D6.2 Cost-Benefit Analysis: Case studies

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CHANGE RECORDS

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08	21.11.2018	Minor corrections	C. Brenna (UBOC), L. Bazant (AZD)

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1 INTRODUCTION

1.1 EXECUTIVE SUMMARY

This deliverable deals with the economic evaluation of the project solution, i.e. GNSS based train positioning with ETRMS/ETCS, from the community point of view. The CBA applies the economic model at the case study level via UBOC's own assumptions on unit costs that are not disclosed in accordance with the Antitrust agreement of the STARS Consortium, and investigate the public convenience of the project, by means of techniques complying with the EC Guidelines; and producing aggregate indicators such as the project's Net Present Value, Internal Rate of Return (if relevant) and Benefit/Cost Ratio.

The analyses are applied to nine case studies and are completed by sensitivity analyses that investigate the impact of the variability of some of the initial assumptions concerning unit cost items or parameters that affect the overall comparison of costs and savings.

The analysis in this document and the calculation of figures have been performed based on the current understanding of the feasibility of a GNSS based positioning system on railways, which in turn is based on the virtual balise concept. Following projects, such as Shift^{2}Rail, are coming to the conclusion that additional items could have to be added to the base architecture considered here. Furthermore, the development of the technology could allow a decrease in some cost item or the use of cheaper innovative solutions for some modules. The consequence is that the results shown here are valid for the project architecture described in D6.1, and then the economical evaluation will have to be updated, and the Benefit/Cost ratio re-calculated in case of any change of it.

1.2 DEFINITIONS AND ACRONYMS

Acronym	Meaning
BCR	Benefit/Cost Ratio
BTM	Balise Transmission Module
CAPEX	CAPital Expenses
CBA	Cost Benefit Analysis
ENPV	Economic Net Present Value
ERTMS	European Rail Traffic Management System
ETCS	European Train Control System
GNSS	Global Navigation Satellite System
IM	Infrastructure Manager
OBU	On Boar Unit
OPEX	OPerating Expenses
PA	Public Administration

RU	Railway Undertaking
TAL-S	Track Area Local Server
TSS	Train Signaling Suppliers
TLC	Telecommunications
VBR	Virtual Balise Reader

2 OBJECTIVE AND METHODOLOGICAL APPROACH

The goal of the current deliverable is to assess the attractiveness, from a public point of view, on investing in a GNSS-based ETCS train positioning solution compared to the traditional, balise-based ETCS train positioning solution.

As described in the D6.1, two scenarios are considered:

- PROJECT SCENARIO: investment, implementation and running of an innovative GNSS-based ETCS technological solution on a define line;
- BASELINE SCENARIO: investment, implementation and running of the traditional and balise-based ETCS technological solution on a define line.

The CBA is then performed comparing cost and benefits arising in the project scenario against the ones arising in the baseline scenario from a public point of view.

The following figure highlights the rationale of the CBA methodology.

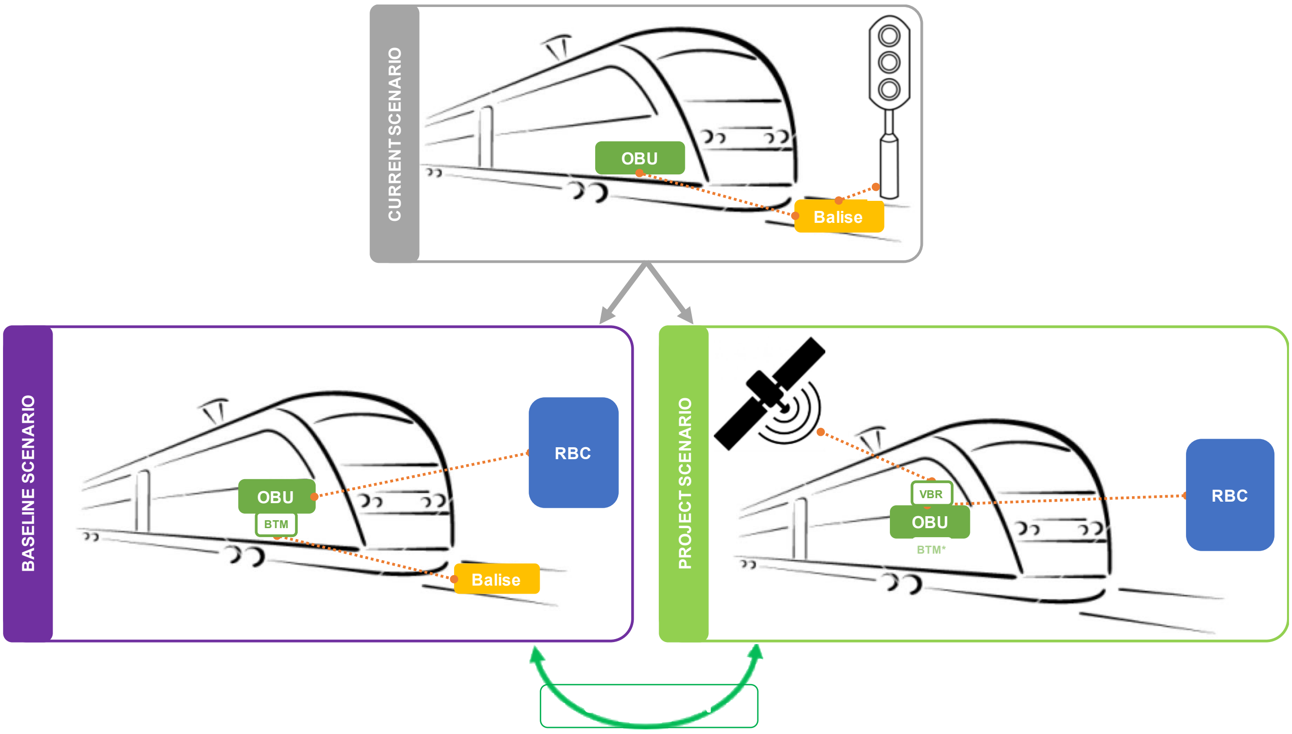

Table 1: CBA methodological approach

2.1 CASE STUDY DEFINITION

As described in D6.1, three main case study are considered in term of line characteristics:

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

The characteristics of these lines type are illustrated in detail in the following tables.

	LINE		VEHICLES			PRODUCTION		
	LineKm	TrackKm	Vehicles	% dedicated vehicles	TrKm/ Vehicle	Train/day	Train/y	Production/y (TrKm)
LOCAL	100	105	6	100%	200.000	28	10.220	1.022.000
REGIONAL	100	190	13	90%	250.000	80	29.200	2.920.000
MAIN	100	200	24	50%	350.000	144	52.560	5.256.000

	LINE		BALISES				
	LineKm	TrackKm	Balise/Km	TOT Balises	% virtualizable balises	Phisical balises	Virtual balises
LOCAL	100	105	2,5	263	100%	-	263
REGIONAL	100	190	3,0	570	90%	57	513
MAIN	100	200	3,0	600	75%	150	450

Table 2: Type of line characteristics

Possible real example of each of the described theoretical case study line could be as follows:

1. LOCAL LINE: Čížčenice - Volary [CZ]; Avezzano - Roccasecca [IT]; Schwäbisch Hall - Stuttgart [DE]; Bischofshofen - Selzthal [AT].
2. REGIONAL LINE: Parma - La Spezia [IT]; Cagliari - San Gavino [IT]; Wroklav - Poznan [PL].
3. MAIN LINE: Milano - Bologna [IT]; Wien - Linz [AT]; Lyon - Dijon [FR]; Koln - Frankfurt [DE].

The lines differ for:

- Share of double track length: LOCAL LINE is only 5% double track and 95% single track; REGIONAL LINE is 90% double track and 10% single track; MAIN LINEis 100% double track.
- Share of dedicated vehicles, that is an inverse proxy of the interconnection of the line in analysis with the rest of the railway network: the LOCAL LINE is considered as “isolated line”, that is, the service on this line is operated by a dedicated fleet and no other services are operated on this line; on the REGIONAL LINE 90% of the services are operated by a dedicated fleet operating only on the line in analysis, but there are also a remaining 10% of services operated by fleets operating on other lines of the network too; on the MAIN LINE, 50% of the services are operated by a dedicated fleet operating only on the line in analysis, and the other half are operated by fleets operating on other lines of the network too.
- Production: on the LOCAL LINE 28 services a day are operated, that is compatible with an hourly service operated for 14 hours a day; on the REGIONAL LINE 80 services a day are operated, that is compatible with a service with 30’ frequency and one with 120’ frequency, both operated for 16 hours a day; on the MAIN LINE 144 services a day are operated, that is compatible with a service with 15’ frequency operated for 18 hours a day.
- Number of virtualizable balises: on the LOCAL LINE all the balises are assumed to be managed as virtual due to the simplicity of the line and the absence of long tunnel or GNSS under-coverage

areas; on the REGIONAL LINE 90% of balises are assumed to be managed as virtual; on the MAIN LINE 75% of balises are assumed to be managed as virtual due to more complexity of the network and the presence of more interconnections and junctions.

As described in D6.1, further differentiation is applied as concerns the operational environment in:

4. DENSE AREA;
5. MEDIUM AREA;
6. ISOLATED AREA.

The type of location of the line imply differences in the maintenance cost of the physical balises, as per following model (with values of the base case; sensible figures are not disclosed):

Step	Factor	Dense	Medium	Isolated
A	Number of technicians	2		
B	Individual cost per hour (€/hour)	29		
C	**Average distance of intervention (hours)**	**1.5**	**5**	**10**
D=2*C+1	Mean time to repair	3	11	21
E	Cost of balise (provision and storage)	*n.d.*		
F = (A*B*D)+E	Cost per intervention	*n.d.*		
G	Mean Time Between Failures (hours)	*n.d.*		
H	No. of failures per year per balise	*n.d.*		
I	**Interventions due to vandalism/theft as % of *H***	***50%***		
J = H*(1+J)	Tot interventions per year per balise	*n.d.*		
K = F*J	Maintenance cost per year per balise (€)	22.8	28.6	36.3

Table 3: Balise maintenance cost structure

The parameters defining the case studies (including the bolded elements in the above table) are in most cases (cfr cap. 6) subject to sensitivity analysis in order to account for the possible variations of their characteristics.

Combining these 3 + 3 lines different characterisation, 9 case studies can be analysed, as summarised in the following table.

	1 - LOCAL LINE	2 - REGIONAL LINE	3 - MAIN LINE
A - DENSE AREA	CBA **LD**	CBA **RD**	CBA **MD**
B - MEDIUM AREA	CBA **LM**	CBA **RM**	CBA **MM**
C - ISOLATED AREA	CBA **LI**	CBA **RI**	CBA **MI**

Table 4: Case studies definition

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

- CBA LD: LOCAL LINE; DENSE AREA
- CBA LM: LOCAL LINE; MEDIUM AREA
- CBA LI: LOCAL LINE; ISOLATED AREA
- CBA RD: REGIONAL LINE; DENSE AREA
- CBA RM: REGIONAL LINE; MEDIUM AREA
- CBA RI: REGIONAL LINE; ISOLATED AREA
- CBA MD: MAIN LINE; DENSE AREA
- CBA MM: MAIN LINE; MEDIUM AREA

- CBA MI: MAIN LINE; ISOLATED AREA

The variables that the sensitivity analysis focuses on (cfr. Cap. 6) are listed here:

VARIABLE	AFFECTED COST ITEM
% of dedicated traction units	*Investment cost in on board equipment*
Kms of network covered by one RBC	*Ground investment cost*
% of physical balises needed in the project scenario	*Ground investment cost*
Average distance of intervention location from maintenance centre in the case of balise malfunction	*Operating costs of balises*
Average impact of vandalism and/or theft	*Operating costs of balises*
Average distance between train at wake-up and first balise	*Time costs (start of mission)*

Table 5: Variables representing parameters

Variables representing costs:

- Unit cost of TAL-Server
- Additional unit cost of OBU in the project scenario
- Unit cost of balise
- Unit cost of track database

Further benefits could arise in the practice, mainly related to the RU, but they will be not considered in this analysis since marginal or unable to quantify, as the one that follow:

- Increase of the availability of the onboard equipment because the reduction of unreliability of signalling system due to failures of balises, meaning less maintenance costs for this system;
- Reduction of problems related on-board odometry in the condition of low adhesion rail/wheel. Meaning saving in energy and time for unnecessary braking and savings for time spent at starts of mission;
- Increase of the capacity of the line due to the improvement of train position accuracy.

3 THE CBA FOR LOCAL LINE CASE STUDIES

This paragraph shows the cost benefit analysis for each of the 3 case studies related to local line, with respect to the dense, medium and isolated area.

The following table summarizes the characteristics of the local line, as described in paragraph 2.1.

LineKm	100
TrackKm	105
Vehicles	6
% non-dedicated vehicles	100%
TrKm/ Vehicle	200.000
Train/day	28
Train/y	10.220
Production/y (TrKm)	1.022.000
Balise/Km	2,5
TOT Balises	-
% virtualizable balises	100%
Phisical balises	-
Virtual balises	-

Table 6: Local line characteristics

The tables in the following sections summarise the results of the cost analyses in the time horizon; it is important to underline again that **the elaborations only include the differential figures between baseline and project scenario. Null values in the tables imply that the cost figures for the concerned items are equal in both scenarios.**

3.1 CASE STUDY LD | LOCAL LINE; DENSE AREA

The following table summarizes the aggregate data of the ENPV and of the cumulated flow related to the implementation costs in the baseline scenario, that is in the case a traditional ERTMS L2 technological solution is chosen and implemented.

LOCAL LINE; DENSE AREA - BASELINE SCENARIO	ENPV	Cumulated flow
CAPEX GROUND	*421.075*	*506.048*
ETCS planning, installation, interfacing	-	-
RBC	-	-
TAL-Server	-	-
Track Database	-	-
Digitalization campaign	-	-
Physical balises	421.075	506.048
CAPEX BOARD	*155.829*	*165.240*
ETCS	-	-
BTM	155.829	165.240
VBR	-	-
OPEX GROUND	*78.942*	*148.132*
RBC	-	-
TAL-Server	-	-
Recalibration of track database	-	-
Physical balises Dense area	78.942	148.132
Physical balises Medium area	-	-
Physical balises Isolated area	-	-
OPEX BOARD	*144.175*	*270.540*
OBU modules	144.175	270.540
OTHER OPEX	-	-
Energy for braking and slowdown	-	-
Time wasted for braking and slowdowr	-	-
Time cost for start of mission	-	-
Missed revenues on train slots for IM	-	-
Missed revenues on train slots for RU	-	-
TOTAL Baseline	**800.021**	**1.089.960**

Table 7: Case study LD | Baseline scenario

The following table summarizes the aggregate data of the ENPV and of the cumulated flow related to the implementation costs in the project scenario, that is in the case an innovative ERTMS L2 technological solution, in which the odometer measurement is corrected by the position data received by virtual balises instead of physical balises, is chosen and implemented.

