

D6.1 Economic model and scenarios

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1 INTRODUCTION

1.1 EXECUTIVE SUMMARY

This document illustrates the main methodological elements of the overall Impact Analysis, the object of WP6.

In particular, it presents:

- The overall approach, which is based on the Cost-Benefit Analysis methodology and aims to compare differential scenarios with a discounted flows technique.
- The definition of the alternative scenarios considered (the Baseline scenario, with the traditional ERTMS solution; and the Project scenario, with the innovative GNSS-based ERTMS.
- An economic model of ERTMS, for both scenarios, which includes the description of the main cost and revenue elements, the main parameters required for their estimations the involve players. This document does not quantify unit cost items; such figures will be assumed and used for the elaborations only in following deliverables.
- The case studies that will be considered for the application of the CBA and impact analyses (D6.4 will however include an expansion of the economic results to a wider scale).

Acronym	Meaning	Mentions
BTM	Balise Transmission Module	pp. 7, 8, 12, 18, 21, 27
CAPEX	CAPital EXpenses	рр. 11-19
СВА	Cost Benefit Analysis	pp. 5, 20, 26
ERTMS	European Rail Traffic Management System	pp. 5, 7, 8, 13, 15, 17-20, 23, 25
IM	Infrastructure Manager	pp. 5, 11, 14-16, 20-24
OBU	On Boar Unit	рр. 5-27
OPEX	OPerating EXpenses	рр. 11-25
RU	Railway Undertaking	pp. 11, 19, 22-24, 27
TAL-S	Track Area Local Server	р. 13
TSS	Train Signalling Supplier	pp. 14-17, 19, 20
TLC	Telecommunications	pp. 7-9, 17, 19
VBR	Virtual Balise Reader	Pp 8, 12, 19

1.2 DEFINITIONS AND ACRONYMS



2 OBJECTIVE AND METHODOLOGICAL APPROACH

The analysis aims to compare the costs and savings generated by the upgrade from a "traditional" ERTMS Level 2 solution to a GNSS-based solution.

Quantification of costs and benefits when upgrading to an ERTMS Level 3 solution are not within the scope of this analysis. Note that from a GNSS point of view the case of using GNSS versus traditional Eurobalises for train positioning is essentially the same for ERTMS Level 2 and ERTMS Level 3, as the only difference between a balise based implementation and one using GNSS would be the elimination of balises in the track and the addition of a GNSS positioning system on-board the trains.

Other differences in cost between ERTMS Level 2 and ERTMS Level 3 will result e.g. from the possible elimination of track vacancy proving systems and the implementation of onboard train integrity supervision, which are both independent from GNSS. As ERTMS Level 3 is however currently not fully defined and as there are currently no implementations of ERTMS Level 3 which could be used as reference scenarios the further analysis only mentions ERTMS Level 2.

The analysis applied from a "public" perspective (whose results are the object of D6.2) does not separate costs and savings occurring for different players involved in the rail system; this will however be crucial in the "impact analysis", object of D6.3, that will analysis the differential costs and savings for each individual type of saving.

The analysis relies on the Cost-Benefit Analysis methodological approach and it employs the "Discounted cash flows" technique, in that it compares the costs and savings on a long time horizon, discounting the items that occur in the future with a certain discount rate.

The time horizon includes 2 years for the investment in a certain line, and 30 years of operations, as this is the assumed service life of most investments involved in the project. N.B. Balises are assumed to have a 20 year service life instead.

The discount rate is 4% as suggested by the DG Regio Guide to CBA, 2014.

The following economic performance indicators can be determined with respect to the project:

 Economic net present value (ENPV), that is the discounted difference of total social costs and total social benefits year by year.
 From a mathematical point of view ENPV is:

$$ENPV = \sum_{t=0}^{t=n} \frac{(B_t - C_t)}{(1+r)^t}$$

Where:

ENPV = Economic Net Present Value

 B_t = Benefits (inflows) in year t



 C_t = Costs (outflows) in year t,

r = Discount rate

The ENPV should be greater than zero for the project to be desirable from an economic standpoint. In fact, in this case, the discounted value of the benefits is greater than the discounted value of the related costs.

