Deliverable 2.6
Specification of Cost-Benefit Analysis and learning curves, Final release

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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.

The development of the CBA performed in the present deliverable has been based on the input of D2.4, in which the methodological elements of the CBA were sketched, together with a literature review of examples of quantitative and qualitative assessment of benefits of developing software with the adoption of FM in railway sector. The literature review showed that only few references show 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.

To identify the economic impact of the use of formal methods (FM) in the development of standard interfaces (SI), guidelines and specifications in the railway safety domain, against the Baseline Scenario represented by no use of formal methods, D2.4 described the case study (RBC/RBC handover interface, as defined and technically specified in D2.2 and D2.3) assumed to represent one of the most impactful operation on which the adoption of FM may generate benefits for Infrastructure Managers (IMs) and stakeholders involved in its development.

In 4SECURail the CBA is developed from the "point of view" of the infrastructure manager, and it is composed of Financial and Economic Analysis. The former includes the assessment of additional costs borne, and additional savings accrued by an infrastructure manager faced by the choice to use formal methods. The latter includes benefits for users, i.e. passengers of train services, and for the "society" at large.

Relevant categories of costs and benefits for the CBA have been identified, such as additional costs for learning FM and for developing tender specifications with FM for the procurement of a railway signalling component, savings in SW development, verification and validation, benefits for rail users due to higher maintenance efficiency, higher service availability and time saved for lower probability of service disruption. The quantitative assessment of these cost and benefit categories was possible by integrating the outcome of the demonstrator developed in 4SECURail, and assumptions based on literature and 4SECURail Consortium's knowledge and experience. The assessment was made difficult by the 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. Within the limited scope of the 4SECURail, it has been possible to streamline a micro, bottom-up case based on the point of view of one IM.

The CBA suggest that - in the case of railway signalling standards - efforts and costs for formal analysis of the system requirements are likely being distributed among the various entities supporting the standard itself, and not to a single IM. Benefits are spread over the entire supply chain, including suppliers, if economies of scale in SW development and the learning curve (i.e. progress in learning FM) are activated among IMs and suppliers. The "multi-supplier" mode enabled by FM is likely generating time and cost savings for rail safety industry. Benefits for users and society are relevant and sensible, although they have been quantified by making (realistic) assumptions on the higher maintenance efficiency generated by the adoption of FM by IMs. Once those assumptions are made, the analysis show benefits for users and society that may justify public granting of the adoption of FM in the railway safety domain.

Abbreviations and acronyms

Abbreviation / Acronyms	Description
B/C R	Benefit/Cost Ratio
CAPEX	Capital Expenditure (Investment Costs)
CBA	Cost-Benefit Analysis
D #.#	Deliverable #.#
ERTMS	European Rail Traffic Management System
FM	Formal Methods
HECT	Handbook of External Costs of Transport
HS	High Speed
IM	Infrastructure Manager
IRR	Internal Rate of Return
IXL	Interlockings
JU	Joint Undertaking
LCC	Life Cycle Costs
MBSD	Model Based Software/System Development
NPV	Net Present Value
OMG	Object Management Group
OPEX	Operating Expenditure (Operational Costs)
PM	Person-month
RBC	Radio Block Centre
SysML	Systems Modeling Language
UML	Unified Modeling Language
VoT	Value of Time
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 of 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 (RBC/RBC handover interface) 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.
The development of the CBA performed in the present deliverable has been based on the input of D2.4, in which the methodological elements of the CBA were sketched, together with a literature review of examples of quantitative and qualitative assessment of benefits of developing software with the adoption of FM in railway sector. The literature review showed that only few references show 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.
To identify the economic impact of the use of formal methods (FM) in the development of standard interfaces (SI), guidelines and specifications in the railway safety domain, against the Baseline Scenario represented by no use of formal methods, D2.4 described the case study (RBC/RBC handover interface, as defined and technically specified in D2.2 and D2.3) and the business case on which the Cost-benefit analysis is developed in 4SECURail. The business case was developed in cooperation with X2RAIL-2 and based on X2RAIL-2 "semi-formal methods development" business case, as defined in X2RAIL-2 D5.3 (section 6.3.4).

The present deliverable stems from the analysis started in D2.4, which is a preliminary release of the Cost-benefit analysis finalised in D2.6. Some sections, relevant to identify the main elements of the analysis, have been reprised from D2.4.

2 Elements of the 4SECURail approach to Cost-Benefit Analysis

The present section summarises the main methodological elements of the CBA as identified in D2.4. In 4SECURail the CBA is developed deploying the usual methodological elements and steps of the CBA (as defined e.g. in the EC Guide to Cost-Benefit Analysis [3]), 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;
- Calculation of monetized values of benefits for the IM, 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, IRR, B/C R[1]) 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.

The present report describes the way by which the CBA developed in 4SECURail fulfils the methodological elements of the CBA and provides results in terms of financial feasibility and socio-economic convenience of the adoption of FM in railway safety.

As concerns the <u>time-horizon</u> of the analysis, i.e. the time interval in which costs and benefits are allocated (and discounted over time), D2.4 (Section 3.2) suggested that FM may be no longer considered in the medium future, approximately in 10 years. It leads to the necessity to consider a 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. Thus, following a cautionary approach, a time horizon of 15 years has been assumed for the CBA, corresponding to three learning cycles (as defined in 3.1.2.

2.1 The case study, Project and Baseline Scenarios

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 such 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, the rationale for its choice and the adaptability to the business case proposed (see 2.3) have been defined in D2.4. The CBA is developed by comparing the Project with the Baseline Scenario:
Project Scenario: development of system specification of RBC/RBC handover interface (as technically 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;

[1] Net Present Value, Internal Rate of Return, Benefit/Cost Ratio, respectively. See list of abbreviations and acronyms.

- 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 (here called "Formal Methods") and the Baseline (here called "Classic") scenario.

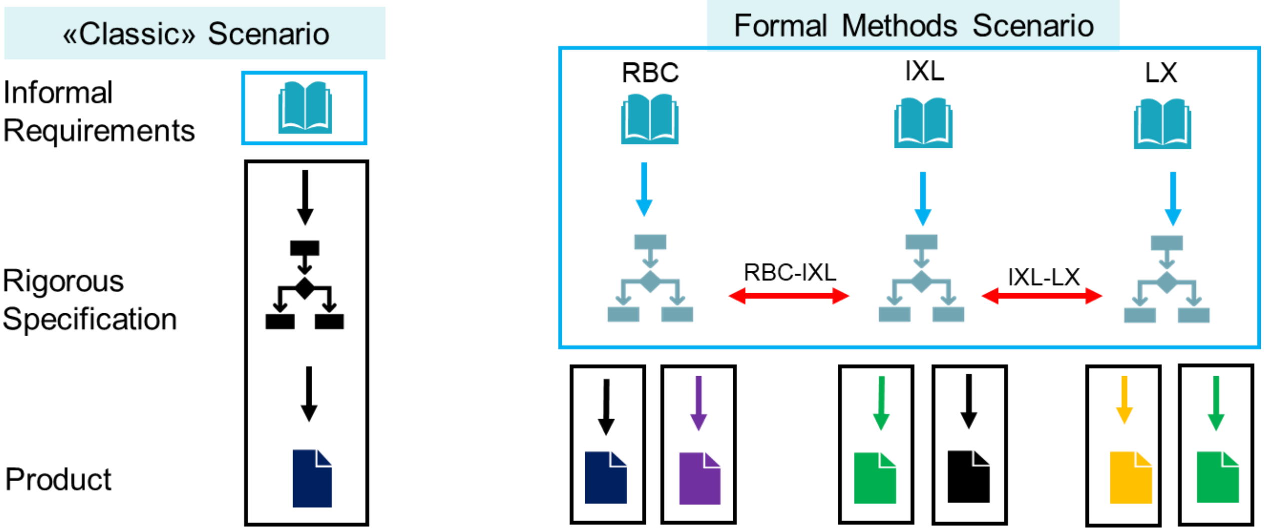

Figure 1 – "Formal Methods" vs. "Baseline" scenario, as defined in D2.1

As described in detail 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) [7]. 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 using 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.
As described in D2.4, The "Project Scenario" is represented by the right side of the figure ("Formal Methods Scenario"), 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 2.3). 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.