LOCAL LINE; DENSE AREA - PROJECT SCENARIO	ENPV	Cumulated flow
CAPEX GROUND	*75.991*	*80.580*
ETCS planning, installation, interfacing	-	-
RBC	-	-
TAL-Server	21.643	22.950
Track Database	21.643	22.950
Digitalization campaign	32.705	34.680
Physical balises	-	-
CAPEX BOARD	*155.829*	*165.240*
ETCS	-	-
BTM	-	-
VBR	155.829	165.240
OPEX GROUND	*3.337*	*6.263*
RBC	-	-
TAL-Server	3.337	6.263
Recalibration of track database	-	-
Physical balises Dense area	-	-
Physical balises Medium area	-	-
Physical balises Isolated area	-	-
OPEX BOARD	*144.175*	*270.540*
OBU modules	144.175	270.540
OTHER OPEX	*-*	*-*
Energy for braking and slowdown	-	-
Time wasted for braking and slowdowr	-	-
Time cost for start of mission	-	-
Missed revenues on train slots for IM	-	-
Missed revenues on train slots for RU	-	-
TOTAL Project	**379.332**	**522.623**

Table 8: Case study LD | Project scenario

The following table summarizes the differential results related to the implementation of the project scenario with the respect to the implementation of the baseline scenario in the case study in analysis. The differential impacts are highlighted by cost category (CAPEX; OPEX and ground; board), then total ENPV, cumulated flow, and BCR are shown.

LOCAL; DENSE — TOTAL	ENPV	Cumulated flow
∂ CAPEX GROUND	345.084	425.468
∂ CAPEX BOARD	-	-
∂ OPEX GROUND	75.604	141.870
∂ OPEX BOARD	-	-
∂ OTHER OPEX	-	-
TOTAL DIFFERENTIAL RESULT	**420.689**	**567.337**
BCR	**2,11**	

Table 9: Case study LD | Differential impact

The CBA of the case study related to a local line in a dense area highlights a positive differential impact of the implementation costs envisaged in the project scenario with respect to the ones envisaged in the baseline scenario, with a positive ENPV of 421 k€ and 567 k€ of cumulated flow.

As expected, the differential results in the sub-categories of cost highlight:

- a positive impact (that is a saving in the project scenario with respect to the baseline scenario) for what concerns the ground side, due to the fact that the project scenario does not envisage any investment nor maintenance cost related to physical balises;
- no impact for what concerns the on-board side, due to the fact that the BTM and VBR investment and maintenance cost are first assumed to be equal;
- no impact for what concerns other OPEX, as prudentially assumed in D6.1.

The overall BCR is equal to 2.11, bigger than the minimum acceptable value of 1, that is the cut-off value used to decide whether to carry out the investment envisaged in the project scenario or not.

The CBA related to local line in dense area, then, shows the public convenience of choosing an ERTMS innovative and GNSS-based solution with the respect to the traditional balise-based technological solution.

3.2 CASE STUDY LM | LOCAL LINE; MEDIUM AREA

The following table summarizes the aggregate data of the ENPV and of the cumulated flow related to the implementation costs in the baseline scenario, that is in the case a traditional ERTMS L2 technological solution is chosen and implemented.

LOCAL LINE; MEDIUM AREA - BASELINE SCENARIO		ENPV	Cumulated flow
	CAPEX GROUND	*421.075*	*506.048*
	ETCS planning, installation, interfacing	-	-
	RBC	-	-
	TAL-Server	-	-
	Track Database	-	-
	Digitalization campaign	-	-
	Physical balises	421.075	506.048
	CAPEX BOARD	*155.829*	*165.240*
	ETCS	-	-
	BTM	155.829	165.240
	VBR	-	-
	OPEX GROUND	*100.359*	*188.320*
	RBC	-	-
	TAL-Server	-	-
	Recalibration of track database	-	-
	Physical balises Dense area	-	-
	Physical balises Medium area	100.359	188.320
	Physical balises Isolated area	-	-
	OPEX BOARD	*144.175*	*270.540*
	OBU modules	144.175	270.540
	OTHER OPEX	*-*	*-*
	Energy for braking and slowdown	-	-
	Time wasted for braking and slowdowr	-	-
	Time cost for start of mission	-	-
	Missed revenues on train slots for IM	-	-
	Missed revenues on train slots for RU	-	-
	TOTAL Baseline	**821.437**	**1.130.147**

Table 10: Case study LM | Baseline scenario

The following table summarizes the aggregate data of the ENPV and of the cumulated flow related to the implementation costs in the project scenario, that is in the case an innovative ERTMS L2 technological solution, in which the odometer measurement is corrected by the position data received by virtual balises instead of physical balises, is chosen and implemented.

LOCAL LINE; MEDIUM AREA - PROJECT SCENARIO	ENPV	Cumulated flow
CAPEX GROUND	*75.991*	*80.580*
ETCS planning, installation, interfacing	-	-
RBC	-	-
TAL-Server	21.643	22.950
Track Database	21.643	22.950
Digitalization campaign	32.705	34.680
Physical balises	-	-
CAPEX BOARD	*155.829*	*165.240*
ETCS	-	-
BTM	-	-
VBR	155.829	165.240
OPEX GROUND	*3.337*	*6.263*
RBC	-	-
TAL-Server	3.337	6.263
Recalibration of track database	-	-
Physical balises Dense area	-	-
Physical balises Medium area	-	-
Physical balises Isolated area	-	-
OPEX BOARD	*144.175*	*270.540*
OBU modules	144.175	270.540
OTHER OPEX	*-*	*-*
Energy for braking and slowdown	-	-
Time wasted for braking and slowdowr	-	-
Time cost for start of mission	-	-
Missed revenues on train slots for IM	-	-
Missed revenues on train slots for RU	-	-
TOTAL Project	**379.332**	**522.623**

Table 11: Case study LM | Project scenario

The following table summarizes the differential results related to the implementation of the project scenario with the respect to the implementation of the baseline scenario in the case study in analysis. The differential impacts are highlighted by cost category (CAPEX; OPEX and ground; board), then total ENPV, cumulated flow and BCR are shown.

TOTAL – LOCAL; MEDIUM	ENPV	Cumulated flow
∂ CAPEX GROUND	345.084	425.468
∂ CAPEX BOARD	-	-
∂ OPEX GROUND	97.021	182.057
∂ OPEX BOARD	-	-
∂ OTHER OPEX	-	-
TOTAL DIFFERENTIAL RESULT	**442.105**	**607.525**
BCR	**2,17**	

Table 12: Case study LM | Differential impact

The CBA of the case study related to a local line in a medium area highlights a positive differential impact of the implementation costs envisaged in the project scenario with respect to the ones envisaged in the baseline scenario, with a positive ENPV of 442 k€ and 607 k€ of cumulated flow.

As expected, the differential results in the sub-categories of cost highlight:

- a positive impact (that is a saving in the project scenario with respect to the baseline scenario) for what concerns the ground side, due to the fact that the project scenario does not envisage any investment nor maintenance cost related to physical balises;
- no impact for what concerns the on-board side, due to the fact that the BTM and VBR investment and maintenance cost are first assumed to be equal;
- no impact for what concerns other OPEX, as prudentially assumed in D6.1.

The overall BCR is equal to 2.17, bigger than the minimum acceptable value of 1, that is the cut-off value used to decide whether to carry out the investment envisaged in the project scenario or not.

The CBA related to local line in medium area, then, shows the public convenience of choosing an ERTMS innovative and GNSS-based solution with the respect to the traditional balise-based technological solution.

3.3 CASE STUDY LI | LOCAL LINE; ISOLATED AREA

The following table summarizes the aggregate data of the ENPV and of the cumulated flow related to the implementation costs in the baseline scenario, that is in the case a traditional ERTMS L2 technological solution is chosen and implemented.

LOCAL LINE; ISOLATED AREA - BASELINE SCENARIO	ENPV	Cumulated flow
CAPEX GROUND	*421.075*	*506.048*
ETCS planning, installation, interfacing	-	-
RBC	-	-
TAL-Server	-	-
Track Database	-	-
Digitalization campaign	-	-
Physical balises	421.075	506.048
CAPEX BOARD	*155.829*	*165.240*
ETCS	-	-
BTM	155.829	165.240
VBR	-	-
OPEX GROUND	*127.129*	*238.555*
RBC	-	-
TAL-Server	-	-
Recalibration of track database	-	-
Physical balises Dense area	-	-
Physical balises Medium area	-	-
Physical balises Isolated area	127.129	238.555
OPEX BOARD	*144.175*	*270.540*
OBU modules	144.175	270.540
OTHER OPEX	*-*	*-*
Energy for braking and slowdown	-	-
Time wasted for braking and slowdowr	-	-
Time cost for start of mission	-	-
Missed revenues on train slots for IM	-	-
Missed revenues on train slots for RU	-	-
TOTAL Baseline	**848.208**	**1.180.382**

Table 13: Case study LI | Baseline scenario

The following table summarizes the aggregate data of the ENPV and of the cumulated flow related to the implementation costs in the project scenario, that is in the case an innovative ERTMS L2 technological solution, in which the odometer measurement is corrected by the position data received by virtual balises instead of physical balises, is chosen and implemented.

LOCAL LINE; ISOLATED AREA - PROJECT SCENARIO		ENPV	Cumulated flow
	CAPEX GROUND	75.991	80.580
	ETCS planning, installation, interfacing	-	-
	RBC	-	-
	TAL-Server	21.643	22.950
	Track Database	21.643	22.950
	Digitalization campaign	32.705	34.680
	EGNOS	-	-
	Physical balises	-	-
	CAPEX BOARD	155.829	165.240
	ETCS module	-	-
	BTM module	-	-
	VBR module	155.829	165.240
	OPEX GROUND	3.337	6.263
	RBC	-	-
	TAL-Server	3.337	6.263
	Recalibration of track database	-	-
	Physical balises Dense area	-	-
	Physical balises Medium area	-	-
	Physical balises Isolated area	-	-
	OPEX BOARD	144.175	270.540
	OBU modules	144.175	270.540
	EGNOS	-	-
	OTHER OPEX	-	-
	Energy for braking and slowdown	-	-
	Time wasted for braking and slowdowr	-	-
	Time cost for start of mission	-	-
	Missed revenues on train slots for IM	-	-
	Missed revenues on train slots for RU	-	-
	TOTAL Project	**379.332**	**522.623**

Table 14: Case study LI | Project scenario

The following table summarizes the differential results related to the implementation of the project scenario with the respect to the implementation of the baseline scenario in the case study in analysis. The differential impacts are highlighted by cost category (CAPEX; OPEX and ground; board), then total ENPV, cumulated flow and BCR are shown.

LOCAL; ISOLATED	TOTAL		
		ENPV	Cumulated flow
	∂ CAPEX GROUND	345.084	425.468
	∂ CAPEX BOARD	-	-
	∂ OPEX GROUND	123.792	232.292
	∂ OPEX BOARD	-	-
	∂ OTHER OPEX	-	-
	TOTAL DIFFERENTIAL RESULT	**468.876**	**657.760**
	ERR	**n.c.**	
	BCR	**2,24**	

Table 15: Case study LI | Differential impact

The CBA of the case study related to a local line in an isolated area highlights a positive differential impact of the implementation costs envisaged in the project scenario with respect to the ones envisaged in the baseline scenario, with a positive ENPV of 469 k€ and 658 k€ of cumulated flow.

As expected, the differential results in the sub-categories of cost highlight:

- a positive impact (that is a saving in the project scenario with respect to the baseline scenario) for what concerns the ground side, due to the fact that the project scenario does not envisage any investment nor maintenance cost related to physical balises;
- no impact for what concerns the on-board side, due to the fact that the BTM and VBR investment and maintenance cost are assumed to be the same;
- no impact for what concerns other OPEX, as prudentially assumed in D6.1.

The overall BCR is equal to 2.24, bigger than the minimum acceptable value of 1, that is the cut-off value used to decide whether to carry out the investment envisaged in the project scenario or not.

The CBA related to local line in isolated area, then, shows the public convenience of choosing an ERTMS innovative and GNSS-based solution with the respect to the traditional balise-based technological solution.

4 THE CBA FOR REGIONAL LINE CASE STUDIES

This paragraph shows the cost benefit analysis for each of the 3 case studies related to regional line, then to respect of the dense, medium and isolated area.

The following table summarizes the characteristics of the regional line, as described in paragraph 2.1.

LineKm	100
TrackKm	190
Vehicles	13
% non-dedicated vehicles	90%
TrKm/ Vehicle	250.000
Train/day	80
Train/y	29.200
Production/y (TrKm)	2.920.000
Balise/Km	3,0
TOT Balises	-
% virtualizable balises	90%
Phisical balises	-
Virtual balises	-

Table 16: Regional line characteristics

4.1 CASE STUDY RD | REGIONAL LINE; DENSE AREA

The following table summarizes the aggregate data of the ENPV and of the cumulated flow related to the implementation costs in the baseline scenario, that is in the case a traditional ERTMS L2 technological solution is chosen and implemented.

REGIONAL LINE; DENSE AREA - BASELINE SCENARIO		ENPV	Cumulated flow
	CAPEX GROUND	*914.334*	*1.098.846*
	ETCS planning, installation, interfacing	-	-
	RBC	-	-
	TAL-Server	-	-
	Track Database	-	-
	Digitalization campaign	-	-
	Physical balises	914.334	1.098.846
	CAPEX BOARD	*342.824*	*363.528*
	ETCS	-	-
	BTM	342.824	363.528
	VBR	-	-
	OPEX GROUND	*171.417*	*321.658*
	RBC	-	-
	TAL-Server	-	-
	Recalibration of track database	-	-
	Physical balises Dense area	171.417	321.658
	Physical balises Medium area	-	-
	Physical balises Isolated area	-	-
	OPEX BOARD	*317.185*	*595.188*
	OBU modules	317.185	595.188
	OTHER OPEX	-	-
	Energy for braking and slowdown	-	-
	Time wasted for braking and slowdowr	-	-
	Time cost for start of mission	-	-
	Missed revenues on train slots for IM	-	-
	Missed revenues on train slots for RU	-	-
	TOTAL Baseline	**1.745.760**	**2.379.220**

Table 17: Case study RD | Baseline scenario

The following table summarizes the aggregate data of the ENPV and of the cumulated flow related to the implementation costs in the project scenario, that is in the case an innovative ERTMS L2 technological solution, in which the odometer measurement is corrected by the position data received by virtual balises instead of physical balises, is chosen and implemented. An integrated platform that provides both BTM and VBR functions and a more accurate and lower estimation of TrackDB and Digitalization CAPEX costs would lead to further economic advantages.

REGIONAL LINE; DENSE AREA - PROJECT SCENARIO	ENPV	Cumulated flow
CAPEX GROUND	*167.424*	*190.465*
ETCS planning, installation, interfacing	-	-
RBC	-	-
TAL-Server	21.643	22.950
Track Database	21.643	22.950
Digitalization campaign	32.705	34.680
Physical balises	91.433	109.885
CAPEX BOARD	*685.648*	*727.056*
ETCS	-	-
BTM	342.824	363.528
VBR	342.824	363.528
OPEX GROUND	*20.479*	*38.428*
RBC	-	-
TAL-Server	3.337	6.263
Recalibration of track database	-	-
Physical balises Dense area	17.142	32.166
Physical balises Medium area	-	-
Physical balises Isolated area	-	-
OPEX BOARD	*634.369*	*1.190.376*
OBU modules	634.369	1.190.376
OTHER OPEX	*-*	*-*
Energy for braking and slowdown	-	-
Time wasted for braking and slowdowr	-	-
Time cost for start of mission	-	-
Missed revenues on train slots for IM	-	-
Missed revenues on train slots for RU	-	-
TOTAL Project	**1.507.921**	**2.146.325**

Table 18: Case study RD | Project scenario

The following table summarizes the differential results related to the implementation of the project scenario with the respect to the implementation of the baseline scenario in the case study in analysis. The differential impacts are highlighted by cost category (CAPEX; OPEX and ground; board), then total ENPV, cumulated flow and BCR are shown.