Note that the difference between ENPV and FNPV (Financial NPV) is that the former uses accounting prices or the opportunity cost of goods and services instead of imperfect market prices, and it includes as far as possible any social and environmental externalities. This is because the analysis is done from the point of view of society, not just the project owner. Because externalities and shadow prices are considered, some projects with low or negative FNPV may show positive ENPV.

• Economic rate of return (ERR), that is the discount rate at which the NPV is equal to 0.

ERR is calculated by solving the following formula, with the meaning of letters as the same as in NPV formula.

$$\sum_{t=0}^{t=n} \frac{(B_t - C_t)}{(1 + ERR)^t} = 0$$

The ERR should be greater than the social discount rate for the project to be desirable from an economic standpoint.

When ERR is less than the SDC (Social Discount Rate, that could be fixed as the cost of public founding in the long run) the proposed alternative project should be rejected since its return rate is not enough.

 Benefit/Cost ratio (BCR), that is the ratio between total discounted economic benefits and total discounted economic costs of the project.
 Another form of the ENPV criterion is called Benefit-Cost Ratio (BCR), which is, in effect, another way of comparing the present value of the proposed alternatives costs with benefits. Instead of calculating the ENPV by subtracting present value of Costs from the present value of Benefits we divide present value of Costs into the present value of Benefits. In mathematical terms:

$$BCR = \frac{\sum_{t=0}^{t=n} \frac{(B_t)}{(1+r)^t}}{\sum_{t=0}^{t=n} \frac{(C_t)}{(1+r)^t}}$$

The BCR should be greater than one for the project to be desirable from an economic standpoint.

3 SCENARIO DEFINITION

The Cost-Benefit Analysis is carried out as a differential analysis between two potential scenarios.

The baseline scenario represents the case in which the current technology is implemented, while the project scenario represents the case in which a different and innovative technological solution is chosen.

3.1 THE BASELINE SCENARIO

The baseline scenario represents the case in which the current technology is implemented, then the balise-based ERTMS solution.



Figure 1: Baseline scenario architecture

In the baseline scenario the train in localised through physical balises fixed on the railway line, as envisaged by the current ERTMS specification. The actual train location is continuously computed by the OBU through the odometer and the measurement error is systematically corrected when the train passes on the following physical balise. The OBU of the train, in fact, is provided with a BTM module able to read the balises. Data are continuously exchanged between the OBU of the train and the RBC through the TLC system.

3.2 THE PROJECT SCENARIO

The project scenario represents the case in which a technological innovation is introduced in the ERTMS ecosystem. In this case, the technological innovation consists in the replacement of the majority of physical balises with the virtual balise concept.



Figure 2: Project scenario architecture



In the project scenario the train in localised through an innovative technology called virtual balise concept. Instead of fixing physical balises on the railway line, the train is localised at discrete points - so that the ERTMS specifications don't need to be changed on this point - through the satellite signal provided by various global satellite navigation systems and their related subsystems.

The OBU is able to receive satellite signal from the global satellite navigation systems Galileo, GPS and GLONASS whose signals are augmented by EGNOS.

This project scenario envisages only one solution for the augmentation, which is EGNOS, since other studies showed the preference of this system with respect to other proprietary solutions in term of social and economic convenience. The limitations of EGNOS are however addressed in the assumptions as follows:

- To cope with the very limited coverage of railway lines by the geo-stationary EGNOS satellite(s) it is assumed that EGNOS data is received by the ERTMS ground segment (radio block centre) through a dedicated and protected ground service from the EGNOS ground segment, and then distributed to the trains via the GMS-R radio link (or any other follow up radio system).
- To address the limited protection of the EGNOS signals against unintentional or intentional interferers if received from space it is assumed that the transmission of ENGOS data through the dedicated ground service and the GSM-R radio link is sufficiently protected by necessary means (e.g. encryption).
- To address some doubts about the applicability of the protection levels defined for aviation
 also for rail applications it is envisaged that the protection levels of a dedicated EGNOS "rail"
 ground service could be adjusted to suit rail application requirement. Note that this would be
 very difficult if EGNOS data is received through the space segment, as data formats would
 have to be changed, but should be much easier if only a dedicated ground service is used.