2.2 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.

As described in D2.4, the CBA takes into account the following stakeholders, and their economic interactions with the IM:

- "EULYNX follow-up": a body in which multiple IMs cooperate to develop common Standard Interfaces (SI), to be used as input for the development of tender specifications (developed with the use of FM);
- Suppliers: 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.

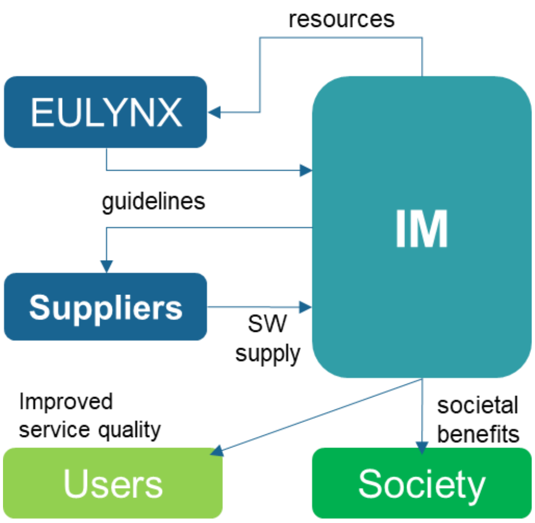

Figure 2 – The point of view of the CBA

2.3 The business case

The case study, as described in 2.1, 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 through a tendering process, 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.
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 2.1 – 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]. The 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. The specifications developed with the use of FM are released to several suppliers bidding in the tender;
c. V&V (verification and validation) costs: 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".

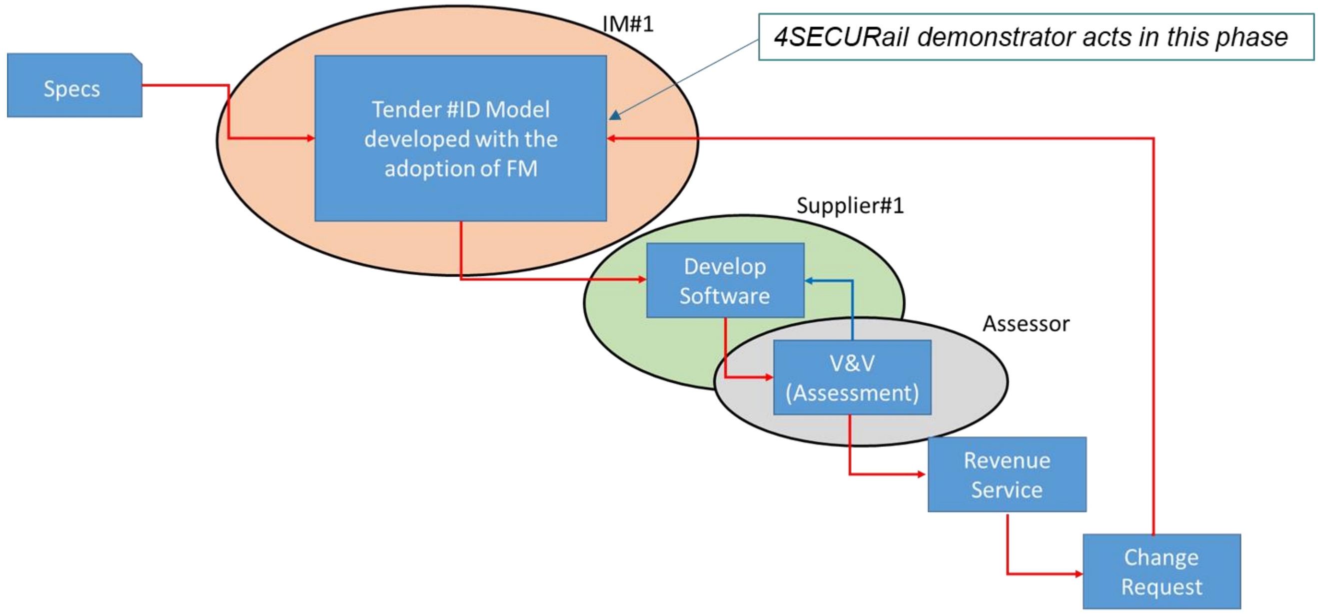

Figure 3 - X2RAIL-2 business case "semi-formal methods development", revised by 4SECURail

As a key aspect of the business case, "change requests" have been defined in D2.4. "Change requests" are not due to the detection of interoperability errors, 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.

This assumption has a key relevance for the CBA, since the adoption of FM is assumed to generate economies of scale both in the development of tender specification for change requests and in the SW development.

2.4 Cost and benefit categories

The cost and benefit categories which are relevant for the CBA have been defined in D2.4. They are reported in the following chart with corresponding measurement units, and clustered by relevant stakeholders. The chart distinguishes between investment costs (CAPEX) and operational costs (OPEX), as borne by the IM and the supplier.

	Cost/Benefit Item		Meas. unit	Monetary meas unit
Investment costs (CAPEX)	"EULYNX follow-up" -		Person-days	€/day
	RBC (or similar device) Purchase price		€/software/year	
		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	€/day
Operational costs (OPEX)	Time to define requirements for RBC/RBC interface supply through FM		Person-days	€/day
	SW Licences 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 it is evident from Figure 4, a major part of the cost/benefit items are borne/gained by 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, which however may benefit from savings accrued by other stakeholders involved in the process, such as the suppliers.
Assumptions on signs of differentials between Project and Baseline scenarios have been made for each cost item: those written in red in Figure 4 are assumed to increase in the Project scenario, while green items are assumed to decrease, representing net benefits.
From the list of cost items proposed in D2.4, one has been dropped: training costs potentially borne by suppliers to “learn FMs” are assumed to be negligible: SW suppliers receive specifications developed by IMs with FMs within the tender process with no need to undertake specific training.

The last four items represent net benefits by definition and their quantitative magnitude (and occurrence) has to be assessed in the CBA. The full explanation of cost and benefit items was given in D2.4.

3 Assessment of costs and benefits for IM

The quantitative assessment of costs and benefits for the IM faced to the choice between Baseline and Project Scenario 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 2.4 is a complex activity, requiring a detailed analysis of different sources. Such activities imply 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 first source for the assessment of costs is the input coming from the demonstrator, as defined and technically specified in D2.2 and D2.3. Differently from the statement made in D2.4, the CBA has catered a bottom-up assessment of time related costs connected to the development of the demonstrator, providing different scenarios prospecting different degrees of learning and implementation of the same process (i.e. developing specifications for the RBC/RBC interface with the use of FM) performed by an IM.

The assessment phase continues with the attribution of costs assessed by market survey and/or by calculation based on internal knowledge and expertise of 4SECURail partners.

In case no information is available from the previous sources, the assessment of specific cost and benefit items has been based on (duly explained) assumptions of minimum values necessary to counterbalance costs and benefits. This has entailed the execution of the final step necessary to conclude the CBA, i.e. the sensitivity analysis with the calculation of the switching value of key cost and benefit items, identifying which ones are the most relevant to ensure a net positive balance between costs and benefits.

