Deliverable 2.4
Specification of Cost-Benefit Analysis and learning curves, 1st release

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[1] Sirti S.p.A. was awarded the Open Call and signed the Grant Agreement for 4SECURail. In December 2020, the BU Transportation of Sirti S.p.A. became a new company called Sirti Transportation srl, 100% owned by Sirti SpA. On February 9th 2021 Sirti Transportation srl was totally acquired by MER MEC SpA, changing the name into MER MEC STE srl. At the time this deliverable is written, the procedure for the replacement of Sirti with MER MEC STE in this project is still ongoing. Therefore, the name SIRTI appears in this deliverable when documents, facts, events from up to February 2021 are reported. The name MER MEC STE appears when referring to documents, facts, events from February 2021 on.

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Executive Summary

One of the objectives of the 4SECURail project is to perform a Cost-Benefit Analysis (CBA) of the adoption of formal methods in the railway environment, and specifying the learning curve. A fully fledged CBA has never been applied to cases of FM adoption in railway sector. Literature show examples of quantitative and qualitative assessment of benefits of developing software with the adoption of FM in railway sector. Out of 29 literature records surveyed, only 8 show any kind of quantitative results, and only a part of this sub-cluster indicates useful insights in terms of costs and time of FM application in comparison to the Baseline scenario. However, no cases of application of full CBA methodology, with the calculation of financial and economic feasibility indicators, have been detected.

In Task 2.4, 4SECURail is due to identify – by means of a Cost-Benefit Analysis (CBA) - the economic impact of the use of formal methods (FM) in the development of standard interfaces, guidelines and specifications in the railway safety domain, against the Baseline Scenario represented by no use of formal methods. In line with this main objective, 4SECURail has identified a case study which is due to represent one of the most impactful operation on which the adoption of FM may generate benefits for Infrastructure Managers (IMs), stakeholders involved in its development.

The case study is the subsystem identified to exercise the formal methods demonstrator: the RBC/RBC handover interface, as defined and technically specified in D2.2 and D2.3.

4SECURail approach assumes that the CBA is developed from the “point of view” of the IM. This means that the analysis has to assess additional costs borne, and additional revenues and benefits accrued by a rail infrastructure manager faced by the choice to use FM. However, the role of stakeholders which operational and investment costs/savings are relevant for IMs (i.e. software developers) is considered. Benefits for users, i.e. passengers of train services, and for the “society” as a whole is considered too.

A preliminary identification of relevant categories of costs and benefits for the CBA has been performed. Cost and benefit categories, their magnitude and economic sign have been discussed within 4SECURail WP2 partnership and submitted to experts. The identification has been made among economic items for which a difference between Baseline and Project scenario is likely occurring. Relevant measurement units have been identified. The quantitative assessment of costs and benefits (D2.6 in November 2021) is the basis for the calculation of the feasibility and convenience indicators that constitute the outcome of the CBA. The task is made difficult by lack of fully comparable case studies, data confidentiality issued by SW developers, and by the rather low diffusion of FM adoption cases endowed by quantitative cost data.

In the framework of the first 4SECURail WP2 workshop (June 2020) a survey among acknowledged FM-experts and representatives of IMs was performed, accompanied by a questionnaire and a pairwise comparison between each proposed cost and benefit category, to provide an insightful ranking of cost/benefit categories, indicating the main streams on which the CBA should focus: (i) The higher system availability in case of service disruption is considered as the most relevant benefit category, leading to significant benefits for rail users in terms of saved time; (ii) The higher maintenance efficiency is considered as the second ranked benefit category; (iii) FM adoption is important for IMs since it allows significant savings in V&V costs; (iv) The purchase price deriving from savings in SW development has a moderate importance, according to the experts; (v) The cost of SW licenses, although confirmed as an additional cost, is considered as the less relevant category. The expert survey output has provided insights on the “learning curve” concept: experts believe that learning costs for using FM on the same railway safety interface development are rather similar for “pioneer” IM and other IMs issuing new tender guidelines for the same device.

Abbreviations and acronyms

Abbreviation / Acronyms	Description
AHP	Analytical Hierarchy Process
CAPEX	Capital Expenditure (Investment Costs)
CBA	Cost-Benefit Analysis
CCS	Command and Control Systems
D #.#	Deliverable #.#
ERTMS	European Rail Traffic Management System
ETCS	European Train Control System
FM	Formal Methods
IM	Infrastructure Manager
IXL	Interlockings
JU	Joint Undertaking
LCC	Life Cycle Costs
MAAP	Multi-Annual Action Plan
MBSD	Model Based Software/System Development
OPEX	Operating Expenditure (Operational Costs)
RBC	Radio Block Centre
VDM	Vienna Development Method
V&V	Verification and Validation
WP	Work Package

1 Background – Cost-Benefit Analysis in 4SECURail workplan

One of the objectives of the 4SECURail project is to perform a Cost-Benefit Analysis (CBA) of the adoption of formal methods in the railway environment, and specifying the learning curve.
In Task 2.4, 4SECURail is due to identify – by means of a Cost-Benefit Analysis (CBA) - the economic impact of the use of formal methods (FM) in the development of standard interfaces, guidelines and specifications in the railway safety domain, against the Baseline Scenario represented by no use of formal methods. The process runs in parallel to the other 4SECURail WP2 activities, which includes the prototyping a FM Demonstrator to be exercised with a selected case study. The use of FM in the railway context covers many distinct aspects, from the definition of verifiable requirements to the construction of a more affordable and efficient development process.
In line with this main objective, 4SECURail has identified a case study which is due to represent one of the most impactful operation on which the adoption of FM may generate benefits for IMs and other stakeholders involved in its development.

1.1 The CBA subject: RBC/RBC handover interface

The subject of the CBA, i.e. the "case study", is the subsystem identified to exercise the formal methods demonstrator: the RBC/RBC handover interface, as defined and technically specified in D2.2 and D2.3. The development of an interface is taken in 4SECURAIL as the subject of the CBA as it is considered as one of the elements which can benefit most from the adoption of FM in a standard SW development process in railway sector.
The case study is nested into a business case (see 2.2) defined to identify actions required to develop the RBC/RBC interface into a final product by suppliers, and evaluate the effects on time-to-market generated by the use of FM. Every action in the business case is influenced by the decision to develop specification with the use of FM in the case study, as further described in 2.2.
The reasons for the choice of RBC/RBC interface as case study, and in turn as the CBA subject are the following. RBC/RBC interface:

- is a typical product where development processes of different suppliers meet;
- already supports well established railway operational modes;
- offers good opportunities to translate safety related requirements into formally verifiable properties;
- is explicitly finalised to connect systems from different suppliers;
- It is more relevant and also more accessible for evaluation than other interfaces (e.g. interface between Interlocking and field objects), the implementation of which is usually proprietary.

In line with these assumptions, the CBA is developed by comparing the Project with the Baseline Scenario, whose descriptions mirror and integrate those defined in D2.3 (Ch.5.2):
Project Scenario: development of system specification of RBC/RBC handover interface (as described in D2.3 Ch.5) and deployment of the business case for the development of the final product, both implemented with the use of FM. Namely:

- system specifications are formalized by IMs using MBSD and FM;
- suppliers use MBSD and FM to assess that their work is compliant with the specifications issued by IMs, taking advantage of the work already done by IMs when formalizing the specifications.

Baseline Scenario: development of system specification of RBC/RBC handover interface (as described in D2.3 Ch.5) and deployment of the business case for the development of the final product, with no adoption of FM. Namely:

- the IM produces system specifications for procurement in the form of documents written in natural language;
- suppliers develop systems and products on the basis of these specifications in a traditional way, i.e. without using Model Based Software Development MBSD ("semi"-formal methods) tools and FM.

The following image, from D2.1, schematically describes the difference between the project scenario and the Baseline (here called "Classic") scenario.

