balise reduction ratio will be high due to a lower number of stations and switches. They are not concerned by axle counter (not used for high-speed lines) but reduction of track circuit is also considered. In the case of ERTMS / ETCS Level 3 regional line, the balise reduction ratio will be lower. Axle counters and track circuits are also considered, depending on the type of asset used.

All business cases will use an average projected reduction ratio defined by the group

4.2.5. Business Case - Other parameters

Another major benefit of the track occupancy concept will concern item group 3 & 4 (capacity, punctuality, GHG savings, …). **In the present study, these parameters were not taken into consideration.** We will consider the qualitative impact of these parameters in our conclusion.

However, for any precise CBA in continuing or dedicated studies, these items should be considered, especially capacity increase that will significantly improve the CBA results for IMs and RUs.

4.2.6. Business Case – Transition period and backward compatibility

Board and track systems are evolving when being upgraded at ERTMS / ETCS Level. Backward compatibility refers to the capacity of upgraded train to circulate on non-upgraded track. This is the reason why the balise reader function remains unchanged in both scenario.

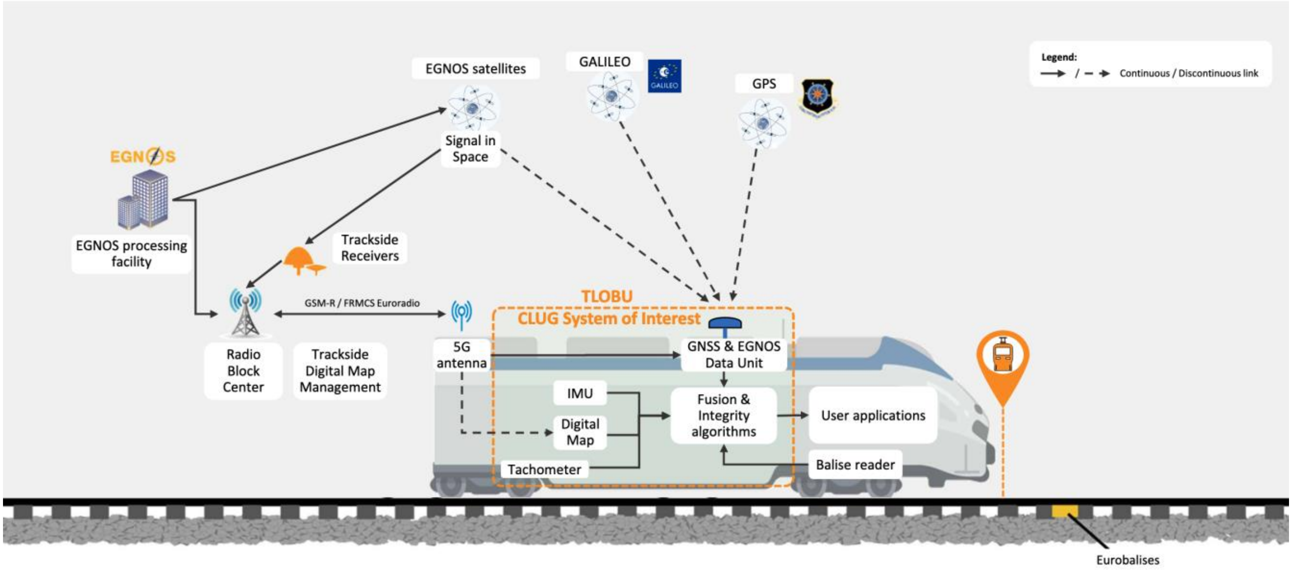

Table 12 - Example high-level concept as presented in the CLUG project [The CLUG Concept, clugproject.eu]

ERTMS / ETCS Level 3 evolution versus the ERTMS / ETCS Level 2 standard will mainly result in the partial reduction of CCS assets, on one hand, and include a new on-board unit function on the other hand. Therefore, upgraded an ERTMS / ETCS Level 3 track will only be able to accept a ERTMS / ETCS Level 3 compatible trains, while an ERTMS / ETCS Level 3 train will maintain a backward compatibility with an ERTMS / ETCS Level 2 track, as mentioned above.

Transition period could then become very complex and cannot be simulated in a generic business case. This is the reason why the presented CBA calculation will not include any additional transition or migration period OPEX costs and assumes the full conversion of the on-board and subsystems prior to the operational period.

4.3. Parameters Values

The CBA addresses two objectives: providing calculations to make business cases individual analysis as well as comparative analysis between business cases. The model uses a list of parameters that underlies the calculation. Some of them are common to each business case in order to enable the benchmark, the others being specific to each business case.

4.3.1. CBA Period and rate

- **The CBA T0 date:** the year that determines the project's economic conditions and the date of the net present value. In the following example, it is 2022.
- **The transition period:** 10 years, during which all capital expenditures for the target scenario (ground, system and rolling stock) are supposed to be invested.
- **The operational period**: 20 years, where the difference in operational expenditure (ground, system and rolling stock) is calculated. It represents the average system lifespan.
- **The inflation rate**: 2% which is applied to the current cost reference (CAPEX & OPEX), being a standard value that were used in the majority of previous CBA studies.
- **The discount rate:** it enables the actualisation of the project cash flow. It is generally **fixed at 3.5 %,** in accordance with the “Guide to cost-benefit analysis of investment projects” of the Directorate General Regional Policy of the European Commission.

BUSINESS CASE SPECIFICATION	REFERENCE DATE	YEAR	2022
	TRANSITION PERIOD	YEAR	10
	EXPLOITATION PERIOD	YEAR	20
	INFLATION RATE	%	2,0%
	DISCOUNT RATE	%	3,5%

Table 13 - Business Case Common Period & Rate

4.3.2. ITEMS Contribution Rate

The methodology stipulates that the item contribution to the CBA calculation can also be a parameter that could be adjusted in any single business case. Within the context of our study, the following values have been frozen:

- For items of group 1 and 2, the contribution to the CBA calculation is 100%.
- For items of group 3 and 4, at this stage of maturity of the Track Occupancy Concept, it has been decided not to take them into account (0% contribution), a generic and benchmark approach being not relevant. Nevertheless, a qualitative assessment would be made that will support the main decision.

4.3.3. On-board systems

The implementation of the LOC-OB unit to cover the on-board GNSS-based localisation function is a direct output of the TO Concept. As such, the CAPEX and OPEX additional cost is a common value to all the business case. The following assumptions have been chosen (refer to section 4.3.3).

