OCORA

Open CCS On-board Reference Architecture

Economic Model

CCS System Life Cycle Costing Scenario Studies

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Management Summary

The economic justification for the OCORA raison d'être and tooling that support OCORA technical decision making is presented. Essential precondition for this document is that it represents the fleet owner point of view, but with a keen eye on business interests of the supply industry and on infrastructure manager's needs. The model aims to provide analytic tools that help to satisfy common business objectives.

This document provides the results of first test runs, assessing life cycle impact on CCS LCC as a means to demonstrate the plausibility of the modelling approach.

The test runs prove, that life cycle expectancy of the CCS system, have a direct impact on life cycle costing, as might be expected. Based on that result of the scenario assessment, the modelling output demonstrates that the model provides predictable output.

These initial test runs also demonstrate that the model must be further developed for which recommendations are made.

Revision history

Version	Change Description	Initial	Date of change
1.00	Official version for OCORA Release R1	JH/NPA	03.12.2021
1.01	Decoupled document from a specific OCORA release	JH/NPA	10.06.2022
1.11	Review for R4	VI	12.06.2023

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References

Reader's note: please be aware that the numbers in square brackets, e.g. [1], as per the list of referenced documents below, is used throughout this document to indicate the references to external documents. Wherever a reference to a TSI-CCS SUBSET is used, the SUBSET is referenced directly (e.g. SUBSET-026). OCORA always reference to the latest available official version of the SUBSET, unless indicated differently.

[1] OCORA-BWS01-010 – Release Notes

[2] OCORA-BWS01-020 – Glossary

[3] OCORA-BWS01-030 – Question and Answers

[4] OCORA-BWS01-040 – Feedback Form

[5] OCORA-BWS03-010 – Introduction to OCORA

[6] OCORA-BWS03-020 – Guiding Principles

[7] OCORA-BWS04-010 – Problem Statements

[8] OCORA-BWS06-010 – Economic Model – Guiding Principles - Assumptions - Assessment Criteria

[9] OCORA-BWS06-020 – Economic Model

[10] OCORA-BWS06-030 – Economic Model – Model Description

[11] OCORA-BWS06-040 – Economic Model – User Manual

[12] Verband der Bahnindustrie in Deutschland e. V., Die Zukunft Der Schiene Soll Rasch Beginnen, Umfassender Konzeptvorschlag: Aus- und Umrüstung von Schienenfahrzeugen mit ETCS-Bordgeräten, www.bahnindustrie.info.

[13] ERTMS Coordinator Work Plan, May 2020

1 Introduction

1.1 Purpose of the document

This document reports on the output of only one specific, out of a multitude of possible modelling scenarios, i.e. the impact of life cycle expectancy on the recurrent life cycle cost of the EVC core of the ERTMS based CCS system. This scenario study has no intention to present definite conclusions on such cost, it is to be understood as a mere attempt in a series of many, to test the plausibility and scalability of the OCORA economic model and its methodology. Therefore, any conclusions are to be understood as assumptions that could support further investigation.

The purpose of this document is to reflect first results of the development of a scenario-based approach that supports sensitivity to analyse and measure the effects of applying various assumptions and their different parametrisation in economic evaluations. The goal of testing different scenarios in this phase of development of the OCORA economic model, is primarily to test and improve the methodology and substantiate underlying assumptions and their parametrisation through trial and error and discussions with stakeholders. As such, this document mirrors a 'work in progress' state of affairs and needs to be judged as such. It is specifically intended first of all, to spark discussion.

This document is addressed to experts in the CCS domain and to any other person, interested in the OCORA concepts for on-board CCS. The reader is invited to provide feedback to the OCORA collaboration and can, therefore, engage in shaping OCORA. Feedback to this document and to any other OCORA documentation can be given by using the Feedback Form [4].

If you are a railway undertaking, you may find useful information to compile tenders for OCORA compliant CCS building blocks, complete on-board CCS system, or on-board CCS replacements for functional upgrades or life-cycle reasons.

If you are an organisation interested in developing on-board CCS building blocks according to the OCORA standard, information provided in this document can be used as input for your development.

Please be aware that in this early stage of development, any values generated by the model do NOT represent monetary values (in Euro) but only allow quantified comparison between scenario outcomes that result from variations in assumptions and parametrisation.

1.2 Applicability of the document

The document is currently considered informative but may become a standard at a later stage for OCORA compliant on-board CCS solutions. Subsequent releases of this document will be developed based on a modular and iterative approach, evolving within the progress of the OCORA collaboration.

1.3 Context of the document

This document is published as part of an OCORA Release, together with the documents listed in the Release Notes [1]. Before reading this document, it is recommended to read them. If you are interested in the context and the motivation that drives OCORA we recommend reading the Introduction to OCORA [5], the Guiding Principles [6], and the Problem Statements [7]. The reader should also be aware of the Glossary [1] and the Question and Answers [3].

This document aims at providing the reader a first introduction to the economic justification for the OCORA *raison d'être* and tooling that support OCORA technical decision making. Essential precondition for this document is, that it represents the fleet owner point of view, but with a keen eye on business interests of the supply industry and on infrastructure manager's needs. The model aims to provide analytic tools that help to satisfy common business objectives.