3.1 CAPEX and OPEX borne by IM

The first step for the cost assessment is the calculation of costs (both CAPEX and OPEX) borne by an IM faced with the choice to develop specifications through FM. The CAPEX and OPEX, additional against the Baseline Scenario, have been assessed through the process described as follows, starting from gathering the input from the demonstrator, and then making necessary assumptions on costs, unit values and scope of the analysis.

3.1.1 Input from the demonstrator

The experience developed during the demonstrator allowed the estimation of costs connected to the development of the tender specifications for the IM. The present section describes the assessment of time effort for each FM language learning activity and for the development of specifications with FM. Based on the demonstrator experience, and taking into account the specific knowledge and expertise conditions by which the demonstrator was developed within the consortium, three scenarios can be assumed:

- The "observed demonstrator" effort, based on the effort recorded in the demonstrator for each activity.

- The “general case” effort, particularly relevant for language learning activities, assuming the situation in which the IM undertakes a more in-depth learning, estimated with the effort required by an academic course on UML based software engineering.
- The “advanced case”, assuming real advanced mastering of the topic, including the analysis all the related OMG documents.

For the calculation of time-related costs relevant for the CBA, when the observed demonstrator effort is not the only available scenario, the effort connected to the “general case” is assumed.

The time-related efforts are assumed to be additional against the Baseline Scenario as concerns language learning activities (A to E in the following box), whilst a baseline scenario effort of 2.0 person-months (PM) has been assumed for design activities (G to P). The baseline scenario represents the effort required to design specifications in natural language, i.e. without the use of FM.

Language learning activities

A) Design Language learning

The demonstrator is based on the adoption of SysML/UML as the design language.

Actually, an extremely small fragment of the SysML/UML notation has been used, whose knowledge can be considered well known or learnable with a minimal effort.

On the contrary, the complete mastering of this notation (requiring the knowledge of the official OMG documents such as UML-Spec, SysML-spec, pSSM, pSCS. fUML, ALF) would require a much greater effort.

The *observed demonstrator* effort can be estimated in 0.3 person months.

The effort for a more in-depth learning can be estimated with the effort required by an academic course on UML based software engineering (6 CFU) corresponding to 125 hours (1.0 person month). A real advanced mastering of the topic, including the analysis all the related OMG documents can probably grow to 2.0 person months.

Activity effort (SysML/UML): 0.3 PM *observed demonstrator* effort, **1.0 general case**, 2.0 advanced case

B) Design Tools learning

In the demonstrator two SysML/UML design tools have been experimented:

- a commercial MBSE design tool (SPARX-EA), and

- a prototype of academic design/verification tool (UMC)

In the final application of the demonstrator (Task 2.3) only the UMC tool has been used.

Being the demonstrator based on a strict subset of the UML notation, also the design tool learning estimate can be split in what actually measures, and what likely in a more general case.

Efforts for learning the tool for system design, measured by a consortium partner without previous knowledge of the topic, can be estimated as follows, also considering that:

- Only the SPARX-EA solution has the level of industrial maturity required for the industrial use.
- Several commercial alternatives to the SPARX-EA framework can be found in the market (e.g Dessault Magic Draw, PTC, Rhapsody); they require comparable learning efforts.

Activity effort:
UMC: 0.1 PM observed demonstrator effort, **0.2 general case**
SPARX-EA: 0.5 PM observed demonstrator effort, 1 pm general case

C) Formal Modelling Language learning
4SECURail demonstrator has experimented three formal modelling notations: UMC, ProB and LNT. The tool UMC, being UML based, plays both the role of a design and formal modelling tool.
Also, in this case only a small fragment of the modelling language features has been used, therefore the learning effort experienced with the demonstrator is smaller than what required in a more general case.
In the UMC case, the effort for learning the formal modelling language has already been considered as effort for learning the design tool notation.
Also, in this case the effort observed with the demonstrator is smaller than what likely requested in a more general case, because of the limited features exploited. For the CBA, the "general case" effort referred to ProB has then taken into account.

Activity effort:
ProB: 0.5 PM *observed demonstrator* effort, **0.7 general case.**
LNT: 0.7 pm *observed demonstrator* effort, 1.0 general case.

D) Formal Verification Language learning
For "Formal Verification Language learning" we mean the learning of temporal logics notations needed to perform the model checking of the system designs, since all the experimented tools allows this approach to formal verification. As described in D2.5, temporal logics can be used in a lightweight or advanced way. Both alternatives are reasonable, but they clearly require different efforts. The lightweight approach basically allows the detection of deadlocks, reachability and invariant properties, runtime errors. The advanced approach allows the specification of any other custom property expressible in the logical notation. The effort for building the necessary background on temporal logics issues is likely the same for the three tools considered.
The effort for the advanced case is estimated with the effort required by following an academic course on model checking and temporal logics.

Activity effort temporal logics: **0.2 PM observed demonstrator and general case**, 0.5 pm advanced case.

E) Formal verification tool learning
Verification tool learning means the effort needed to learn the specific verification functionalities provided by the verification framework. These functionalities may go beyond model checking, and extend to constraint solving, model reduction and abstractions, equivalence verification, refinement verification, and possibly in learning the use of the associated scripting languages.
As in the previous activity, a *lightweight* use of formal methods might not require the use of such further forms of analysis. A more general use of the verification frameworks might exploit also some of these features, and an advanced use might be necessary to extract from the tool all its possible power. In this case the efforts for the tool learning have been estimated as follows, taking into account UMC as the tool used in the demonstrator.

Activity effort:
UMC: 0.4 PM *observed demonstrator* effort, **0.5 pm general case**, 0.6 advanced].
ProB: 0.4 PM *observed demonstrator* effort, 0.7 pm general case, 1.0 advanced].
LNT: 1.0 PM *observed demonstrator* effort, 1.5 pm general case, 2.0 advanced].

Summing up the efforts considered for each activity, **the total reference time effort for learning activities considered for the CBA is 2.7 person-months.**

Design activities

F) Scope of the Specification: size in terms of number of requirements
The initial requirements document (D2.3) contains 79 System Requirements.
The final demonstrator Deliverable (D2.5) rewrite the initial requirements in new **50** requirements excluding 10 non-functional requirements and 12 requirements related to non-modelled configuration options.
System Requirements Size: 50

G) Design
In this case the *observed demonstrator* effort needed to disambiguate the initial requirements, to construct the semi-formal UML model and to encode it as executable UML design is considered. This figure includes the effort to develop specific implementations of the abstract features specified in the requirements. This activity has been performed in the demonstrator using UMC and only in part with SPARX-EA.

UMC system design: **2 pm *observed demonstrator* effort**

H) Debugging
The debugging of the system design has been performed with UMC.
In this case for debugging, we mean just static analysis, interactive animation and lightweight verification of the system (e.g. deadlock analysis).
From this point of view, debugging with UMC overlaps with initial step of formal analysis, still conducted with UMC. Anyway, the effort has been considered for the CBA.

UMC debugging of the system: **0.5 pm *observed demonstrator* effort**

I) Formal Modelling
The UMC system design is already a formal model, and then no additional effort would be needed. However, in the demonstrator two other formal notations and tools have been used (ProB and LNT). ProB and LNT models of the system have been generated mechanically with no effort using available specific translation tools (UMC2ProB, UMC2LNT).
Even if the UML design was not done in UMC, but using other SysML frameworks, the effort of this task should be considered as nil because the availability of automatic translation tools from SysML/UML to other formal notations is considered a *mandatory* requirement for the exploitation of formal methods.

It should be considered that, at the current state of art, to our knowledge no commercial SysML/UML frameworks seem to support this kind of automatic model transformation.
No additional effort for Formal Modelling has then been considered for the CBA.