Note that the achievable safety level of GNSS based train positioning against requirements of rail applications still needs to be investigated further. It is however assumed in this study that EGNOS is an absolute must for such applications, as GNSS signals received from space are unprotected against unintentional and intentional interferences. Rail safety standard do however require that such interferences are being considered and that measures are provided to ensure that the required safety level is maintained even if such interferences are present. The train location is continuously computed by the OBU through the odometer and the measurement error is systematically corrected when the train meets the following virtual balise. The OBU, in fact, is provided with a VBR module able to receive the satellite signal. Data are continuously exchanged between the OBU of the train and the RBC through the TLC system.

3.3 THE TECHNOLOGICAL INNOVATION APPRAISED BY THE ANALYSIS

The only difference between the baseline and the project scenario consists in the localisation system, that is the technology chosen for the provision of absolute reference positions, both in regards to longitudinal position along the track and track number in the case of multi track arrangements. In the baseline scenario the physical balise solution is chosen, in the project scenario the virtual balise concept, implying the use of the global satellite navigation systems signal, is chosen. Only the changes due to this technological innovation is appraised. The consequence is that, as a first level of analysis, the baseline scenario will consider the cost of physical balises and of an OBU provided with a BTM module, while the project scenario will not consider the cost of physical balises but just the one of an OBU provided with a VBR module as well as possible trackside measures.

The TLC solution, whether to choose a dedicated GSM-R network or a multi-bearer TLC solution, is out of the scope of this analysis and the related cost and benefits are considered invariant between the two analysed scenarios.





4 STRUCTURE OF THE MODEL

The economic model defines a number of levels of cost estimation that can be listed in a consequential bottom-up chain of variables, as follows.



The relations among cost factors and cost items are the key aspect which defines the economic model. Other than that, the further levels of cost estimations are achieved just by summing the previous levels: cost items sum up to quantify cost blocks, cost blocks sum up to quantify cost categories, and so on.

Looking at this list from the end result, we can point out that the analysis considers the following main cost areas for each alternative solution:

Costs of implementation of the solution + Other differential impacts





The **costs of implementation** are the capex and opex of the items directly connected to the system operation, e.g. the investment costs in RBC or the maintenance costs of telecommunication equipment, etc.

The **other impacts** are either indirect savings or indirect additional costs that the implementation of a system generates in other areas of the involved players' operations with respect to the alternative solution. E.g., in the theoretical situation whereby a certain solution allows the infrastructure manager to increase the capacity of a congested line as compared to the alternative, this generates benefits for both the IM in terms of added value of tracks sold and the RU in terms of added value of train services. Such impacts will be labeled as "additional costs" for the baseline solution rather than "savings" for the project; however, the different definition does not have impact in the estimations.



It is necessary to underline that implementation costs will be considered only in their differential components. For example, if a certain implementation cost item (e.g. personnel costs) is equal for both alternatives, then it will not be included in the sum of all costs.

All costs and savings are computed in a unique time horizon which is defined by the duration of the investment phase and the duration of the service life of the main components of the systems. Should the service lives of other components differ, the analysis will include new investment cycles (if the service life is shorter) or residual values (if it is longer).

In the above figures, the last impact category (environmental) is highlighted in green because it concerns solely the analysis from the public point of view and are not considered relevant for the analyses from the operators' perspectives (whereas safety issues are relevant for the operators as well because accidents are not only a social cost in terms of deaths and injuries, but also financial costs because of the damages to assets).

The following table shows a list of cost items, grouped up and listed according to the levels shown in the previous figures. The list includes items that are relevant for either one of the solutions or both.

Block	Item	CAPEX	OPEX
Ground	RBC	~	\checkmark
	TrackDatabase	~	~
	ETCS planning, installation, interfacing	~	~
	Balises	~	~
	EGNOS data interface	~	~
	GSM-R infrastructure	~	~
On Board Unit (OBU)	ETCS module	~	~
	BTM module	~	\checkmark
	VBR module	~	\checkmark
	GSM-R module	~	\checkmark

Implementation costs



Other differential impacts

Block	Item	CAPEX	OPEX
Train	Energycosts		\checkmark
	Time costs (train operations)		\checkmark
	Time costs (start of mission)		\checkmark
Capacity	Missed revenues of train slots		\checkmark
	Missed added value of train operations		\checkmark
	Reduction of externalities		\checkmark
Safety	Accident costs		\checkmark

The next section is dedicated to providing an illustration of each cost item, including what are the players impacted by them (both as those who bear the costs and who benefit), and the way in which related cost factors affect their quantification.