For any background information, we refer the reader to the Economic Model – Guiding Principles [8], the Economic Model - Model Description [10], and the applied algorithms for cost calculation in the Economic Model [9].

2 Scenario description

In the first test runs of the model, the objective is to test if the model provides 'feasible' results. In this context, 'feasible' is defined as an output that does not appear counterfactual from an expert point of view. While this is a subjective assessment criterion, it demonstrates that the model generates results explainable in objective terms. This is an important step since it gives confidence that the further development process will provide credible output. Nevertheless, next steps include rigorous analysis, assessment and testing of both underlying assumptions and the applied algorithms. The model currently enables analysing the effects of life cycle expectancy of CCS costing profiles (see specifically [9], [10] and [11] for details). Two situations are considered and compared:

1. the Pre-OCORA situation, representing the actual market situation;
2. the OCORA situation, reflecting the impact of establishing the OCORA architecture.

Then, considering the CCS configuration, the model differentiates between;

1. the EVC to be part of the delivery of new rolling stock;
2. the EVC to be part of retrofit of existing rolling stock

Based on the following assumptions, test runs were executed with the model [9].

Two fleet scenarios have been considered:

1. European scale (2020 Ruete report [13] low bound figures)
2. National scale – One 100 vehicles fleet

Test runs were made based on an assumed CCS average life expectancy of 5, 7 and 10 years. The resulting BPS roadmaps for the five-year scenario is in **Figure 1**. For the seven-year and ten-years scenario, see respectively **Figure 2** and **Figure 3**.

Lifecycle		Product: PBS ROADMAP																																			
CCS Core/ Peripheral or external	CCS Subsystem Component	EVC as is solution	pre-O.	OCORA Full Modular Solution	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050	2051	2052	2053	2054
					First HW and SW release																																
CCS	On-board CCS		x							TSI					TSI					TSI					TSI					TSI					TSI		
CCS Core	Core CCS		x								Obso (HW)					Obso (HW)					Obso (HW)					Obso (HW)					Obso (HW)					Obso (HW)	
CCS Core	Core CCS - ATP (ETCS Core)		x						Update SW		Upgrade (HW/SW)		Update SW		Update	Upgrade (HW/SW)	Update SW			Update	Upgrade (HW/		Update SW		Update	Upgrade (HW/		Update SW		Update	Upgrade (HW/		Update SW		Update	Upgrade (HW/S	
CCS Core	CCS addon - NTC-STM																																				
CCS Core	CCS addon - ATO																																				
CCS Core	CCS addon - other functions/services																																				
CCS peripherals	Communication and interfaces		x																																		
CCS peripherals	I/O Ports		x																							Obso (HW)											
CCS peripherals	Functional Vehicle Adapter (FVA)		x																							Obso (HW)											
CCS peripherals	UVCC		x																							Obso (HW)											
CCS peripherals	Gateway		x																							Obso (HW)											
CCS peripherals	MCG (GSM-R, FRMCS…)		x										FRMCS (HW/SW)								6G (SW)												7G (SW)				
CCS peripherals	Sensoring		x																																		
CCS peripherals	ETCS Sensoring (eg Odo, BTM, LTM)																																				
CCS peripherals	Train Loc (GNSS, Inertial…)		x																							Obso (HW)											
CCS peripherals	Perception sensoring (other sensors)																																				
CCS peripherals	DMI		x																							Obso (HW)											
CCS tools	Tools																																				
CCS tools	Testing tools (eg test bench, simulator)																																				
CCS tools	Maintenance tools																																				
CCS tools	Training tools																																				

Figure 1 PBS roadmap for a 5-years CCS system life expectancy

Lifecycle **Product: PBS ROADMAP**

CCS Core/ Peripheral or external	CCS Subsystem Component	EVC as is solution	pre-O.	OCORA Full Modular Solution	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050	2051	2052	2053	2054
					First HW and SW release																															
CCS	On-board CCS		x							TSI					TSI					TSI					TSI					TSI					TSI		
CCS Core	Core CCS		x								Obso (HW)							Obso (HW)							Obso (HW)							Obso (HW)					
CCS Core	Core CCS - ATP (ETCS Core)		x						Update SW		HW/SW		Update SW		Update SW		Update	HW/SW		Update SW		Update SW		Update	HW/SW		Update SW		Update SW		Update	HW/SW		Update SW		Update SW	
CCS Core	CCS addon - NTC-STM																																				
CCS Core	CCS addon - ATO																																				
CCS Core	CCS addon - other functions/services																																				
CCS peripherals	Communication and interfaces		x																																		
CCS peripherals	I/O Ports		x																							Obso (HW)												
CCS peripherals	Functional Vehicle Adapter (FVA)		x																							Obso (HW)												
CCS peripherals	UVCC		x																							Obso (HW)												
CCS peripherals	Gateway		x																							Obso (HW)												
CCS peripherals	MCG (GSM-R, FRMCS…)		x										FRMCS (HW/SW)								6G (SW)												7G (SW)				
CCS peripherals	Sensoring		x																																		
CCS peripherals	ETCS Sensoring (eg Odo, BTM, LTM)																																				
CCS peripherals	Train Loc (GNSS, Inertial…)		x																							Obso (HW)												
CCS peripherals	Perception sensoring (other sensors)																																				
CCS peripherals	DMI		x																							Obso (HW)												
CCS tools	Tools																																				
CCS tools	Testing tools (eg test bench, simulator)																																				
CCS tools	Maintenance tools																																				
CCS tools	Training tools																																				