REGIONAL; DENSE — TOTAL	ENPV	Cumulated flow
∂ CAPEX GROUND	746.910	908.381
∂ CAPEX BOARD	- 342.824	- 363.528
∂ OPEX GRUND	150.938	283.230
∂ OPEX BOARD	- 317.185	- 595.188
∂ OTHER OPEX	-	-
TOTAL DIFFERENTIAL RESULT	**237.839**	**232.895**
BCR	**1,16**	

Table 19: Case study RD | Differential impact

The CBA of the case study related to a regional line in a dense area highlights a positive differential impact of the implementation costs envisaged in the project scenario with respect to the ones envisaged in the baseline scenario, with a positive ENPV of 237 k€ and 233 k€ of cumulated flow.

The differential results in the sub-categories of cost highlight:

- a positive impact (that is a saving in the project scenario with respect to the baseline scenario) for what concerns the ground side, due to the fact that the project scenario envisages a reduced number of physical balises;
- a negative impact (that is a loss in the project scenario with respect to the baseline scenario) for what concerns the on-board side, due to the fact that the project scenario envisages further equipment (the VBR) and the related maintenance cost;
- no impact for what concerns other OPEX, as prudentially assumed in D6.1.

The negative impact for what concerns the on-board side is fully compensated by the positive one for what concerns the ground side, then the total impact results positive.

The overall BCR is equal to 1.16, bigger than the minimum acceptable value of 1, that is the cut-off value used to decide whether to carry out the investment envisaged in the project scenario or not. The development of the technology, for example allowing the use of an integrated platform for both the BTM and the VBR functions or a cheaper Track-DB or digitalization CAPEX costs would obviously lead to a better BCR than computed above.

The CBA related to regional line in dense area, then, shows the public convenience of choosing an ERTMS innovative and GNSS-based solution with the respect to the traditional balise-based technological solution.

4.2 CASE STUDY RM | REGIONAL LINE; MEDIUM AREA

The following table summarizes the aggregate data of the ENPV and of the cumulated flow related to the implementation costs in the baseline scenario, that is in the case a traditional ERTMS L2 technological solution is chosen and implemented.

		ENPV	Cumulated flow
REGIONAL LINE; MEDIUM AREA - BASELINE SCENARIO	**CAPEX GROUND**	*914.334*	*1.098.846*
	ETCS planning, installation, interfacing	-	-
	RBC	-	-
	TAL-Server	-	-
	Track Database	-	-
	Digitalization campaign	-	-
	Physical balises	914.334	1.098.846
	CAPEX BOARD	*342.824*	*363.528*
	ETCS	-	-
	BTM	342.824	363.528
	VBR	-	-
	OPEX GROUND	*217.921*	*408.923*
	RBC	-	-
	TAL-Server	-	-
	Recalibration of track database	-	-
	Physical balises Dense area	-	-
	Physical balises Medium area	217.921	408.923
	Physical balises Isolated area	-	-
	OPEX BOARD	*317.185*	*595.188*
	OBU modules	317.185	595.188
	OTHER OPEX	*-*	*-*
	Energy for braking and slowdown	-	-
	Time wasted for braking and slowdowr	-	-
	Time cost for start of mission	-	-
	Missed revenues on train slots for IM	-	-
	Missed revenues on train slots for RU	-	-
	TOTAL Baseline	**1.792.264**	**2.466.485**

Table 20: Case study RM | Baseline scenario

The following table summarizes the aggregate data of the ENPV and of the cumulated flow related to the implementation costs in the project scenario, that is in the case an innovative ERTMS L2 technological solution, in which the odometer measurement is corrected by the position data received by virtual balises instead of physical balises, is chosen and implemented.

REGIONAL LINE; MEDIUM AREA - PROJECT SCENARIO	ENPV	Cumulated flow
CAPEX GROUND	167.424	190.465
ETCS planning, installation, interfacing	-	-
RBC	-	-
TAL-Server	21.643	22.950
Track Database	21.643	22.950
Digitalization campaign	32.705	34.680
Physical balises	91.433	109.885
CAPEX BOARD	685.648	727.056
ETCS	-	-
BTM	342.824	363.528
VBR	342.824	363.528
OPEX GROUND	25.130	47.155
RBC	-	-
TAL-Server	3.337	6.263
Recalibration of track database	-	-
Physical balises Dense area	-	-
Physical balises Medium area	21.792	40.892
Physical balises Isolated area	-	-
OPEX BOARD	634.369	1.190.376
OBU modules	634.369	1.190.376
OTHER OPEX	-	-
Energy for braking and slowdown	-	-
Time wasted for braking and slowdowr	-	-
Time cost for start of mission	-	-
Missed revenues on train slots for IM	-	-
Missed revenues on train slots for RU	-	-
TOTAL Project	**1.512.571**	**2.155.051**

Table 21: Case study RM | Project scenario

The following table summarizes the differential results related to the implementation of the project scenario with the respect to the implementation of the baseline scenario in the case study in analysis. The differential impacts are highlighted by cost category (CAPEX; OPEX and ground; board), then total ENPV, cumulated flow and BCR are shown.

REGIONAL; MEDIUM — TOTAL	ENPV	Cumulated flow
∂ CAPEX GROUND	746.910	908.381
∂ CAPEX BOARD	- 342.824	- 363.528
∂ OPEX GRUND	192.792	361.768
∂ OPEX BOARD	- 317.185	- 595.188
∂ OTHER OPEX	-	-
TOTAL DIFFERENTIAL RESULT	**279.693**	**311.434**
BCR	**1,18**	

Table 22: Case study RM | Differential impact

The CBA of the case study related to a local line in a medium area highlights a positive differential impact of the implementation costs envisaged in the project scenario with respect to the ones envisaged in the baseline scenario, with a positive ENPV of 279 k€ and 311 k€ of cumulated flow.

The differential results in the sub-categories of cost highlight:

- a positive impact (that is a saving in the project scenario with respect to the baseline scenario) for what concerns the ground side, due to the fact that the project scenario envisages a reduced number of physical balises;
- a negative impact (that is a loss in the project scenario with respect to the baseline scenario) for what concerns the on-board side, due to the fact that the project scenario envisages further equipment (the VBR) and the related maintenance cost;
- no impact for what concerns other OPEX, as prudentially assumed in D6.1.

The negative impact for what concerns the on-board side is fully compensated by the positive one for what concerns the ground side, then the total impact results positive.

The overall BCR is equal to 1,60, bigger than the minimum acceptable value of 1, that is the cut-off value used to decide whether to carry out the investment envisaged in the project scenario or not. The development of the technology, for example allowing the use of an integrated platform for both the BTM and the VBR functions or a cheaper Track-DB or digitalization CAPEX costs would obviously lead to a better BCR than computed above.

The CBA related to regional line in medium area, then, shows the convenience of choosing an ERTMS innovative and GNSS-based solution with the respect to the traditional balise-based technological solution.

4.3 CASE STUDY RI | REGIONAL LINE; ISOLATED AREA

The following table summarizes the aggregate data of the ENPV and of the cumulated flow related to the implementation costs in the baseline scenario, that is in the case a traditional ERTMS L2 technological solution is chosen and implemented.

REGIONAL LINE; ISOLATED AREA - BASELINE SCENARIO	ENPV	Cumulated flow
CAPEX GROUND	*914.334*	*1.098.846*
ETCS planning, installation, interfacing	-	-
RBC	-	-
TAL-Server	-	-
Track Database	-	-
Digitalization campaign	-	-
Physical balises	914.334	1.098.846
CAPEX BOARD	*342.824*	*363.528*
ETCS	-	-
BTM	342.824	363.528
VBR	-	-
OPEX GROUND	*276.052*	*518.004*
RBC	-	-
TAL-Server	-	-
Recalibration of track database	-	-
Physical balises Dense area	-	-
Physical balises Medium area	-	-
Physical balises Isolated area	276.052	518.004
OPEX BOARD	*317.185*	*595.188*
OBU modules	317.185	595.188
OTHER OPEX	*-*	*-*
Energy for braking and slowdown	-	-
Time wasted for braking and slowdowr	-	-
Time cost for start of mission	-	-
Missed revenues on train slots for IM	-	-
Missed revenues on train slots for RU	-	-
TOTAL Baseline	**1.850.395**	**2.575.566**

Table 23: Case study RI | Baseline scenario

The following table summarizes the aggregate data of the ENPV and of the cumulated flow related to the implementation costs in the project scenario, that is in the case an innovative ERTMS L2 technological solution, in which the odometer measurement is corrected by the position data received by virtual balises instead of physical balises, is chosen and implemented.

REGIONAL LINE; ISOLATED AREA - PROJECT SCENARIO	ENPV	Cumulated flow
CAPEX GROUND	*167.424*	*190.465*
ETCS planning, installation, interfacing	-	-
RBC	-	-
TAL-Server	21.643	22.950
Track Database	21.643	22.950
Digitalization campaign	32.705	34.680
Physical balises	91.433	109.885
CAPEX BOARD	*685.648*	*727.056*
ETCS	-	-
BTM	342.824	363.528
VBR	342.824	363.528
OPEX GROUND	*30.943*	*58.063*
RBC	-	-
TAL-Server	3.337	6.263
Recalibration of track database	-	-
Physical balises Dense area	-	-
Physical balises Medium area	-	-
Physical balises Isolated area	27.605	51.800
OPEX BOARD	*634.369*	*1.190.376*
OBU modules	634.369	1.190.376
OTHER OPEX	*-*	*-*
Energy for braking and slowdown	-	-
Time wasted for braking and slowdowr	-	-
Time cost for start of mission	-	-
Missed revenues on train slots for IM	-	-
Missed revenues on train slots for RU	-	-
TOTAL Project	**1.518.385**	**2.165.960**

Table 24: Case study RI | Project scenario

The following table summarizes the differential results related to the implementation of the project scenario with the respect to the implementation of the baseline scenario in the case study in analysis. The differential impacts are highlighted by cost category (CAPEX; OPEX and ground; board), then total ENPV, cumulated flow and BCR are shown.

REGIONAL; ISOLATED — TOTAL	ENPV	Cumulated flow
∂ CAPEX GROUND	746.910	908.381
∂ CAPEX BOARD	- 342.824	- 363.528
∂ OPEX GROUND	245.110	459.941
∂ OPEX BOARD	- 317.185	- 595.188
∂ OTHER OPEX	-	-
TOTAL DIFFERENTIAL RESULT	**332.011**	**409.607**
BCR	**1,22**	

Table 25: Case study RI | Differential impact

The CBA of the case study related to a local line in an isolated area highlights a positive differential impact of the implementation costs envisaged in the project scenario with respect to the ones envisaged in the baseline scenario, with a positive ENPV of 332 k€ and 409 k€ of cumulated flow.

As expected, the differential results in the sub-categories of cost highlight:

- a positive impact (that is a saving in the project scenario with respect to the baseline scenario) for what concerns the ground side, due to the fact that the project scenario envisages a reduced number of physical balises;
- a negative impact (that is a loss in the project scenario with respect to the baseline scenario) for what concerns the on-board side, due to the fact that the project scenario envisages further equipment (the VBR) and the related maintenance cost;
- no impact for what concerns other OPEX, as prudentially assumed in D6.1.

The negative impact for what concerns the on-board side is fully compensated by the positive one for what concerns the ground side, then the total impact results positive.

The overall BCR is equal to 1,22, bigger than the minimum acceptable value of 1, that is the cut-off value used to decide whether to carry out the investment envisaged in the project scenario or not. The development of the technology, for example allowing the use of an integrated platform for both the BTM and the VBR functions or a cheaper Track-DB or digitalization CAPEX costs would obviously lead to a better BCR than computed above.

The CBA related to regional line in isolated area, then, shows the convenience of choosing an ERTMS innovative and GNSS-based solution with the respect to the traditional balise-based technological solution.

5 THE CBA FOR MAIN LINE CASE STUDIES

This paragraph shows the cost benefit analysis for each of the 3 case studies related to main line, then to respect of the dense, medium and isolated area.

The following table summarizes the characteristics of the main line, as described in paragraph 2.1.

LineKm	100
TrackKm	200
Vehicles	24
% non-dedicated vehicles	50%
TrKm/ Vehicle	350.000
Train/day	144
Train/y	52.560
Production/y (TrKm)	5.256.000
Balise/Km	3,0
TOT Balises	-
% virtualizable balises	75%
Phisical balises	-
Virtual balises	-

Table 26: Main line characteristics

The following paragraphs highlight the aggregated value of the CBAs.

5.1 CASE STUDY MD | MAIN LINE; DENSE AREA

The following table summarizes the aggregate data of the ENPV and of the cumulated flow related to the implementation costs in the baseline scenario, that is in the case a traditional ERTMS L2 technological solution is chosen and implemented.

MAIN LINE; DENSE AREA - BASELINE SCENARIO		ENPV	Cumulated flow
	CAPEX GROUND	*962.457*	*1.156.680*
	ETCS planning, installation, interfacing	-	-
	RBC	-	-
	TAL-Server	-	-
	Track Database	-	-
	Digitalization campaign	-	-
	Physical balises	962.457	1.156.680
	CAPEX BOARD	*623.317*	*660.960*
	ETCS	-	-
	BTM	623.317	660.960
	VBR	-	-
	OPEX GROUND	*180.439*	*338.588*
	RBC	-	-
	TAL-Server	-	-
	Recalibration of track database	-	-
	Physical balises Dense area	180.439	338.588
	Physical balises Medium area	-	-
	Physical balises Isolated area	-	-
	OPEX BOARD	*576.700*	*1.082.160*
	OBU modules	576.700	1.082.160
	OTHER OPEX	*-*	*-*
	Energy for braking and slowdown	-	-
	Time wasted for braking and slowdowr	-	-
	Time cost for start of mission	-	-
	Missed revenues on train slots for IM	-	-
	Missed revenues on train slots for RU	-	-
	TOTAL Baseline	**2.342.912**	**3.238.388**

Table 27: Case study MD | Baseline scenario

The following table summarizes the aggregate data of the ENPV and of the cumulated flow related to the implementation costs in the project scenario, that is in the case an innovative ERTMS L2 technological solution, in which the odometer measurement is corrected by the position data received by virtual balises instead of physical balises, is chosen and implemented.

MAIN LINE; DENSE AREA - PROJECT SCENARIO	ENPV	Cumulated flow
CAPEX GROUND	*316.605*	*369.750*
ETCS planning, installation, interfacing	-	-
RBC	-	-
TAL-Server	21.643	22.950
Track Database	21.643	22.950
Digitalization campaign	32.705	34.680
Physical balises	240.614	289.170
CAPEX BOARD	*1.246.633*	*1.321.920*
ETCS	-	-
BTM	623.317	660.960
VBR	623.317	660.960
OPEX GROUND	*48.447*	*90.909*
RBC	-	-
TAL-Server	3.337	6.263
Recalibration of track database	-	-
Physical balises Dense area	45.110	84.647
Physical balises Medium area	-	-
Physical balises Isolated area	-	-
OPEX BOARD	*1.153.399*	*2.164.320*
OBU modules	1.153.399	2.164.320
OTHER OPEX	*-*	*-*
Energy for braking and slowdown	-	-
Time wasted for braking and slowdowr	-	-
Time cost for start of mission	-	-
Missed revenues on train slots for IM	-	-
Missed revenues on train slots for RU	-	-
TOTAL Project	**2.765.084**	**3.946.899**

Table 28: Case study MD | Project scenario

The following table summarizes the differential results related to the implementation of the project scenario with the respect to the implementation of the baseline scenario in the case study in analysis. The differential impacts are highlighted by cost category (CAPEX; OPEX and ground; board), then total ENPV, cumulated flow and BCR are shown.