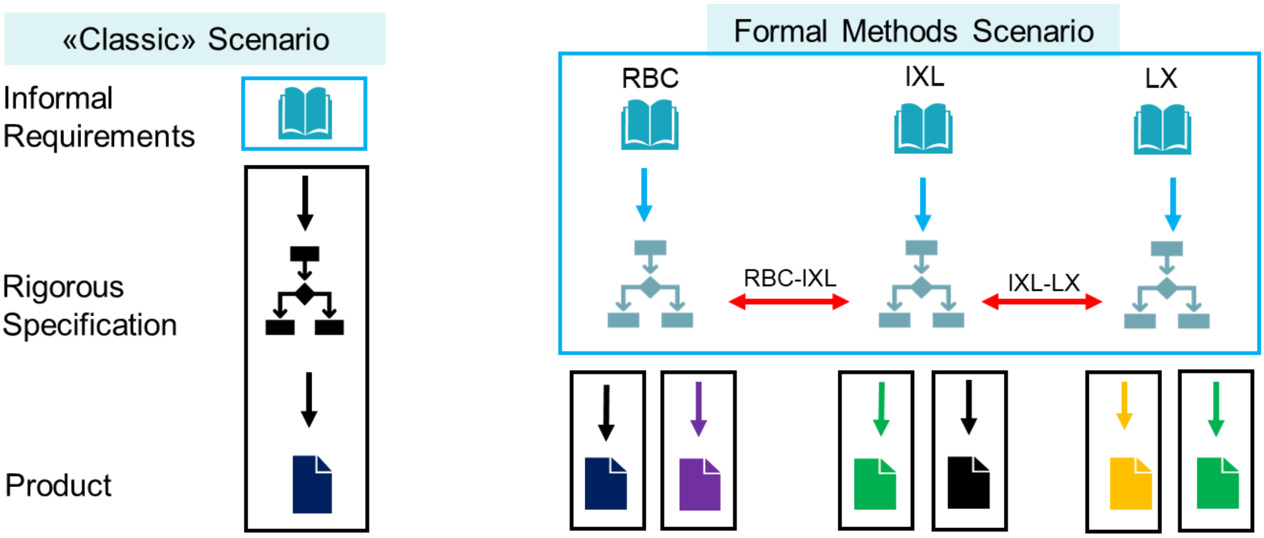


Figure 1 – "Formal Methods" vs. "Baseline" scenario, as defined in D2.1

As described in details in D2.1, the figure depicts the scheme followed by an IM to apply (semi) formal methods in the development of railways signalling systems, namely "*Development of Systems with Standardised Interfaces*", as defined in X2RAIL-2 D5.1 (section 5.4.1) [18]. In this model, the IM has to provide a validated specification of a desired equipment to the suppliers.
In the "classic" scenario (assumed as the "Baseline Scenario" in the present CBA), the IM generates an "informal" system requirements document, not developed by the use of any FM. The document is used by the developer to build an initial executable specification of the system, and then refine it into a final product.
The "Project Scenario" is represented by the right side of the figure, in which the IM provides the same rigorous/verifiable specification – developed with the use of FM - to multiple different suppliers that develop equivalent products, in a "tender model" (see 2.2). The definition of a rigorous specification of the system is under IM responsibility, in an even more complex framework in which the IM develops specifications for a multitude of subsystems ("system of systems mode", as defined in D2.1), each developed by a different supplier called by different tenders, that must correctly interact among themselves.

The case study on which the CBA is developed represents the case of RBC/RBC handover interface development, as a case of benchmark between the two models depicted in Figure 1.

2 The 4SECURail approach to Cost-Benefit Analysis

A fully fledged CBA has never been applied to cases of FM adoption in railway sector. Literature (see Ch.4) show examples of quantitative and (mainly) qualitative assessment of benefits of developing software with the adoption of FM in railway sector. However, no cases of application of full CBA methodology, with the calculation of financial and economic feasibility indicators, have been detected.

In 4SECURAIL, starting from the present deliverable and ending with D2.6 (due in November 2021), the goal is to apply CBA methodological elements to the case study "RBC/RBC handover interface", as representative of the FM adoption in the development of railway safety devices. CBA will be developed by following methodological elements recommended by the EC "Guide to Cost-Benefit Analysis", edited by DG REGIO in 2014 [1].

To this extent, the CBA is composed of Financial and Economic Analysis.

Financial analysis will have the goal of assessing the feasibility of the adoption of FM in the handover interface development. The analysis must be developed from the "point of view" of the stakeholder considered as the most relevant in the process, i.e. the actor bearing additional investment costs (CAPEX), modifying the operational cost (OPEX) structure vs. the "do-nothing" scenario, and getting additional revenues from the practice. In 4SECURAIL case, the point of view of an IM faced to the choice of adopting FM will be adopted. However, the role of suppliers will be taken into account as far as the cost differential (positive or negative) accrued by SW suppliers in the development of interfaces following requirements developed by using FM are reflected into change of the price of the SW purchased by the IM.

Economic Analysis will have the goal to assess and quantify impacts for the society and stakeholders thereof. As concerns the latter category of benefits, particular attention will be devoted to the assessment of benefits for users, generated if the probability of service disruption is lower if railway safety systems are procured and developed using FM. Moreover, the CBA will scan the existence and the magnitude of benefits for the users, generated e.g. if rail services are made more reliable with lower probability of service disruption, and for the society, occurring in case the analysis detects that the use of FM in railway safety has impact on the decrease of accidents, or at least FM have a role in the fulfilment of SIL-4 safety standards or achieving even higher safety integrity levels.

The CBA will be developed deploying methodological elements and steps of the CBA, as follows:

- Definition of Business Case, time-horizon and discount rate;
- Identification of additional investment costs (CAPEX) and operational costs (OPEX) of the adoption of FM in the selected RBC-RBC handover interface case study, and their difference against the Baseline Scenario. As concerns OPEX borne by the IM, two scenarios will be identified, taking into account the alternative adoption of Open source and proprietary SW for the definition of specification through the use of FM;

- Calculation of monetized values of benefits for the IM, railway undertakings (producer surplus), rail service users (consumer surplus) and the society.
- Definition of learning scenarios and corresponding learning curves, i.e. scenarios towards the (faster or slower) adoption of formal methods by IMs in EU;
- Calculation of financial and economic feasibility indicators (NPV, F/ERR, B/C ratio) for each identified scenario;
- Sensitivity analysis, calculation of switching values of relevant variables and identification of the conditions ensuring the financial and economic feasibility of the adoption of formal methods by IMs and suppliers.

2.1 The point of view of the CBA

4SECURail approach assumes that the CBA is developed from the "point of view" of the IM. This means that the analysis has to assess additional costs borne, and additional revenues and benefits accrued by a rail infrastructure manager faced by the choice to use FM. However, the need to include stakeholders connected with IMs enhances the adoption of an integrated perspective, in which operational and investment costs/savings borne by other stakeholders are relevant for IMs too, against the baseline scenario.

A first key assumption is that IMs provide resources to a common body established to develop and define "Standard Interfaces" (SI). The model on which 4SECURail analysis is inspired is EULYNX, which role in the development of SI is described in details in D2.1 (5.1.3). The CBA considers costs borne by IMs to establish a follow-up of EULYNX to issue new guidelines on SI in railway safety sector, relevant for the adoption and spreading of FM use.

EULYNX is the cooperation body established by IMs, "for defining and standardising interfaces in the future digital control command communication, signalling and automation system, the goal is a significant reduction of the lifecycle cost for signalling systems" (EULYNX website).

A recent study by ProRail and TU Eindhoven [4] developed comparison methodologies in two subsystems Point and Train Detection System, to create additional SysML models based on EULYNX documents. The main conclusions of the study are the following:

- *The implementation of traceability has indicated that the requirements specification of EULYNX cannot fully be traced back to INESS*[2]
- *The implementation of simulation methodologies has shown the advantages of models over the textual way of specification to ProRail*
- *Although EULYNX potentially shows its benefit in modeling to ProRail, it is still too soon to decide whether or not EULYNX is mature*
- *The active involvement of ProRail in the verification and validation process of EULYNX is one of the factors. A better working process between EULYNX and the IMs is needed*

EULYNX follow-up is assumed to be the body in which IMs develop and agree upon guidelines to use FM and develop verified SI. This is relevant for the CBA, since IMs are assumed to provide effort to EULYNX follow-up by temporarily deploying human resources.

[2] INESS – Integrated European Signalling System, EU FP7 Project, http://iness.eu/Context-Objectives

At the same time, the role of suppliers is relevant too: additional costs, or benefits in terms of shorter time needed for SW development, are reflected in the price paid by IMs to purchase RBC (of which RBC/RBC handover interface is a key component).
Users, i.e. passengers of train services, are included in the chart since they would benefit from the lower probability of service disruption.
Finally, the "society" is included in the CBA as the analysis – as stated above - has the parallel aim to detect and assess potential benefits generated in terms of increased railway safety.
The following diagram sketches the assumed interdependencies between stakeholders relevant for the CBA.