TYPE	ITEMS	Target SCENARIO vs Reference SCENARIO	CAPEX	OPEX
Board	LOC-OB 2 per train (1 in front, 1 in end)	Additional cost	40 000 €/unit	5% maintenance cost
Board	Odometry function 2 per train (1 in front, 1 in end)	Savings - suppression of the function	25 000 €/unit	10% maintenance cost

System Data	TO Extended Digital Mapping	Additional cost	100 €/KM	50 €/KM/year
Board	On-board TIMS Function	System Cost	10 000 €/train	10% maintenance cost

Table 14 – On-board System Common CAPEX & OPEX

The CAPEX values have been frozen, after a partner benchmark:

- The unit cost of the LOC-OB unit has been assessed by the EUG-LWG at the level of 40 K€ per unit. It is a target cost defined by the corresponding OCORA working group.
- The odometry function suppression will bring a 25 K€ CAPEX savings per unit.
-

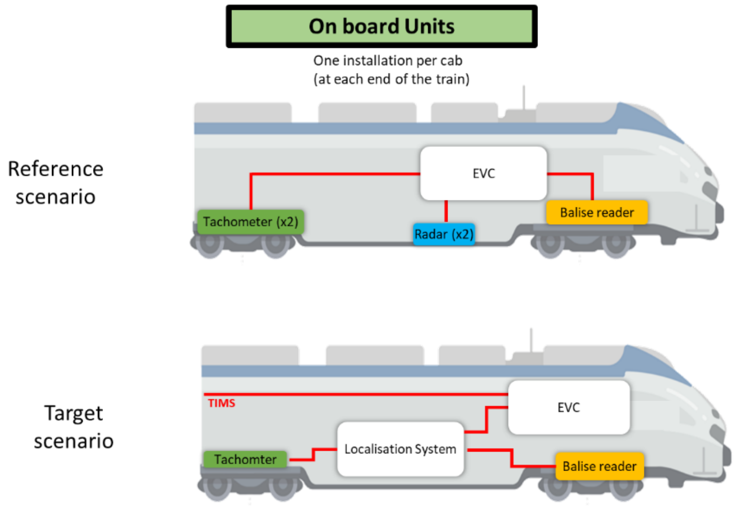

Figure 6- Example high-level concept as presented in the CLUG project [The CLUG Concept, clugproject.eu]

In general, OPEX rates for a such system are in the order of magnitude of 10% of the CAPEX amount per year. This is the case for the odometry system, subjected to mechanical stress (shocks, vibrations). In contrast, the LOC-OB unit is much more isolated from mechanical disturbances and its design practices will be based on modularity. Following this, it is expected to be easier to maintain compared to today's odometry system. Then the OPEX ratio can be reduced to 5%. It will not exceed 2 K€ per year.

4.3.4. Digital mapping

The use of map data within the CCS system is already necessary for the reference ERTMS / ETCS Level 2 scenario. The digital mapping consists of a set of data available and different functions and/or processes for creating, updating and maintaining those data.

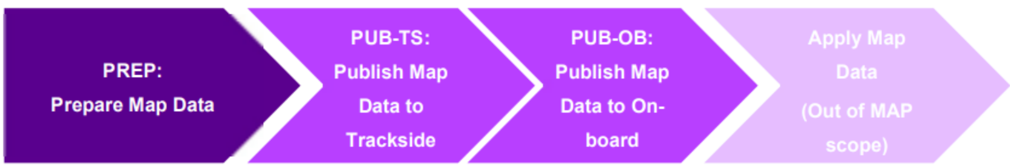

Figure 7 - Digital Map Process

The cost of this function is a compilation of three different parts: "Data Preparation and collection", "Map Development and Map Implementation" and "Operational Use". Within the scope of our study, we decided to consider any system development burden cost. It is not possible to define a proper project distributive key as there are other consumers besides LOC-OB.

The data-collecting step is an operation which is common to ETCS 2 and 3. There is no additional cost between scenarios. It is the processing of map data that brings differences to get the right level of precision to enable the GNSS localisation function. The LWG has defined that an additional CAPEX cost needs for this specific purpose, of 100 €/track km. In this case, the maintenance cost or data update is quite significant to maintain the required precision. It has been assessed at 50 €/track km / year.

All the other values are specific to any single business case.

4.3.5. Track Side Assets

The following rules have been selected for the balise, axle counter and track circuit reduction impact to the CBA calculation:

- CAPEX cost: This cost is specific to any single business case, depending on the country/IM partner accounting cost.
- OPEX cost: We have considered a maintenance cost per year being 10% of CAPEX cost.
- TDS assets reduction ratio (ie : % of difference between quantity of assets between Target scenario vs reference scenario)

CCS ASSETS REDUCTION RATIO	AVERAGE FOR THE NETWORK	HIGH-SPEED LINE	REGIONAL LINE
BALISE	50%	70%	30%
AXEL COUNTER	50%	NA	50%
TRACK CIRCUIT	50%	50%	50%

Table 15 - CCS Reduction Ratio

4.4. Model Calculation engine

The calculation is composed of five phases:

- **Phase 1:** Evaluation of CAPEX differences between the target scenario and reference scenario with 2022 economic conditions:
  - CAPEX savings on CCS assets (balise, axel counter, track circuit):
    $$unit\ cost \cdot \frac{qty}{km} \cdot track\ km \cdot reduction\ ratio$$
    Unit Cost X Qty/per km X Track Km X Reduction Ratio
  - CAPEX increases on-board assets:
    $$unit\ cost \cdot \#\ of\ unit\ per\ train \cdot \#\ of\ trains + \frac{add.digital\ cost}{km} \cdot track\ km$$

GROUP	ITEM	DELTA CAPEX
		K€
BOARD	LOC-OBU	-8 000
	ODOMETRY FUNCTION	5 000
	Digital Mapping	-100
	TIMS Function	-1 000
	TOTAL	-4 100
TRACK	Balise	8 337
	Axle Counters	20 443
	Track Circuit	3 453
	TOTAL	32 233

- **Phase 2:** Evaluation of OPEX differences between target scenario and reference scenario with 2022 economic conditions:
  - OPEX savings on CCS assets (balise, axel counter, track circuit):
    Unit Maintenance Cost/year X Qty/per km X Track Km X Reduction Ratio
  - OPEX on-board Assets expenses:
    Unit Loc OB Cost X Nb of Unit/Train (for TIM function) X Number of train +
    Digital cost dedicated to Localisation (Additional digital cost / km X Track Km)

GROUP	ITEM	DELTA OPEX
		K€/Y
BOARD	LOC-OBU	-400
	ODOMETRY FUNCTION	500
	Digital Mapping	-50
	TIMS Function	-100
	TOTAL	-50
TRACK	Balise	502
	Axle Counters	1 049
	Track Circuit	215
	TOTAL	1 766

- **Phase 3:** Projection CAPEX differences to the year of the beginning of target scenario operations (impact of inflation during the transition period)
- **Phase 4:** Projection of OPEX differences for all the years of the exploitation phase of the target scenario (impact of inflation)
- **Phase 5:** Actualisation of the above cash flow, determining the Net Present Value (NPV) of the project.

PROJECT NVP K€	48 518	23 489	25 028
YEAR	TOTAL	DELTA CAPEX	DELTA OPEX
	K€	K€	K€
2032	36 385	34 294	2 091
2033	2 133	0	2 133
2034	2 176	0	2 176
2035	2 219	0	2 219
2036	2 264	0	2 264
2037	2 309	0	2 309
2038	2 355	0	2 355
2039	2 402	0	2 402
2040	2 450	0	2 450
2041	2 499	0	2 499
2042	2 549	0	2 549
2043	2 600	0	2 600
2044	2 652	0	2 652
2045	2 705	0	2 705
2046	2 760	0	2 760
2047	2 815	0	2 815
2048	2 871	0	2 871
2049	2 928	0	2 928
2050	2 987	0	2 987
2051	3 047	0	3 047

EXAMPLE

4.5. Results Presentation

The CBA displays a range of different absolute and relative results that support different analysis angles. By convention, a saving, or benefit is presented as a positive value for the calculation and an additional expense as a negative value for the calculation.

- NPV CAPEX: It shows the difference between the investment in on-board system and the saving of CCS assets:
- NPV OPEX: It is the same approach for the annual maintenance expenses.
- NPV BOARD: It calculates the contribution of board assets, cumulating their CAPEX and OPEX.
- NPV TRACK: It calculates the contribution of track assets, cumulating their CAPEX and OPEX.
- NPV: It is the absolute CBA results projected in the year 2022 economic conditions.

