OCORA

Open CCS On-board Reference Architecture

Introduction to OCORA
Beta Release

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1.10	Final Version for Release	RM	2020-06-29

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References

The following references are used in this document:

[1] OCORA-10-001-Beta – Release Notes

[2] OCORA-30-005-Beta – Alliances

[3] OCORA-40-001-Beta – System Architecture

[4] OCORA-90-002-Beta – Glossary

1 Introduction

1.1 Document context and purpose

This document is published as part of the OCORA Beta release, together with the documents listed in the Release Notes [1]. It is the second release of these documents which means that they are still under construction and will be further refined in consecutive, releases. New releases of this document and topic specific documentation will be developed in a modular and iterative approach.

The reason for publishing OCORA products in releases is to periodically provide information on the OCORA philosophy, on the progress made in different work streams and to enable the audience to provide us with their valuable feedback. Your feedback is much appreciated since it will allow us to further improve our work and prevent potential mistakes.

This document aims to provide the reader with a comprehensive reference to the approach the OCORA members envisage to achieve the objectives defined in the OCORA Memorandum of Understanding. These objectives concentrate on enabling the rapid automation and digitalisation of rail products and services in order to reduce total cost of ownership, increase productivity and customer value and control investment and operational risks.

The aim of this document is to introduce the reader into the OCORA Beta Release, including basic principles ruling the OCORA collaboration and fundamental concepts of OCORA architecture design.

1.2 Why should I read this document?

This document is addressed to both decision makers and experts in the CCS domain and to any other person, interested in the OCORA effort to boost rail transportation productivity and profitability, ensuring an enduringly competitive and sustainable rail sector in Europe. That requires affordable CCS On-board equipment that supports high performance, safe and secure rail services to satisfy ever changing (end) user requirements. This document illustrates what principles and criteria the OCORA partners adhere to in order to achieve these overall, corporate objectives.

The reader should also be aware of the Glossary [4].

2 Why OCORA in general?

ERTMS today is widely deployed throughout Europe, targeting 15,000 km of tracks to be equipped by 2023 and 51'000 km by 2030. Nevertheless, ERTMS still has to achieve its main goals: cross border (or rather: cross deployment) interoperability, controllable cost, and satisfying performance levels. At the same time, ERTMS is an important enabler for the automation and digitalisation of an interoperable railway in Europe. The constraints to be eliminated to allow the European rail sector full benefit from ERTMS, are:

1. Current control-command and signalling on-board solutions in Europe are driving significant investment and maintenance costs as well as complexity and uncertainty for fleet interoperability ;
2. Solutions do not consider the differences in life cycles between its constituents or parts;
3. The ERTMS specifications are written in natural language and error-prone with different possible interpretations by different suppliers;
4. Major innovations ("game changers") around the ETCS core are to be deployed in the next decade to boost the railway sector efficiency (i.e. ATO, fail-safe train localization, next radio communication system, …).

Recognizing that a coherent, modular, upgradeable, interchangeable, reliable and secure system architecture is paramount to overcome these challenges for the overall control-command and signalling system of the European railway sector, the intent is to establish the **O**pen **C**CS **O**n-board **R**eference **A**rchitecture (referred to as "OCORA"), in coherence with and complementarity to the trackside control-command and signalling subsystem.

3 What is OCORA?

OCORA is first and foremost a platform for cooperation to the benefit of the European Railway sector. Guiding principles, rules and regulations agreed between OCORA members, are expressed in the OCORA Memorandum of Understanding (MoU) and the OCORA Code of Conduct (CoC).

Members collaborate on the development of an open reference architecture for on-board command-control and signalling systems that supports the mutually agreed OCORA objectives (Chapter 6). Collaboration takes place in working groups. Each working group is responsible for specific tasks, topics or issues. Working group(s) and participating experts are appointed by the OCORA management team.

OCORA is not a legal entity and cannot exert owner rights. In case collaboration projects would lead to financial commitments for the members, these commitments will have to be formally agreed prior to execution.

The funding members of OCORA are:

- Deutsche Bahn AG
- Schweizerische Bundesbahnen SBB
- NS Groep N.V.
- SNCF for itself and in the name of SNCF Mobilités and SNCF Réseau
- ÖBB-Produktion GmbH

OCORA is open to any railway undertaking or train keeper willing to accept the MoU and CoC. Ideally, all members are having delegates that actively support one or several working groups.

4 Key OCORA collaborative principles

OCORA as a collaboration of its members, acts according to the key principles defined in the MoU and CoC:

1. OCORA is first and foremost a technical collaboration platform for its members. OCORA output will be made available to any stakeholder of the railway community.
2. As expressed in the CoC, OCORA acts in full conformity with existing competition law under any circumstances and within the existing sectoral regulatory framework. CR proposals formulated by OCORA, will e.g. be registered for further treatment through existing channels like CER or EUG.
3. Although OCORA aims at standardisation of the on-board CCS function, it does not envisage to set up a formal, “de iure” standard. However, OCORA will develop for its members and third parties, specifications for procurement purposes, following the examples of e.g. EULYNX.