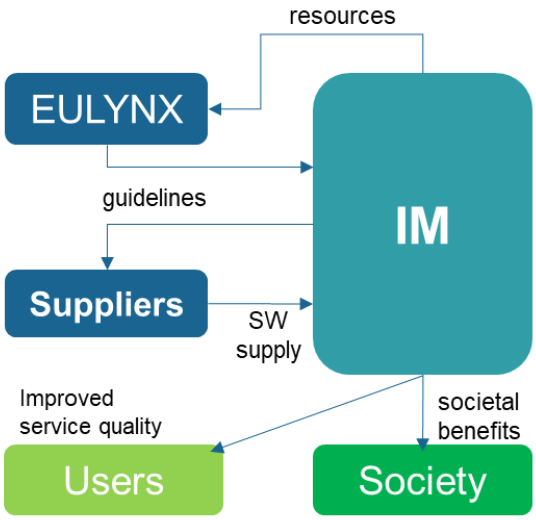


Figure 2 – The point of view of the CBA

2.2 The business case

As explained in 1.1, the case study is nested in a business case, developed to identify activities on which the adoption of FM may have impact on costs and development time. The CBA adopts a business model which includes operations and activities implemented by IMs, from the definition of specifications to the revenue service (e.g. when the product developed by the use of FM is released to the IM and in the market) and change requests.
As the case study is focused on the development (with FM) of the specifications to be included in the tender for the RBC procurement, the following figure evidences the role and the "position" of the case study in the business model, assuming – as explained in 1.1 – that the use of FM in the definition of specifications influences all activities performed by IM and supplier to provide the SW product.

The business model is based on X2RAIL-2 "semi-formal methods development" business case, as defined in X2RAIL-2 D5.3 (section 6.3.4) [1]. That business case includes:

a. the adoption of a "tender model", in which tender requirements are developed – with the use of FM - on the basis of specifications defined outside the IM (e.g. EULYNX);
b. the development of "tender details", as defined in X2RAIL-2 D5.3 (section 6.3.4), performed by the IM, at the same time that the tender is prepared. This approach amends the X2RAIL-2 one, since it is assumed that the SW supplier/developer does not cooperate with the IM in the definition of "tender details", nor they are assumed to be fine-tuned

after the tender assignment. In line with the approach defined in 1.1, the specifications developed with the use of FM are released to several suppliers bidding in the tender;

c. V&V (verification and validation) costs: X2RAIL2 introduces the role of “Assessors” due to perform V&V. In 4SECURail business case, V&V costs are borne by suppliers. Enhancing the adoption of the “multi-supplier” mode, V&V is made once per tender, until a change request triggers the adoption of a new tender;

d. The “revenue service” is the phase starting when the SW is put into operation at the IM.

The following figure depicts the business case adopted, based on X2RAIL-2 D5.3 scheme for “semi-formal methods development”.

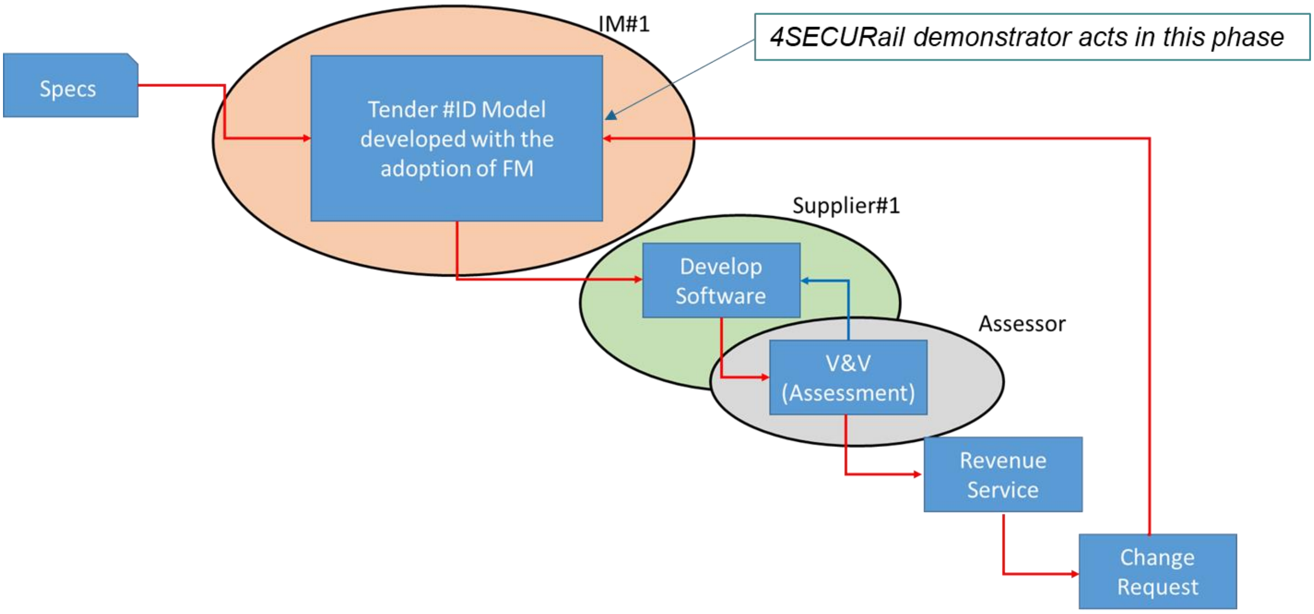


Figure 3 - X2RAIL-2 business case “semi-formal methods development”, revised by 4SECURail

A key point in the definition of the business case regards the identification of “change request” cases, their taxonomy of cases, who asks for change requests, and the possibility that change requests are promoted by the same IM procuring the original SW, or by other IMs.

For the current analysis, “change requests” are not due to the detection of interoperability errors, that are assumed to be minimised with the adoption of FM. Therefore change request is assumed as an update of the system due to (e.g.):

- New interoperability features (e.g. new ERTMS release)
- New on-board or ground system interfaces
- Other new features

Change requests are issued by IMs through new tenders, facilitated by the adoption of FM. As a key assumption of the model, and differently from the Baseline Scenario, the use of FM allows the definition of interoperable SI that, on the one hand makes the tender issuing process easier for the IM in case of change request, while on the other hand enables all the suppliers – at least those having bid for the “original” SW procurement - to respond to the change request. A key aspect enhanced by this approach to change requests is the lower dependence from a single long-term supplier, which is likely having impact on development costs.

2.3 Cost and benefit categories

The definition of the business case made in 2.2 entails the identification of activities for which differences in investment and operational costs are suitable between the Project and the Baseline Scenarios. The next step of the CBA methodological foundation is the identification of cost categories for which such differences are assumed to exist.
Moreover, it has to identify other cost categories, relevant for the IM external to the process identified in the “business case”, that are impacted – i.e are lower or higher than in the Baseline Scenario - by the adoption of SW implemented with RBC/RBC handover interface developed with the use of FM.
Finally, since the ultimate objective of the CBA is to identify and assess benefits for the whole society, the definition of costs and benefits within the analysis range has to include possible societal and environmental benefits generated by the implementation of the “project scenario”, and assess their occurrence and magnitude.

A preliminary identification of relevant categories of costs and benefits for the CBA has been performed. Cost and benefit categories, their magnitude and economic sign have been discussed within 4SECURAIL WP2 partnership and submitted to experts.
The identification has been made among economic items for which a difference between Baseline and Project scenario is likely occurring. Relevant measurement units have been identified. The preliminary selection of cost and benefit categories with corresponding measurement units is reported in the following chart, in which categories are also clustered by relevant stakeholders. The chart distinguishes between investment costs (CAPEX) and operational costs (OPEX), as borne by the IM and the supplier. It is worth noting that some cost items may be considered in both categories (e.g. SW licenses, that may be considered as CAPEX in a balance sheet, but are generally paid by the subscribers year by year on a regular basis).
In the third category of items, benefits for the users of rail transport services (passengers) are included. The last category is represented by “externalities”, i.e. benefits not directly accounted by IMs but gained by the society as a whole in the Project scenario.

As it is evident from Figure 4, the major part of the cost/benefit items relate to IMs (or, more properly, to one single IM). However, the scheme identifies also cost items assumed to be borne by the suppliers (i.e. by one developer, supplying one IM) and paid out by the IM through the SW purchase price. The latter is assumed to decrease with respect to the Baseline scenario, as a result of the savings accounted for by the supplier. This process reminds that the CBA is developed taking the point of view of IMs, that however may benefit from savings accrued by other stakeholders involved in the process, such as the suppliers.
Preliminary assumptions have been made on signs of differentials between Project and Baseline scenarios: cost items written in red in Figure 4 are assumed to increase in the Project scenario, while green items are assumed to decrease, representing net benefits. The last four items represent net benefits by definition and their quantitative magnitude (and occurrence) has to be assessed in the CBA. At the same time, the magnitude and the actual sign of cost differentials have

to be verified in the CBA process as an outcome of the analysis.