MAIN; DENSE – TOTAL	ENPV	Cumulated flow
∂ CAPEX GROUND	645.852	786.930
∂ CAPEX BOARD	- 623.317	- 660.960
∂ OPEX GRUND	131.992	247.678
∂ OPEX BOARD	- 576.700	- 1.082.160
∂ OTHER OPEX	-	-
TOTAL DIFFERENTIAL RESULT	**- 422.173**	**- 708.512**
BCR	**0,85**	

Table 29: Case study MD | Differential impact

The CBA of the case study related to main line in a dense area highlights a negative differential impact of the implementation costs envisaged in the project scenario with respect to the ones envisaged in the baseline scenario, when considered as present values, that is as discounted cash flows. The ENPV, in fact, is negative and equal to -422 k€. In this case study, the cumulated cash flow is also negative and equal to -708 k€.

The differential results in the sub-categories of cost highlight:

- a positive impact (that is a saving in the project scenario with respect to the baseline scenario) for what concerns the ground side, due to the fact that the project scenario envisages a reduced number of physical balises;
- a more relevant negative impact (that is a loss in the project scenario with respect to the baseline scenario) for what concerns the on-board side, due to the fact that the project scenario envisages further equipment (the VBR) and the related maintenance cost;
- no impact for what concerns other OPEX, as prudentially assumed in D6.1.

The negative impact for what concerns the on-board side is not compensated - in present value - by the positive one for what concerns the ground side, then the total impact results negative.

The overall BCR is equal to 0.85, lower than the minimum acceptable value of 1, that is the cut-off value used to decide whether to carry out the investment envisaged in the project scenario or not.

The development of the technology, for example allowing the use of an integrated platform for both the BTM and the VBR functions or a cheaper Track-DB or digitalization CAPEX costs would obviously lead to a better BCR than computed above.

The CBA related to main line in dense area, then, shows that under the base assumptions it is not convenient to choose an ERTMS innovative and GNSS-based solution with the respect to the traditional balise-based technological solution.

5.2 CASE STUDY MM | MAIN LINE; MEDIUM AREA

The following table summarizes the aggregate data of the ENPV and of the cumulated flow related to the implementation costs in the baseline scenario, that is in the case a traditional ERTMS L2 technological solution is chosen and implemented.

MAIN LINE; MEDIUM AREA - BASELINE SCENARIO		ENPV	Cumulated flow
	CAPEX GROUND	*962.457*	*1.156.680*
	ETCS planning, installation, interfacing	-	-
	RBC	-	-
	TAL-Server	-	-
	Track Database	-	-
	Digitalization campaign	-	-
	Physical balises	962.457	1.156.680
	CAPEX BOARD	*623.317*	*660.960*
	ETCS	-	-
	BTM	623.317	660.960
	VBR	-	-
	OPEX GROUND	*229.391*	*430.445*
	RBC	-	-
	TAL-Server	-	-
	Recalibration of track database	-	-
	Physical balises Dense area	-	-
	Physical balises Medium area	229.391	430.445
	Physical balises Isolated area	-	-
	OPEX BOARD	*576.700*	*1.082.160*
	OBU modules	576.700	1.082.160
	OTHER OPEX	*-*	*-*
	Energy for braking and slowdown	-	-
	Time wasted for braking and slowdowr	-	-
	Time cost for start of mission	-	-
	Missed revenues on train slots for IM	-	-
	Missed revenues on train slots for RU	-	-
	TOTAL Baseline	**2.391.864**	**3.330.245**

Table 30: Case study MM | Baseline scenario

The following table summarizes the aggregate data of the ENPV and of the cumulated flow related to the implementation costs in the project scenario, that is in the case an innovative ERTMS L2 technological solution, in which the odometer measurement is corrected by the position data received by virtual balises instead of physical balises, is chosen and implemented.

MAIN LINE; MEDIUM AREA - PROJECT SCENARIO	ENPV	Cumulated flow
CAPEX GROUND	*316.605*	*369.750*
ETCS planning, installation, interfacing	-	-
RBC	-	-
TAL-Server	21.643	22.950
Track Database	21.643	22.950
Digitalization campaign	32.705	34.680
Physical balises	240.614	289.170
CAPEX BOARD	*1.246.633*	*1.321.920*
ETCS	-	-
BTM	623.317	660.960
VBR	623.317	660.960
OPEX GROUND	*60.685*	*113.874*
RBC	-	-
TAL-Server	3.337	6.263
Recalibration of track database	-	-
Physical balises Dense area	-	-
Physical balises Medium area	57.348	107.611
Physical balises Isolated area	-	-
OPEX BOARD	*1.153.399*	*2.164.320*
OBU modules	1.153.399	2.164.320
OTHER OPEX	-	-
Energy for braking and slowdown	-	-
Time wasted for braking and slowdowr	-	-
Time cost for start of mission	-	-
Missed revenues on train slots for IM	-	-
Missed revenues on train slots for RU	-	-
TOTAL Project	**2.777.322**	**3.969.864**

Table 31: Case study MM | Project scenario

The following table summarizes the differential results related to the implementation of the project scenario with the respect to the implementation of the baseline scenario in the case study in analysis. The differential impacts are highlighted by cost category (CAPEX; OPEX and ground; board), then total ENPV, cumulated flow and BCR are shown.

MAIN; MEDIUM — TOTAL	ENPV	Cumulated flow
∂ CAPEX GROUND	645.852	786.930
∂ CAPEX BOARD	- 623.317	- 660.960
∂ OPEX GRUND	168.706	316.572
∂ OPEX BOARD	- 576.700	- 1.082.160
∂ OTHER OPEX	-	-
TOTAL DIFFERENTIAL RESULT	**- 385.458**	**- 639.618**
BCR	**0,86**	

Table 32: Case study MM | Differential impact

The CBA of the case study related to main line in a medium area highlights a negative differential impact of the implementation costs envisaged in the project scenario with respect to the ones envisaged in the baseline scenario, when considered as present values, that is as discounted cash flows. The ENPV, in fact, is negative and equal to -385 k€. In this case study, the cumulated cash flow is also negative and equal to -639 k€.

The differential results in the sub-categories of cost highlight:

- a positive impact (that is a saving in the project scenario with respect to the baseline scenario) for what concerns the ground side, due to the fact that the project scenario envisages a reduced number of physical balises;
- a more relevant negative impact (that is a loss in the project scenario with respect to the baseline scenario) for what concerns the on-board side, due to the fact that the project scenario envisages further equipment (the VBR) and the related maintenance cost;
- no impact for what concerns other OPEX, as prudentially assumed in D6.1.

The negative impact for what concerns the on-board side is not compensated - in present value - by the positive one for what concerns the ground side, then the total impact results negative.

The overall BCR is equal to 0.85, lower than the minimum acceptable value of 1, that is the cut-off value used to decide whether to carry out the investment envisaged in the project scenario or not.

The development of the technology, for example allowing the use of an integrated platform for both the BTM and the VBR functions or a cheaper Track-DB or digitalization CAPEX costs would obviously lead to a better BCR than computed above.

The CBA related to main line in a medium area, then, shows that under the base assumptions it is not convenient to choose an ERTMS innovative and GNSS-based solution with the respect to the traditional balise-based technological solution.

5.3 Case study MI | Main line; Isolated area

The following table summarizes the aggregate data of the ENPV and of the cumulated flow related to the implementation costs in the baseline scenario, that is in the case a traditional ERTMS L2 technological solution is chosen and implemented.

MAIN LINE; ISOLATED AREA - BASELINE SCENARIO		ENPV	Cumulated flow
	CAPEX GROUND	962.457	1.156.680
	ETCS planning, installation, interfacing	-	-
	RBC	-	-
	TAL-Server	-	-
	Track Database	-	-
	Digitalization campaign	-	-
	Physical balises	962.457	1.156.680
	CAPEX BOARD	623.317	660.960
	ETCS	-	-
	BTM	623.317	660.960
	VBR	-	-
	OPEX GROUND	290.581	545.268
	RBC	-	-
	TAL-Server	-	-
	Recalibration of track database	-	-
	Physical balises Dense area	-	-
	Physical balises Medium area	-	-
	Physical balises Isolated area	290.581	545.268
	OPEX BOARD	576.700	1.082.160
	OBU modules	576.700	1.082.160
	OTHER OPEX	-	-
	Energy for braking and slowdown	-	-
	Time wasted for braking and slowdowr	-	-
	Time cost for start of mission	-	-
	Missed revenues on train slots for IM	-	-
	Missed revenues on train slots for RU	-	-
	TOTAL Baseline	**2.453.055**	**3.445.068**

Table 33: Case study MI | Baseline scenario

The following table summarizes the aggregate data of the ENPV and of the cumulated flow related to the implementation costs in the project scenario, that is in the case an innovative ERTMS L2 technological solution, in which the odometer measurement is corrected by the position data received by virtual balises instead of physical balises, is chosen and implemented.

MAIN LINE; ISOLATED AREA - PROJECT SCENARIO		ENPV	Cumulated flow
	CAPEX GROUND	316.605	369.750
	ETCS planning, installation, interfacing	-	-
	RBC	-	-
	TAL-Server	21.643	22.950
	Track Database	21.643	22.950
	Digitalization campaign	32.705	34.680
	Physical balises	240.614	289.170
	CAPEX BOARD	1.246.633	1.321.920
	ETCS	-	-
	BTM	623.317	660.960
	VBR	623.317	660.960
	OPEX GROUND	75.983	142.579
	RBC	-	-
	TAL-Server	3.337	6.263
	Recalibration of track database	-	-
	Physical balises Dense area	-	-
	Physical balises Medium area	-	-
	Physical balises Isolated area	72.645	136.317
	OPEX BOARD	1.153.399	2.164.320
	OBU modules	1.153.399	2.164.320
	OTHER OPEX	-	-
	Energy for braking and slowdown	-	-
	Time wasted for braking and slowdowr	-	-
	Time cost for start of mission	-	-
	Missed revenues on train slots for IM	-	-
	Missed revenues on train slots for RU	-	-
	TOTAL Project	**2.792.620**	**3.998.569**

Table 34: Case study MI | Project scenario

The following table summarizes the differential results related to the implementation of the project scenario with the respect to the implementation of the baseline scenario in the case study in analysis. The differential impacts are highlighted by cost category (CAPEX; OPEX and ground; board), then total ENPV, cumulated flow and BCR are shown.

TOTAL			
MAIN; ISOLATED		ENPV	Cumulated flow
	∂ CAPEX GROUND	645.852	786.930
	∂ CAPEX BOARD	- 623.317	- 660.960
	∂ OPEX GROUND	214.599	402.688
	∂ OPEX BOARD	- 576.700	- 1.082.160
	∂ OTHER OPEX	-	-
	TOTAL DIFFERENTIAL RESULT	**- 339.565**	**- 553.502**
	BCR	**0,88**	

Table 35: Case study MI | Differential impact

The CBA of the case study related to the main line in an isolated area highlights a negative differential impact of the implementation costs envisaged in the project scenario with respect to the ones envisaged in the baseline scenario, when considered as present values, that is as discounted cash flows. The ENPV, in fact, is negative and equal to -339 k€. In this case study, the cumulated cash flow is also negative and equal to -553 k€.

The differential results in the sub-categories of cost highlight:

- a positive impact (that is a saving in the project scenario with respect to the baseline scenario) for what concerns the ground side, due to the fact that the project scenario envisages a reduced number of physical balises;
- a more relevant negative impact (that is a loss in the project scenario with respect to the baseline scenario) for what concerns the on-board side, due to the fact that the project scenario envisages further equipment (the VBR) and the related maintenance cost;
- no impact for what concerns other OPEX, as prudentially assumed in D6.1.

The negative impact for what concerns the on-board side is not compensated - in present value - by the positive one for what concerns the ground side, then the total impact results negative.

The overall BCR is equal to 0.88, lower than the minimum acceptable value of 1, that is the cut-off value used to decide whether to carry out the investment envisaged in the project scenario or not.

The development of the technology, for example allowing the use of an integrated platform for both the BTM and the VBR functions or a cheaper Track-DB or digitalization CAPEX costs would obviously lead to a better BCR than computed above.

The CBA related to the main line in an isolated area, then, shows that under the base assumptions it is not convenient to choose an ERTMS innovative and GNSS-based solution with the respect to the traditional balise-based technological solution.

6 SUMMARY OF THE CBA FOR ALL THE CASE STUDIES

The following table summarizes the results of the CBA for each of the 9 analysed case studies.

	ENPV	Cumulated flow	BCR	Project solution convenient under the base assumptions
CUT OFF VALUE	***> 0***	***> 0***	***> 1***	
Local; Dense	420.689	567.337	2,11	**YES**
Local; Medium	442.105	607.525	2,17	**YES**
Local; Isolated	468.876	657.760	2,24	**YES**
Regional; Dense	237.839	232.895	1,16	**YES**
Regional; Medium	279.693	311.434	1,18	**YES**
Regional; Isolated	332.011	409.607	1,22	**YES**
Main; Dense	- 422.173	- 708.512	0,85	**NO**
Main; Medium	- 385.458	- 639.618	0,86	**NO**
Main; Isolated	- 339.565	- 553.502	0,88	**NO**

Table 36: Case study MI | Differential impact

Under the base assumptions, the GNSS-based solution has the potential to generate a positive Benefit/Cost ratio for the railway system as a whole, in the Local and Regional case studies, whereas the results are negative for the case studies in the Main lines.

The reasons mainly involve:

- the lower percentage of balises that can be used as virtual as opposed to physical;
- the fact that a higher number of trains need to be equipped with the solution's additional on-board modules because, under the initial assumptions, there is a higher chance of using the same trains on other lines – differently equipped – of the network.

The development of the technology, for example allowing the use of an integrated platform for both the BTM and the VBR functions or a cheaper Track-DB or digitalization CAPEX costs could obviously lead to a convenience of the Main line case studies too.

The following chapter will deepen the analysis by showing the variation of the economic indicators under different assumptions.

7 SENSITIVITY ANALYSES

7.1 METHODOLOGY

The analyses presented in this chapter are aimed at showing the results of the CBA of the case studies after variations of the initial assumptions on some of the variables of the analysis, considered as the most relevant. This methodology is particularly useful in the framework of this analysis as unit cost items cannot be disclosed and are often represented by ex-ante estimations whose solidity cannot be ascertained via either factual comparison or industry survey.

The steps of the sensitivity analysis are as follows:

1) Selection of the range of discrete variations (in % over the original value of the concerned variable) to apply
2) Application of the first variation
3) Recording of the new results, in terms of BCR
4) Re-iteration of steps 1-3 for the entire range of variation selected
5) Selection of the most critical variables, i.e those which the results show the higher elasticity[1] to.
6) Calculation of the switching value for said variables, i.e. the exact value of the variable that yields a BCR exactly equal to 1.

The results of the analysis will be expressed in absolute terms when the results do not disclose sensitive unit cost inputs by means of backwards estimations, otherwise as % variation of the original assumption.

7.2 SELECTED VARIABLES

The following list includes the cost factors that work as variables in the model and whose value are the focus of a sensitivity analysis in order to analyse the modification of the CBA final indicators deriving from their variation.

VARIABLE	AFFECTED COST ITEM
% of dedicated traction units	*Investment cost in on board equipment*
% of physical balises needed in the project scenario	*Investment ground cost*
Average distance of intervention location from maintenance centre in the case of balise malfunction	*Operating costs of balises*
Average number of unnecessary brakings per 1,000,000 train-km	*Energy costs*
Average distance between train at wake-up and first balise	*Time costs (start of mission)*

[1] The elasticity is the ratio of the variation between the results and the variation between the input variables.