L) Tracing the Design
The rewritten version of the requirements, the semi-formal UML models, and the UMC/Prob/LNT models are kept aligned, propagating each modification initiated in any of these artifacts to the others. This task has been performed manually.

Tracing the Design: 0.3 PM *observed demonstrator* effort

M) Tracing the formal model
This part has already been covered by the previous point.
The translation from the UMC models to the other formal notation is done automatically, preserving the structure of the model and the comments present in it.
No additional effort for Formal Modelling has then been considered for the CBA.

N) Specifying properties
This activity refers to the effort needed for the encoding in terms of temporal logics of the properties to be verified through model checking. This activity has been performed by the demonstrator in a limited way, with the formalization of relatively simple properties.

Specification of properties: 0.2 PM *observed demonstrator* effort

O) Verifying properties
This case includes both the effort needed to design and implement the verification scenarios, upon which to verify the properties by model checking, and the actual verification effort. This case also considers the analysis of properties using model abstraction and reduction techniques.

Verification of properties: **2 PM *observed demonstrator* effort**

P) Debugging the Formal Model
This activity includes the effort needed to plan the design of the verification scenarios, and the effort to analyse the model checking counter-examples and more in general the results generated by the formal analysis. This activity has been performed in a limited way in the demonstrator, sufficient however to achieve a satisfactory level of confidence on the correctness of the design.
It is considered that a real industrial use would invest more time in this activity to achieve an even higher level of confidence on the quality of the analysed standard interface.

Debugging formal model: 2 PM *observed demonstrator* effort.

Summing up the efforts considered for ach activity, **the total reference time effort for design activities considered for the CBA is 7.0 person-months.**
The time effort for design activity is compared to the effort assumed for the Baseline Scenario (2.0 PM), assessing an additional effort of 5.0 PM for the Project Scenario.

3.1.2 Assumptions on learning costs, scope of FM application and other CAPEX

Once assessed the time efforts borne by IMs to learn FM and design specifications with the use of FM, assumptions have to be made on the other cost and staff variable to assess the total CAPEX to be borne by the IM to develop the Project Scenario.
Key to assess investment costs for learning is defining the learning scope of the FM application, to i.e. assessing how many similar specifications can be developed with the use of FMs once the IM has undertaken the investment on FM learning, and how many staff components are necessary.
The following assumptions have been made.

Learning frequency: the training process, and the related learning costs are assumed to borne by the IM every 5 years. This is due to assume possible staff turnover and other circumstances that determine the need to revamp the IM's internal knowledge on FM.

Staff mix: the need to cooperate between staff of different seniority within the IM is assumed in the CBA as the need to hire "newly skilled" staff (junior trainees) to side senior engineers and learn together FM. Thus, it is assumed that 3 IM staff (one senior + 2 junior-trainees) are deployed to develop specifications through FM in the tendering business model. The annual cost for staff, based on Consortium's internal knowledge, is assumed 70.000 €/year for senior engineers and 27.000 €/year for junior and trainees. To simulate the likely ramp-up of juniors' wage over years, the staff cost of juniors is assumed to increase by 10% each year over the 5-year period of the learning cycle. The staff cost of juniors is restored to the base level after the 5th year, when a new learning cycle begins.

Change requests: each change request, as defined in 2.3 and in D2.4, is assumed to require the development of new tender details and specifications, developed with the use of FM. Such specifications are assumed to be developed with a lower effort than deployed for the "primitive" specification, 4.0 PM instead of 5.0 PM. As duly explained in 3.1, this is the differential effort between the Project and the Baseline scenario.

Staff capacity exploitation: the need to exploit the workforce trained in FM leads to the assumption of full exploitation of the working time of the "taskforce" staff of the team deployed to develop specifications with FM. Since the total working time of each taskforce is 36 PM, the total number of specifications potentially developed in a year is 5. However, following a cautionary approach, for the present CBA the layout assumed to cover the total taskforce work potential in one year is the development of 1 new tender specification + 4 change requests per year. Specifications for change requests are assumed to be developed starting from the second year of the timeline, whilst only a single specification for a new tender is developed in the first year.

Following these assumptions, the calculation of learning costs is made applying the effort ("general case") estimated in 3.1 (2.6 PM). Thus, the investment cost (CAPEX) for learning is **26.867 €**, borne by the IM every 5 years.

3.1.2.1 Software licences

As already specified in D2.4 and in 2.4, the IM is assumed to endow its taskforce deployed to develop specifications through FM by purchasing a sufficient number of licences of the most appropriate software. This is the other CAPEX, other than staff cost, assumed to be borne by the IM in the present CBA.

The first assumption is that licences are “floating”, i.e. they can be used by more than one user, but not at the same time. Assuming that IM’s taskforces are made of three staff, two licences are required as minimal equipment. Moreover, according to a market survey undertaken by the Consortium among the main SW producers, licences issued as “perpetual”, i.e. they potentially do not need to be renewed. However, the renewal of licences after 5 years, i.e. after the end of each learning cycle, has been assumed.

The same market survey allowed the assessment of purchase cost of SW licences. Some guidelines on the choice have been followed in line with the experience developed in the demonstrator. As described in 3.1, the goal to develop a formal analysis starting from a mapping SW (from UML schemes to ProB models) has been reached in 4SECURail demonstrator with the deployment of a prototype of academic design/verification tool (UMC). However, it is assumed that IMs endow themselves of a SW widely available and tested in the market, at least to perform mapping and generate documentation.

This condition is possible with the already mentioned SPARX[2] software, which – according to the market survey among the best-known brands[3] – appears to be the less expensive SW to fulfil the purpose of the case study with the necessary components and user-friendliness. The choice was made also taking into account to ensure that suppliers (i.e. software developers called through a tender process to develop RBC, in the case study) can respond with the necessary flexibility to change requests. For this reason, more complex and expensive products such as SCADE have not been considered since they risk binding the suppliers to the use (and the purchase itself) of the software, with little opportunity to recover the CAPEX and definitely against the multiple-supplier principle on which 4SECURail business case is built. The Consortium is nevertheless aware of the advantage that the use of software like SCADE could bring in the certification process. However, this advantage it is not considered sufficient to pay off the investment.

Once made these assumptions, a CAPEX of **1.800 €** for the purchase of two SPARX (floating, perpetual) licences has been considered for the CBA.

3.1.3 Summary of CAPEX and OPEX

The above-described process allows the calculation of the total cost of learning and specifications development, as borne by the IM during the 15-year time horizon. The following table summarises all calculations made, in line with the assumptions and the input from the demonstrator.
The calculation of total costs covers all cost items assumed to be borne by the IM in 2.4, clustered into CAPEX (learning and SW licences) and OPEX (Specification development costs).