CBA Results	Unit	Item Group 1	Item Group 1 & 2
NPV CAPEX	K€		
NPV OPEX	K€		
NPV BOARD	K€		
NPV TRACK	K€		
NPV CAPEX	K€/KMTrack		
NPV OPEX	K€/KMTrack		
NPV BOARD	K€/KMTrack		
NPV TRACK	K€/KMTrack		
NPV	K€		
NPV	K€/KMTrack		

Table 16 - CBA Result Parameters

The model will provide two sets of calculation:

- Results focusing on the Localisation Item from Group 1 only (refer to section 4.2.3).
- Results including item Group 1 and Group 2

This will clarify, when necessary, the contribution of the pure ERTMS L3 GNSS localisation function.
The business case benchmark also requires relative figures. This is given by dividing the above figure by the track length of the business case in km.

4.6. **Model Limitation**

The TO CBA model was established in order to make general and fast calculations on a simplified business case, in order to refine implementation strategies and benchmark situations at the European level. In that respect, the calculation has several limitations:

- CAPEX and OPEX precision for the existing trackside assets: we consider the direct cost mentioned in the partner accounting systems.
- CAPEX / OPEX of some infrastructure additional constituent to support the Track Occupancy full implementation (i.e., GNSS augmented services in cities when needed along the trackside).
- No decommissioning costs have been considered.
- Costs due to the effect of interrelations between track-side assets and infrastructure processes such as tamping have not been taken into account.
- The rolling stock sizing: it is a parameter with high sensitivity to the CBA results. However, it remains difficult to assign the weight of the CAPEX and OPEX cost of train upgrades just to one business case scenario, as they might circulate in other lines. We made the best and fair assumption possible.
- Qualitative approach for item groups 3 and 4: Capacity increase, passenger service level improvement, more efficient fleet management and high contribution to GHG savings end green transportation are, among others, genuine benefits of the project. But the general quantification approach to those benefits would be subject to debate. An in-depth qualitative assessment is recommended at this stage of the study.
- A specific transition strategy or detailed project duration could not be included in the scope of this general study.

5. Business Case Application

5.1. Business case presentation

This section provides the description of the 6 business cases that have been selected by LWG partners SNCF, SBB, RFI and DB. The principle has been to scan a large variety of traffic situations to experiment with the model and try to draw a general conclusion and a specific conclusion.

Business CASE IDEN-TIFICATION	BC N°	BC1	BC2	BC3	BC4	BC5	BC6
	HOLDER	SNCF	SNCF	SBB	DB	RFI	RFI
	NAME	LGV +	HPMV	National	National	Regional	HSTB
Business CASE TYPE	TYPE	High Speed	Régional	Mixed	Mixed	Régional	HIGH SPEED
	USAGE	Passenger	Passenger	Passenger - freight	Passenger - Freight	Passenger	Passenger

Table 17 - Business Case Identification

The table below recaps common assumptions of all business cases.

LOC-OBU	CAPEX	€	40 000
	OPEX	€/ YEAR	2 000
	QTY / TRAIN	NB	2
Odometry Function	CAPEX	€	-25 000
	OPEX	€/year	-2 500
	QTY / TRAIN	NB	2
DIGITAL MAPING	CAPEX	€ / KM	100
	OPEX	€/ YEAR / KM	50
TIMS Function	CAPEX	€/unit	10 000
	OPEX	€/unit/year	1 000

The other Business Case data remains confidential.

5.2. BC 1 – SNCF – LGV +

5.2.1. Business Case Presentation

The business case deals with the Paris – Lyon High speed line.

Business CASE IDENTIFICATION	BC N°	BC1
	HOLDER	SNCF
	NAME	LGV +
Business CASE TYPE	TYPE	High Speed
	USAGE	Passenger
BUSINESS CASE SPECIFICATION	SINGLE TRACK	2
	DUAL TRACK	650
	ROLLING STOCK	60

Table 18 - BC1 Identification

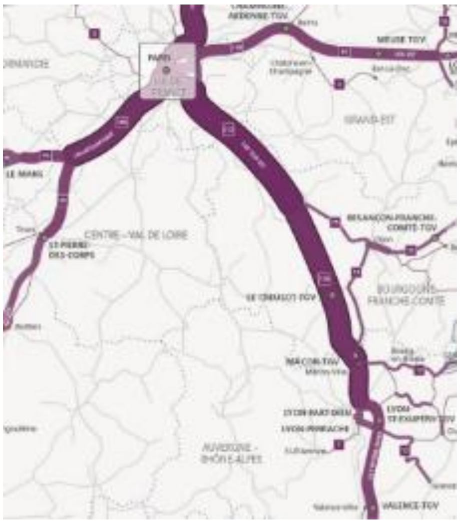

Figure 8 - BC1 Line

5.2.2. Business Case Parameters

Those data are confidential.

Table 19 - BC1 Parameters

5.2.3. Business Case Results & Analysis

BC IDENTIFICATION	**HOLDER**	**NAME**	
BC1	SNCF	LGV +	
	RESULTS	**Items Group 1**	**Items Group 1 +2**
NPV CAPEX	K€ / Km	3	7
NPV OPEX	K€ / Km	10	16
NPV BOARD	K€ / Km	- 2	-4
NPV TRACK	K€ / Km	14	26
NPV / KM	K€ / KM	12	22

Table 20 - BC1 Results

5.3. **BC 2 – SNCF – HPMV**

5.3.1. Business Case Presentation

The regional rail network between Marseille and Ventimiglia makes it possible to connect territories with a high population density. Nearly 270 trains, in both directions, travel on this axis on average every day. The typology of the line, which is made up of a single section between Marseille and Ventimiglia, in fact, favours chains of delays. It is also very likely that the demand for transport will continue to increase in the coming years and will require the creation of new services and new capacity.

A ERTMS / ETCS Level 3 project on this line will target gains in regularity, capacity increase and maintenance cost savings.

The table below presents the business case parameters.

Business CASE IDENTIFICATION	BC N°		BC2
	HOLDER		SNCF
	NAME		HPMV
Business CASE TYPE	TYPE		Régional
	USAGE		Passenger
BUSINESS CASE SPECIFICATION	SINGLE TRACK	KM	26
	DUAL TRACK	KM	259
	ROLLING STOCK	QTY	106

Table 21 - BC2 Identification

Figure 9 - BC2 Line

5.3.2. Business Case Parameters

A large modernization program has been launched for this line to upgrade its signalisation system to the ERTMS / ETCS Level 2. Then, the reference scenario parameters for our CBA are resulting from the current project outputs, with Eurobalises and new generation of axel counters as track side assets.

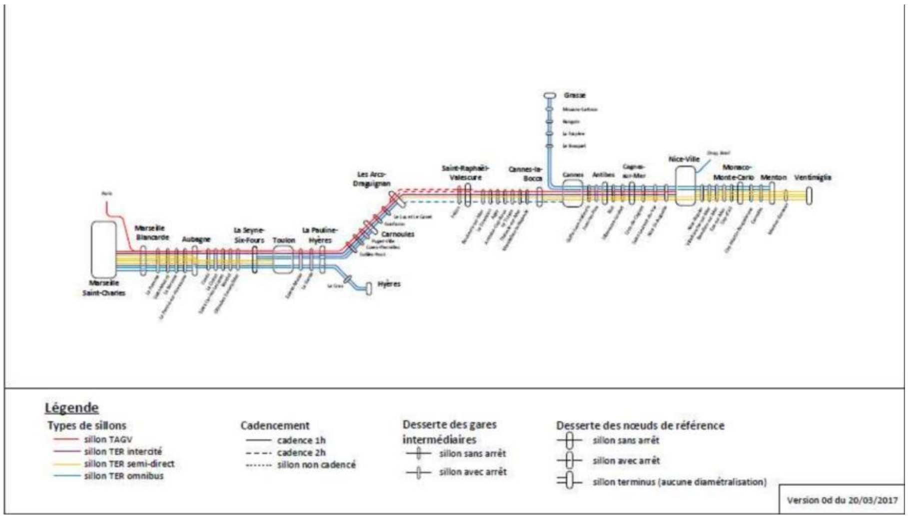

Figure 10 - BC2 Line Details

The business case takes into account the line proven CAPEX cost, as well as all the others common value decided for the study. Those data are confidential.