Additional % of train-km allowed by the elimination of the odometric error (working assumption)	*Missed revenues of train slots*

Table 37: Variables representing parameters

Variables representing costs:

- Unit cost of TAL-Server
- Unit cost of balises
- Additional cost of OBU in the project scenario
- Unit cost of track database

7.3 Simulations for the Local line

7.3.1 Sensitivity analysis

The following graphs show both the range of variations of the concerned variable and the corresponding results in terms of BCR.

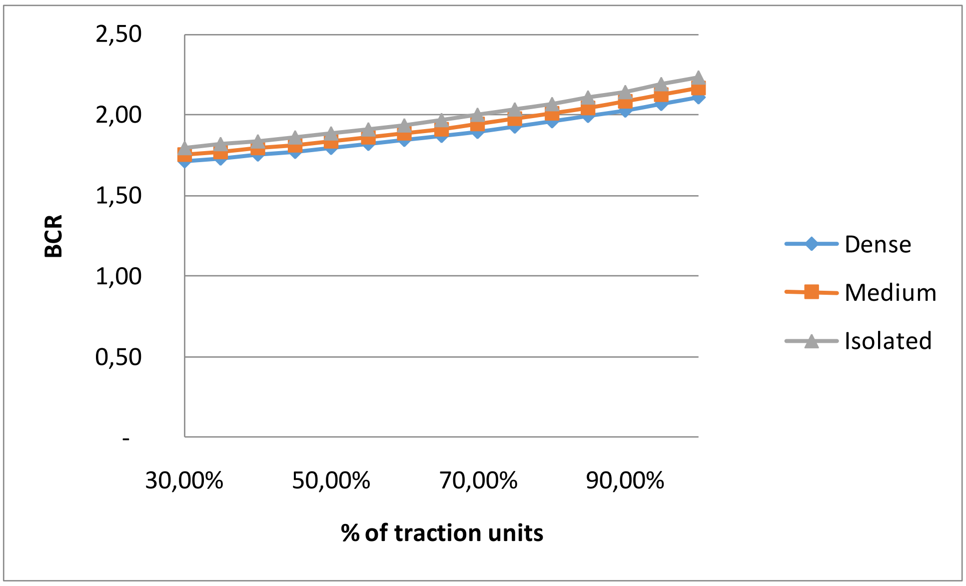

Table 38: Sensitivity analysis for Local lines: % of dedicated traction units

The above charts shows that as the share of dedicated traction units increases, the project becomes more convenient. This is an expected result in that a fleet that is not shared with other operations in other sections of the network does not need to be equipped with multiple systems, therefore the on board capex decrease. However, the sensitivity of the results to the variation of this variable is not high, as the BCR remains well above the unity even with more prudential assumptions.

The next variable (% of virtual balises on total balises) shows a relevant gap between the original assumption (100%) and the other values because in the base assumption the lack of physical balises allows to avoid the investment in the BTM, thus generating savings not only for ground costs but also for the on board equipment.

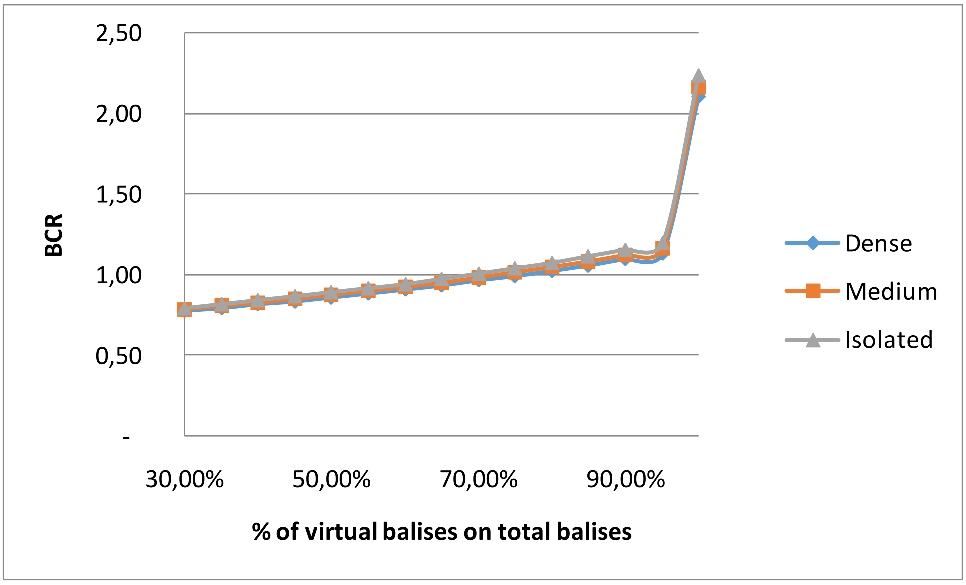

Table 39: Sensitivity analysis for local lines: % of virtual on total balises

If all balises can be virtualised (100%) the BCR is remarkably high (>2) since the elimination of all physical balises allows to remove a relevant capex i.e. the equipment of BTM on board. The decline of the share of virtual balises has a sensitive impact on the project's convenience, as the BCR gets below 1 when the % is lower than some 70%. The switching value analysis (cfr. Par. 7.3.2) will illustrate this in detail.

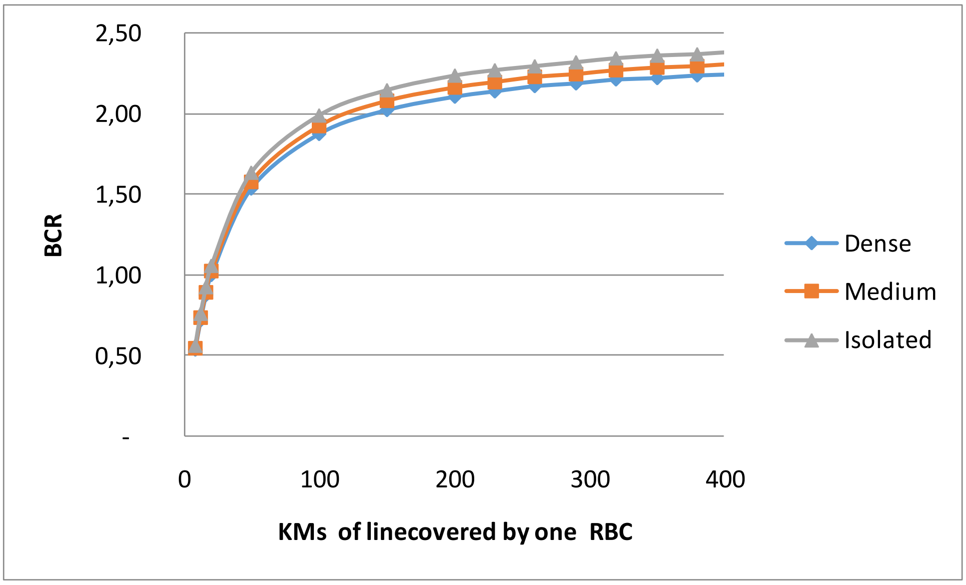

Table 40: Sensitivity analysis for Local lines: coverage of RBCs

The coverage (expressed in kms) of RBC does not negatively impact the convenience of the project unless very low – and unrealistic – values are assumed. On the other hand the value of this variables, the less the BCR benefits of its marginal increase.

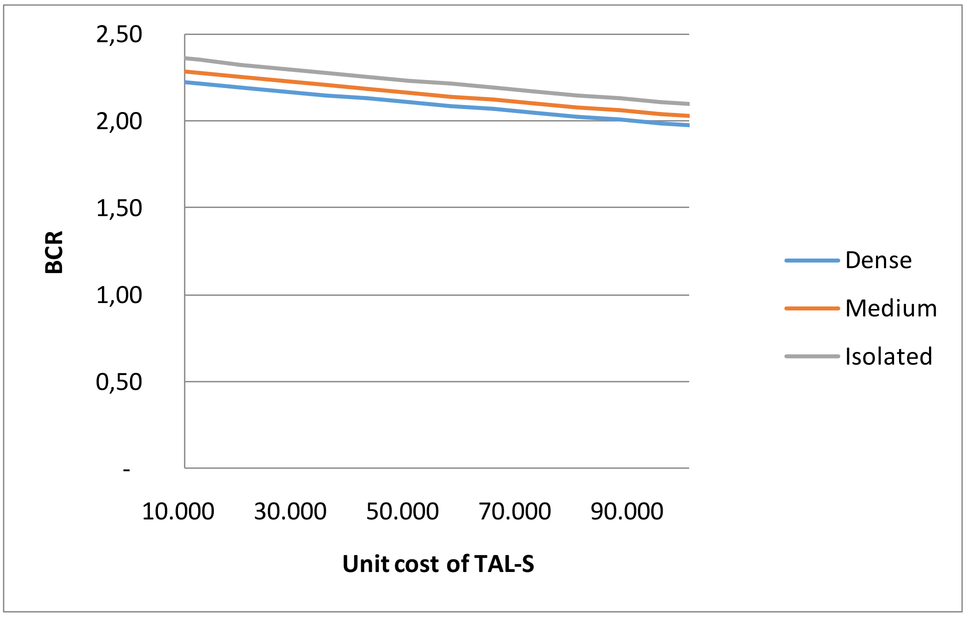

Table 41: Sensitivity analysis for Local lines: Unit cost of TAL-S

The unit cost of TAL-S is a capex element that does not seem to be critical in determining the overall convenience of the project.

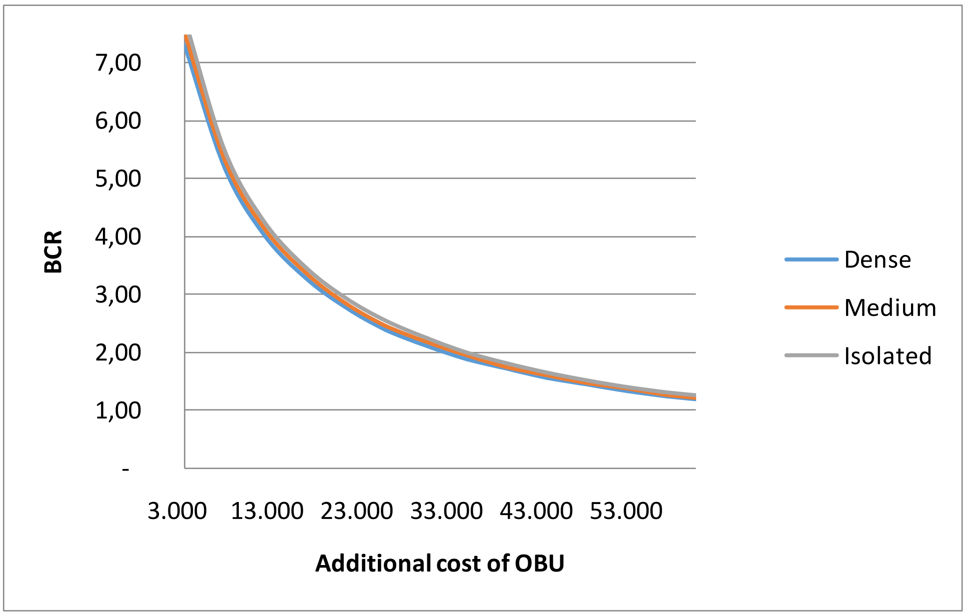

Table 42: Sensitivity analysis for Local lines: Additional cost of OBU per unit

The sensitivity of the BCR indicator from the assumption on the additional cost of OBUs in the project scenario is particularly relevant and will be investigated in par.7.3.2.

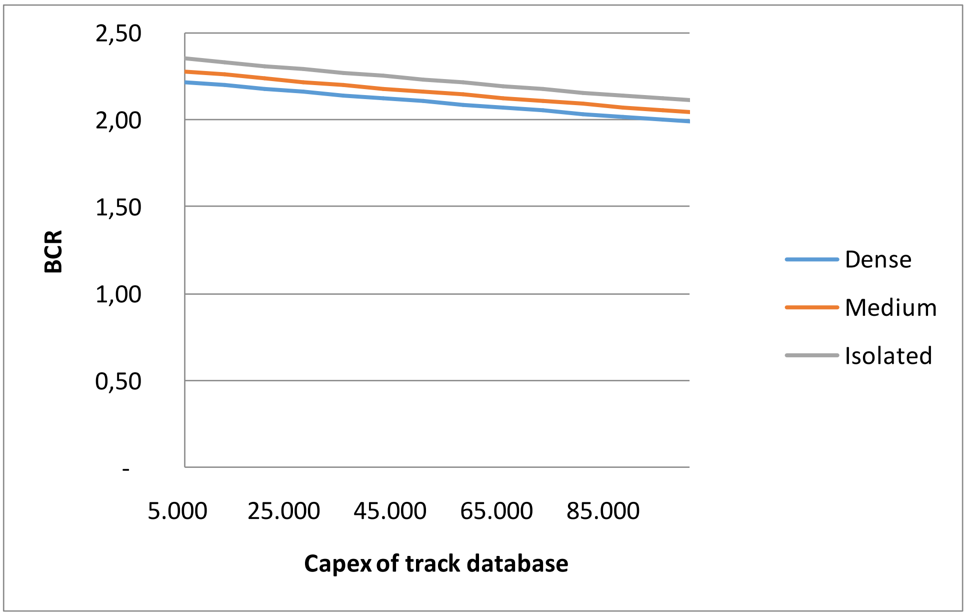

Table 43: Sensitivity analysis for Local lines: Unit cost of track database

The unit cost of track database is a capex element that does not seem to be critical in determining the overall convenience of the project.

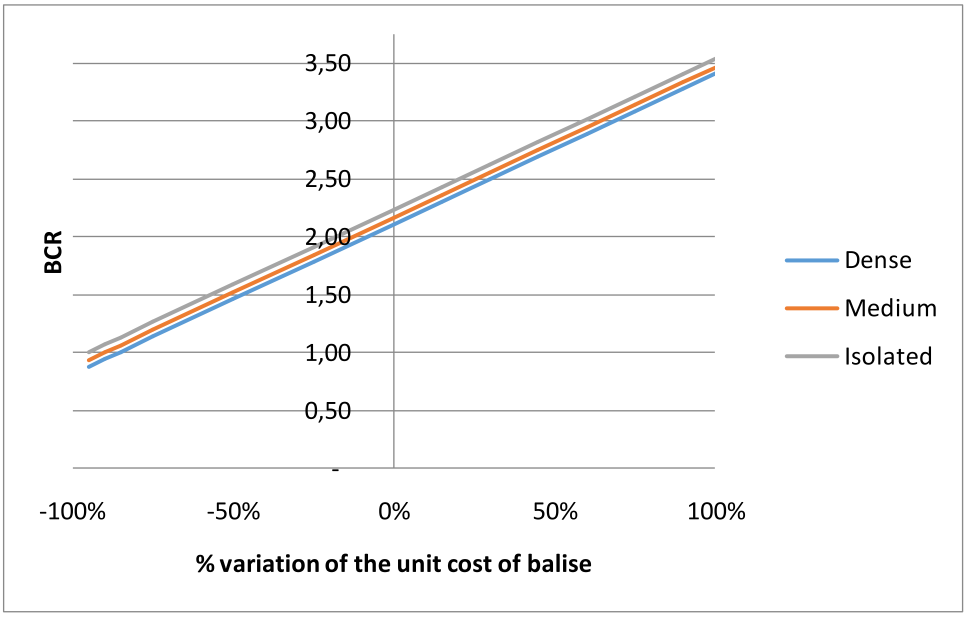

Table 44: Sensitivity analysis for Local lines: Unit cost of physical balise

The unit cost of the physical balises turns out to be quite important: its variation is capable to greatly affect the project's convenience. However, the cases where it leads the BCR to be below 1 are extremely prudential and unrealistic.