4.1 IMPLEMENTATION COST ITEMS

1) RBC

Cost category	Implementation cost
Cost type	Capex and opex
Cost block	Ground
Scenarios	This item is relevant in the project scenario and (with cost differences)in the baseline ERTMS L2 scenario
Description and cost factors	The Radio Block Centre (RBC) is a key component of ERTMS from level 2 on. It compiles information from the interlocking and trains in its control area and sends movement authorities and other information to individual trains, taking into account a safe distance to the train ahead. On the basis of this, each train is able to calculate its braking distance and optimal speed.
	For the purpose of this analysis, all the additional components needed to run the system in the project scenario (including the data interface between EGNOS and the RBC) are represented in the cost of TAL-S (Track Area Local Server) which in the project scenario adds to the cost of the RBC, as compared to the one in the baseline scenario.
	RBC components (€/unit).
Related parameters	 Number of necessary RBC units to equip the concerned line(s). This can be linked to either:



	 the number of traction units running in the line(s) (an average of 1 RBC per 90 trains is first assumed) the length of the line(s) in km (an average of 1 RBC per 200 km is first assumed)
Involved players	The RBC capex is borne by the IM and represents a revenue for the train signalling suppliers (TSS).

2) Track Database

Cost category	Implementation cost
Cost type	Capex and opex
Cost block	Ground
Scenarios	This item is relevant in the project scenario only.
Description and cost factors	The Track Database is a key component of the GNSS-based ETCS solution. In fact, it works as a permanent storage and update at the RBC allowing transmission of RBC area track data to the train where needed, such as in a movement authority.
	Once the track database is installed, a track digitalization campaign is needed, covering the whole concerned network.
	Ordinary maintenance of the Track Database derives from the fact that any change in the network will have to be reflected in the database (aviation databases for example are updated every 28 days).
	The cost of the track digitalisation campaign is expressed in €/Linekm.
	The cost of recalibration can be expressed in €/LineKm as well and will be a % of the cost of the digitalization campaign.
	It is also relevant to define how the database is used onboard. If uploaded manually (as in the aviation sector), it becomes a cost factor for the train operator; if via radio, as initially assumed, then it is a negligible cost.
Related parameters	 Track Database: 1 per RBC or per IM Frequency (in years) of the recalibration campaign Frequency of updates due to changes in trackside
Involved players	The Track Database capex and opex are borne by the IM and represents revenue for the train signalling suppliers (TSS).



3) ERTMS provision, planning and interfacing

Cost category	Implementation cost
Cost type	Сарех
Cost block	Ground
Scenarios	This item is relevant in all ERTMS-based scenarios .
Description and cost factors	The investments on the lines consist in the investment on the ground equipment and on ERMTS central control system. Such investments are articulated over different dimensions: ERMTS, GSM-R, central controls system, that is the RBC (Radio Block Centre) and balises, each with planning, installation, interfacing and commissioning.
	However, in this analysis, the RBC, balises and GSM-R are treated separately. The residual components of this cost item can be considered as invariant among all ERTMS-based scenarios. The cost of provisioning, planning and interfacing can be expressed in €/LineKm .
Related parameters	-
Involved players	The cost is borne by the IM and represents revenue for the signalling industry.
Involved players	The capex cost of balises is borne by IMs and is a revenue for TSS. Opex are an operating cost for IMs.

4) Balises

Cost category	Implementation cost
Cost type	Capex and opex
Cost block	Ground
Scenarios	This item is relevant in the project scenario and (with differences in the number of units) in the baseline ERTMS-based scenario as well.
Description and cost factors	The physical balises are the main equipment used for the train localisation and it is included in all the ETCS scenarios. The difference between the baseline and the projects scenarios is the number of balises needed for the ETCS solution. In the baseline scenario a balise-based ETCS solution is envisaged, then balises are used to determine the train's position. On the contrary, in the project scenarios, the train is basically localized through the virtual balise concept, that is a GNSS-based solution. However, some physical balises are required in the project scenario too because



	they can guarantee an enhancement of the localization in critical locations where GNSS reception is poor, such as long tunnels.
	The standard capex is a unit cost (€/unit) that includes the balise provision, the balise fixing system, the installation and commissioning.
	The opex of balises are represented only by their maintenance cost. Maintenance of balises consists in their replacement, as they cannot be "fixed" in case of damage or malfunctions.
	Since they are expected to be critical cost factors, the factors affecting the maintenance costs are presented in a dedicated box hereby.
Related parameters	(see box 4.a)
Involved players	The capex cost of balises is borne by IMs and is a revenue for TSS. Opex are an operating cost for IMs.