Figure 2 PBS roadmap for a 7-years CCS system life expectancy

Lifecycle **Product: PBS ROADMAP**

CCS Core/ Peripheral or external	CCS Subsystem Component	EVC as is solution	pre-O.	OCORA Full Modular Solution	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050	2051	2052	2053	2054
					First HW and SW release																															
CCS	On-board CCS		x							TSI					TSI					TSI					TSI					TSI					TSI		
CCS Core	Core CCS		x								Obso (HW)										Obso (HW)										Obso (HW)						
CCS Core	Core CCS - ATP (ETCS Core)		x						Update SW		HW/SW		Update SW		Update SW		Update SW		Update SW		HW/SW		Update SW		Update SW		Update SW		Update SW		HW/SW		Update SW		Update SW		Update
CCS Core	CCS addon - NTC-STM																																				
CCS Core	CCS addon - ATO																																				
CCS Core	CCS addon - other functions/services																																				
CCS peripherals	Communication and interfaces		x																																		
CCS peripherals	I/O Ports		x																				Obso (HW)																
CCS peripherals	Functional Vehicle Adapter (FVA)		x																				Obso (HW)																
CCS peripherals	UVCC		x																				Obso (HW)																
CCS peripherals	Gateway		x																				Obso (HW)																
CCS peripherals	MCG (GSM-R, FRMCS…)		x										FRMCS (HW/SW)								6G (SW)												7G (SW)				
CCS peripherals	Sensoring		x																																		
CCS peripherals	ETCS Sensoring (eg Odo, BTM, LTM)																																				
CCS peripherals	Train Loc (GNSS, Inertial…)		x																				Obso (HW)																
CCS peripherals	Perception sensoring (other sensors)																																				
CCS peripherals	DMI		x																				Obso (HW)																
CCS tools	Tools																																				
CCS tools	Testing tools (eg test bench, simulator)																																				
CCS tools	Maintenance tools																																				
CCS tools	Training tools																																				

Figure 3 PBS roadmap for a 10-years CCS system life expectancy

Please note that the scenarios tested here address the effects of OCORA only on fleet level and do NOT differentiate fleets into vehicle types. As remarked in the guiding principles, main assumptions and general assessment criteria document [8], integration costs are dominated by fleet composition rather than fleet size.

3 Test run findings

The first test runs have analysed and calculated the effects of OCORA in the previously described scenarios as far as OPEX are concerned.

The scenarios have been performed for this 1.0 release with the tool introduced in [9] and described in [10].

In particular, the “delta costs” (costs difference between the different solutions and the EVC “as is”) are evaluated with a “Life Cycle” perspective (different product PBS roadmaps scenarios):

- for a “software adaptation”;
- for a “hardware adaptation”;
- for a “system evolution”.

The two scenarios aim at showing the impact on the implementation of the pre-OCORA architecture in comparison with the existing EVC architecture.

3.1 Scenario 1: European scale / low bound figures

For this scenario, the figures considered for the acquisition and retrofit of vehicles are listed in **Table 1**.

SCENARIO WITH: Fleet to equip/retrofit	OCORA (insert above product n	Type	Product used	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036
Fleet 1	EMU/DMU Class 1	new build	EVC	407	555	817	1099	1365	1651	1769	1819	1765	1605	1415	1214
Fleet 2	EMU/DMU Class 2	retrofit	EVC	42	192	393	609	813	930	1090	1128	1087	964	766	505
Fleet 1	EMU/DMU Class 1	new build	pre-O.	407	555	817	1099	1365	1651	1769	1819	1765	1605	1415	1214
Fleet 2	EMU/DMU Class 2	retrofit	pre-O.	42	192	393	609	813	930	1090	1128	1087	964	766	505
	Total fleet			449	747	1210	1708	2178	2581	2859	2947	2852	2569	2181	1719

SCENARIO WITH: Fleet to equip/retrofit	OCORA (insert above product n	Type	Product used	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050	2051	2052	2053	2054
Fleet 1	EMU/DMU Class 1	new build	EVC																		
Fleet 2	EMU/DMU Class 2	retrofit	EVC																		
Fleet 1	EMU/DMU Class 1	new build	pre-O.																		
Fleet 2	EMU/DMU Class 2	retrofit	pre-O.																		
	Total fleet			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 1 Ruete low bound scenario ERTMS on-bord roll out figures, newly built and retrofit

As remarked in the introductory document [16], this European fleet is constituted of a multitude of technically different vehicle types. In this test run, this aspect is not taken into account..

In **Table 2**, the results are presented for fleet development as in the previous table.