	Cost/Benefit Item		Meas. unit	Monetary meas unit
Investment costs (CAPEX)	"EULYNX follow-up" - Costs to issue new guidelines for using FM Costs for the definition of SI using issued guidelines		Person-days (assumed the deployment of personnel of associated IMs))	€/day
	RBC (or similar device) Purchase price		€/software/year	
		Training costs	Person-days	€/day
		Savings in SW management/assistance	Person-days	€/day
		Lower development time	Person-days	€/day
		Costs for SW verification and validation	Person-days	€/day
	Learning / personnel training costs		Person-days (2-4)	€/day
Operational costs (OPEX)	Time to define requirements for RBC/RBC interface supply through FM		Person-days	€/day
	SW Licenses for requirements development through FM		€/software/year	
	Costs for RBC acceptance, verification and validation		Person-days	€/day
	Higher maintenance efficiency		Replacement costs	€/year
	Higher availability in case of service disruption (lower penalties from service contracts)		# service disruptions/year (prob.)	€/day penalty
Benefits for users	Lower service disruptions		# hours saved by users	€/pax*hour
Externalities	Lower accident risks		Accidents/year	€/accident (external costs)

IM | suppliers | users | society

Figure 4 – Cost and benefit categories breakdown

As per the figure, the following cost and benefit categories have been preliminarily identified:

"EULYNX follow-up" - Costs to issue new guidelines for using FM

This category includes costs borne by the IM for the definition of SI using guidelines developed in an initiative developed on EULYNX model. Costs, to be expressed in Euro/day, are assumed as proportional to the person-days of personnel deployed to the "EULYNX follow-up" by the associated IM.

Training costs
Additional costs are assumed to be borne both by the supplier, to train the personnel to the use of MBSD software, and by the IM, to train selected staff to the development of tender guidelines by the use of FM.

Lower development time
This time-related cost category aims to assess the time required, i.e. the hours spent by the number of persons employed, to develop the SW component with guidelines settled by the tender with the use of FM. Costs for development, measured in €/person-day, are assumed lower than the Baseline scenario.

Savings in SW management/assistance
This cost category relates to the costs for post-sale assistance (i.e. for bug fixing) borne by the supplier. They are assumed as lower than in the Baseline scenario, assuming that a SW developed with the use of FM is more reliable and requires less intervention by the developer in the revenue service phase at the IM. This implies that the developer can offer a lower rate for maintenance when responding to a tender for SW supply.

Costs for SW verification and validation
As per the business case described in 2.2, V&V costs are borne by suppliers. The CBA has to assess whether such cost is lower or higher in comparison to the baseline.

RBC purchase price
The last four categories described above are assumed to determine cost savings (all expressed in terms of €/person-hour) that are assumed to be reflected in a lower purchase price for the IM. In the present case study and business case, the IM obtains lower-priced offers in response to the tender for RBC supply.

Time to define requirements for RBC/RBC interface supply through FM
The IM is assumed to deploy staff time to define the requirements for RBC/RBC interface supply, to be inserted in the tender specifications. The sign of this time-related cost – different from cost for training provision and time-cost to attend learning courses of FM modelling language – is uncertain in comparison to the baseline scenario: the CBA has to assess whether the use of FM implies savings of resources in the definition of requirements by the IM preparing a tender.

SW Licenses for requirements development through FM
Developing requirements with the use of FM requires that the IM is supplied with a specific SW for mapping and code generation. The costs for licensing are assumed to be paid on a yearly basis.

Costs for RBC acceptance, verification and validation
The CBA has to assess if the use of FM implies higher operational costs for V&V and final acceptance of the RBC by the IM.

Higher maintenance efficiency

The expected lower need of SW maintenance is reflected in higher maintenance efficiency, measures in lower costs for replacements (€/year).

Higher availability in case of service disruption
This expected benefit category is internalised by the IM in terms of lower penalties – as stated in service contracts – to be paid to the train operator in case of service disruptions due to malfunctioning of the RBC or other related signalling or safety systems. This assumption implies that any penalties paid by a railway undertaking to the purchasing body of rail public transport services (e.g. a local Public Administration) is reverted and fully recognised by the IM in case the service disruption is caused by systems managed by the IM. This benefit is assessed in terms of number of service disruptions per year.

Lower service disruptions
The latter benefit category generates likely even higher benefits for rail transport service users, as passengers save transport time (more properly, reduce the probability to waste time) if the probability of service disruptions is lower. This benefit category is measured in terms of €/pax*h, assuming a standard value of time (available per country and trip purpose) and applied to the total saved hours in a year.

Lower accident risks
The impact on rail safety generated by the use of FM has to be investigated. If verified, the related societal benefit is measured in terms of lower (probability of) accidents per year, assuming scenarios of accident reduction and applying literature reference values[3] for unit external costs of accidents.

A more detailed clustering of costs for the creation of requirements has been developed. The assessment of each cost category at such level of details has already revealed to be more difficult and heavily depending from available data at IMs, from past and comparable experiences. The assessment would highly depend by particular choices of the followed process, e.g. by the choice of the formal verification tool, by the need of commercial training, and by assuming different learning costs in higher or lower learning curves.

[3] As for example country-specific values reported by the Handbook of External Costs of Transport, 2019 [25].

Licensing	Cost of Licensing for Formal Verification Tool	Euro/year
	Cost of Training for Design Tool	Euro/year
	Cost of Training for Formal Verification Tool	Euro/year
Time-related costs	Time Required for Design Language learning	Euro/person-hour
	Time Required for Design Tool Learning	Euro/person-hour
	Time Required for Formal Modelling Language learning	Euro/person-hour
	Time Required for Formal Verification Language Learning	Euro/person-hour
	Time Required for Formal Verification Tool Learning	Euro/person-hour
	Scope of the Specification: size of the input specification in terms of number of requirements	# requirements
	Time required for Design	Euro/person-hour
	Time required for Debugging	Euro/person-hour
	Time required for Formal Modelling	Euro/person-hour
	Time required for tracing the Design	Euro/person-hour
	Time required for tracing the Formal Model	Euro/person-hour
	Time required for specifying properties	Euro/person-hour
	Time required to verify properties	Euro/person-hour
	Time required to debug the formal model	Euro/person-hour

Figure 5 – Detailed list of time-related and licensing costs categories

3 Assessment of costs and benefits

The quantitative assessment of costs and benefits is the basis for the calculation of the feasibility and convenience indicators that constitute the outcome of the CBA.
Assigning values to the cost and benefit categories defined in 2.3 is a complex activity, requiring a detailed analysis of different sources. Such activities implies to scan the availability of comparable case studies, and the corresponding availability of quantitative information about their results. In particular, comparable case studies have to indicate the differential (in time, costs, etc.) between comparable Baseline and Project scenarios, respectively characterised by non-use and use of FM in the development of railway safety components, or at least in the railway sector.
The assessment of costs and benefits is made even more difficult by the lack of a fully-fledged CBA in FM domain, by data confidentiality issued by SW developers, and by the rather low diffusion of FM adoption cases endowed by quantitative comparisons with the reference scenarios.
On the other side, a full bottom-up assessment of costs is not possible in 4SECURail since recording of specific time-efforts for the demonstrator development is not foreseen.

The full assessment of costs and benefits will be performed and described in D2.6 (due in November 2021), which will include the final results of the CBA. The present deliverable reports two preliminary steps of the process: the literature review on FM and the expert survey made in preparation and during the 1st Technical Workshop of 4SECURail.

3.1 Literature review

This section describes the main outcome of the survey among literature references on FM reviewed by the contributors. References have been taken starting from X2RAIL-2 deliverables and have been complemented by academic papers and reports surveyed by the team.
Among the very wide academic and grey literature available on FM use in industry applications, 22 records were selected and reviewed as they provide (at least qualitative) input for the CBA, and/or quantitative and monetary figures which can be used as reference for the development of the present CBA on the Project scenario vs. the Baseline.
The outcome of the literature review is reported in Table 2. Although the literature on FM applications in industry and railway sector is wide since at least 40 years, quantitative results, applicable to the present CBA case, are very limited. Out of 29 literature records surveyed, only 9 show any kind of quantitative results, and only a part of this sub-cluster indicates useful insights in terms of costs and time of FM application in comparison to the Baseline scenario.

The starting point and base document of the review is X2RAIL-2 D5.1 [18]. The results of the survey made among railway industry in 2018 (within X2RAIL-2 WP5) showed that FMs may provide significant benefits in terms of:

- improved safety,
- requirement quality and reliability,
- reduced time-to-market / cost.