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[2] SPARX Enterprise Architect – Ultimate. https://sparxsystems.us/solutions/ [10]

[3] The costs of licence of other SWs such as “IBM Engineering Systems Design Rhapsody - Architect for Systems Engineers”, “Widnchill” and “NoMagic” have been surveyed

	year	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*
Learning and specification development																
Additional staff (senior)	#	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Additional staff (junior/trainee)	#	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Unit staff cost (senior)	€/y	70.000	70.000	70.000	70.000	70.000	70.000	70.000	70.000	70.000	70.000	70.000	70.000	70.000	70.000	70.000
Unit staff cost (junior/trainee)	€/y	27.000	29.700	32.670	35.937	39.531	27.000	29.700	32.670	35.937	39.531	27.000	29.700	32.670	35.937	39.531
Staff costs-IM	€/y	124.000	129.400	135.340	141.874	149.061	124.000	129.400	135.340	141.874	149.061	124.000	129.400	135.340	141.874	149.061
Learning-general case	PM	**2,6**					2,6					2,6				
Learning costs	**€/y**	**26.867**					**26.867**					**26.867**				
Development effort (single specification)	PM	7,0	7,0	7,0	7,0	7,0	7,0	7,0	7,0	7,0	7,0	7,0	7,0	7,0	7,0	7,0
Development effort (single specification)-BASELINE	PM	2,0	2,0	2,0	2,0	2,0	2,0	2,0	2,0	2,0	2,0	2,0	2,0	2,0	2,0	2,0
Specification development cost	€/y	51.667	53.917	56.392	59.114	62.109	51.667	53.917	56.392	59.114	62.109	51.667	53.917	56.392	59.114	62.109
Specifications/year	*#*	*5*	*5*	*5*	*5*	*5*	*5*	*5*	*5*	*5*	*5*	*5*	*5*	*5*	*5*	*5*
Potential specification development cost	*€/y*	*258.333*	*269.583*	*281.958*	*295.571*	*310.545*	*258.333*	*269.583*	*281.958*	*295.571*	*310.545*	*258.333*	*269.583*	*281.958*	*295.571*	*310.545*
Development effort (change request)	PM	4,0	4,0	4,0	4,0	4,0	4,0	4,0	4,0	4,0	4,0	4,0	4,0	4,0	4,0	4,0
No. change requests/year	#		4	4	4	4	4	4	4	4	4	4	4	4	4	4
Specification development cost (spec.+change requests)	**€/y**	**51.667**	**140.183**	**146.618**	**153.697**	**161.483**	**134.333**	**140.183**	**146.618**	**153.697**	**161.483**	**134.333**	**140.183**	**146.618**	**153.697**	**161.483**
SW Licences	€/y	1.800					1.800					1.800				
Total cost of learning and spec. development	**€/y**	**80.333**	**140.183**	**146.618**	**153.697**	**161.483**	**163.000**	**140.183**	**146.618**	**153.697**	**161.483**	**163.000**	**140.183**	**146.618**	**153.697**	**161.483**

Table 1 – Learning and specification development – annual costs (CAPEX + OPEX)

As per Table 1, costs for the development of specifications (one + change requests per year))range from nearly 80.000 €/year assessed at the beginning of the time horizon, to nearly 140.000 €/year at the second year of the learning cycle, to **160.000 €/year** at the end of the learning cycle, i.e. in the year characterized by the highest cost of juniors/trainees.

3.2 Savings in SW development and V&V

As specified in 2.4, additional costs and potential savings brought by FM to the development of RBC/RBC interface (and RBC software) by IM's suppliers (i.e. SW developers) are assumed to be reverted to SW purchase price: if the supplier saves on development and verification and validation (V&V) costs, such savings determine a proportional decrease of the purchase price of the SW ordered (through a tender process) by the IM. This assumption is once again in line with the full-competitive perspective adopted in 4SECURail, made possible – or at least facilitated - by the adoption of FM in the development of specifications, which ultimately determines a lower dependence of an IM from a single long-term supplier.

According to the Consortium's internal knowledge on time and costs for developing RBC-RBC interface (or case studies having similar complexity) vs Baseline scenario (interface developed without FM-tender specification), the following assumptions have been applied for the CBA:

<u>SW Development:</u> if specifications are developed with FM in the tender, the potential savings in th SW development are estimated around 20% on a baseline effort of 12 PM. Time savings are assumed to be focused on debugging activities, which are expected to be less time consuming with FM. The time saving figure assumed for the CBA is **2.4 PM per SW development.**

<u>V&V:</u> the effort for V&V made by the Assessor at the supplier's premises is assumed to be reduced by 20% on a baseline effort of 3 PM. The time saving figure assumed for the CBA is **0.6 PM per V&V process.** Savings are focused on Verification phase of the V&V process. Additionally, the supplier is assumed to save **3.000 Euro** on the lump sum cost for the Assessor.

The savings per time/cost category are summarised in the following table.

Time/cost category	Baseline	+/- Δ
RBC-RBC Interface development	12 PM	-20%
V&V effort	3 PM	-20%
V&V Assessor costs	6.000 €	-3.000 €

Table 2 – Assumptions on time and cost savings for SW development

Assuming a standard labour cost of 72.000 Euro/year (6.000 Euro/PM) for skilled engineers deployed by suppliers, the total cost savings gained by the supplier for each SW development (of a complexity comparable to the case study) is **21.000 Euro.** This figure is considered for the CBA without any sensitivity analysis.

When comparing the figures of Table 1 and the unit savings calculated in this section, it is evident that the convenience for the IM to adopt FM is connected to the economies of scale generated by

the replication of savings in SW development into the implementation of SW and components (similar to the first one) in reply to change requests, issued by the IM through further tender processes.
Since such economies of scale are likely verifiable but not easily quantifiable, the analysis has followed up with the identification – by means of sensitivity analysis - of the optimal scale for which the additional resources deployed by the IM generate enough savings in purchase price to balance the additional investment and operational effort. Questions for this sensitivity analysis are the following:

- What is the business scale for which the higher effort borne by IM is balanced by savings in the development of the interface?
- How much suppliers should save in the development of interfaces similar to the case study in reply to change request, to ensure a competitive purchase price (i.e. lower than higher CAPEX and OPEX borne by the IM), over years?

Such analysis can be developed by assuming different and increasing time savings to develop interfaces after change requests: the "base" time saving is 20%, in line with the assumption made for the main specification. Then 30% and 40% savings have been assumed.

In the following figure unit costs are applied to time effort for the development of the main specification and change request responses, assuming – in line with the frequency of tendering by IMs assumed in 3.1.2 – the response to one main tender with FM-based specifications, and 4 change requests. As evidenced in the figure, the break-even between additional costs borne by IM and savings is verified, according to 4SECURail demonstrator input, if the purchase price of SW upon change requests is -40% vs. the baseline.

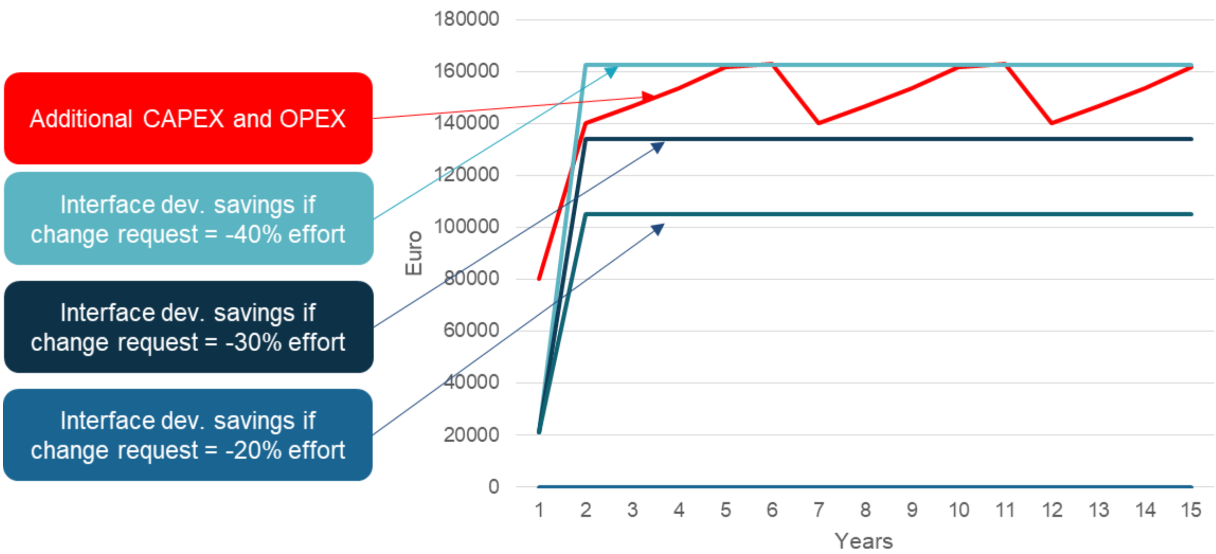

Figure 5 – Cost savings in SW development vs. additional CAPEX and OPEX

When assuming 40%-time savings in SW development in case of change requests, the total annual savings for suppliers are **162.600 €/year**, which overcome additional costs borne by IMs every year except the ending learning cycle one, i.e. when the labour cost has increased to the maximum assumed during the learning cycle. The calculation process is evidenced in the following table, which covers the first two years of the time-horizon (i.e. the first one, with no change requests, and the second one, having a cash flow identical to all other years in the period).