The next two variables (average distance of intervention and impact of vandalism and theft on the number of interventions) affect the calculation of the maintenance costs of balises.

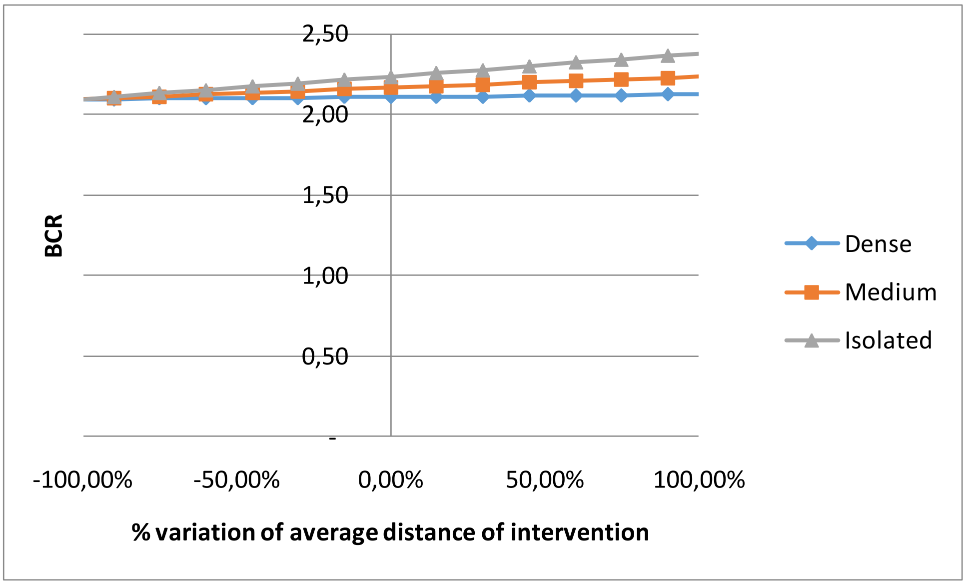

Table 45: Sensitivity analysis for Local lines: average distance of intervention

The distance to be covered for balise maintenance interventions turns out to be a low-impact variable in the project's economic analysis, except, partly, for isolated areas. Similar remarks can be made for the impact of vandalism and theft, as shown below.

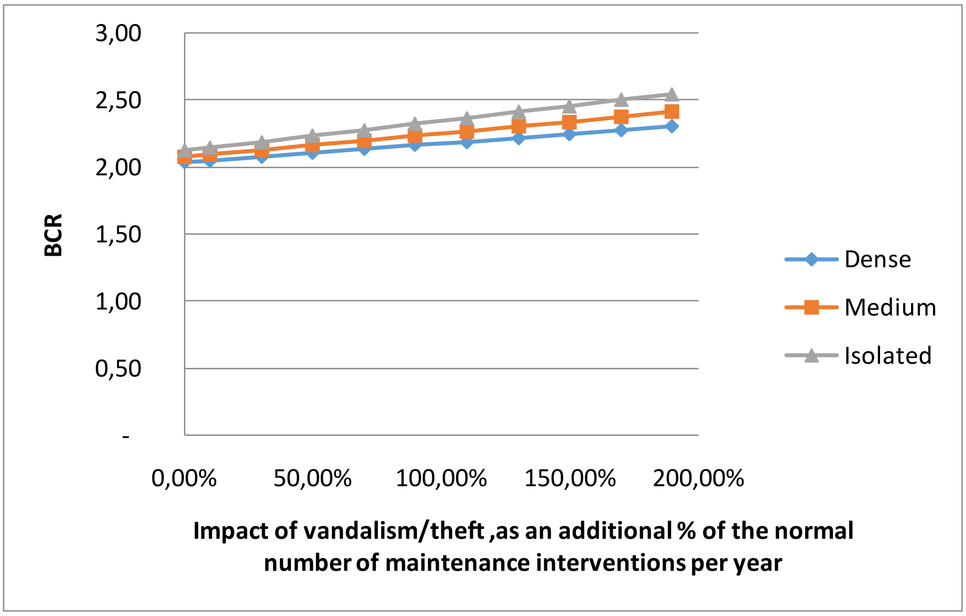

Table 46: Sensitivity analysis for Local lines: Impact of vandalism/theft

7.3.2 Critical variables and switching values.

The following table shows the relative elasticity for each of the above illustrated variables

Variable	Elasticity
% of dedicated traction units	0,33
% of virtual balises on total	2,39
KMs per RBC	0,19
Avg distance variation	0,03
Impact of vandalism/theft	0,07
Unit cost of TAL-S	*n.d.*
Additional cost of OBU	*n.d.*
Track db cost	*n.d.*
Unit cost of balise	*n.d.*

Table 47: Sensitivity analysis for Local lines: Elasticities

The results of the sensitivity analysis suggest that the most critical results for the convenience of the GNSS-based technology with the respect to the traditional balise based solution in Local lines (even though some of them cannot be disclosed to avoid backwards estimation of sensitive unit cost items) are:

- The % of physical balises which can omitted by implementing virtual balises
- The savings achieved per balise which is replaced by a virtual balise
- The additional cost of adding VBR functionality to the on-board equipment

The first and the second item affect the savings generated by the solution, whereas the third one affects the additional cost.

The values of such inputs that yield a BCR = 1 (switching values) are:

Variable	Dense	Medium	Isolated	*Note*
% of virtual balises	75%	72%	69%	(minimum threshold)
Additional cost of OBU (€)	72.062	74.199	76.869	(maximum threshold)
Unit cost of balise (€)	203	162	66	(minimum threshold)

Table 48: Sensitivity analysis for Local lines: Switching values

The use of an integrated platform for both BTM and VBR functions will have a positive impacts on this sensitivity analysis.

7.4 SIMULATIONS FOR THE REGIONAL LINE

7.4.1 Sensitivity analysis

The following graphs show both the range of variations of the concerned variable and the corresponding results in terms of BCR, for the Regional line case study.

Despite starting from a different initial BCR the variations emerging from the charts show similar sensitivities as in the Local case.

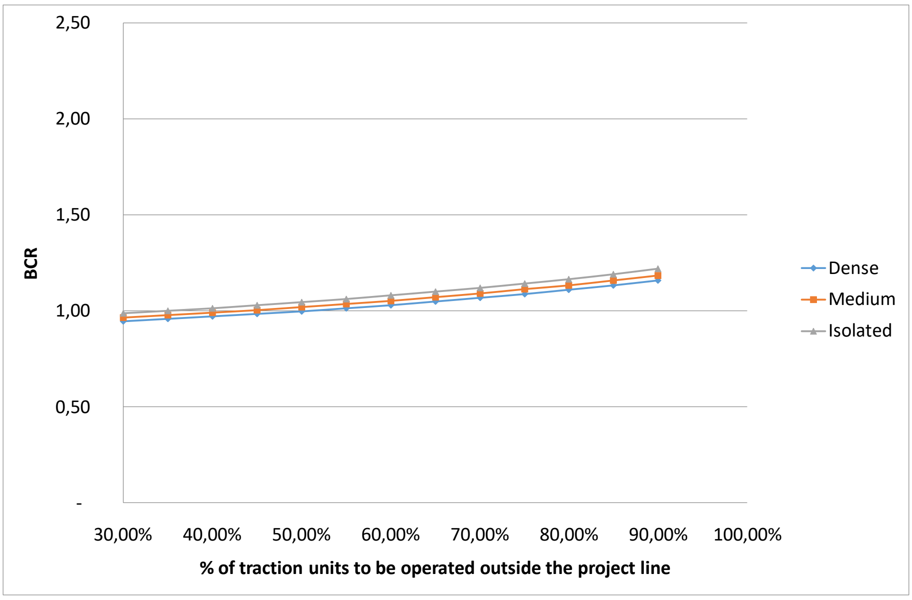

Table 49: Sensitivity analysis for Regional lines: % of dedicated traction units to be operated

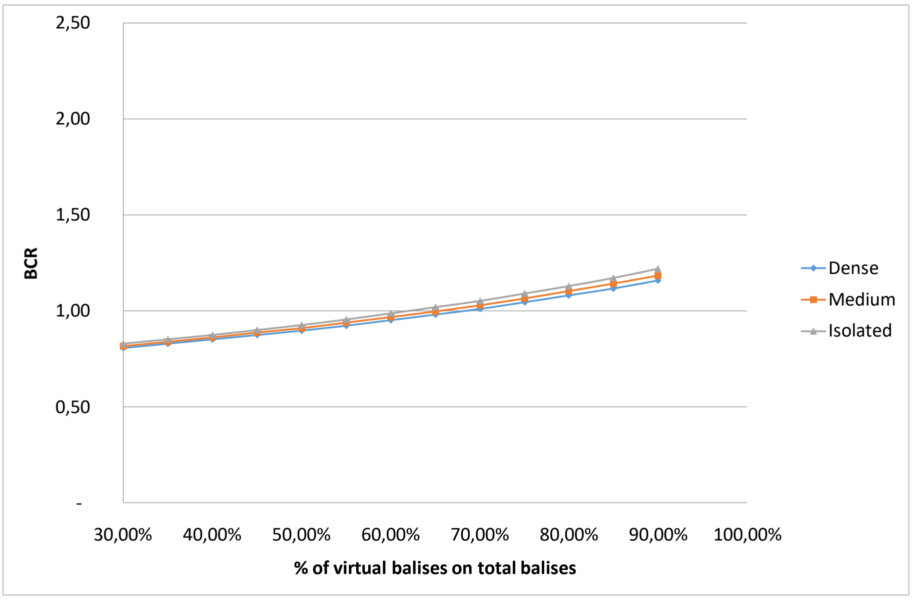

Table 50: Sensitivity analysis for Regional lines: % of virtual on total balises

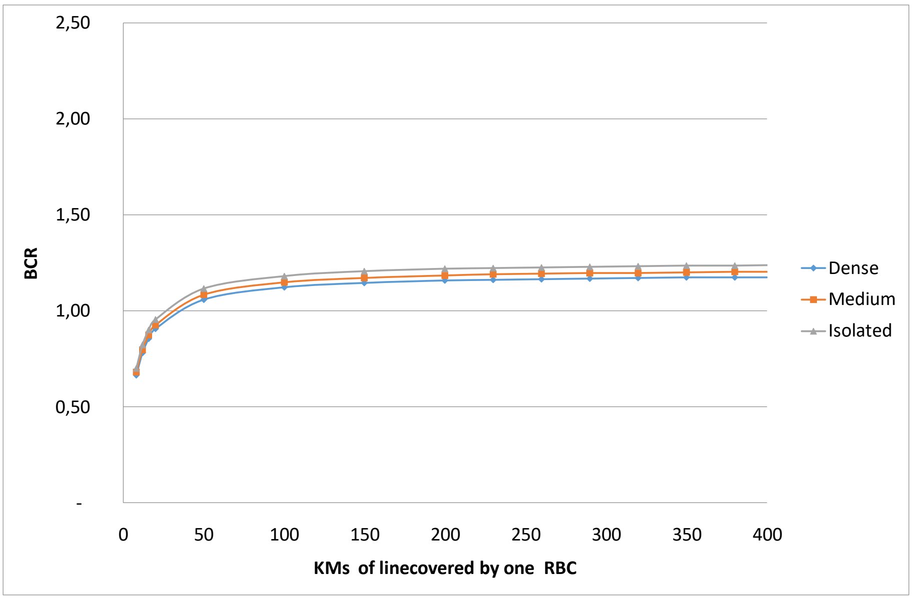

Table 51: Sensitivity analysis for Regional lines: coverage of RBCs

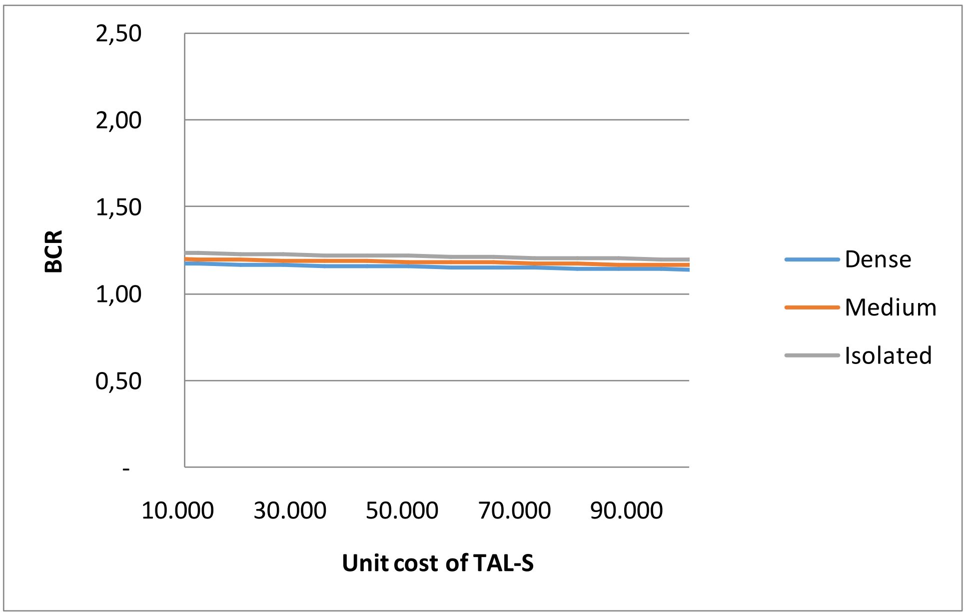

Table 52: Sensitivity analysis for Regional lines: Unit cost of TAL-S

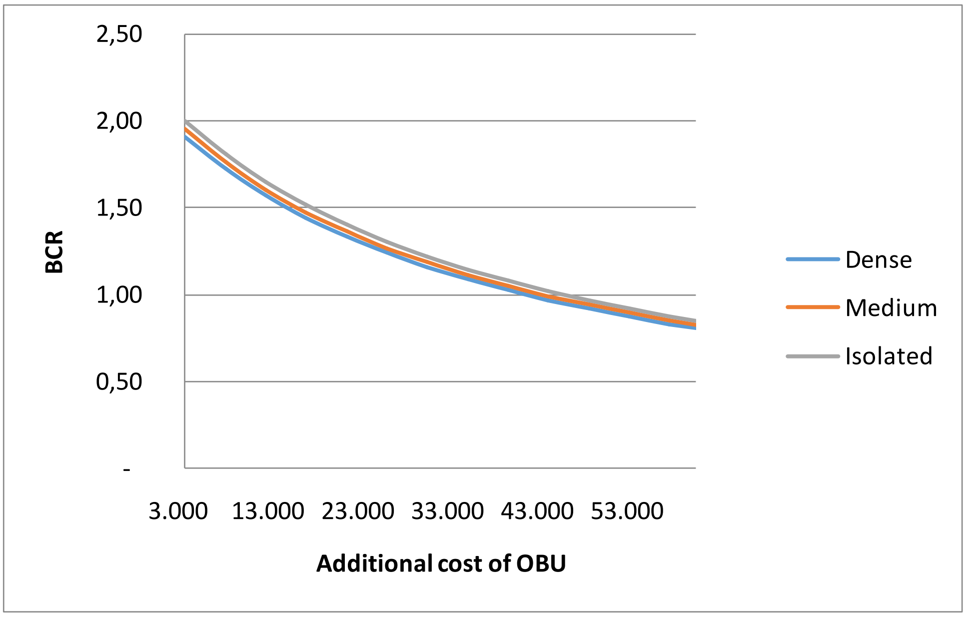

Table 53: Sensitivity analysis for Regional lines: Additional cost of OBU per unit