At the same time, that survey indicates a “high learning curve”, i.e. barriers towards the use of FM raised by railway engineers mindset, as a significant obstacle for FM adoption. The survey reported that *“While FMs are “Highly Recommended” in applicable standards, it is not sufficiently clear how to use FMs cost-effectively, and the lack of a business case providing a clear picture of what can be*

achieved using FMs".
While being a powerful inspiring factor for the present CBA, the survey made by X2RAIL-2 did not provide any quantitative insight.

Among literature reporting the outcome of FM expert surveys, "The 2020 Expert Survey on Formal Methods" [11] is one of the widest and most recent surveys aimed at indicating the perceptions of FM experts of transport and other industrial sectors about benefits brought by the use of FM and formal analysis tools.

Do you believe that formal methods, together with the rigorous use of formal analysis tools, can deliver the promise of:

	Definitely	Probably	Probably not	Definitely not	N/A
Better software quality	81.5%	16.9%	0.8%	0.0%	0.8%
Improved system safety	92.3%	7.7%	0.0%	0.0%	0.0%
Enhanced cybersecurity	65.4%	31.5%	0.8%	0.0%	2.3%
Higher performance systems	27.7%	46.2%	19.2%	0.0%	6.9%
Cheaper software development	19.2%	40.8%	30.0%	5.4%	4.6%
Reduced time to market	19.2%	37.7%	31.5%	4.6%	6.9%
Easier certification	61.5%	35.4%	2.3%	0.0%	0.8%
Easier long-term maintenance	60.0%	36.9%	2.3%	0.0%	0.8%

Figure 6 – Extract of the 2020 Expert Survey on Formal Methods (Source: [11])

As depicted in the figure, almost all experts agree that the improvement of "system safety" is one of the main benefits connected to the use of FM, followed by the improvement of SW quality, enhanced cybersecurity, easier certification and easier maintenance. Experts were doubtful about the FM impact in decreasing the cost of SW development.
However, the 2020 survey does not provide quantitative insights on any savings or benefits.

X2RAIL-2 D5.3 (Ch.8) reports the main savings and benefits of FM adoption in railway safety, as estimated in other relevant projects by IMs and metro line managers. Among them, the following quantitative results are reported:

- 15% reduction in installation and maintenance costs (SNCF, in ARGOS project) [5];
- 25% reduction in Global validation costs (RATP);
- no software bugs reported, although "large amount of software programs needed" (Stockholm Public Transport).

The same D5.3 defines an important input for the CBA, assuming 30 years as the time horizon, equal to the lifetime of the reference system[4].
The deliverable ends up by concluding that *"Change requests due to software issues in revenue service systems carry large costs, as all life cycle phases must be carried out again: e.g. specification updates required, software development/correction, V&V and approvals. Significant indirect costs can also be associated with such software issues (e.g. delayed or interrupted revenue service).*

[4] In X2RAIL-2 case, trackside safety part of ERTMS L3, irrespective of use of FM.

The proposed solution is expected to reduce costs that are due to poor quality, and result in fewer software issues, due to improved quality of requirements (in the RMI). It would impact all life cycle phases. LCC [Life Cycle Costs] benefits considered are mainly restricted to software development and V&V, revenue service and phase 6 change requests. The following objectives are formulated for the proposed solution's LCC benefits:
• The number of new software releases due to change requests is reduced by 50%.
• The time to develop software and perform V&V is reduced by 40%.
• The cost to develop software and perform V&V is reduced by 25%."

It is worth noticing that such quantitative targets set by X2RAIL-2 are admittedly "guesswork estimates".

Other interesting insights, with elements likely applicable to the present CBA, were found in the analysis of financial savings brought by the use of Model-Based Systems Engineering (MBSE) made by Krasner in 2015 [14]. The survey made among 4000 SW developers and managers showed that the addition of model-based systems engineering delivers a 55% reduction in total development cost. In particular:

- Between 2010 and 2015 the average cost per MBSE development has dropped by 83.8%. This can be attributed by increased productivity, and it may give an insight of the effects of triggering the learning curve;
- The number of total developer months (i.e. the staff resources deployed) per project developed with MBSE decreased from 137 (2010) to 73 (2015). The latter figure is 54% lower than the corresponding figure of project developed without the use of MBSE.

In the Metrô Rio case study [9] a bottom-up analysis of bug detection and correction costs for comparable rail/metro projects was performed. Main results showed that the cost of formal modeling is 30% higher than manual coding, due to higher costs for graphic editing (slower than textual editing) and the need of training. However, this greater effort is payed back by the cost reduction of the code verification activities (about 70% in total, with respect to a manual coding based process).

In 2014, Bibi S. et al. [3] reported on issues preventing the wide use of FM in commercial applications. Among issues reported, lack of skilled persons with mathematical background among SW engineers, inadequate tool support, increase in development cycle, and high costs, which lead to consider the FM use as unfeasible even if the SW quality is enhanced. According to the survey made, *"implementing successful FM in an organization also need to purchase the tools for supporting these methods, training of engineers and designers, and effort and time to incorporate formal methods in the existing software development process, with other expenditure"*. As it is easy to note, this qualitative statement is in line with the CBA purpose and mirrors many of the cost categories surveyed here. On the benefit side, the paper reports that only 30% effort is required for the (automated) verification by using formal techniques compared to the baseline scenario. Costs for testing (within OPEX, in the present CBA) are reduced, although the paper does not quantify the reduction magnitude. According to the paper, the main advantage of using FM is on defects detection at early stage: FM for developing controls software could result in a 63% fewer defects. The following figure (reported in [1]) summarises the main differences – with interesting quantitative data, applicable to the Project-Baseline scenario comparison – between effort required for relevant SW development activities, performed by simulation vs. use of FM.

Subtasks	Simulation	Formal verification
Preparation	Simulation script is generated by register tool	Properties are generated by register tool
Execution	3 days of simulation time	1.5 days for automatic set-up of 31 register block set-up and exhaustive verification of 12,600 properties
Analysis effort	60,000 entries to be analysed	No additional effort
Quality of analysis	Not-exhaustive, semi-automatic, error prone	Exhaustive, automatic, fail-safe
Total effort	3 days compute time + 2 days manual effort	1.5 days compute time (70% less than simulation)

Table 1 – Formal Verification vs. Simulation (Source: [3])

Finally, the rather dated survey made by Woodcock et al. in 2009 [24] among 62 industrial projects reported that half of the panel (53% and 56% respectively) realised no effect on time and cost by the use of FM, whilst almost one third (35% and 37% respectively) experienced benefits in terms of reduced time and cost of development. The update of that survey made in 2021 led to very similar results [10].

Author	Title	Type	Year	Topic for FM analysis	Input for CBA	Quantitative
Christer Löfving, Arne Borälv, Daniel Fredholm [17]	XRAIL-2 D5.2 "Formal Methods Application"	Report	2020	FM Application within X2RAIL-2 WP5 "Formal Methods and Standardisation for Smart Signalling Systems"	figure 23 - Use case for tender-based safety requirements (Pg 86) Figure 24 - Overview of formal verification process applied pg (87) Table 16 Effort in the TCG track using Rational Rhapsody (pg 212)) 17.4.3 Effort Consumption (pg 145) Table 15 Software development effort and workload distribution in the traditional development track. (pg 182)	yes
Romain Aïssat Arne Borälv [1]	X2Rail-2 - D5.3 – Business Case	Report	2020	Reference business cases developed in X2RAIL-2 and indications on LCC	Figure 2 - Life cycle phases; Figure 8 Sketch of FMs use in the business case (pg 32), Table 2 Investments required (per phase and actor (pg 34), Table 6 Effort consumed by each development track (Formal Development), Table 4 Number of requirements falsified during formal verification (Subtask 6 - V&V), for each development track	yes
Garavel, ter Beek et al. [11]	The 2020 Expert Survey on Formal Methods	Paper	2020	Multi-sectorial application of FM	Expert survey on benefits of FM (page 12)	yes
Prover	Signal modernization at Stockholm Metro	Article	2020	Application of FM in computer - based interlockings	Stockholm Metro adopted Formal Verification after having had a few incidents caused by design errors that had not been discovered by the traditional manual review process	no
Mario Gleirscher et al. [12]	Formal methods in dependable systems engineering: a survey of professionals from Europe and North America	Paper	2020	Use of FM in mission-critical software domains, examining industrial and academic views - cross-sectional on-line survey	-	no
Ter Beek et al. [22]	Adopting Formal Methods in an Industrial Setting: The Railways Case	Paper	2019	FM and tools in the railway sector	Fig. 5. Relevant quality aspects of FM (as in ASTRAIL and X2RAIL-2)	no
Bernhard Winkler [23]	Architecture-driven, Multi-concern and Seamless Assurance and Certification of Cyber-Physical Systems	Paper	2018	Case studies description and business impact	Table 2. Impact of IEC 61508 Standards on Intelligent Electrical Networks and Safety Improvement	no
ERTMS Users Group – EULYNX [7]	Reference CCS Architecture Based on ERTMS. White paper, 12-07-2018.	Paper	2018	Characteristics and (qualitative) benefits of the implementation of the Reference CCS Architecture developed using FM	The main targets and quality attributes of the RCA are: 1)Low LCC 2)A single modular framework 3)Migratability 4)Adaptability 5) Safe Investment"	no
David Burroughs - IRJ [5]	SNCF develops new-generation interlockings with €1bn Argos partnership	Article	2018	New generation of computer-controlled interlockings	According to SNCF, computer controlled new generation interlocks allow a 15% reduction in its budget for procurement, maintenance and future modernisation; reducing the cost, staffing and lead	yes