	year	***1***	***2 and onwards***
Time savings interface development	PM	2,4	2,4
Time savings V&V	PM	0,6	0,6
V&V costs (Assessor) savings	Euro	3.000	3.000
Assumed PM time saving development change request	40%		
Time savings interface development (change request)	PM	4,8	4,8
Staff cost supplier	Euro/PM	6.000	6.000
Development and V&V cost savings (single interface)	Euro/year	21.000	21.000
Development and V&V cost savings (single change request)	Euro/year		35.400
Potential cost savings (5 interfaces)	*Euro/year*	*105.000*	*105.000*
Assumed cost savings (interface + change requests)	**40%**	**21.000**	**162.600**
	30%	21.000	133.800
	20%	21.000	105.000

Table 3 – Calculation of savings in SW development and V&V

3.3 Net benefits for the IM – Financial indicators

Following the calculations and the assumptions made above, assuming that cost savings enjoyed by suppliers are passed on to prices (to decrease SW purchase price), the IM face net cash flow savings over the time horizon, quantifiable by calculating the cumulated cash flow. This can be calculated by comparing the additional CAPEX and OPEX (calculated in 3.1) and savings (calculated in 3.2). The same comparison allows the calculation of the Financial Analysis indicators (NPV, calculated with the 4% discount rate recommended by the EU CBA Guide, Financial IRR), as key results of the first part of the CBA (see introductory paragraph of Section 2).

The following table and chart evidence that IMs benefit from a net positive cash flow during the 15-year period considered for the CBA. At the end of the time horizon, the net positive cash flow is **85.000 €.** Indicators of the Financial analysis are highly positive: **NPV is 50.917 € and IRR is 17,9%**. Such values demonstrate the financial feasibility of the adoption of FM from the point of view of a single IM.

	year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Financial Analysis																
CAPEX and OPEX for IM		-80.333	-140183	-146618	-153697	-161483	-163000	-140183	-146618	-153697	-161483	-163000	-140183	-146618	-153697	-161483
Savings in SW development		21000	162600	162600	162600	162600	162600	162600	162600	162600	162600	162600	162600	162600	162600	162600
Cash flow		**-59333**	**22417**	**15982**	**8903**	**1117**	**-400**	**22417**	**15982**	**8903**	**1117**	**-400**	**22417**	**15982**	**8903**	**1117**
Cumulated cash flow		**-59333**	**-36917**	**-20935**	**-12032**	**-10915**	**-11315**	**11102**	**27083**	**35986**	**37103**	**36703**	**59120**	**75102**	**84005**	**85122**
NPV	**€ 50.917**															
IRR	**17.9%**															

Table 4 – Cash flow (Euro/year) and Financial Analysis indicators

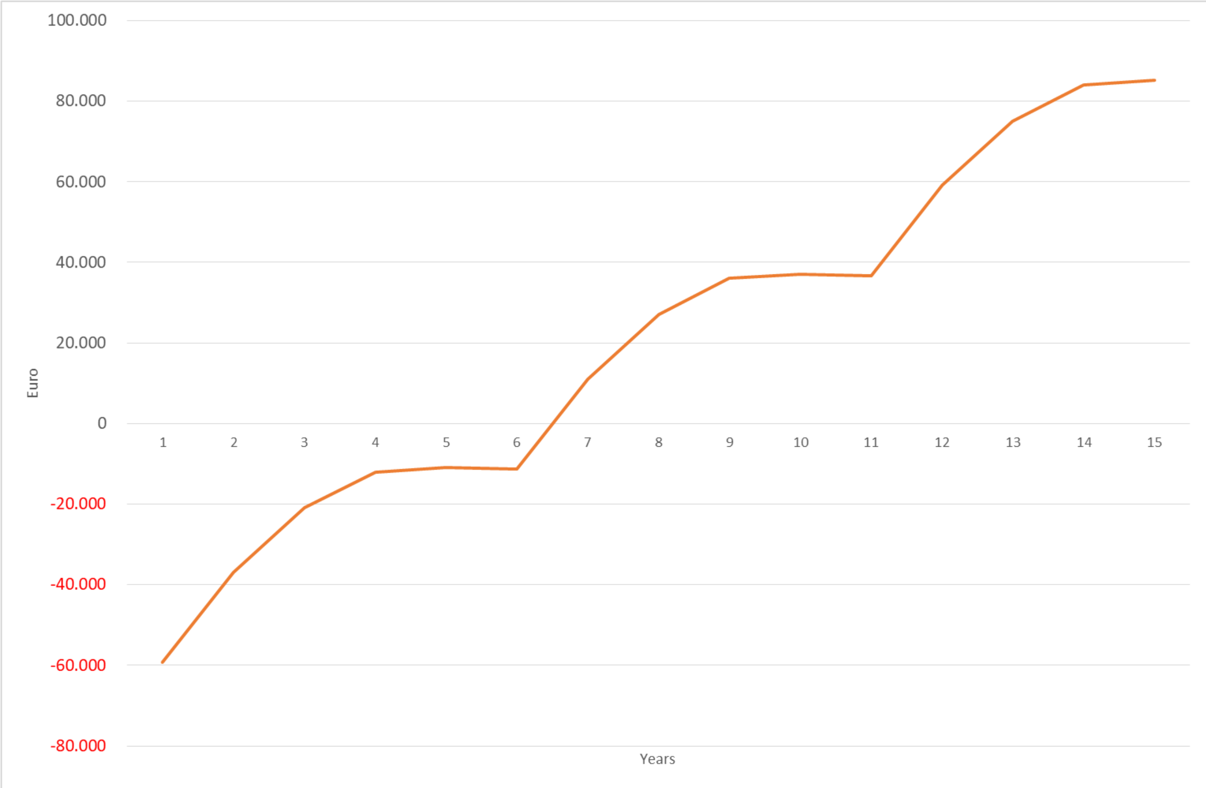

Figure 6 – Cumulated cash flow trend

4 Assessment of benefits for higher maintenance efficiency

The Economic Analysis, i.e. the second part of the CBA, aims at assessing the benefits due to higher maintenance efficiency, higher service availability and time saved for lower probability of service disruption.

The first step of the assessment of benefits is the quantification of service disruptions that may happen on a rail line due to failure of RBC/RBC handover interface. Among possible causes of failure, those leading to service disruptions due to the ambiguity of specifications (i.e. those potentially avoidable by the development of specification by use of FM) are very rare according to 4SECURail Consortium's knowledge (0.1% of total cases).

The calculation of penalties avoided due to avoidance of service disruptions is possible by applying penalties prescribed by Performance Regimes set in the IMs Network Statements. Such penalties have been considered as avoided if service disruptions are avoided. Thus, the related amount saved by the IM is taken into account as net benefit in the CBA.

Moreover, avoided service disruptions or interruptions mean avoided delays for passengers, which can be monetised applying the appropriate value of Time (VoT).