4.a) Balise maintenance due to MTBF and to vandalism or theft

Cost category	Implementation cost
Cost type	Opex
Cost block	Maintenance
Description, and cost factors	Eurobalises are subject to failure with a certain MTBF, as any other technical system. Failed balises have to be replaced, which includes not only the cost of the balise but also cost for travel, track access etc.
	Furthermore, Eurobalises have been subject to vandalism in some countries, requiring more frequent replacement than it is to be expected due to the predicted MTBF.
	Such costs depends on the following factors:
	 The unit cost of provision of the balise The stock cost of the balise units; The maintenance personnel cost.
Related parameters	 Number of personnel per intervention Average distance of intervention location from maintenance centre (to be differentiated among case studies) Frequency of maintenance interventions (to be differentiated among case studies), depending on the frequency of balise failure Frequency of vandalism and/or theft



5) GSM-R infrastructure

Cost category	Implementation cost
Cost type	Capex and opex
Cost block	Ground
Scenarios	This item is relevant in all ERTMS-based scenarios.
Description and cost factors	Telecommunication (TLC) components are included in all the scenarios since it is a crucial element of the ERTMS for the connectivity and the communication between the train and the RBC.
	The GSM-R network is composed by different subsystems:
	• The BTS (Base Transceiver Station), that is responsible of the signal diffusion. The network of BTS is named BSS (Base station subsystem). A BTS site cost is composed by the costs of the BTS itself, of a shelter where to allocate the equipment, of the tower and the ones related to installation and validation. The total cost of a BTS site is valued in €/unit . The density of the BTS network paired with the rail network is a relevant parameter to asses the overall cost.
	• The BSC (Base Station Controller), that is responsible for the coordination of the BSS, then of the BTSs. The total cost of a BSC site is included in the cost figure described for the RBC and it is invariant for all scenarios since the BSC is needed regardless of the number of BTSs.
	• The repeater. The cost of a repeater is composed by the repeater itself, the shelter where to allocate the equipment, the tower, the cables and optical fibre, the cable duct, where needed, and the costs related to installation and validation. The total cost of a repeater is valued in $\textbf{€}$ /unit and it is needed only in tunnels.
	• The NSS (Network Switching Subsystem), that is the component of the GSM system that carries out call switching and mobility management functions for mobile phones roaming on the network of base stations. Its cost is included in the cost figure described for the RBC.
	A standard unit capex figure for GSM-R can been assessed in terms of €/LineKm .
	However, this cost item is invariant throughout all relevant scenario. Therefore, it will not be included in the analysis.
Related parameters	n.r.
Involved players	n.r.



6) OBU: ETCS system

Cost category	Implementation cost
Cost type	Capex and opex
Cost block	On Board
Scenarios	This item is relevant in the project scenario and (with cost differences) in the baseline ERTMS L2 scenario
Description and cost factors	This is the standard ETCS equipment required on board to runon lines equipped with ETCS Level 2. Its cost is invariant throughout scenarios.
Related parameters	N.r.
Involved players	N.r.

7) OBU: BTM

Cost category	Implementation cost
Cost type	Capex and opex
Cost block	On Board
Scenarios	This item is relevant in the baseline ERTMS L2 scenario and in some versions the project scenario .
Description and cost factors	The BTM (Balise Transmission Module) is the part of the ETCS that allows to read balises. The standard unit cost figure for the investment in a BTM is expressed in €/unit , including redundancy.
	As concerns the project scenario, assumptions on the possibility of complete virtualisation of the balises will be applied for the future, so that BTM will be included in such scenario whenever it is assumed that physical balises persist in the concerned lines.
	Similarly, in the case of traction units employed in lines other than the ones that are subject to a project-scenario upgrade, BTMs are also necessary in order to ensure interoperability.
	Operating costs are related to its maintenance and can be expressed in €/unit per year as a % of the capex.
Related parameters	 No. of units per trainset (1 unit/trainset is assumed) Dummy variable, year by year, to account for the presence/absence of physical balises in the project scenario % of traction units that are operated in lines outside the project % of capex reflecting the yearly opex



Involved players All OBU modules are a cost for RUs and are provided by TSSs.