Table 22 - BC2 Parameters

5.3.3. Business Case Results & Analysis

BC IDENTIFICATION	HOLDER	NAME	
BC2	SNCF	HPMV	
	RESULTS	Items Group 1	Items Group 1 +2
NATURE	UNIT	VALUE	VALUE
NPV CAPEX	K€ / Km	-6	1
NPV OPEX	K€ / Km	12	23
NPV BOARD	K€ / Km	-10	-29
NPV TRACK	K€ / Km	12	37
NPV / KM	K€ / Km	7	24

Table 23 - BC2 Results

The results of this business case fall along the average value of all business cases:

- A global NPV of 7 €/km for Item Group 1 and 24 K€/km for Item Group 1 +2.
- The targeted scenario will also bring its contribution to the expectations in capacity increase (Over 30%) and service level improvement (reduction of 5 minutes of the average delays).

5.4. **BC 3 – SBB – NATIONAL**

5.4.1. Business Case Presentation

BUSINESS CASE IDENTIFICATION	BC N°	BC3	
	HOLDER	SBB	
	NAME	National	
BUSINESS CASE TYPE	TYPE	Mixed	
	USAGE	Passengers - Freight	
BUSINESS CASE SPEC	SINGLE TRACK	KM	1’360
	DUAL TRACK	KM	1’900
	ROLLING STOCK	QTY	1’900
	REFERENCE DATE	YEAR	2022

Table 24 - BC3 Identification

Figure 11 - Map of the rail network in Switzerland

The business case for the Swiss federal railways SBB covers most of the network in Switzerland. The network is fully electrified, operating with mixed traffic meaning that freight and passenger trains use the same infra-structure, and one of the densest railway networks in the world. As the country is relatively small, the network has a few specialties:

- The travel time from east to west or north to south is approximately 4h for each.
- Trains are running with synchronized timetables meaning that trains are leaving central knots at full or half hours.
- The traffic is not strictly divided into regional, city, intercity, or high-speed lines. The only high-speed segment of the network is the Gotthard Base Tunnel with 250 km/h.
- The network is fully compatible with ETCS. Most of the lines are at Level 1, Level 2 has preferably been used for new lines.

The assumptions for the business case are the following:

1. SBB Infrastructure maintains 1'360 km of single tracks and 1'900 km of multi-tracks. Multi-tracks describe lines that consist of at least two tracks. In the business case, the multi-tracks are handled as dual tracks.
2. The rolling stock running on the infrastructure of SBB composes of approximately 1500 passenger trains and 400 cargo locomotives.

All data is publicly available under reporting.sbb.ch.

5.4.2. Business Case Parameters

Those data remain confidential.

Table 25 - BC3 Parameters

5.4.3. Business Case Results and Analysis

BC IDENTIFICATION	HOLDER	NAME	
BC3	SBB	National	
	RESULTS	**Items Group 1**	**Items Group 1 +2**
NATURE	UNIT	VALUE	VALUE
NPV CAPEX	K€ / Km	1	71
NPV OPEX	K€ / Km	11	15
NPV BOARD	K€ / Km	-7	-20
NPV TRACK	K€ / Km	20	106
NPV / KM	K€ / KM	12	85

Table 26 - BC3 Results

Using the explained CBA model and the presented parameters, the business case of the Track Occupancy Concept for SBB results in the following parameters:

Overall, the NPV of the complete business case causes a prognostic benefit of 12 €/KM (Item Group 1) and 85 K€/km (Item Group 1 & 2).

Reasons for the positive CBA for SBB could be the following:

- Switzerland has relatively high investment and purchasing costs due to its high prices, own currency, and high wages. Therefore, the reduction of assets will have a massive impact on the overall costs.
- Investing in an all-in-one network requires high CAPEX but also has a relatively fast breakeven as the return on investment is higher.
- The distribution of track release infrastructure is very dense due to the high-frequency traffic. A reduction of track assets has therefore a significant positive impact on the business case. It is the reason why the NP for Item group 1+2, encompassing all type of TDS (Balise, Axel counters and Track circuit) is so high in this business case.

Consequently, the presented CBA for SBB with all assumptions and simplifications suggests a full rollout of the Track Occupancy Concept for the Swiss rail network.

5.5. BC 4 – DB – NATIONAL

5.5.1. Business Case Presentation

Business CASE IDENTIFICATION	BC N°		BC4
	HOLDER		DB
	NAME		NATIONAL
Business CASE TYPE	TYPE		MIXT
	USAGE		Passenger - Freight
BUSINESS CASE SPEC	SINGLE TRACK	KM	60 000
	DUAL TRACK	KM	0
	ROLLING STOCK	QTY	10 500

Table 27 – BC4 Identification

For this analysis, the whole track network of Deutsche Bahn has been taken into account. The rail network currently comprises of ~33,000km. However, this only represents a fraction of the overall kilometres to be equipped since train stations, passing sidings etc. also need to be taken into account. Considering this, the overall kilometres are ~60,000km. For this analysis, no differentiation has been made between single and dual track. The majority of the German railway network is a mixed traffic usage with only small parts separated. This was one of the reasons not to differentiate between different scenarios but to concentrate on one single application.

While the rollout of ETCS is ongoing in the German railway system, so far there are individual tracks which have been equipped with the technology. Until 2030, there shall be ~8,000km equipped with ETCS according to the European Rail Traffic Management System European deployment plan from 2017.

The rolling stock using the German railway system stands at >13,000 trains. For the purpose of this exercise, 10,500 trains have been used as an input to account for the fact that not all trains are likely to be equipped with the track occupancy concept (e.g., not considering historic trains).

5.5.2. Business Case Parameters

Those data remain confidential.

Table 28 – BC4 Parameters

The assumed parameters for this cost-benefit analysis can be found in the table above. Some remarks on the assumed numbers:

- CAPEX values originate from first reference projects as well as indications from industry.
- OPEX values are only indicative since basically no numbers can be generated from real values running over longer periods of time; therefore, mostly a portion of CAPEX is used as a basis.
- All numbers need to be seen as part of the strategic planning rather than a concrete operative rollout scenario for the Germany-wide railway system. This means that when planning tracks operatively numbers like quantity per kilometre can widely differ.
- Figures represent the current status of planning. The values are constantly evolving depending on numbers ordered, economic factors like inflation and resources, etc.
- The reduction of field elements is a current assumption from experts, which needs to be further explored. It should also be mentioned that while costs and benefits assigned to the track occupancy concept, may in reality only occur in combination with other technologies to be leveraged.