		CCS Costs			
5 years	New Build	1 360 055	Fleet 1	EMU/DMU Class 1	EVC
		747 427	**Fleet 2**	**EMU/DMU Class 2**	**EVC**
	Retrofit	925 817	Fleet 1	EMU/DMU Class 1	pre-O.
		509 058	Fleet 2	EMU/DMU Class 2	pre-O.
	Total	**2 107 483**	**Fleet 1**	**EMU/DMU Class 1**	**EVC**
-32%		1 434 875	Fleet 2	EMU/DMU Class 2	pre-O.
7 years	New Build	1 466 708.84	Fleet 1	EMU/DMU Class 1	EVC
		807 102.13	**Fleet 2**	**EMU/DMU Class 2**	**EVC**
	Retrofit	**977 699.40**	**Fleet 1**	**EMU/DMU Class 1**	**pre-O.**
		537 792.25	Fleet 2	EMU/DMU Class 2	pre-O.
	Total	1 970 262	Fleet 1	EMU/DMU Class 1	EVC
-33%		1 316 077	Fleet 2	EMU/DMU Class 2	pre-O.

10 years	**New Build**	**1 180 513.20**	**Fleet 1**	**EMU/DMU Class 1**	**EVC**
		647 189.28	**Fleet 2**	**EMU/DMU Class 2**	**EVC**
	Retrofit	**789 439.34**	**Fleet 1**	**EMU/DMU Class 1**	**pre-O.**
		433 709.67	Fleet 2	EMU/DMU Class 2	pre-O.
	Total	1 827 702	Fleet 1	EMU/DMU Class 1	EVC
-33%		1 223 149	Fleet 2	EMU/DMU Class 2	pre-O.

Table 2 Results for the European scale (low bound) deployment scenario, for the three CCS life expectancies

In conclusion:

- the model provides plausible results for those considered scenarios;
- this scenario demonstrates the impact of extended life expectancy on the expenditure on fleet level. Substantial savings are feasible when CCS life expectancy can be extended.

Given the size of the fleet, non-recurrent integration costs, specifically the need for prototyping, etc., can be reimbursed over a huge fleet, so they will have little impact on overall cost. For this and other reasons, the scenario has only minor relevance to cost-benefit assessment of the OCORA and non-OCORA condition.

In Annex 1: Test scenario output in graphs, graphical outputs of the test scenarios have been visualised. The graphs show the relative values for replacement, soft- and hardware costs relevant to their life cycle. As explained above, they reflect cost developments for both newly built and existing rolling stock (retrofit) in a 'non-OCORA' and 'OCORA' environment. Consolidated, the results are reflected in **Figure 4**.