8) OBU: VBR module

Cost category	Implementation cost
Cost type	Capex and opex
Cost block	On Board
Scenarios	This item is relevant in the project scenario only.
Description and cost factors	The VBR (Virtual Balise Reader) is the module allowing the reception of the GNSS signal and the detection of the virtual balise. It includes all functionality to manage GNSS-based positioning. The standard unit cost figure for the investment in a VBR is expressed in €/unit including redundancy. Operating costs are related to its maintenance and can be expressed in €/unit per year as a % of the capex.
Related	No. of units per trainset
parameters	 % of capex reflecting the yearly opex
Involved players	All OBU modules are a cost for RUs and are provided by TSSs.

9) OBU: GSM-R

Cost category	Implementation cost
Cost type	Capex and opex
Cost block	On Board
Scenarios	This item is relevant in all ERTMS scenarios.
Description and cost factors	ETCS on board equipment is endowed with a TLC part enabling the communication between the train and the RBC. In the ERTMS standard, the GSM-R is the envisaged TLC technology. The module allows the radio and telecommunication between the train and the RBC via the dedicated GSM-R network.
	Cost figures, both in terms of capex and opex (maintenance and TLC services) are invariant throughout the ERTMS scenarios, and are therefore not considered in the analysis.
Related parameters	N.r.
Involved players	N.r.



10)EGNOS

Cost category	Implementation cost
Cost type	Орех
Cost block	Satellite
Scenarios	This item is relevant in the project scenario only.
Description and cost factors	The EGNOS augmentation service is expected to be fundamental element of the GNSS-based ERTMS solution. It is represented by the systems providing a satellite augmentation service, to increase the precision of the satellite geo-localisation as well as to monitor the integrity of the system.
	The EGNOS service includes the distribution of EGNOS data to the RBCs.
	A preliminary assumption is needed in this respect, about whether or not the access to signals and data needed for the geo-localisation are considered, as in the aviation sector, free of charge. If yes, then no opex is to be included in the analysis. If not, an operating cost for the rail sector needs to estimated.
	This can be done following the assumptions of the EGNOS CBA for the aviation sector ¹ . In particular, according to the mentioned approach, the costs allocated to the aviation sector were proportional to the aviation share of GNSS revenues per sector as per the GNSS Market Report 2015. For aviation, this share equals 1%; for rail, it equals 0.2%. The total fixed costs per year calculated in the mentioned report range from \in 911 million to \in 1.9 billion, and it is thereby assumed that 75% of them are allocated to Galileo and 25% to EGNOS.
Related parameters	 The underlying assumption on whether such service will be provided for free.
Involved players	The item is an opex for the IMs provided by external service suppliers via the TSS.

¹EGNOS in Aviation CBA, Final report, GSA. December 2015



4.2 **OTHER DIFFERENTIAL COST ITEMS**

11)Energy costs

Cost category	Other differential impacts
Cost type	Opex
Cost block	Train operation efficiency
Description, cost factors and related parameters	In the physical balise-based system, the possibility of errors occurring in the detection of the balise by the BTMmay result in an unnecessary activation of the automatic braking. The unnecessary braking and slowdowns imply a cost in term of brake pads consumption, in energy consumed for the reacceleration and time wasted for slowdown.
	If GNSS positioning could help reduce such errors, such costs would be saved in the GNSS-based system.
	The model for estimating such saved costs relies on the following factors and parameters:
	 The average number of unnecessary brakings per train*km The average speed of the train at the moment of the error The unit cost of energy
	 The amount of energy needed to accelerate the train from 0 to the original speed, which in turn depends on the weight of the concerned train
	Also, an assumption is needed throughout the case studies regarding the share of potential energy recovered during the braking that gets wasted rather than being absorbed by other trains in the same section of the line. This depends on qualitative considerations regarding the type of line, the frequency of trains and the length of headways.
	The model leads to a €/event figure.
	The average number of events per year will yield an additional energy cost for the non-project scenarios in €/year .
	However, the initial assumption is prudential and assumes that GNSS positioning does not reduce brakings and slowdowns as compared to the traditional balises.
Involved players	The cost is borne by the IMs.