Some possible scenarios have been assumed, applied on two Italian lines (Milano Rogoredo – Melegnano for non-High Speed – highly congested node, relevant for regional services, Firenze-Bologna for HS line), to assess benefits for users of magnitude of benefits for users in case cancellations or delays are avoided due to higher maintenance efficiency generated by FM. The process is visualised in the following figure.

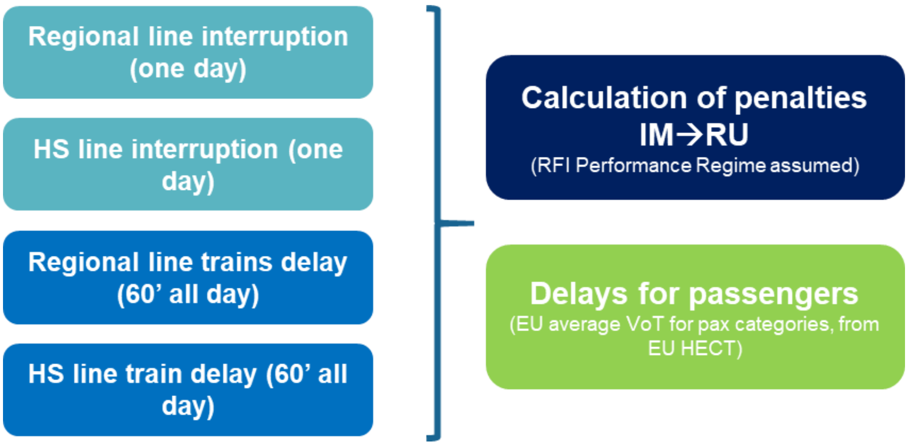

Figure 7 – Benefit for users – assessment process

4.1 Avoided penalties

The calculation of penalties has been based on the Performance Regime in force on the Italian rail Network, issued by RFI and valid until 2023 [8]. The values of penalties applied to service interruptions (train cancellations) and delays caused by the IM (and passed on to railway operators) are the following:

- Delay 60 minutes: 4.5 € per minute = **300 €** (applied both on HS lines and rail nodes).
- Train cancellations: 120 € (applied both on HS and regional services).

The simulation has assumed a service disruption causing 60' delay or train cancellation during one day on both reference Italian lines, for which a daily traffic of 116 trains (Milano-Melegnano) and 109 trains (Firenze-Bologna HS) is reported in the Network Statement [9].

The calculation of penalties avoided is reported in the following table, which assumes one service disruption (connected to one RBC/RBC interface developed with FM) in the first year, and 5 service disruptions (RBC/RBC interface + 4 change requests) per year, in line with the assumptions made for annual tender developments made in Section 3. As evidenced in the table, the service disruptions avoided have a value ranging from nearly **13.000 €/event** in case of cancellations, **32-34.000 €/event** in case the service disruptions cause 60' delays. Such values are taken into account as benefits in the CBA.

Of course, the assumption of one service disruption avoided per FM-based interface development is a guesswork estimate, based on the probability of service disruptions due to the ambiguity of specifications mentioned above and reported by 4SECURail Consortium's internal knowledge. However, the value of penalties avoided per event is in line with the 0.1% of total penalties issued to IM and passed on to railway operators in the Italian rail network in a year, according to the latest value publicly available (2016) [5]. This enhances the credibility of the assumptions made for the present CBA.

	year	*1*	*2 and onwards*
Unit penalty-regional (delay 60 min)	Euro	300	
Unit penalty-HS (delay 60 min)	Euro	300	
Unit penalty-regional (cancellation)	Euro	120	
Unit penalty-HS (cancellation)	Euro	120	
Trains-regional	#/day	116	
Trains-HS	#/day	109	
Penalties cancellation-regional	Euro/year	13.920	69.600
Penalties cancellation-HS	Euro/year	13.080	65.400
Penalties delay 60 min-regional	Euro/year	34.800	174.000
Penalties delay 60 min-HS	Euro/year	32.700	163.500

Table 5 – Calculation of penalties avoided

4.2 Benefits for users - time saved for passengers

Assuming the service disruptions avoided as described above for the four scenarios, benefits for users are assessed by applying a standard occupation rate (passenger/train) to regional and HS services, and a standard value of time (VoT) which are saved if the service disruptions are avoided.

Assuming EU-27 standard values for both dimensions, the occupancy rates assumed for the CBA are the following:

- 100 passenger/train for regional services
- 238 passenger/train for HS services[4] [4].

The VoT for passengers of both service categories are the following. EU-27 values are reported in the Handbook of External Costs of Transport (HECT) [2]. Values have been calculated as average between values for main travel purposes:

- 9,7 €/p*h for regional services
- 11,2 €/p*h for HS services.

Applying 2 hours delay to the train cancellation scenarios, and assuming the same "main specification + change request" frequency described above, the annual value of time saved thanks to higher maintenance efficiency brought by the use of FM is estimated to range between **112.000 €/year** in case of 60' delay on regional services, to **581.000 €/year** in case of HS services cancellation. Those values rise to 562.000 €/year and 2,9 M€/year respectively, if change requests are taken into account. The following table describes the calculations made.

	Year	***1***	***2 and onwards***
Avg occupance rate-regional-EU	pax/train	100	100
Avg occupance rate-HS-EU	pax/train	238	238
VoT pax regional	Euro/p*h	9,7	
VoT pax HS	Euro/p*h	11,2	
Hours attributed per cancellation		2	
VoT saved regional-cancellation	Euro/year	225.040	1.125.200
VoT saved HS-cancellation	Euro/year	581.101	2.905.504
VoT saved regional-delay 60 min	Euro/year	112.520	562.600
VoT saved HS-delay 60 min	Euro/year	290.550	1.452.752

Table 6 – Calculation of value of time saved by users

4.3 Benefits from increased safety

The CBA has listed potential benefits from increased safety among the possible effects of FM adoption. The quantitative assessment of lower safety effects with degradated mode (not SIL4) assumed when a component of a safety critical system is unavailable, is hard to predict due to lack of benchmark. However, safety benefits are qualitatively verified since FM decrease the probability of degradated mode running.

4.4 Net benefits – Economic Analysis

The assessment of all benefit categories surveyed and assumed for the CBA allows the calculation of the Economic Analysis indicators (NPV, calculated with the 3% discount rate recommended for Economic Analysis by the EU CBA Guide, Benefit/Cost Ratio – B/C R), as key results of the first part of the CBA (see introductory paragraph of Section 2). The Economic analysis takes into account

[4] Figures available from the EUROSTAT Transport Database, retrieved 23/11/2021 (https://ec.europa.eu/eurostat/web/transport/data/database). EU-27 average figures calculated as the ratio between pkm rail passenger performance (Rail transport of passengers [TTR00015]) and rail network length (Total length of railway lines [TTR00003]).

the discounted cash flows of all cost and benefit categories surveyed[5] to assess, by means of the above-mentioned indicators, the net convenience of the FM adoption for the society as a whole (IM, users and all other involved stakeholders).
Figures in table evidence that the society benefit from a net positive cash flow during the 15-year period considered for the CBA. At the end of the time horizon, the net positive cash flow is **9 M€.** Indicators of the Economic analysis are highly positive: **NPV is 7.067 M€ and B/C R is 5,05**. Such values demonstrate the economic convenience of the adoption of FM by one single IM, since the process generates (actualised) benefits 5 times higher than cost borne by the IM.
Such benefits are likely higher if FM are applied on a EU-27 scale. The net benefits for users and society may justify public granting of the adoption of FM in the railway safety domain.

The following charts evidence the order of magnitude of the annual (not discounted) value of each benefit category compared to costs. Not surprisingly, and in line with a major part of CBAs developed for rail infrastructure projects, benefits from time saved for passengers are they are by far the most relevant benefit category. It enhances the conclusion that expected benefits for users, although calculated with many (realistic) assumptions, justify the adoption of FM and the necessary investment.