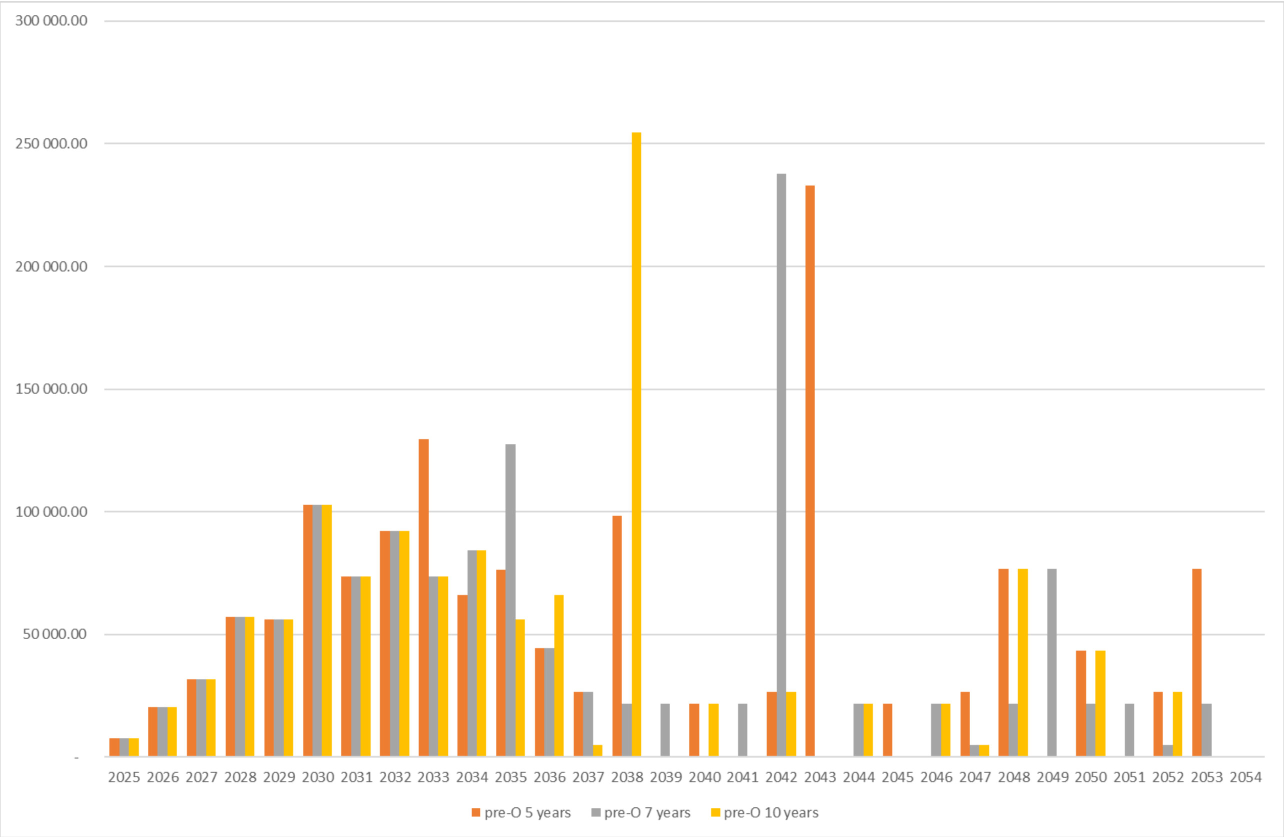

Figure 4 Scenario 1 – costs distribution for the pre-OCORA (pre-O) product and the three 5-, 7- and 10-years CCS life expectancies

For this deployment scenario, the introduction of the OCORA architecture, with the first step being the pre-OCORA product, leads to a reduction of 30% of the CCS OPEX for both considered fleets (fleet 1 – renewed vehicles, fleet 2 – retrofitted vehicles) over the whole life cycle of the vehicles.

When comparing EVC and pre-O products, the three life expectancies lead to the same cost decrease (the input data being based on a base-10 approach, the quantitative results shall not be seen as representative figures).

The graph above shows a different distribution of costs every year, with similar costs for the yearly regular updates, and much lower costs for the upgrades due to the inexistent modularisation introduction of the modularisation.

Compared to the 5-years life expectancy results, the 7-years and the 10-years results bring OPEX decrease of 8% and 15% respectively. Those results were predictable given the restricted scope of the scenarios involved and the restricted articulation of the underlying assumptions and parameters.

Since the goal was to find out if the test runs could provide unexpected outcome, the results give confidence that the general approach is valid as no unexpected outcome is present.

3.2 Scenario 2: National scale – One 100 vehicles fleet

In the next table, the results are presented for a fleet of 100 vehicles. As explained in [16], in fact this should be somewhere between 1 and 5 vehicle types.

	CCS costs	
5 years		
Total	7 635	EVC
-38%	4 740	pre-O.
7 years		
Total	7 463	EVC
-38%	4 644	pre-O.
10 years		
Total	7 119	EVC
-37%	4 454	pre-O.

Table 3 Results for the 100 vehicles fleet deployment scenario, for the three CCS life expectancies

Here too, life cycle costs diminish with an increase in system life expectancy, although it is less pronounced than in the previous scenario from 3.1.

The consolidated scenario test output is represented in **Figure 5** below.