Author	Title	Type	Year	Topic for FM analysis	Input for CBA	Quantitative
				(developed within Argos partnership)	times for commissioning the new interlockings to limit the impact on traffic; and improving the overall performance of the new equipment with better cybersecurity, maintenance and operation	
Anders Linden (PROVER) [16]	A summary of the Signaling Design Automation Forum 2018	Article	2018	Latest evolutions of design automation – software technologies to automate design and verification of railway signaling systems.	Introducing mathematical verification techniques to railway interlockings in order efficiently prove safety.	no
Arcadis [2]	Feasibility study reference system ERTMS	Report	2017	Readiness of IMs to adopt standardized interfaces for ETCS	Short-Term versus Long-Term costs of ERTMS and digital CCS systems (3.3)	no
Edgar Serna M. et al. [21]	Power and Limitations of Formal Methods for Software Fabrication: Thirty Years Later	Paper	2017	FM capabilities, advantages and limitations that prevented their widespread adoption.	Table 1: Power and limitations of formal methods Table 3: Power and limitations of formal methods Table 4: Power and limitations of formal methods	no
Linh Ngoc Bui [4]	Analysis of the Benefits of EULYNX style Requirements Modeling for ProRail	Report	2017	EULYNX is using models for its functional requirement specification and for verification and validation (via model testing). However, ProRail might use models for different purposes.	Qualitative description of benefits of SysML modelling (2.2.2) Compatibility between EULYNX and Prorail (IM) requirements (4.2.4) EULYNX model benefits and its position in ProRail (11.3)	no
Jerry Krasner [14]	**H**ow product development organizations can achieve long-term cost savings using MBSE	Report	2015	Controlling costs across life cycle and product development with MBSE	Table 3.1: Comparing Cost of MBSE and non-MBSE Systems Developments (2010- 2015)	yes
Osaiweran et.al [19]	Evaluating the effect of a lightweight formal technique in industry	Paper	2015	The use of lightweight formal techniques in software engineering	Survey on quality code improvements (decrease of defects) when using FM in SW development (8.1) Baseline of productivity in ASD SW development (8.2) Survey on achieved quality and productivity of industrial projects that incorporated formal methods into software development (9.)	No (except cases for baseline)
Taro Kurita et al. [15]	Practices for Formal Models as Documents: Evolution of VDM Application to "Mobile FeliCa" IC Chip Firmware	Paper	2015	Practices of FM. Performance of latest application of VDM to the development of a firmware	Comparison of the performance of second and third generations of the firmware (pg 4)	yes
Saiqa Bibi, et al. [3]	Formal Methods for Commercial Applications Issues vs. Solutions	Paper	2014	Challenges in the use of formal methods for commercial applications industry.	Figure 2. Formal approaches' effect on cost Table 1. Formal verification vs. simulation. Activity time comparison; Table 2. Defects reduction with formal approaches	yes

Author	Title	Type	Year	Topic for FM analysis	Input for CBA	Quantitative
A.Davis, M.Clark, D.Cofer [4]	Study on the Barriers to the Industrial Adoption of Formal Methods	Paper	2013	Informal survey among stakeholders in the US aerospace domain; barriers to the adoption of FM and suggested mitigations	Perceived high entry cost of doing formal methods, lack of evidence of reduced cost for the second use of FM, psychological barriers, and skills barriers (pg 64). Formal analysis can be expensive in actual cost or measured financial risk.	no
Anthony Hall [13]	Realising the Benefits of Formal Methods	Paper	2013	Real benefits of FM	Fig. 1. Evidence for the achievement of low defect rates. Fig. 2. Cost of correcting a requirements defect according to the stage at which it is discovered. Fig. 3. Progress in Reducing Defect Rates	no
Alessio Ferrari et al. [9]	The Metrô Rio case study	Paper	2012	Bottom-up analysis of bug detection and correction costs for comparable rail/metro projects with code development with FM.	The cost of formal modeling is 30% higher than manual coding, due to higher costs for graphic editing (slower than textual editing) and the need of training. However, this greater effort is payed back by the cost reduction of the code verification activities (about 70%, with respect to a manual coding based process)	yes
John Fitzgerald et al. [10]	Industrial Deployment of Formal Methods: Trends and Challenges	Paper	2013	DEPLOY Project: benefits and challenges to creating and applying FM in industrial settings	Fig. 10.6 Reported effects of use of formal methods on time, cost and quality Fig. 10.7 Perceived overall success of the use of formal methods Fig. 10.10 Intention to use formal methods again	no
J.Woodcock et al. [24]	Formal Method: Practice And Experience	Paper	2009	Survey (2009) of industrial use of FM. .	Fig. 6. effects of the use of formal techniques on time, cost, and quality; Fig. 10. Intention to use formal techniques again	no

Table 2 - Literature review: sources and indication of input for the CBA

3.2 Expert survey

The first 4SECURail WP2 workshop, held in June 2020, was accompanied by the submission of a questionnaire on CBA methodology to 5 acknowledged FM-experts and representatives of IMs. The questionnaire consisted of three main questions on relevant aspects to implement the CBA. Moreover, a pairwise comparison between each proposed cost and benefit category was performed by interviewees to draw preliminary conclusions on the relative importance of such categories.

Main questions:

- Is cost and benefit list relevant and complete? Are interrelations between cost and prices (and between suppliers-IMs) suitable?
- Is a cost (€, time) baseline available in the market (i.e. at IMs) on the definition of requirements of RBC/RBC interface without FM? Is it lower or higher than the same with FM?
- Is the designed learning curve approach suitable and realistic?
- Is it possible to preliminarily estimate benefits for IMs and society in terms of Δ% against the baseline?

The respondents were also asked to rank the relevance and weight of costs and benefits, both by assessing the order of magnitude or expected difference against the Baseline scenario, and by a pairwise comparison, as methodological element of an AHP (Analytical Hierarchy Process), propaedeutic to the development of the CBA.

The following Cost and benefit categories were proposed in the workshop questionnaire.

RBC (or similar device) Purchase price
Learning / personnel training costs
Time to define requirements for RBC/RBC interface supply through FM *(for this category, please assess if – in your opinion – the time would be lower or higher)*
SW Licenses for requirements development through FM
Costs for RBC acceptance, verification and validation
Higher availability in case of service disruption (# service disruptions/year)
Higher maintenance efficiency (Lower replacement costs)
Lower accident risk

The respondents' first common suggestion is that the CBA should consider different elements to implement the CBA. The proposed list of cost and benefit categories is a relevant element but it should include the requirements and output documents required during the software development lifecycle in EN 50128 dividing into an initial stage of software adoption where there are high costs for both the software supplier and the IM'S.

Moreover, several very important elements to deepen the cost-benefit analysis were suggested as follows:

1) FM may be no longer considered in the medium future (approximately in 10 years). It leads to the necessity to consider a shorter time horizon for the analysis, shorter than the usual SW lifetime but in line with the entry into market of a new paradigm for SW development (e.g. introducing AI elements);

2) The cost-benefit ratio of FM adoption is likely being positive within the first generation of FM applications only. The short life cycle of any SW based tool leads automatically to cyclically safety approval cost which cannot be paid by the exclusion of "human staff”
3) The cost categories include both CAPEX and OPEX. However, the cost associated with the functional safety approval (more exactly the cost associated to demonstrate that the FM related SW tools match with the allocated SIL level of the functions taken into consideration) influences the overall business case.
4) FM related SW-Licenses costs are definitely on both sides, IM and supplier.
5) As concerns the split of V&V costs, almost 2/3 of the cost related to V&V matters are on the Supplier side, only 1/3 is usually on the IM side;
6) According to the experts, it is hard to predict that the suppliers will have lower purchase price due to a higher efficiency caused by using FM within the development phase. The use of IT-based project tools is already very common. Some suppliers of railway signalling systems already reduced purchasing prices by 2 up to 5% in case they got project files instead of paper-based data.
7) The effect in terms of “lower accident risk” is not easy to detect, and its relevance has to be further investigated, even by literature.