5.5.3. Business Case Results & Analysis

BC IDENTIFICATION	**HOLDER**	**NAME**	
BC4	DB	NATIONAL	
	RESULTS	**Items Group 1**	**Items Group 1 +2**
NATURE	UNIT	VALUE	VALUE
NPV CAPEX	K€ / Km	1	7
NPV OPEX	K€ / Km	11	21
NPV BOARD	K€ / Km	-3	-7
NPV TRACK	K€ / Km	15	35
NPV / KM	K€ / KM	12	28

Table 29 – BC4 Results

As it can be seen in the table above, the overall cost-benefit analysis suggests a positive NPV. The key reasons for this positive result are:

- Avoidance of costly maintenance of the infrastructure-based system compared to the train centric system
- Currently, the DB Netz system is heavily used and its capacity stretched. Thus, the assumptions for infrastructure field elements such as balises and axle counters and its density are rather conservative to bring as much capacity as possible on the track, which is beneficial for this case

The negative result for NPV Board as well as positive result for NPV Track show that while RUs need to equip trains with on-board equipment, IMs are able to overall benefit due to less field elements and respective maintenance efforts. Thus, financing between RUs and IMs will play a crucial role when discussing actual implementation and rollout efforts.

Although this CBA shows positive results, one should account for the fact, that this model falls short due to partial underestimation of benefits such as, e.g., the avoided costs for blocking the track for maintenance reasons. At the same time, certain cost items such as development costs or project management and planning costs have not been taken into account and are difficult to estimate. However, those costs also arise with other technologies used as an alternative. Additionally, this model does not consider a migration strategy with old technologies and track occupancy technologies working simultaneously, which results in higher costs on the way towards a 100% rollout since more complexities and efforts arise.

5.6. BC 5– RFI – REGIONAL

5.6.1. Business Case Presentation

The regional line between Roccasecca and Avezzano is an 80 km non-electrified single-track low-traffic line. Nearly 10 trains, in both directions, travel on this axis on average every day. The line is currently equipped with the class B train protection system and with a light signalling system.

This line is already planned (and contract assigned) to be equipped with ETCS L2 without luminous signals and without a class B train protection system within the framework of the ERTMS Italian national implementation plan. The renewal of the signalling system is driven by the need to make the operation of the line more sustainable and efficient, with benefits also in terms of punctuality and quality of service; there is not an immediate need for increasing the capacity of the line.

The same line is a candidate for a possible experimentation of ETCS L3 (fixed block sections) solution.

Figure 12 – Roccasecca – Avezzano line profile

Business CASE IDENTIFICATION	BC N°		BC5
	HOLDER		RFI
	NAME		REGIONAL
Business CASE TYPE	TYPE		Régional
	USAGE		Passenger
BUSINESS CASE SPEC	SINGLE TRACK	KM	80
	DUAL TRACK	KM	0
	ROLLING STOCK	QTY	10

Table 30 – BC5 Identification

5.6.2. Business Case Parameters

Those data remain confidential.

Table 31 – BC5 Parameters

5.6.3. Business Case Results & Analysis

BC IDENTIFICATION	HOLDER	NAME	
BC5	RFI	REGIONAL	
	RESULTS	Items Group 1	Items Group 1 +2
NATURE	UNIT	VALUE	VALUE
NPV CAPEX	K€ / Km	-2	-0
NPV OPEX	K€ / Km	3	6
NPV BOARD	K€ / Km	-2	-5
NPV TRACK	K€ / Km	3	11
NPV / KM	K€ / KM	1	6

Table 32 – BC5 Results

This BC5 business case NPV is fairly low (below 1 €/km for Item Group 1 and 6 €/km for Item Groups 1 &2. This is due for the following reason:

The BC5 track distance is very short (80 Km). The reported unit price of balise is low. The reduction of balise refers to a regional line business case (30%). By consequences, the financial benefit of savings due to balise removal will remain small in comparison to the on-board investment.

5.7. **BC 6 – RFI – HSTB**

5.7.1. Business Case Presentation

The HS line between Treviglio and Brescia is a 40 km electrified double track high dense line.

35 High speed trains will be associated to this business case, representing the proportion of the total fleet of the 250 High Speed trains which is operated in the total Italian high speed network of 700 km.

This line is already equipped with ETCS L2 without luminous signals and without class B train protection system.

There is not current plan to migrate towards L3 solutions.

Figure 13 – HSTB line profile

Business CASE IDENTIFICATION	BC N°		BC6
	HOLDER		RFI
	NAME		HSTB
Business CASE TYPE	TYPE		HIGH SPEED
	USAGE		Passenger
BUSINESS CASE SPEC	SINGLE TRACK	KM	0
	DUAL TRACK	KM	100
	ROLLING STOCK	QTY	35

Table 33 - BC6 Identification

5.7.2. Business Case Parameters

Those data remain confidential.

Table 34 - BC6 Parameters

5.7.3. Business Case Results & Analysis

BC IDENTIFICATION	HOLDER		NAME
BC6	RFI		HSTB
	RESULTS	Items Group 1	Items Group 1 +2
NATURE	UNIT		VALUE
NPV CAPEX	K€ / Km	-2	-3
NPV OPEX	K€ / Km	15	15
NPV BOARD	K€ / Km	-5	-13
NPV TRACK	K€ / Km	18	25
NPV / KM	K€ / KM	13	12

Table 35 - BC6 Results

6. Cost Benefit Analysis

6.1. Business Case Benchmark

The partners selected different business cases from their network that enable to:

- Cover a wide variety of situations (high-speed, regional, national, mixed, …)
- Benchmark value for CCS assets (i.e balise CAPEX and OPEX)
- Define the on-board localisation function system cost target
- Agree on average benefits, such as track assets reduction ratio

The table below summarizes all the hypotheses and parameters values for the six business cases:

Business CASE IDENTIFICA-TION	BC N°		BC1	BC2	BC3	BC4	BC5	BC6
	HOLDER		SNCF	SNCF	SBB	DB	RFI	RFI
	NAME		LGV +	HPMV	National	NATIO-NAL	REGIO-NAL	HSTB
Business CASE TYPE	TYPE		High Speed	Régional	Mixt	MIXT	Régional	HIGH SPEED
	USAGE		Passenger	Passen-ger	Passen-ger - freight	Passen-ger - Freight	Passen-ger	Passen-ger
BUSINESS CASE SPEC	SINGLE TRACK	KM	2	26	1 360	60 000	80	0
	DUAL TRACK	KM	650	259	1 900	0	0	100
	ROLLING STOCK	QTY	60	106	1 900	10 500	10	35

Table 36 - BC Parameters summary

6.2. CBA results and analysis for Item Group 1

The following project Net Present Values in K€/km were computed from the CBA engine model implementation. Those results must be interpreted with caution. As mentioned in chapter 4.6, the model has some uncertainty due to the assumptions selected in the scope of this study.