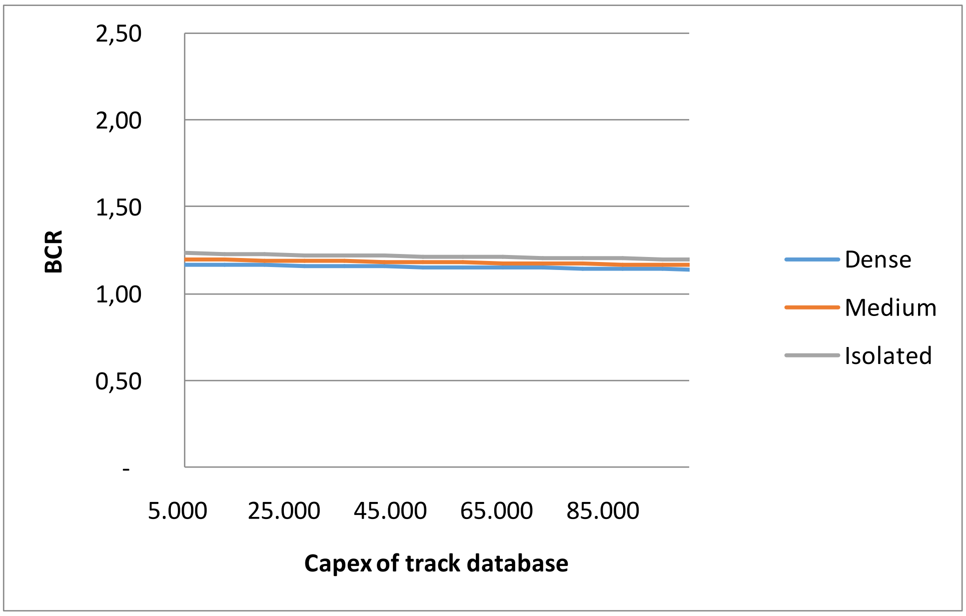

Table 54: Sensitivity analysis for Regional lines: Unit cost of track database

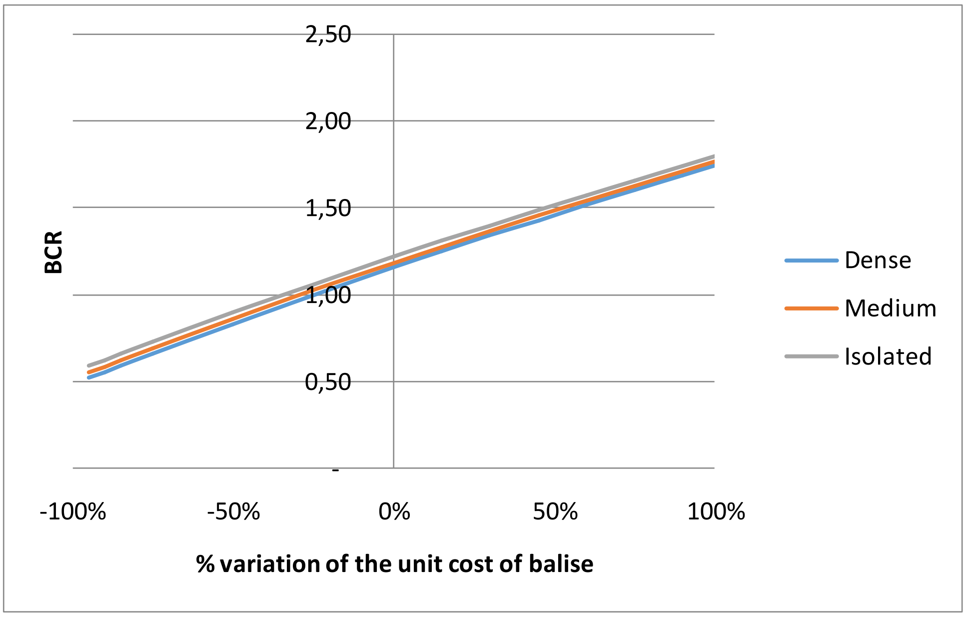

Table 55: Sensitivity analysis for Regional lines: Unit cost of physical balise

The next two variables (average distance of intervention and impact of vandalism and theft on the number of interventions) affect the calculation of the maintenance costs of balises.

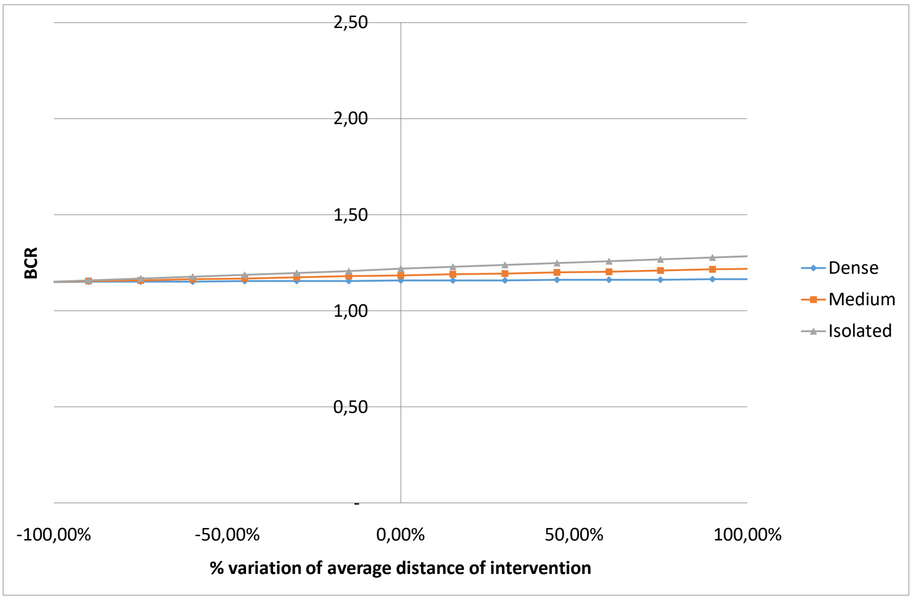

Table 56: Sensitivity analysis for Regional lines: average distance of intervention

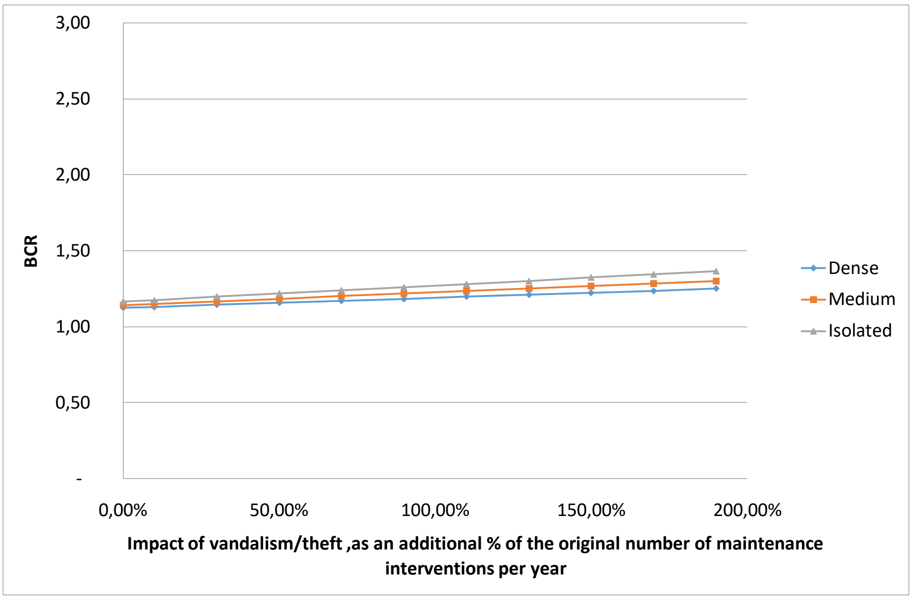

Table 57: Sensitivity analysis for Local lines: Impact of vandalism/theft

7.4.2 Critical variables and switching values

The following table shows the relative elasticity for each of the above illustrated variables

Variable	Elasticity
% of dedicated traction units	0,26
% of virtual balises on total	0,42
KMs per RBC	0,07
Avg distance variation	0,03
Impact of vandalism/theft	0,06
Unit cost of TAL-S	*n.d.*
Additional cost of OBU	*n.d.*
Track db cost	*n.d.*
Unit cost of balise	*n.d.*

Table 58: Sensitivity analysis for Regional lines: Elasticities

The results of the sensitivity analysis suggest that the most critical results for the convenience of the GNSS-based technology with the respect to the traditional balise based solution in Regional lines (even though some of them cannot be disclosed to avoid backwards estimation of sensitive unit cost items) are:

- The % of physical balises which can omitted by implementing virtual balises
- The savings achieved per balise which is replaced by a virtual balise
- The additional cost of adding VBR functionality to the on-board equipment

The first and the second item affect the savings generated by the solution, whereas the third one affects the additional cost.

The values of such inputs that yield a BCR = 1 (switching values) are:

Variable	Dense	Medium	Isolated	*Note*
% of virtual balises	68%	65%	62%	(minimum threshold)
Additional cost of OBU (€)	40.808	42.697	45.035	(maximum threshold)
Unit cost of balise (€)	1054	993	916	(minimum threshold)

Table 59: Sensitivity analysis for Regional lines: Switching values

The use of an integrated platform for both BTM and VBR functions will have a positive impacts on this sensitivity analysis.

7.5 SIMULATIONS FOR THE MAIN LINE

7.5.1 Sensitivity analysis

The following graphs show both the range of variations of the concerned variable and the corresponding results in terms of BCR, for the Main line case study. It is worth underlining that all base cases for the Main line have originally yielded negative results.