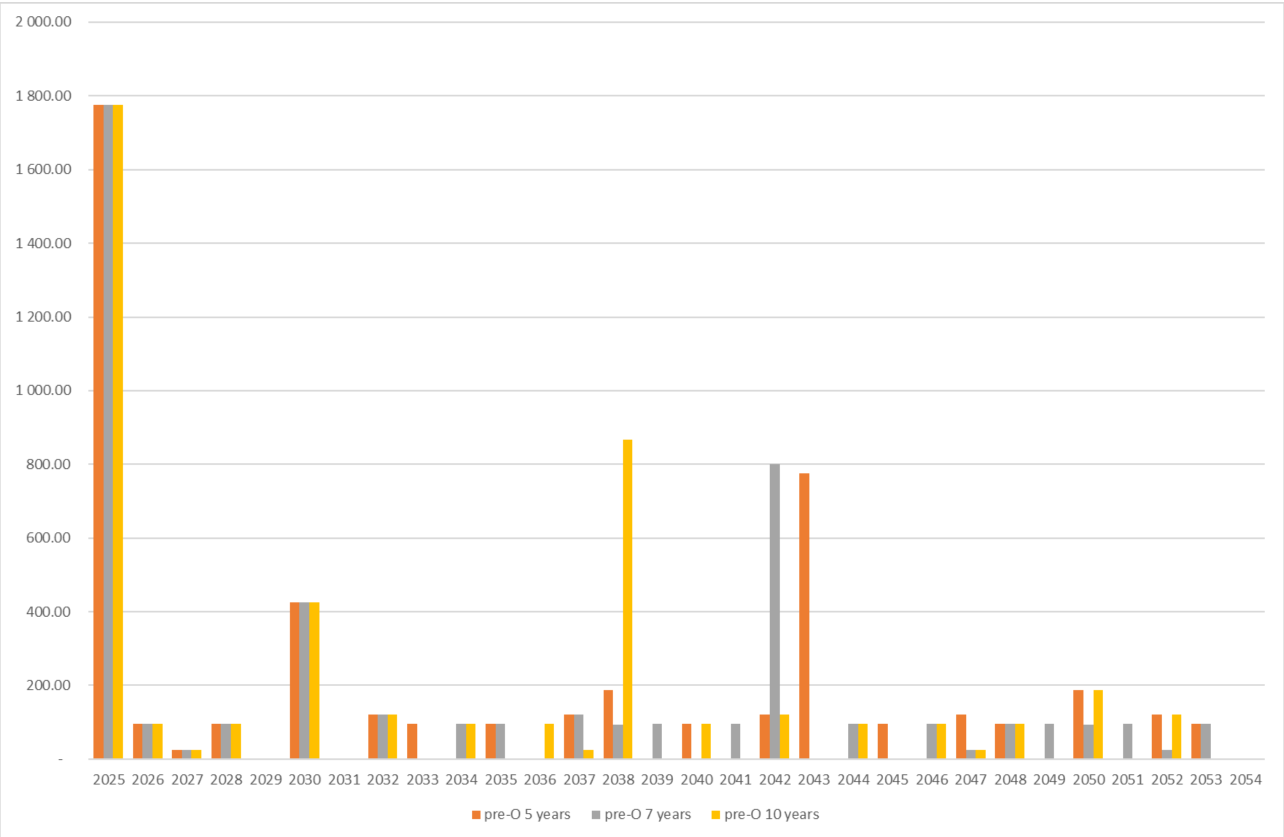

Figure 5 Scenario 2 – costs distribution for the pre-O product and the three CCS life expectancies

In this example, the impact of the introduction of the OCORA architecture is even more significant than the previous scenario, with larger cost reduction.

The test runs do not allow any conclusions on the equation between OCORA and non-OCORA conditions.

4 Further steps

The scenario studies were but a first exploration of the possibilities of economic modelling. The model will be further refined by the OCORA team. Next development steps include (non-limitative):

- refining the model and its associated tool, including costs assessment (in euros):
    - rigorous review and (quality) assessment of underlying assumptions;
    - regular (quality) check of algorithms and model;
    - migration from Excel to an appropriate calculation tool;
    - reinforcement of the description and basic assumptions pertaining to OCORA;
    - refinement of modelling assumptions down to technology choices aligned with OCORA architecture principles. The objective should be for the model to trace in an exhaustive way the effects of implementing the OCORA breakthrough (e.g. technical proposals, design requirements);
    - enhancement of the the model with parameter costs, i.e. all the costs, including the maintenance costs (preventive, curative, repair);
    - exploration of other methods for cost assessment, e.g. by application of a target costing approach, that could be used as e.g., an add-on to check results against each other.
- identifying a library of relevant scenarios (fleets, roadmaps…):
    - develop deployment scenarios to help understand cash flows for different stakeholders involved;
    - ditto regarding deployment and industrialisation scenarios as well as considerations on the capability of the sector to deliver the needed quantities in the different scenarios and for given deployment roadmaps;
    - look into evolving scenario development requirements as a result of running scenarios using the tool.

In addition, following issues may have to be considered:

- include and refine the effects of public funding and financing mechanisms;
- elaborate specific amortization parameters, taking account of variances in one off industrial costs;
- do a sensitivity analysis of the feasibility of the OCORA breakthrough. For each of the breakthrough, the impact must be refined and better quantified, the likeliness to deploy each OCORA breakthrough is to be analysed depending on its investment/benefit ratio;
- enable distinction between cost structures pertaining to vehicle types, e.g. differences in one off cost per train between locomotives and EMU / DMU (not doing so creates a bias for all values and has effects on the final cost calculation). This means that, currently, the model is valid for simulation reasoning purposes only;
- extend the scope to include relevant elements like specific or detailed building blocks, STMs, recycling, etc.

The OCORA Economic Model [9] indicates the added economic value of OCORA for both railways, institutional partners and supply industry. But, they need to be validated and verified by experts, involving railway undertakings and industrial partners. Specifically, there are several points that need to be addressed.

- The quantitative benefit of modularity (direct added value from R&D, instead of routine adaptation for retrofit purpose).
- The rationale for adopting new architecture that enable system upgrade, i.e. more value through collaboration.
- The risk of continuing with today's cost distribution function as CCS will become unaffordable and the adoption of new functions or technologies will further slow down.

OCORA intends to involve the sector in further developing this model as it is enabling enhanced analysis potential to quantitatively identify and validate common business objectives for stakeholders. S2R and its successor are natural places for further improving the modelling approach and values. OCORA considers the

European Commission ERTMS Deployment Management Team to probably be an appropriate source for a set of (or range for) reference assumptions and parameters.