Business CASE IDENTIFICATION	BC N°		BC1	BC2	BC3	BC4	BC5	BC6
	HOLDER		SNCF	SNCF	SBB	DB	RFI	RFI
	NAME		LGV +	HPMV	National	National	Regional	HSTB
	NPV CAPEX	K€ / Km	3	-6	1	1	-2	-2
	NPV OPEX	K€ / Km	10	12	11	11	3	15
	NPV BOARD	K€ / Km	-2	-10	-7	-3	-2	-5
	NPV TRACK	K€ / Km	14	12	20	15	3	18
	NPV / KM	K€ / Km	12	7	12	12	1	13

Table 37 - BC Results Summary Item Group 1

6.2.1. Overall analysis of the CBA – Item Group 1

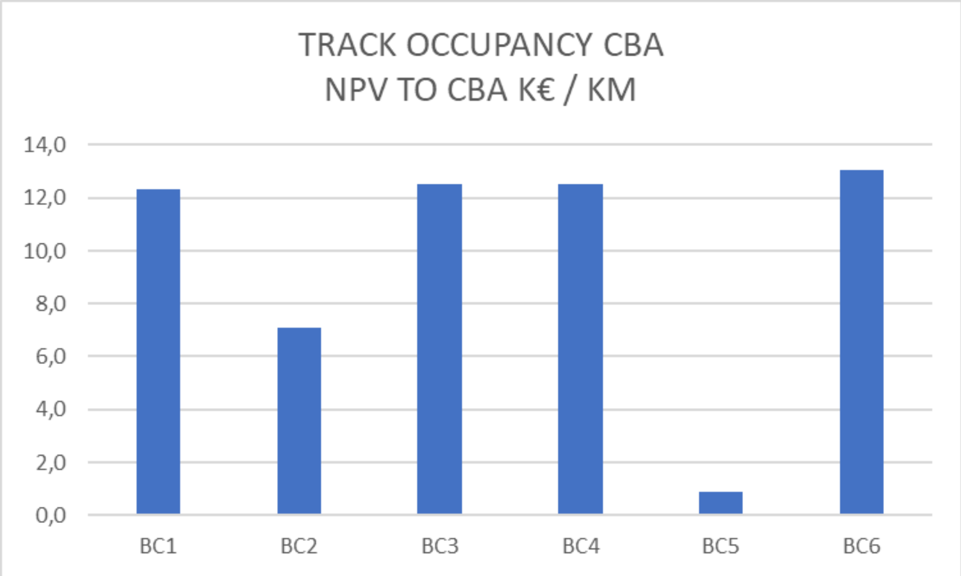

Figure 14 – BC Summary – Item Group 1

Without considering the BC5, the contribution of the localisation item (Group 1) resulting from their NPV balance amounts to a range of 7 to 12 k€/km. The BC5 reports the lowest saving, because the scenario is very specific and does not allow significant savings: short track distance, low balise density, low balise price and low reduction ratio. In this specific case, one could conclude that there is no added value (only risks, design costs, certification cost) to implement the target scenario.

Overall, it means that the saving of balise expenses (CAPEX & OPEX) between the two scenarios during the duration of the project can finance the additional board expenses, which are themselves optimized due to LOC-OBU conception and provide an average benefit of 12 K€/km through the project duration.

The business cases were chosen to analyse three different types of situations: The high-speed line with passenger services only, the regional line and entire networks, with mixed usages (passengers and freight).

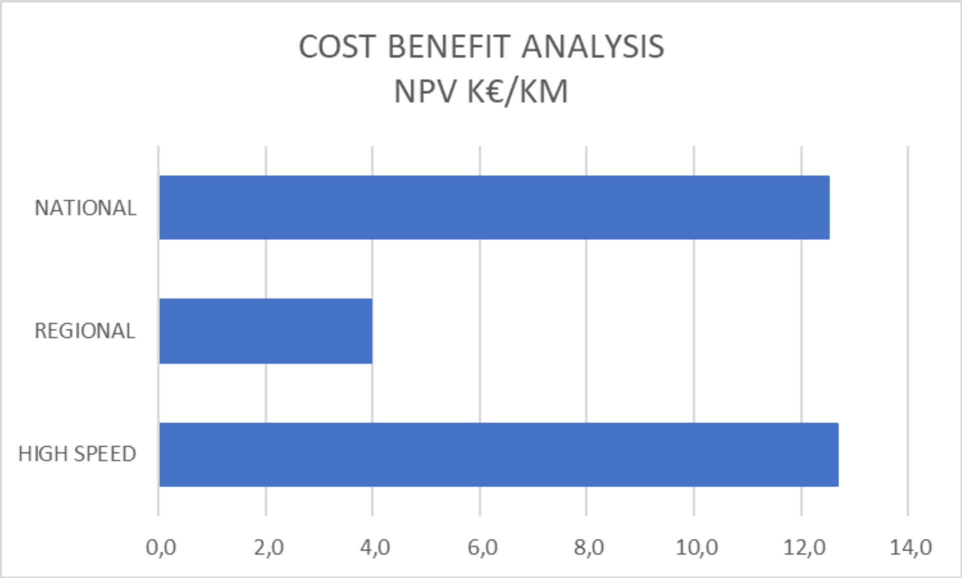

Figure 15 – BC Summary per type of network – Item Group 1

The economic balance might differ for many different aspects (see section 4.2.4: simpler track plan, lower number of stations and switches):

- The initial density of balise is less important (-20% to -40%) in the high-speed line than in the regional line. Moreover, high-speed lines do not use axel counters. So, the potential savings are lower.
- The rolling stock sizing follows different criteria due to the nature of exploitation: speed and capacity versus coverage of a large territory at a lower speed.
- The reasons for switching to an ERTMS system may be different depending on the type of line (capacity increase, punctuality, sustainability, interoperability, both, …).

The benefits will be higher in the case of High Speed line, due to the higher percentage of reduction of balises along the track and for National implementation due to the higher number of kilometres for a given rolling stock, allowing to absorb and average out the cost increase of the rolling stock per kilometre of track.

6.2.2. On-board versus trackside contribution to the CBA – Item Group 1

The on-board versus trackside financial flows comparison is a key point to consider investments to be made by different actors. Indeed, the foundation of the Track Occupancy approach is to transfer the train localisation function from the trackside to on-board assets, to establish a more competitive transportation mode. Rolling stock will be upgraded, with a target to minimize maintenance costs.

The project will initiate the decommissioning process of trackside assets, reporting solid CAPEX and OPEX gains. It is also obvious that the larger the network is, the higher will be the track savings. On the opposite, the larger the rolling stock to upgrade, the higher the investment cost will be.

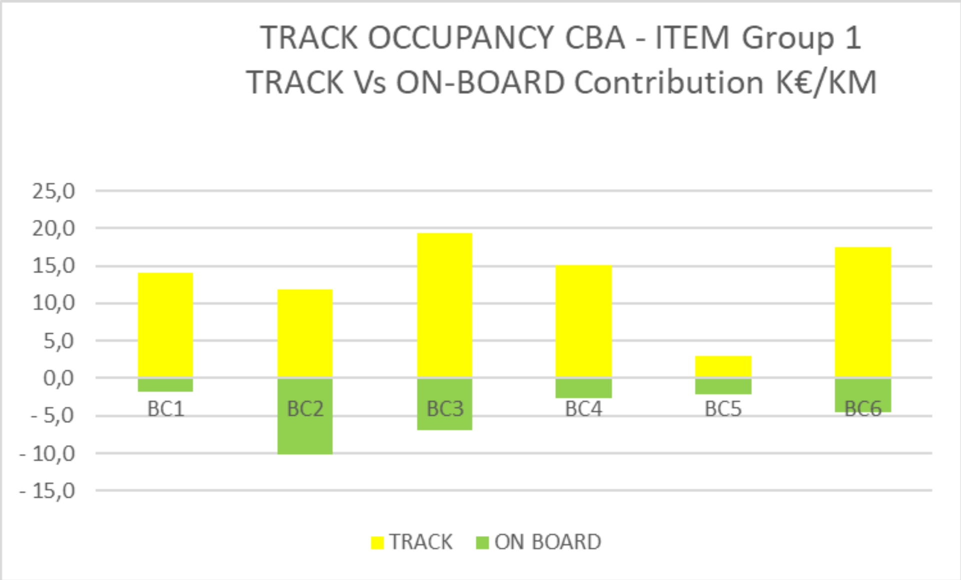

Figure 16 - Track Vs On-Board Contribution Item Group 1

Here is the tendency of our business cases:

- **On-board NPVs reported by K€/Km are slightly negative but under control (below 5 k€/km in average).** The standardization of the design of LOC-OB and optimization of the odometry function minimizes the corresponding CAPEX and improves the OPEX.
- The On-Board NPV value is directly related to the sizing of the Rolling Stock with respect to the number of track kilometres. For a given network, an enlargement of the rolling stock will imply more CAPEX and degrade the negative NPV. This is the case of BC2, a regional network operated at full capacity i.e. with the high number of trains, has the lowest relative NPV value.
- **Track NPVs are above 15 K€/km in average,** depending on the track length of the network and its legacy dotation in trackside assets.