Cost baseline

As concerns cost baseline available in the market for the definition of requirements of RBC / RBC interface without FM (i.e. the Baseline scenario for the present CBA), the answers offered by the experts indicate that there is a baseline available (€) for the cost of the RBC, but not for the RBC/RBC interface. The cost for an RBC/RBC interface could be derived maybe from the experience gathered in past projects, but it is difficult to be sure about the accuracy of such cost calculation.
The analysis on pre-adoption / in use could show that the costs with FM would be higher than without FM, at least at the initial stages of the FM adoption, because the supplier would transfer development costs to the IMs. It seems to be useful to qualitatively compare total person-hours of the conventional (without FM) development and the new development by FM throughout the lifecycle, adding up person-hours of individual methods, as well as their pros and cons. In the workshop, the related cost must be added to the actual RBC/RBC interface but a real benchmark is not easy to be found.
Nowadays there is only a very limited need for RBC/RBC interfaces, this worldwide because IMs still waiting for the “marriage” of Interlockings (IXL) with RBC. Another important element is functional safety related requirements defined in EN 50126-x, EN 50128 and EN 50129 regarding the use of FM related methods, processes & SW based tools. The related cost must be added to the actual RBC/RBC interface ones. However, FM most likely leads to lower risk caused by systematic faults/failures, but safety statistic shows that there is no need for further improve safety.

Learning Curve

As concerns the definition of the learning curve, all the experts agree that initially the learning curve is flat. Maybe a more realistic approach would involve a learning curve not so linear. The decrease would be less intense at the beginning and the quantitative analysis must consider indirect elements. The curve will flatten more because suppliers will not want to share everything so each will have some new or replicated element of learning. And considering to the role of IMs, arguing that all IMs work with the same processes and tools assuming that the curve even resembles an exponential function with a negative exponent.

Pairwise comparison

In the pairwise comparison, respondents were requested to split a 100-point score to each couple of cost/benefit category, to assess the relative importance of one category compared to another. Adopting a simplified version of AHP applied to Multicriteria Analysis (MCA), the sum vector of each pairwise comparison between cost/benefit category has been reported per each of the four experts performing the pairwise comparison (see complete tables in Appendix).

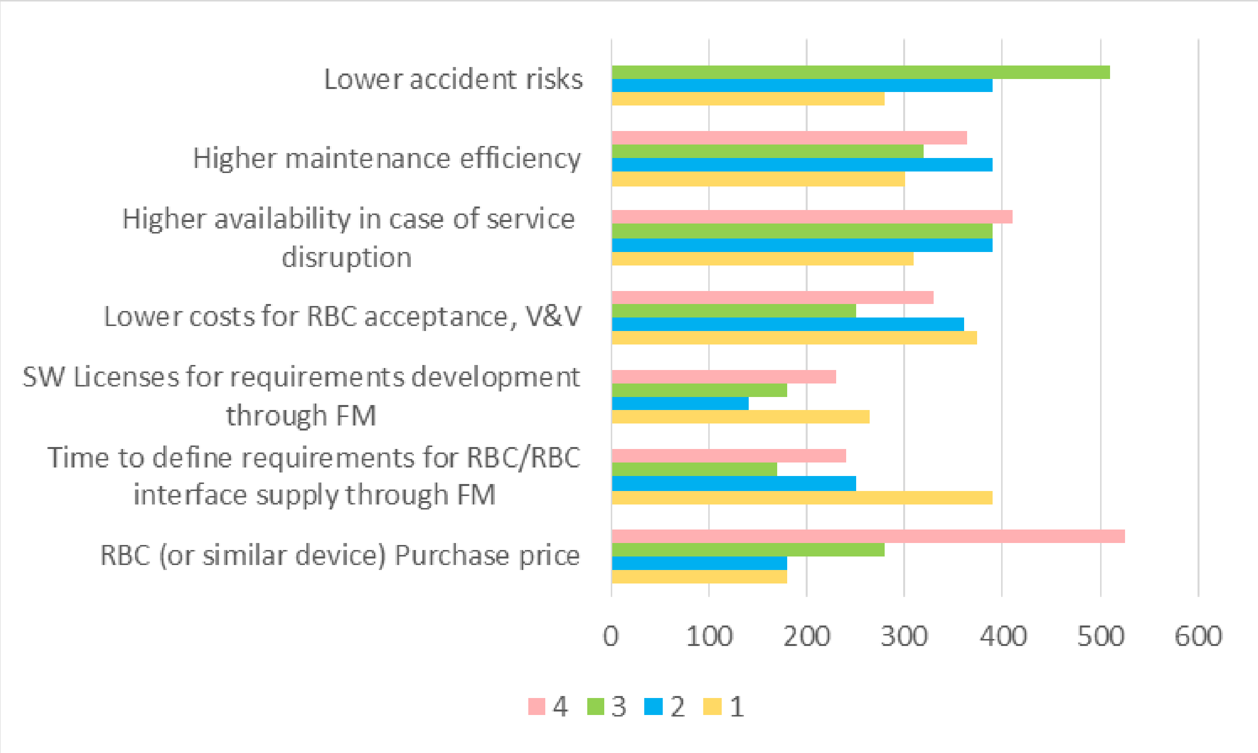


Figure 7 – Pairwise comparison results per participating expert

Results, depicted in Figure 7, report mixed conclusions on the relative and reciprocal relevance of cost and benefit categories.

The highest difference between experts' judgements is on the importance of RBC purchase price: only one expert considered benefits in terms of price reduction as higher than all other cost/benefit categories.

The same applies, even with a higher degree, as concerns improved railway safety. The possible lower accident risks is considered as the most important benefit category by one expert, whilst another attributed all "0" scores to this category, i.e. considering that FM adoption has a nil effect in terms of improved railway safety.

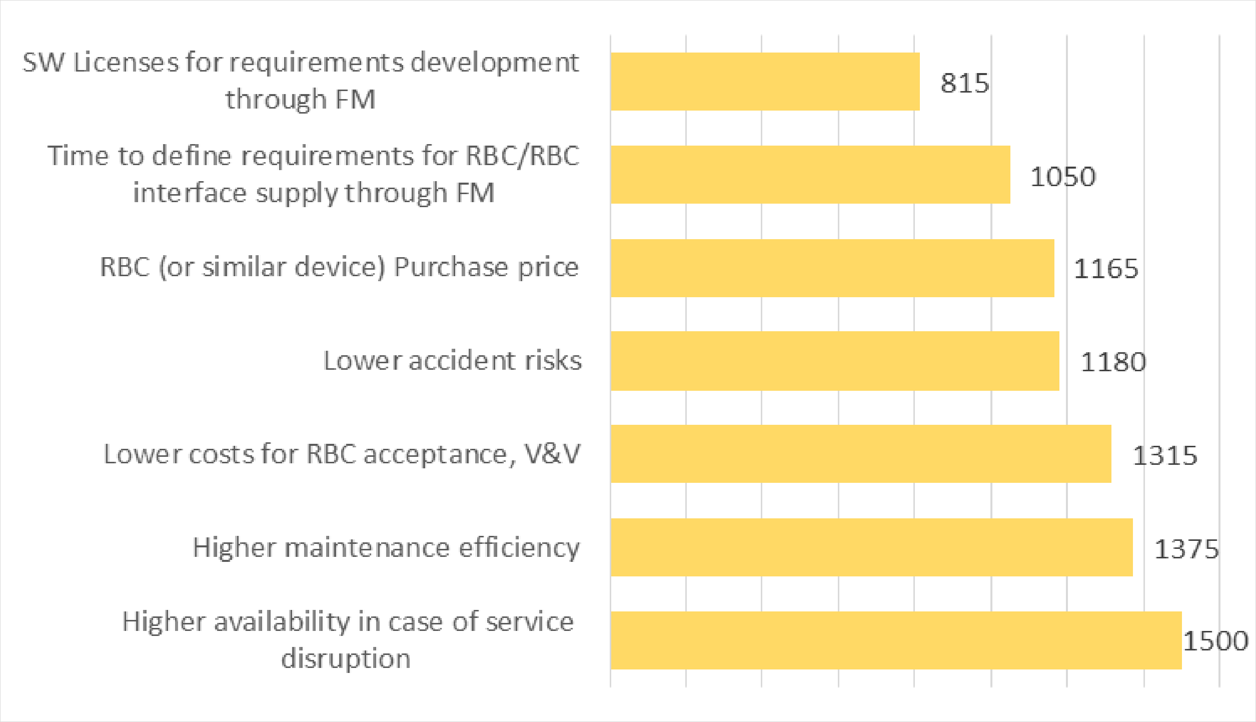


Figure 8 – Pairwise comparison results - overall

The sum of sum vectors, i.e. the sum of scores reported in Figure 7, leads to the outcome showed in Figure 8. Although the expert survey has not provided unanimous results as concerns the assessment of savings and benefits, the pairwise comparison has given an insightful ranking of cost/benefit categories, indicating the main streams on which the CBA should focus:

- The higher system availability in case of service disruption is considered as the most relevant benefit category. It implies the need for the CBA to focus also on benefits for rail users in terms of saved time (as described in 2.3);
- The higher maintenance efficiency is considered as the second ranked benefit category;
- FM adoption is important for IMs since it allows significant savings in V&V costs;
- The purchase price deriving from savings in SW development has a moderate importance, according to the experts;
- The cost of SW licenses, although confirmed as an additional cost, is considered as the less relevant category.