12)Time costs

Cost category	Other differential impacts
Cost type	Opex
Cost block	Train operation efficiency
Description, cost factors and related parameters	If assumed to be relevant, the same events described for the previous cost items (activation of automatic braking) would generate wastes of time for the braking, the reset of the system and then the reacceleration.
	The estimation model considers:
	 an average cost of time per minute, that can be estimated by means of the penalty fare applied by IMs to maintenance operators who don't release the tracks on time. The average time wasted per event. and yields a cost of wasted time expressed in €/event.
	The average number of events per year will yield a cost of wasted time for the non-project scenarios in €/year .
	However, the initial assumption is prudential and assumes that GNSS positioning does not generate different waste times as compared to the traditional balises.
Involved players	The cost is borne by the RUs.

13)Time costs (start of mission)

Cost category	Other differential impacts
Cost type	Opex
Cost block	Train operation efficiency
Description, cost factors and related parameters	Whenever a train starts a service, the current positioning technologies are not able to detect its location on a track, unless a cold movement detector is used. For this reason, at the start of missions trains generally have to run in Staff Responsible Mode (SRM) until the first balise is met, thus being able to detect its location and communicate it to the RBC. SRM implies very low average speeds that keep the potential acceleration of the train at the start of a mission below a certain threshold. This generates a waste of time every time a service starts. In the project scenario, GNSS positioning may be able to locate the train straight at its wake up, allowing to avoid SRM and the waste of time. In order to monetize this waste of time, the estimation is based on the following factors:
	 Max speed in SRM (km/h)



	 Average distance between the train at its wakeup and the first balise where its position is detected (m) Average acceleration of the concerned train(m/s²); Max speed on the concerned (km/h). The amount of saved time equals the delay of a SRM-forced train in reaching its max speed compared to a train with no constraints.
	Assuming a value of time for train operations (€/min), the effect can be expressed in €/train .
	However, an underlying assumption on whether the train is endowed with a cold movement detector is also needed in order to understand whether this saving is actually relevant.
Involved players	The cost is borne by the RUs.

14)Missed revenues of train slots

Cost category	Other differential impacts
Cost type	Орех
Cost block	Capacity
Description, cost factors and related parameters	The GNSS-based technology is expected to have an impact in terms of capacity on the lines, as compared to traditional ERTMS L2. Such impact is based on the reduction of the odometric error.
	Because of the odometric error, for capacity purposes trains are assumed to be longer than their actual length. The use of satellite positioning is expected to decrease this error and therefore increase capacity.
	An initial assumption about the meaningfulness of such decrease is necessary, as it is with all capacity-related cost items presented in this section (cost items 16, 17 and 18). Prudentially the decrease can be assumed to be negligible, however a sensitivity analysis will be carried out to quantify the possible effects.
	On congested lines, this impact becomes actual in that it allows to operate more trains as compared to the alternative scenario. In such cases, one of the relevant effects is that IMs can sell train slots that would be unsold. Therefore, in the non-project scenario missed revenues of train slots can be estimated, via:
	 The average value of a train slot for the IM, in €/train-km. The number of additional train-km's per year in the project scenario. This calculation would require a specific, in depth study for every line at every point in time, therefore assumptions will be made in terms of additional % of train-kms as compared to the starting situations (and will be subject to sensitivity analysis) A €/year figure is then derived.



	However, in the following deliverables of this study it is considered more realistic and prudential to assume that the analysed technological change per se is not enough to generate additional capacity
Involved players	The item represents a missed benefit for IMs.

15) Missed revenues of train operations

Cost category	Other differential impacts
Cost type	Opex
Cost block	Capacity
Description, cost factors and related	A second relevant effect of the increased capacity on a line is the additional economic value of train operations for the RU.
parameters	Such value can be estimated assuming, as its proxy, the average EBIT of similar railway services, in €/train-km.
	Considering, as above, the number of additional train-km's per year, the impact is quantified in €/year .
Involved players	The item represents a missed benefit for RUs.