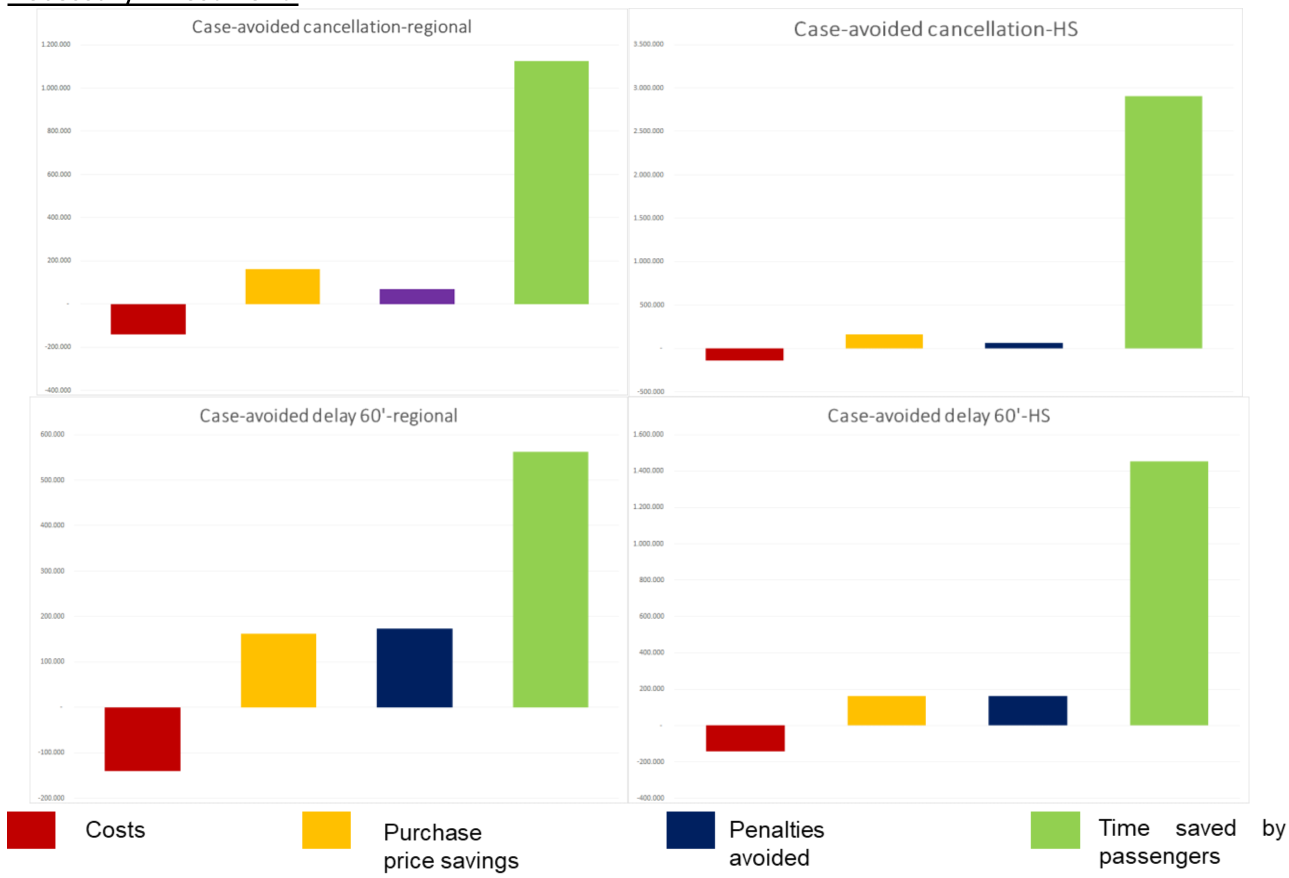

Figure 8 – Value of benefit categories per scenario (Euro/year)

[5] For the cash flow calculation, the "cancellation-HS" scenario for penalties avoided and the "regional-delay 60' scenario for time saved have been taken into account. Following a cautionary approach, such scenarios are those showing the lowest cash flows, leading to more cautionary results.

	year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Economic Analysis																
CAPEX and OPEX for IM		-80.33	-140.18	-146.62	-153.70	-161.48	-163.00	-140.18	-146.62	-153.70	-161.48	-163.00	-140.18	-146.62	-153.70	-161.48
Savings in SW development		21.00	162.60	162.60	162.60	162.60	162.60	162.60	162.60	162.60	162.60	162.60	162.60	162.60	162.60	162.60
Avoided penalties		13.08	65.40	65.40	65.40	65.40	65.40	65.40	65.40	65.40	65.40	65.40	65.40	65.40	65.40	65.40
Time saved for passengers		112.52	562.60	562.60	562.60	562.60	562.60	562.60	562.60	562.60	562.60	562.60	562.60	562.60	562.60	562.60
Cash flow		66.27	650.42	643.98	636.90	629.12	627.60	650.42	643.98	636.90	629.12	627.60	650.42	643.98	636.90	629.12
Cumulated cash flow		66.27	716.68	1360.67	1997.57	2626.68	3254.28	3904.70	4548.68	5185.59	5814.70	6442.30	7092.72	7736.70	8373.60	9002.72
NPV	**7.067 M€**															
B/C Ratio	**5.05**															

Table 7 – Cash flow (kEuro/year) and Economic Analysis indicators

5 Conclusions

The CBA has allowed streamlining a micro, bottom-up case based on the point of view of one IM. However, in the case of railway signalling standards, efforts and costs for formal analysis of the system requirements are likely not be distributed among the various entities supporting the standard itself, and not to a single IM.
Relevant categories of costs and benefits for the CBA have been identified, such as additional costs for learning FM and for developing tender specifications with FM for the procurement of a railway signalling component, savings in SW development, verification and validation, benefits for rail users due to higher maintenance efficiency, higher service availability and time saved for lower probability of service disruption. The quantitative assessment of these cost and benefit categories was possible by integrating the outcome of the demonstrator developed in 4SECURail, and assumptions based on literature and 4SECURail Consortium's knowledge and experience. The assessment was made difficult by the 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. Within the limited scope of the 4SECURail, it has been possible to streamline a micro, bottom-up case based on the point of view of one IM.

Following the calculations and the assumptions made in the CBA, assuming that cost savings enjoyed by suppliers are passed on to prices (to decrease SW purchase price), the IM face net cash flow savings over the time horizon, the CBA evidences that IMs benefit from a net positive cash flow.

The CBA suggest that - in the case of railway signalling standards - efforts and costs for formal analysis of the system requirements are likely being distributed among the various entities supporting the standard itself, and not to a single IM. Benefits are spread over the entire supply chain, including suppliers, if economies of scale in SW development and the learning curve (i.e. progress in learning FM) are activated among IMs and suppliers. The "multi-supplier" mode enabled by FM is likely generating time and cost savings for rail safety industry. Benefits for users and society are relevant and sensible, although they have been quantified by making (realistic) assumptions on the higher maintenance efficiency generated by the adoption of FM by IMs.

The Economic analysis has demonstrated the net convenience of the FM adoption for the society as a whole (IM, users and all other involved stakeholders), since the process generates (actualised) benefits 5 times higher than cost borne by the IM. Such benefits are likely higher if FM are applied on a EU-27 scale. The net benefits for users and society may justify public granting of the adoption of FM in the railway safety domain.
Not surprisingly, and in line with a major part of CBAs developed for rail infrastructure projects, benefits from time saved for passengers are they are by far the most relevant benefit category. It enhances the conclusion that expected benefits for users, although calculated with many (realistic) assumptions, justify the adoption of FM and the necessary investment.

6 References

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