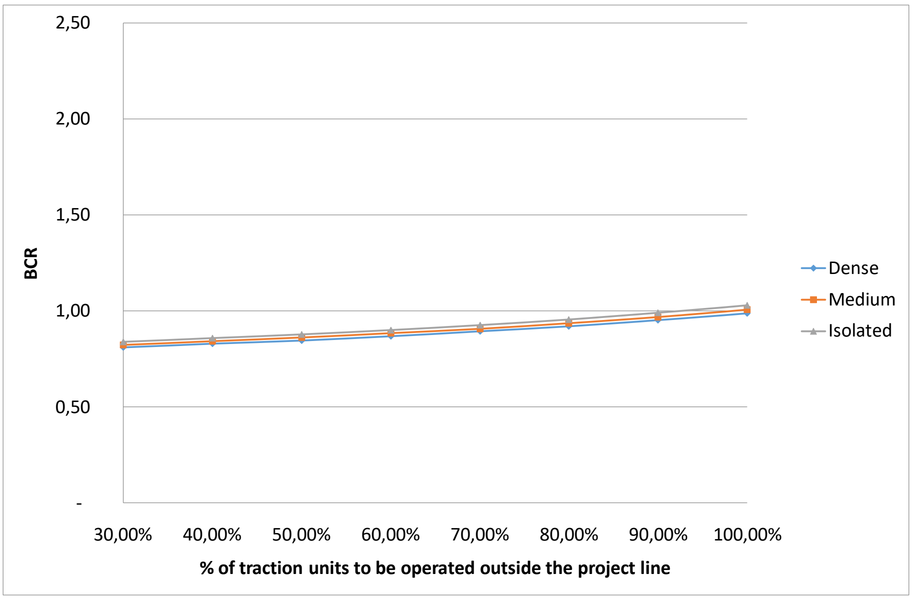

Table 60: Sensitivity analysis for Main lines: % of dedicated traction units

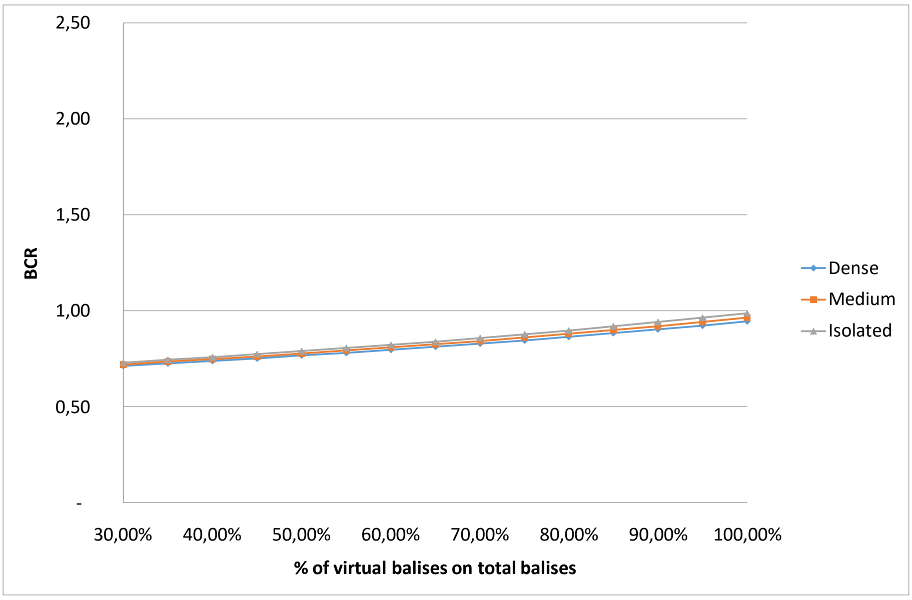

Table 61: Sensitivity analysis for Main lines: % of virtual on total balises

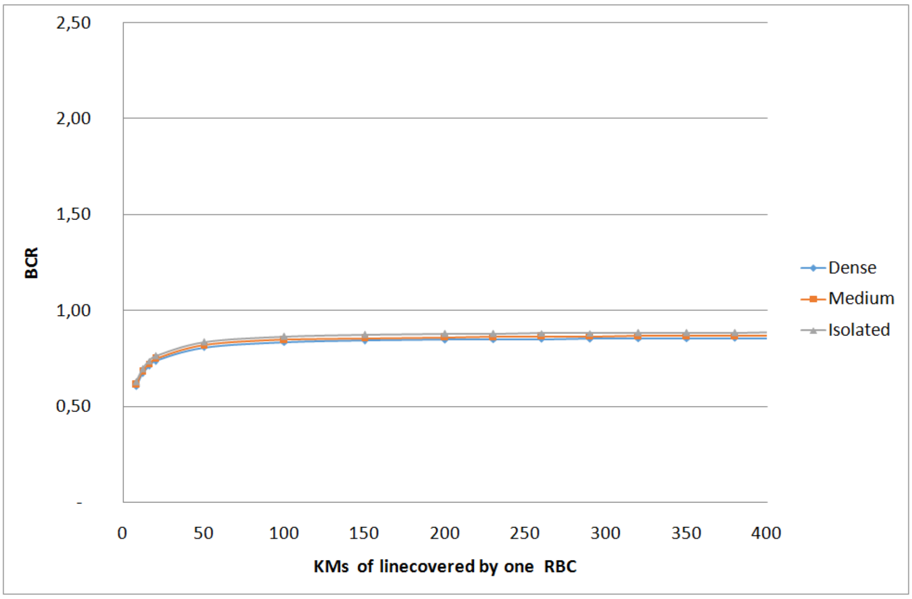

Table 62: Sensitivity analysis for Main lines: coverage of RBCs

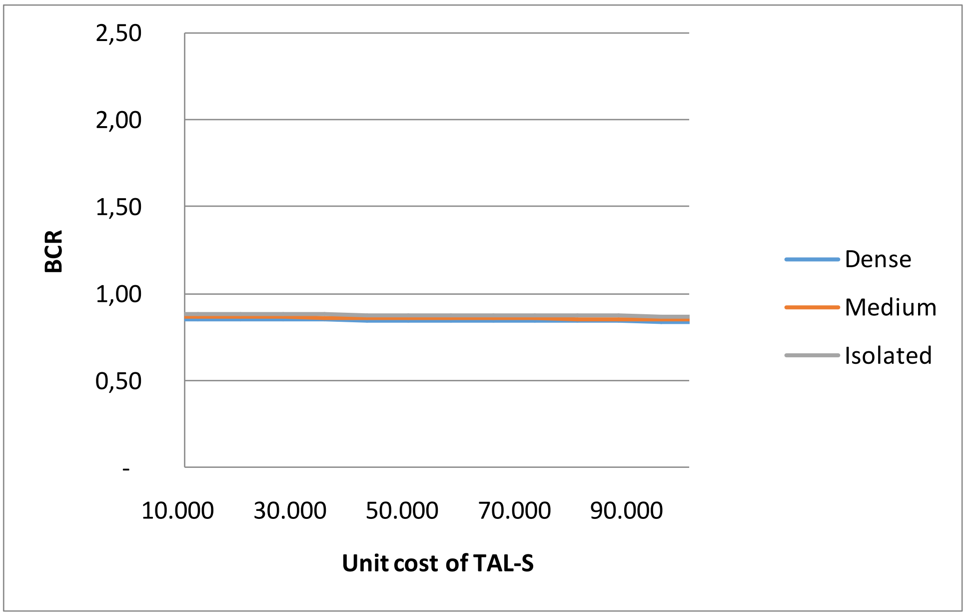

Table 63: Sensitivity analysis for Main lines: Unit cost of TAL-S

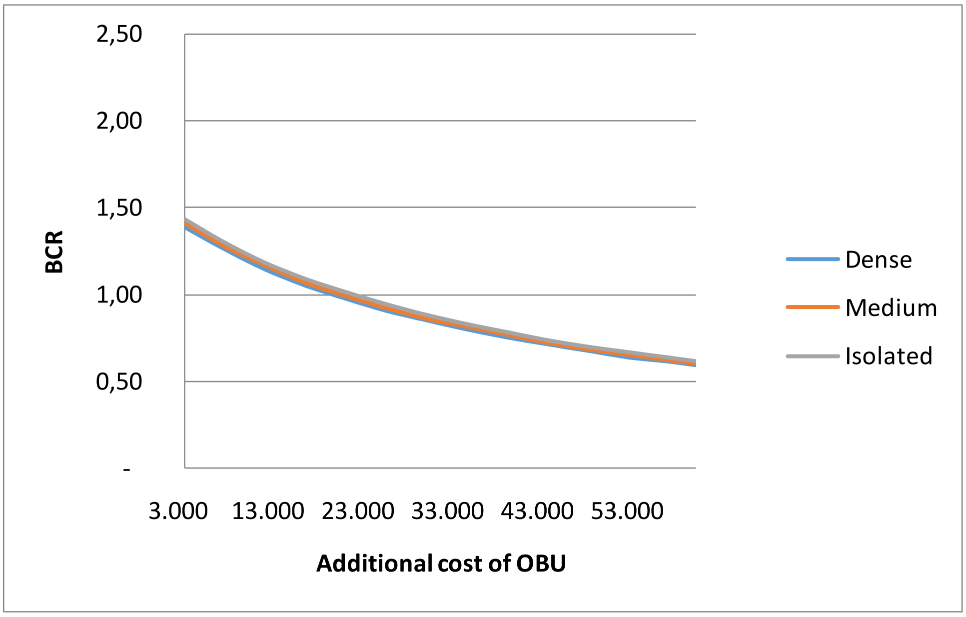

Table 64: Sensitivity analysis for Main lines: Additional cost of OBU per unit

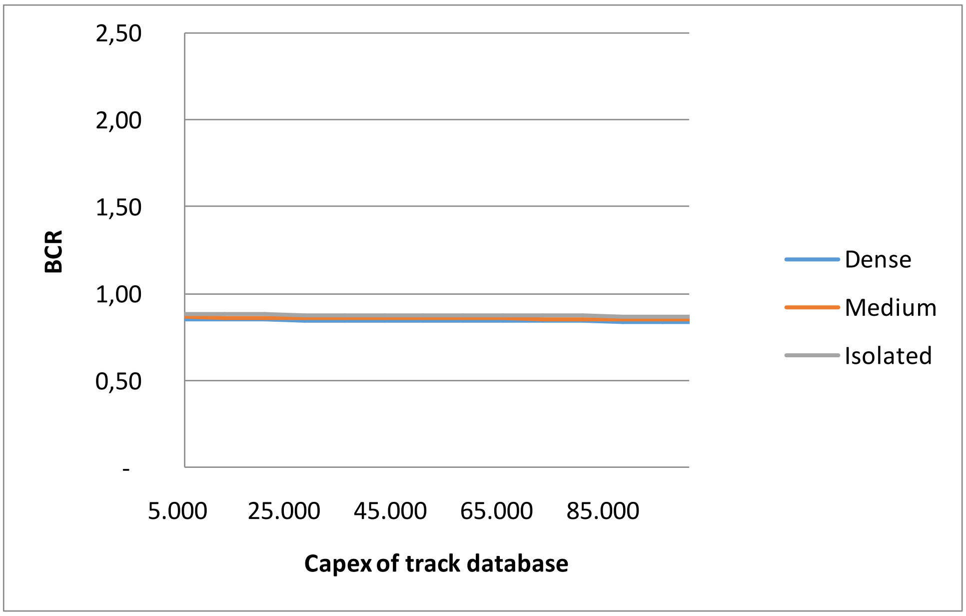

Table 65: Sensitivity analysis for Main lines: Unit cost of track database

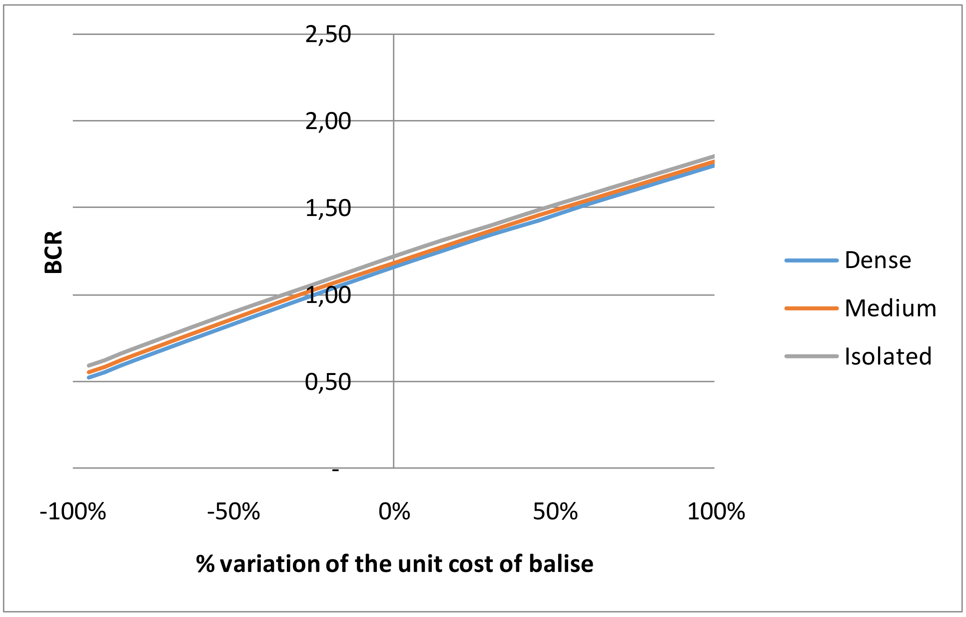

Table 66: Sensitivity analysis for Main lines: Unit cost of physical balise

The next two variables (average distance of intervention and impact of vandalism and theft on the number of interventions) affect the calculation of the maintenance costs of balises.

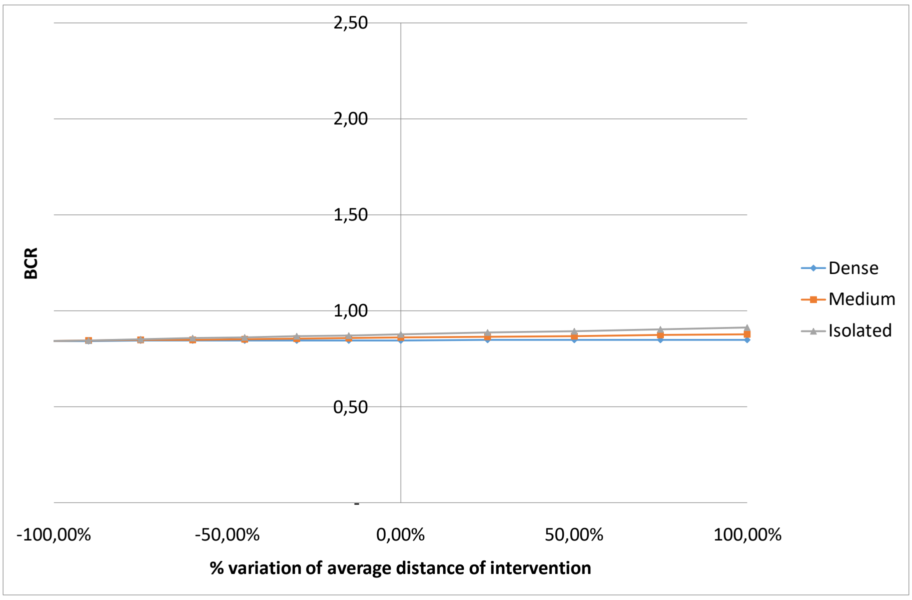

Table 67: Sensitivity analysis for Main lines: average distance of intervention

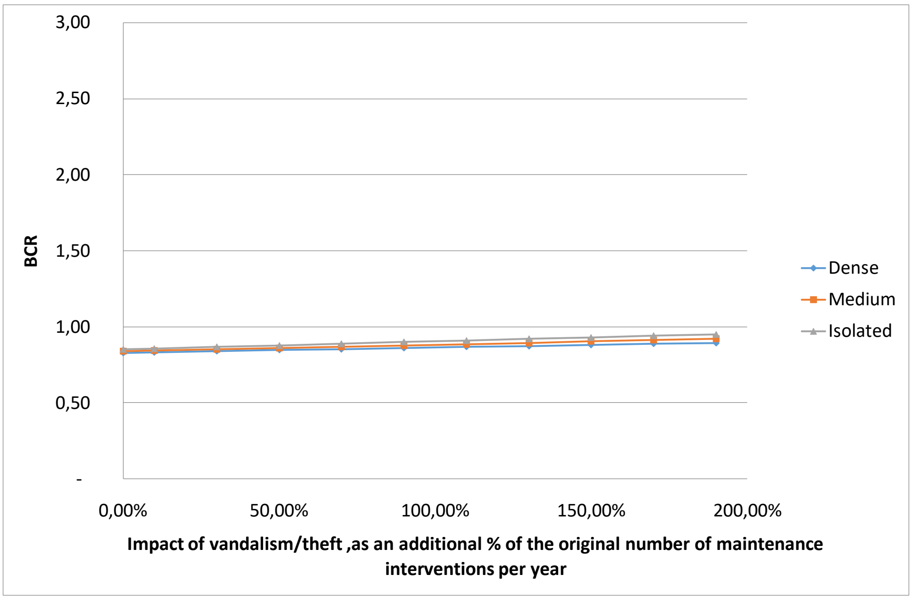

Table 68: Sensitivity analysis for Local lines: Impact of vandalism/theft

7.5.2 Critical variables and switching values

The following table shows the relative elasticity for each of the above illustrated variables

Variable	Elasticity
% of dedicated traction units	0,20
% of virtual balises on total	0,33
KMs per RBC	0,04
Avg distance variation	0,02
Impact of vandalism/theft	0,04
Unit cost of TAL-S	*n.d.*
Additional cost of OBU	*n.d.*
Track db cost	*n.d.*
Unit cost of balise	*n.d.*

Table 69: Sensitivity analysis for Main lines: Elasticities

The results of the sensitivity analysis suggest that the most critical results for the convenience of the GNSS-based technology with the respect to the traditional balise based solution in Main lines (even though some of them cannot be disclosed to avoid backwards estimation of sensitive unit cost items) are:

- The additional cost of adding VBR functionality to the on-board equipment
- The savings achieved per balise which is replaced by a virtual balise

The first on affects the main additional cost, while the second one affects the savings generated by the solution. The values of such inputs that yield a BCR = 1 (switching values) are:

Variable	Dense	Medium	Isolated	*Note*
Additional cost of OBU (€)	19.449	20.328	21.570	(maximum threshold)
Unit cost of balise (€)	2.101	2.040	1.960	(minimum threshold)

Table 70: Sensitivity analysis for Main lines: Switching values

The use of an integrated platform for both BTM and VBR functions will have a positive impacts on this sensitivity analysis.

8 CONCLUSIVE REMARKS

The analyses presented in this deliverable have the objective to investigate the economic convenience of implementing a GNSS-based ERTMS/ETCS solution rather than a traditional ERTMS/ETCS solution in a number of case studies.

Given the uncertainty around some of the fundamental unit cost items and parameters included in the economic model, a special focus has been given to the sensitivity analyses, aimed at pointing out the most critical assumptions and how their possible variations impact on the final economic results.

In general, the analyses have shown that the GNSS-based solution has the potential to generate a positive Benefit/cost ratio, especially in the Local and Regional case studies even under prudential assumptions, whereas in the case of Main lines the conditions of economic preference are stricter for the project scenario, then the benefits are less likely (but not impossible) to cover the costs.

For the Local case, the conditions for achieving a Benefit/Cost ratio > 1 (the first end of the ranges are valid for the “Dense” areas, the last for the “Isolated areas) are the following:

- The share of virtual balises needs to be bigger than 69%-75%
- The additional cost for adding the VBR functionality to the on-board equipment needs to be lower than € 72.000-77.000 per unit
- The saving achieved for reach virtualized balise needs to be above 66-203 euro

For the Regional case:

- The share of virtual balises needs to be bigger than 62%-68%
- The additional cost for adding the VBR functionality to the on-board equipment needs to be lower than € 40.000-45.000 per unit
- The saving achieved for reach virtualized balise needs to be above € 916-1.054

For the Main line case, the initial analysis yields negative results for the project and the conditions for them to become positive are challenging, being either of the following:

- The additional cost for adding the VBR functionality to the on-board equipment needs to be lower than € 19.000-22.000 per unit
- The saving achieved for reach virtualized balise needs to be above € 1.960-2.101

A relevant result of the sensitivity analysis is that, in order to assess the economic feasibility of the GNSS-based solution, it is always more relevant to evaluate the share of “virtualisable" balises and the cost of the additional module on board rather than the savings in operating costs. As stated above, the use of an integrated platform for the BTM and the VBR functions will surely bring to further advantages and possible to have a Benefit/Cost Ratio close to or greater than one for the main lines.

In fact, the former two variables turn out to be, in all case studies, remarkably more critical for the final results compared to the latter.

In other words, the convenience of the project solution as compared to the traditional solution is less dependent on the yearly savings for the operation of balises than it is on the amount of capex born for equipping the trains and of capex saved for installing balises.

This is relevant in that it shifts the question of the economic convenience of the solution from a geographically diverse item (such as the maintenance cost of balises) towards factors that depend on the technological advancements of the solution's development.