16)Reduction of externalities

Cost category	Other differential impacts
Cost type	Opex
Cost block	Capacity
Description, cost factors and related parameters	A second effect of the capacity issues, if actual, derive by the fact that the additional train operations are used by passengers that are shifted from alternative transport modes, most typically the road.
	This implies that in the project scenario a more environmentally friendly mode of transport is used and less externalities are generated for the same transportation demand.
	In order to quantify the external effects, monetary parameters validated by the EC are used, covering the cost of air pollutions, climate change, noise, accidents, soil and water pollution in terms of €/pax-km , per each mode involved.
	Pax-km of additional demand per year is then estimated in order to obtain a €/year of reduction of externalities.
	However, as mentioned before, in the following deliverables it is considered more realistic and prudential to assume that the analysed technological change per se is not enough to generate additional capacity.

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Involved players The item represents a benefit for the community.

17)Accident costs

Cost category	Other differential impacts
Cost type	Орех
Cost block	Safety
Description, cost factors and related parameters	The highest safety level of commercial train operations under the ERTMS standard is expected to be reached in all considered scenarios.
	However, the initial assumption is prudential and assumes that GNSS positioning does not change the safety level of ERTMS as compared to the traditional balises.
Involved players	N.r.



5 CASE STUDIES DEFINITION

Three main cases are considered in term of line characteristics:

- 1. LOCAL LINE
- 2. REGIONAL LINE
- 3. MAIN LINE

A further differentiation will be applied as concerns the operational environment in a s:

- A) DENSE AREA
- B) MEDIUM AREA
- C) ISOLATED AREA

This differentiation is defined in order to take into account the different cost related to the physical balise maintenance that is supposed to be related to the localisation of the balise to be maintained. In fact, it is supposed that lines located in isolated areas are less accessible to the maintenance operators, implying a higher maintenance cost in term of longer trip from the maintenance depot to the localisation of the balise, and could also suffer of a higher breakdown rate.

Hence, 9 base case studies are identified.

	1 - LOCAL LINE	2 - REGIONAL LINE	3 - MAIN LINE
A - DENSE AREA	CBA 1A	CBA 2A	CBA 3A
B - MEDIUM AREA	CBA 1B	CBA 2B	CBA 3B
C - ISOLATED AREA	CBA 1C	CBA 2C	CBA 3C

Table 1: Case studies | CBAs definition

Then, a total of 9 CBA are performed, one for each case study, as follows:

CBA 1A:LOCAL LINE; DENSE AREA

CBA 1B:LOCAL LINE; MEDIUM AREA

CBA 1C: LOCAL LINE; ISOLATED AREA

CBA 2A: REGIONAL LINE; DENSE AREA

CBA 2B: REGIONAL LINE; MEDIUM AREA

CBA 2C: REGIONAL LINE; ISOLATED AREA

CBA 3A: MAIN LINE; DENSE AREA

CBA 3B: MAIN LINE; MEDIUM AREA

CBA 3C: MAIN LINE; ISOLATED AREA

The case studies differential characteristics are briefly presented in the following and derive from own estimations, whereas a proper quantification of all parameters will be defined in Deliverable D6.2.



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Parameter	Local	Regional	Main
% of traction units to be operated outside the project line	0%	10%	50%
Average number of unnecessary brakings per 1,000,000 train-km	46	46	46
Average speed of the train at the moment of the BTM-balise communication error	40 km/h	60 km/h	120 km/h
Unit cost of energy	65 €/MWh	65 €/MWh	65 €/MWh
Amount of energy needed to accelerate the train from 0 to the original speed	3,35 kWh	15,51 kWh	103,40 kWk
Average time wasted by train per BTM-balise communication error	1,01 min	1,53 min	2,67 min
Max speed allowed in SRM	30 km/h	30 km/h	30 km/h
Average acceleration of the concerned train(m/s2)	0,87 m/s²	0,6 m/s ²	0,55 m/s²
Average distance between train at wake-up and first balise	200 m	200 m	350 m
Max speed of the concerned line	120 Km/h	160 km/h	250 km/h
Additional % of train-km allowed by the elimination of the odometric error (working assumption)	5%	5%	5%
Value of time for train	9-11 €/min	14,5-16,5 €/min	23-27 €/min
Average value of train slots for the IM	1,5-2,5 €/train-km	2,75-3,75 €/train-km	6,25-7,25 €/train-km
Average added value of a train service for the RU (EBIT)	n.r. (subsidized services)	0,9 €/train-km	t.b.e.

Parameter	Isolated	Medium	Dense
Average distance of intervention location from maintenance centre	++	=	
Frequency of theft/vandalism on balises		=	++