6.2.3. CAPEX / OPEX Contribution to the CBA – Item Group 1

The CAPEX and OPEX contribution provide a different perspective on the financial economy of the project. In this analysis, track and on-board costs are cumulated to understand the respective contribution over a 20-year period of time between initial investment (CAPEX) and annual maintenance cost (OPEX).

CAPEX is the sum of the additional investment for On-Board System and the reduction of Balise investment (reduction ration between Reference scenario and Target scenario). This is the reason why the CAPEX can be either positive (savings on balise are more important than On-Board additional investment) or negative in the opposite case.

For example, BC1 CAPEX NPV is positive because the balise savings on this long network will be important. At the opposite, BC2 CAPEX NPV is negative for the same reason explained in section 6.3.1.

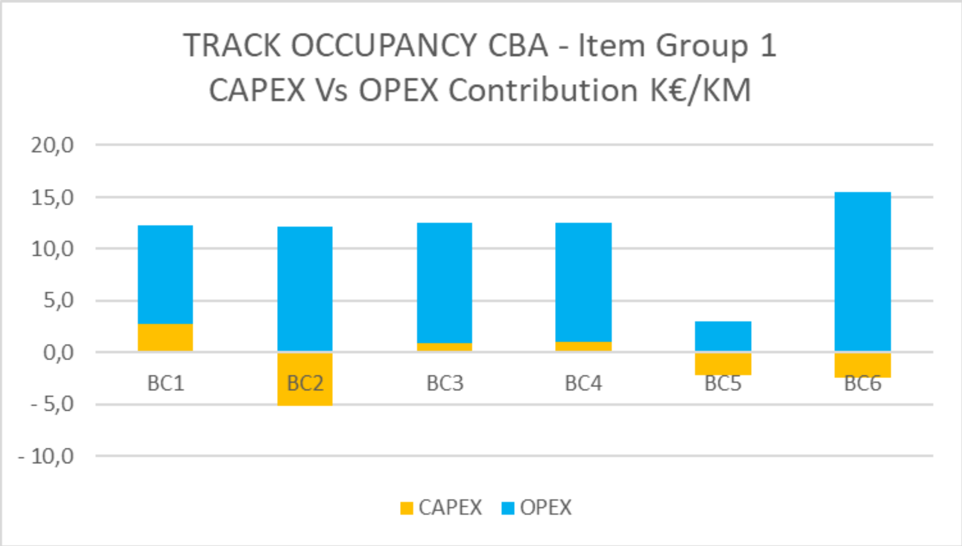

Figure 17 - CAPEX vs OPEX contribution for Item Group 1

The calculation reports two major conclusions:

- Initial investment (CAPEX) remains neutral in average, with a balance between the additional on-board system and the reduction of balise investment flows, in the frame of -5 K€/km to 2,5 K€/km depending on the cases.
- OPEX contributes to a benefit of 10 K€/km in average. Without doubts, the project will provide an improved maintainability and operational cost-effective solution.

6.3. CBA results and analysis for Item Group 1+2

The Item group 2 contribution remains significantly high, considering a reduction ratio of 50% of Axle counters and track circuit when implementing GNSS/TIMS function would be achievable.

The results observed for Item Group1+2 must be considered with caution. The hypothesis of 50% reduction rate for the axle counters and track circuit will highly depend on the track configuration and is therefore an averaged number which will vary significantly depending on the scenario.

Business CASE IDENTIFICA-TION	BC N°		BC1	BC2	BC3	BC4	BC5	BC6
	HOLDER		SNCF	SNCF	SBB	DB	RFI	RFI
	NAME		LGV +	HPMV	National	NATIONAL	REGIONAL	HSTB
	NPV CAPEX	K€ / Km	7	1	71	7	0	-3
	NPV OPEX	K€ / Km	16	23	15	21	6	15
	NPV BOARD	K€ / Km	-4	-29	-20	-7	-5	-13
	NPV TRACK	K€ / Km	26	37	106	35	11	25
	NPV / KM	K€ / Km	22	24	85	28	6	12

Table 38 - BC Results Summary

6.3.1. Overall analysis of the CBA – Item Group 1+2

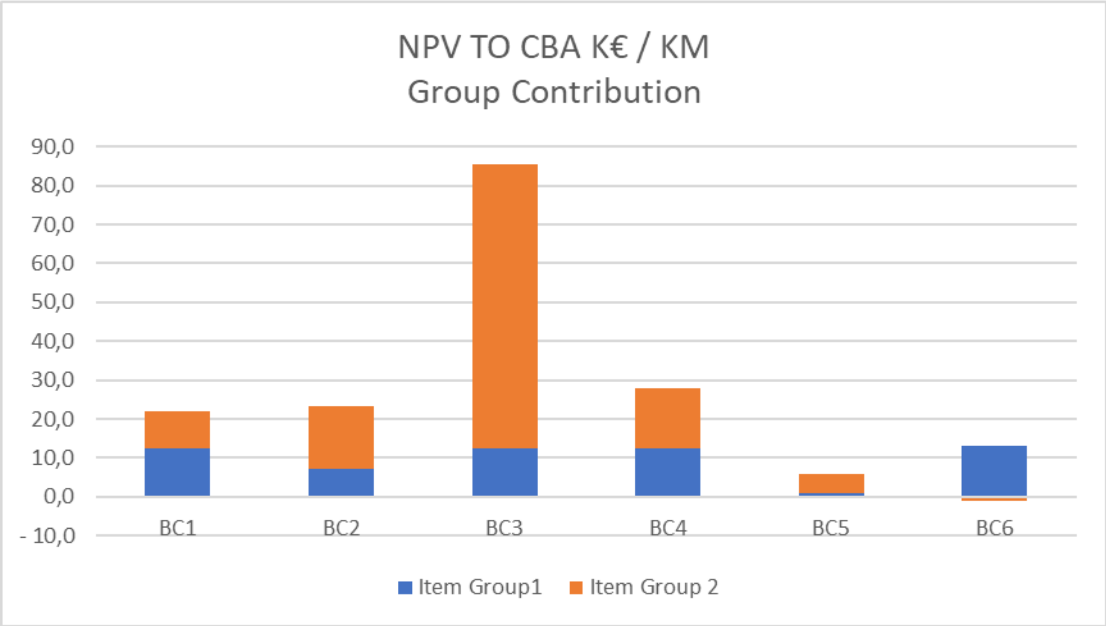

Figure 18 - CBA Results

In BC3, the value is the highest because this business case deals with a national network (high track km) with a very high density of TDS. Consequently, the reported savings will be exceptional. At the opposite, the BC5 and BC6 refers to a short high-speed network (80 km) without any axel counter, In the other cases, the savings of Item group 2 are in the same order of magnitude than the savings of item group 1, between 10 to 15 k€/km.

All CBA are positive after the 20 years of exploitation. The monetization of the item groups 3 and 4 (capacity, punctuality, climate, …) will further improve the case.