Annex 1: Test scenario output in graphs

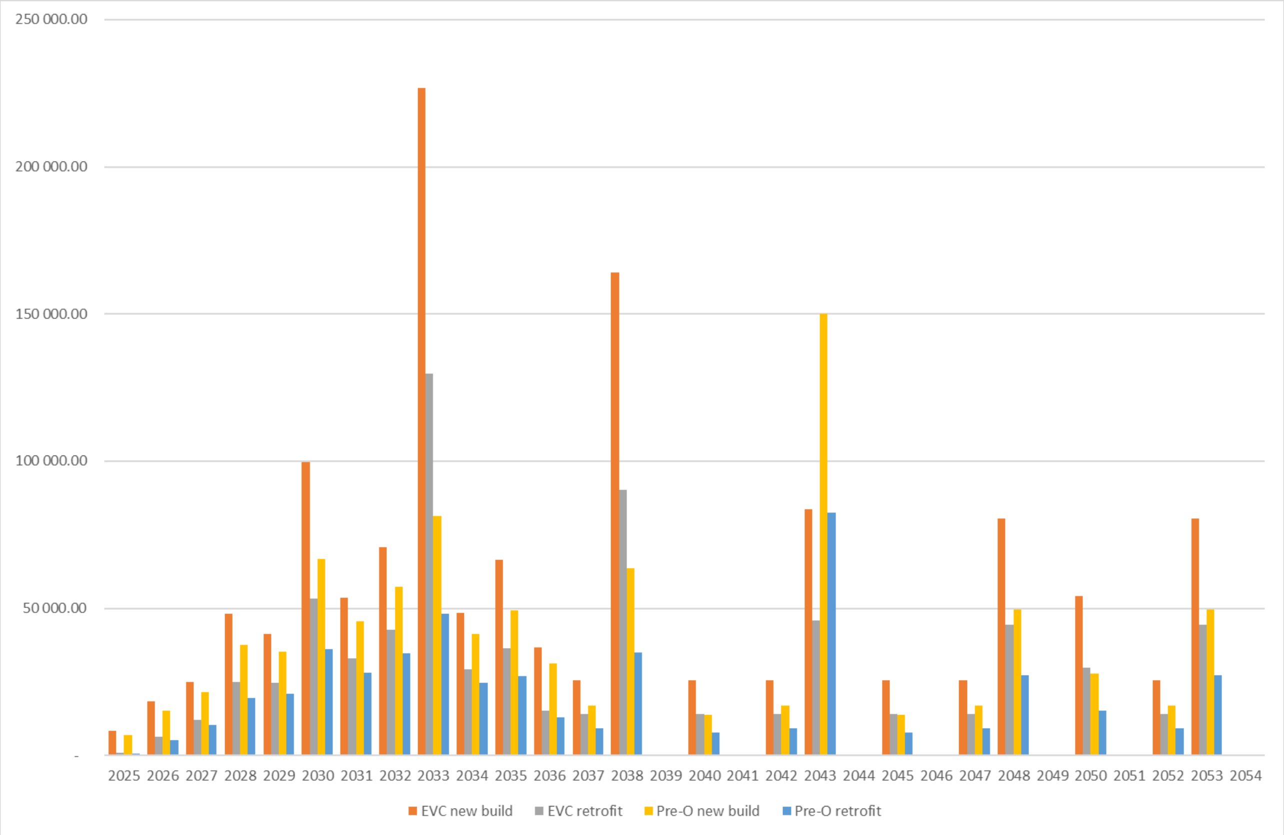

Figure 6 Scenario 1 – costs distribution for EVC and pre-O product for the 5-years CCS life expectancy