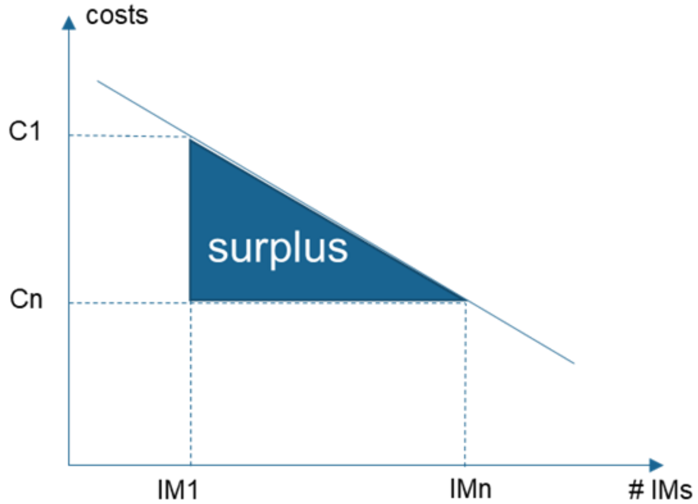
It is interesting to note that overall results of the pairwise comparison are in line with the expert survey made in the above-mentioned 2020 Expert Survey on Formal Methods.

4 The learning curve

4SECURail CBA is required to assess the "learning curve". Such concept may have diverse meanings if applied to the CBA.
The original approach identified by 4SECURail is twofold, regarding both IMs and suppliers:

- IMs are replicating FM adoption: "Replicant" IMs will benefit from lower learning costs vs. the "pioneer IM", since an FM "shelf" will be available, and learning will be possible from consolidated manuals/catalogues, with lower costs for tests.
- Multiple suppliers can apply for the same tender process issued by one IM releasing tender specifications developed with the use of FM: once learned formal specification in the first tender, suppliers will benefit from lower learning costs in the following tenders, in particular if some part of the FM-developed tender specifications are replicated in other tenders and/or by other IMs.

With this approach, the application of the "consumer surplus" theory is applicable to assess benefits deriving from the learning curve, with the assessment of different scenarios of FM diffusion among IMs during a specific timeline. The CBA has to assess how unit costs for the adoption of FMs (and cost savings) for one IM vary as more IMs adopt FMs. In other words, the CBA will assess the slope of the curve represented in the following diagram, in which (learning) costs associated to the n.th IM are lower than those borne by every preceding (i.e. adopting FM before the n.th) IM.



The output of the expert survey (see 3.2) has already provided some insights: experts generally believe that the slope of the curve is rather flat, indicating that benefits for the n.th IM are limited.

While assessing different "learning scenarios", the CBA has to investigate the following further aspects:

1) Matching "learning curve" concept with "change request" definition of X2RAIL-2, detecting any example of economies of scale connected with the diffusion of FM for the specification of railway safety components throughout more than one IM.
2) Guidelines for fine-tuning the learning curve concept:

a. Decrease (as more IMs adopt FM) of the time-related effort needed to learn how to define requirements through FM (IM) and how to develop SW through FM-based requirements (supplier)

b. (in the latter case) How, and if, the learning effort decreases throughout a certain time horizon, due to e.g.:

- Development of similar SW by the same supplier for different IMs
- Replication of components of tender-model in further tenders, by the same IM

3) Learning curve time-horizon: as already stated in the expert survey, the learning curve ends – together with the CBA time-horizon, when the FM-based requirements are no more a paradigm (or a challenge) for IMs, since they are replaced by other paradigms (e.g. AI systems) for development of specifications.

5 Conclusions

In the present deliverable the CBA approach followed by 4SECURail has been described, together with the first analysis tools deployed.

The CBA has been founded by the identification of RBC/RBC handover interface supply as the "case study" relevant for the analysis. The analysis takes the "point of view" of IMs, whereas relevant stakeholders, which costs differentials may affect the cost structure of IMs, are considered. CBA considers also benefits for rail transport service users and society as a whole.

Cost and benefit categories for which the adoption of FM is assumed to generate savings and benefits, have been defined and validated by experts, who also assessed the different credibility and importance of such categories.

The literature review showed that few examples of quantitative analyses are available on the assessment of costs and benefits of FM. If on the one hand this constitutes an important novelty factor for 4SECURail CBA on the selected case study, at the same time it implies a relevant effort and the need to formulate many assumptions for the assessment of costs and benefits of the Project scenario compared to the Baseline.

The next steps of the analysis, which outcome is foreseen in D2.6 (due in November 2021), will lead to a suitable assessment of costs and benefits and to the definition of the final results of the CBA, with conclusions on financial and socio-economic convenience of the adoption of FM in railway sector.

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Appendix: full results of the pairwise comparison

Expert #1

	RBC Purchase price	Time to define requirements for RBC/RBC interface	SW Licenses costs	Lower costs for RBC acceptance and V&V	Higher availability in case of service disruption	Higher maintenance efficiency	Lower accident risks	Sum Vector
RBC Purchase price		20	35	20	30	35	40	**180**
Time to define requirements for RBC/RBC interface	80		60	50	60	70	70	**390**
SW Licenses costs	65	40		35	40	40	45	**265**
Lower costs for RBC acceptance and V&V	80	50	65		60	55	65	**375**
Higher availability in case of service disruption	70	40	60	40		45	55	**310**
Higher maintenance efficiency	65	30	60	45	55		45	**300**
Lower accident risks	60	30	55	35	45	55		**280**

Expert #2

	RBC Purchase price	Time to define requirements for RBC/RBC	SW Licenses costs	Lower costs for RBC acceptance and V&V	Higher availability in case of service	Higher maintenance efficiency	Lower accident risks	Sum Vector
RBC Purchase price		40	60	20	20	20	20	**180**
Time to define requirements for RBC/RBC interface	60		80	50	20	20	20	**250**
SW Licenses costs	40	20		20	20	20	20	**140**
Lower costs for RBC acceptance and V&V	80	50	80		50	50	50	**360**
Higher availability in case of service disruption	80	80	80	50		50	50	**390**
Higher maintenance efficiency	80	80	80	50	50		50	**390**
Lower accident risks	80	80	80	50	50	50		**390**

Expert #3

	RBC Purchase price	Time to define requirements for RBC/RBC	SW Licenses costs	Lower costs for RBC acceptance and V&V	Higher availability in case of service	Higher maintenance efficiency	Lower accident risks	Sum Vector
RBC Purchase price		80	80	50	20	30	20	**280**
Time to define requirements for RBC/RBC interface	20		40	40	20	30	20	**170**
SW Licenses costs	20	60		50	20	20	10	**180**
Lower costs for RBC acceptance and V&V	50	60	50		40	40	10	**250**
Higher availability in case of service disruption	80	80	80	60		70	20	**390**
Higher maintenance efficiency	70	70	80	60	30		10	**320**
Lower accident risks	80	80	90	90	80	90		**510**

Expert #4

	RBC Purchase price	Time to define requirements for RBC/RBC	SW Licenses costs	Lower costs for RBC acceptance and V&V	Higher availability in case of service	Higher maintenance efficiency	Lower accident risks	Sum Vector
RBC Purchase price		90	80	80	80	95	100	**525**
Time to define requirements for RBC/RBC interface	10		50	10	20	50	100	**240**
SW Licenses costs	20	50		20	20	20	100	**230**
Lower costs for RBC acceptance and V&V	20	90	80		20	20	100	**330**
Higher availability in case of service disruption	20	80	80	80		50	100	**410**
Higher maintenance efficiency	5	50	80	80	50		100	**365**
Lower accident risks	0	0	0	0	0	0		**0**