6.3.2. On-board versus trackside contribution to the CBA – Item Group 1+2

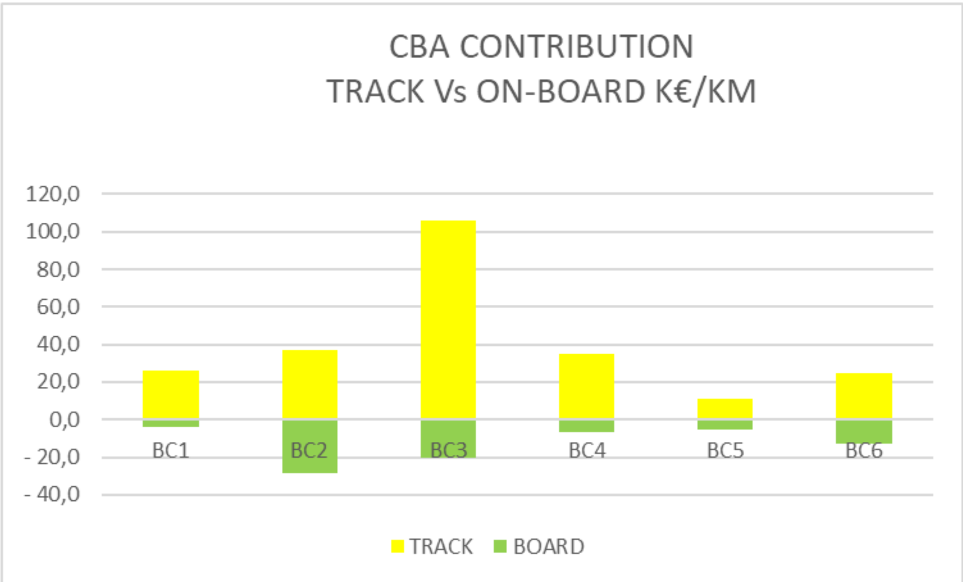

Figure 19 - Track and On-Board Contribution Item Group 1 & 2

Under this 50% reduction hypothesis, the potential gain on the trackside equipment is enormous and shows how beneficial it could be to reduce as much as possible these equipments.

6.3.3. CAPEX / OPEX Contribution to the CBA – Item Group 1+2

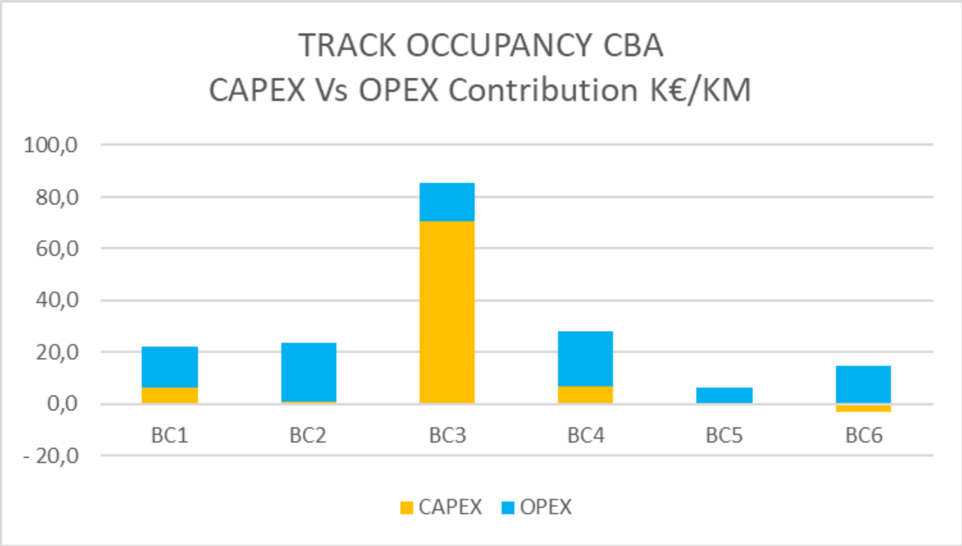

Figure 20 - CAPEX and OPEX Contribution for Item Group 1 & 2

The main difference between this scope to the previous scope limited to Item Group 1 will come from the impact of axle counters and Track circuit reduction between the 2 scenarios.

The BC3 is the most impacted because its reference scenario has a very high density of TDS and a long network. Consequently, the savings value of TDS in its target scenario will be very important (based on a 50% reduction ratio) and significantly improved the NPVs.

7. Conclusions & Recommendations

This document comprises a cost-benefit analysis (CBA) for the track occupancy concept which is part of the RCA's vision for a digitalized and automated railway operation. The document shows positive results, based on partners' examples covering a wide range of situations and the projection of cost-benefit consideration that tends to be representative. The chapter below recalls the main conclusion and recommendations deducted from this study.

7.1. Conclusions

The CBA study covering the upgrade of a reference scenario with ERTMS/ETCS Level 2 standard to a project scenario in ERTMS Level 3 GNSS standard drives to the following conclusions:

- **Conclusion N°1:** The implementation of the Track Occupancy Concept shows a positive Net Present Value when considering only the localisation items of Group 1. The corresponding cost-benefit calculation provides a gain of 7 to 12 k€/km of track for the business cases included in the study. BC5 is not considered for this conclusion because of the limited representativity of this scenario.
- **Conclusion N°2:** The implementation of the Track Occupancy Concept shows a positive Net Present Value when considering only the localisation items of Group 1+2. The corresponding cost-benefit calculation provides a gain of 6 to 85 k€/km of track for the business cases included in the study.
- **Conclusion N°3:** The CBA results tend to prove that a global network transformation (i.e. massive deployment) towards the target scenario (ERTMS/ETCS Level 3) will better balance out the necessary investments on the rolling stock. The modelling of the transition scenario would also be in favour the global network transformation compared to an incremental change of the network.
- **Conclusion N°4:** Additional costs are necessary on-board the trains to implement the target scenario, however these cost increases are limited overall thanks to a lower maintenance cost of the onboard equipment's.
- **Conclusion N°5:** TDS assets CAPEX and OPEX savings have a high contribution on the CBA NPV and proves that it is worth reducing as much as possible the use of these assets on the tracks.

7.2. Recommendations

In order to strengthen the CBA methodology, increase the confidence in the results and mitigate project risks, the following actions are recommended to be implemented:

- **Recommendation N°1:** To fine tune the model, the extension of the operation period from 20 to 30 years will have to be studied, including the replacement of the LOC-OB unit after 15 years.
- **Recommendation N°2:** Explore additional complexities (i.e. migration scenario, interrelations between assets and process of an infrastructure manager) and assess additional costs when applying concept to a national scenario on a global network.
- **Recommendation N°3:** The hypotheses taken for Group 2 items should be refined:
    - The TDS reduction ratio is one of the key factors with high sensitivity to the CBA result. The hypothesis of 50% reduction ratio of the TDS would need to be further studied as it may be very variable depending on the tracks and network types.
    - The TIMS function implementation depends on the type of trains (Fret or passenger) and would need to be studied in more detail.
- **Recommendation N°4:** Adress some items of Group 3 and 4 (capacity increase, increase of punctuality and regularity of operations), taking into consideration that modelling the effect of localization on some of these items will be complicated.
- **Recommendation N°5:** Benchmark cost assumptions (LOC-OB unit targeted price of 40k€) with the industry and adjust the study assumptions, when necessary.

- **Recommendation N°6:** Coordinate migration strategies and benefit sharing mechanism between IMs and RUs.

8. Annexes

8.1. List of Tables

8.2. List of figures