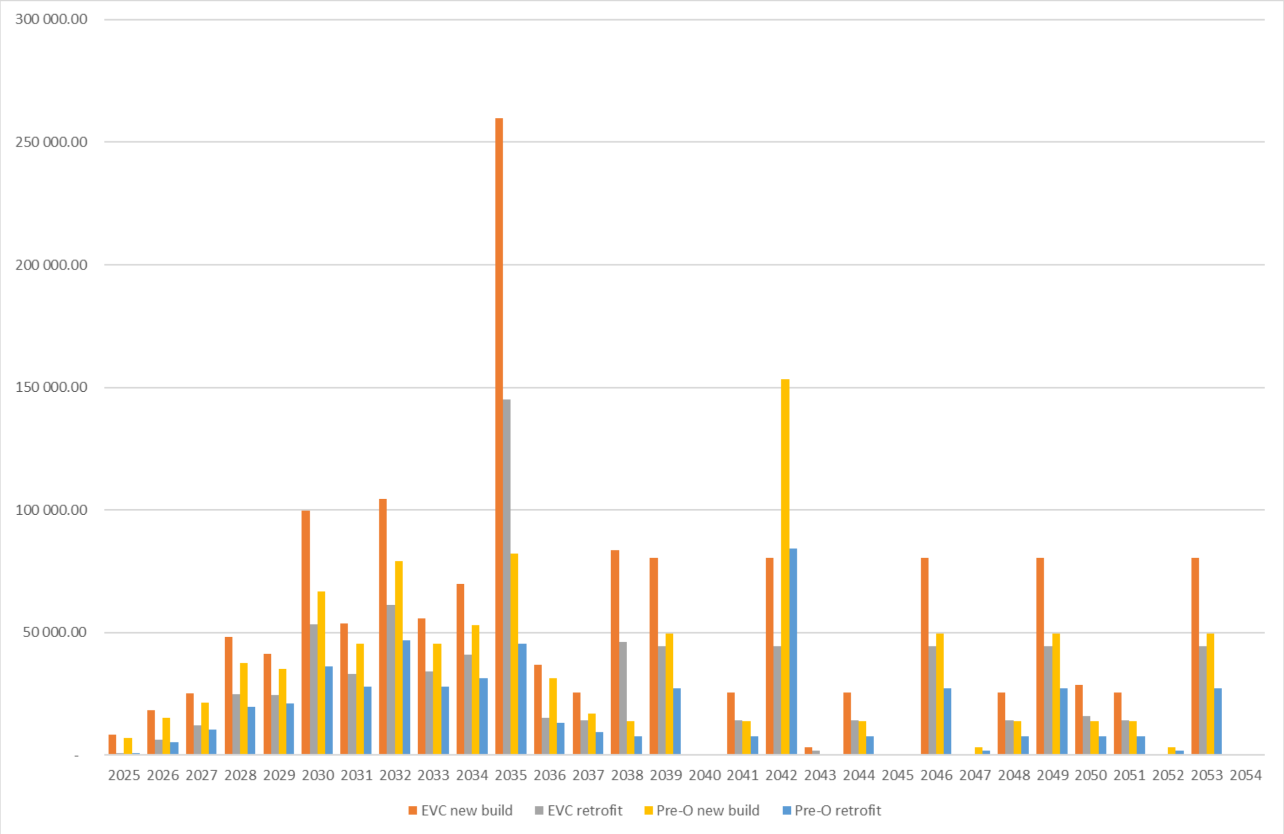

Figure 7 Scenario 1 – costs distribution for EVC and pre-O product for the 7-years CCS life expectancy

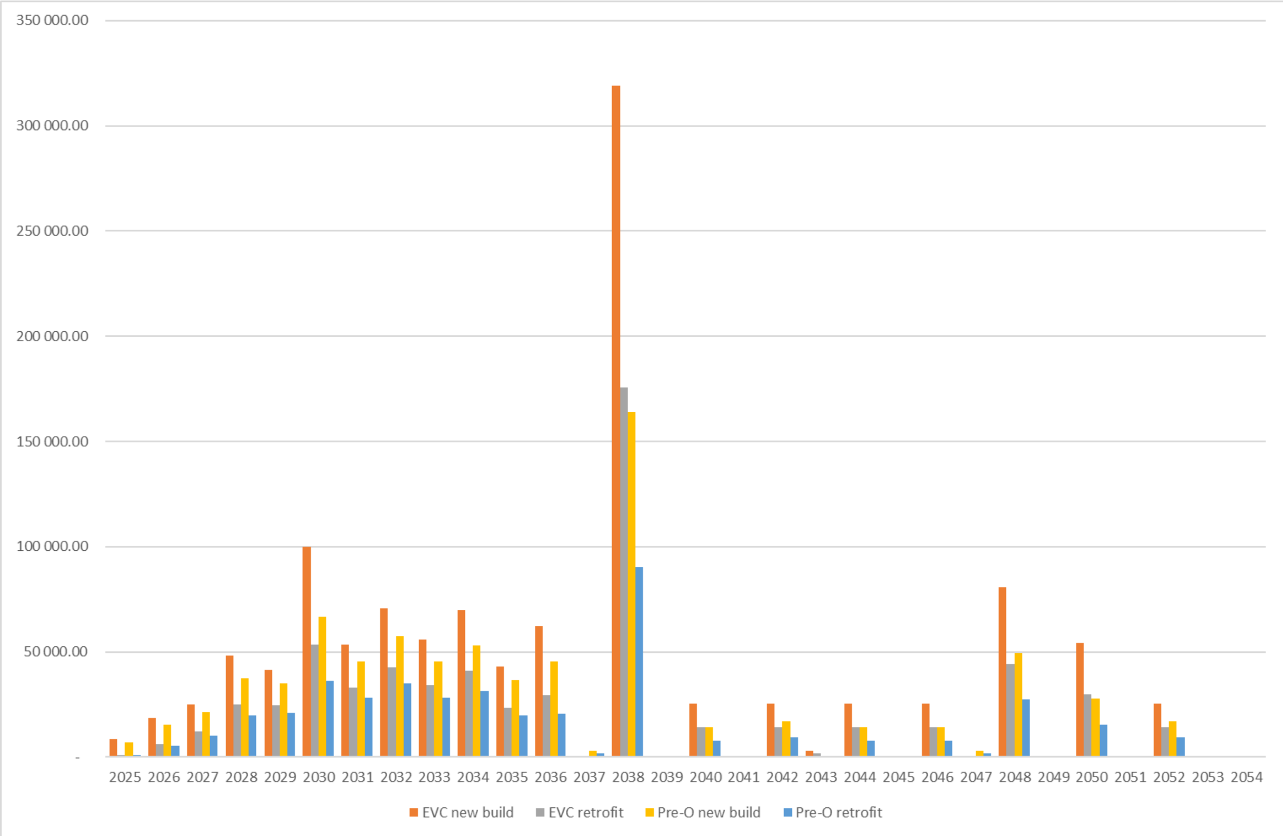

Figure 8 Scenario 1 – costs distribution for EVC and pre-O product for the 10-years CCS life expectancy