The collaboration principles defined in the MoU and CoC and summed up in Chapter 3 have been developed further to clearly communicate by what means the OCORA collaboration aims to achieve its business objectives. Our principles for collaboration are:

1. **Openness**: OCORA is an open collaborative technical platform open to all railway companies. This includes IMs and RUs. It is based on sharing and making publicly available its deliverables for the benefit of the railway sector.
2. **Modularity**: OCORA intends to decompose the on-board CCS subsystem into an optimal/reasonable number of standardized building blocks. System modularity is the basis for a modular safety approach and exchangeability, supporting different life cycles.
3. **Simplification**: OCORA plans to isolate in its architecture the functional blocks that will become obsolete in the foreseeable futures (e.g. GSM-R, class B systems, current balise technology). This is the basis to easily simplify OCORA based implementations, once the respective functions are not needed anymore.
4. **Independence**: OCORA intends to minimize the dependencies between different building blocks and components, such as dependencies between hardware, software and peripherals. This provides the basis for a modular product-based CCS system approach.
5. **Evolvability**: Recognizing that continuous updates and upgrades are paramount to the railway digitalization, OCORA intends to introduce secure upgradability and interchangeability to speed-up the integration of future innovations in a flexible manner and to provide a solid basis for introducing game changers such as FRMCS or ATO.

Both the corporate objectives themselves as well as the translation of those principles in architecture design principles, which provide the preconditions to achieve those objectives, are discussed in the next chapters.

5 OCORA objectives

It is OCORA priority in general to develop a single generic concept for the CCS on-board concept to facilitate:

- the introduction of innovative technologies (starting with the so called ‘game changers’ like ATO and FRMCS) that satisfy the needs and requirements of railway companies while providing a solid and resilient economic foundation for the European signalling industry
- the implementation of full operational interoperability[1] (or: ‘seamless transportation’) on the European rail network, indicating that any vehicle equipped with ETCS, would be able to run on any ERTMS equipped infrastructure without restrictions.

OCORA members agree to collaborate in achieving the following specific objectives:

[1] Please note that this word that is also used in another sense: in ISO 25010 terminology as an indicator the degree to which a system or computer program is composed of discrete components such that a change to one component has minimal impact on other components.

1. To define an Open CCS on-board reference architecture by e.g.:
    - Open standardisation of the ETCS/ATP and ATO train interfaces and functions and other on-board subsystems as plug and play solutions (e.g. a reference runtime platform with open interfaces).
    - Establishing the principles and necessary requirements of the OCORA initiative.
    - Aligning initiatives and ideas already started and find synergies to align scarce resources.

    Streamlining industrialisation processes in particular the certification.
2. To foster and develop the open ETCS/ATP source initiative by using results and experiences from the "openETCS" initiative and sharing common understanding on this initiative.
3. Validate the viability and relevance of the OCORA approach by using e.g. demonstrators.
4. To promote the use of OCORA for the CCS on-board solutions in Europe in order to make it more cost effective, reliable, safe and secure by e.g.:
    - Ensuring consistency on a railway system scale between OCORA and other similar initiatives. This will be done in close coordination with sectoral organizations (e.g. CER, EIM, EPTTOLA, ...), and in close cooperation with joint undertakings, already in charge of defining certain aspects of the ERTMS (e.g. Shift2Rail, EuG, EULYNX, UNISIG, JPCR, UIC, RCA, etc.)
    - Building consensus and getting support from railway companies by means of regular information towards sectoral associations (e.g. members of the group of representative bodies)
    - Facilitating the industrialisation of OCORA results notably certification, through input to and discussions with associations, sectorial organizations, manufacturing companies and joint undertakings (e.g. UNIFE, UNISIG, Shift2Rail, ERL - European Reference Laboratories, etc.)

Achieving these objectives require a stepwise, incremental approach in which some issues can be (or need to be) addressed on a short term while others are more fundamental and therefore more time consuming. As a result, the OCORA perspective stretches over a longer period. However, future fundamental changes ask for swift and decisive action now: continuing the existing paradigm for realisation of ERTMS will stifle future changes. This is why OCORA has already developed and communicated problem statements that point out issues that have to be addressed in the TSI Revision of 2022 as a preparation for more fundamental changes in the near future. OCORA is now preparing detailed proposals for enhancement of the TSI CCS that will be processed through the designated channels.

OCORA primarily has a functional and technical perspective and includes the optimization of the on-board to wayside interface. OCORA closely cooperates with RCA and other stakeholders to ensure that this interface is optimized with the express intention to optimised results with a railway transportation ecosystem focus. Obviously, costs and benefits are not in all cases evenly distributed between IM's and RU's and trade-offs are necessary to achieve the most cost effective solutions on a sector level. This could require arrangements for financial compensation to ensure the enduring cooperation of stakeholders. Although the OCORA collaboration recognizes the importance of establishing such arrangements, these will not be a topic for OCORA Architecture work packages and the issue will, consequently, not be addressed in OCORA Architecture documentation but pushed forward in other sector interest groups (e.g. CER) as foreseen in OCORA alliance document [2]. A close collaboration on a sector scale is on such an issue an essential enabler for fast progress.

6 What are expected OCORA deliverables?

Anticipated results from the OCORA collaboration as defined in the OCORA MoU are:

1. A reference architecture guiding the development of (a specification for) a consistent and modular on-board CCS system.
2. An economic evaluation supporting the OCORA architecture and approach.
3. Robust interface specifications allowing for smooth evolution and migration.
4. Improvements of the regulatory framework as a precondition for rapid introduction and adoption of (global) technological developments in other branches of industry and technology.

5. So called “demonstrators”, “real life application” of products (based on specifications developed within the OCORA framework) to showcase usability and applicability in test environments. One of the first of those demonstrators will be the ‘Minimum Viable Product’ or MVP, the condensed version providing the core functionality of the OCORA platform for both validation and verification as well as authorization purposes.
6. Publications targeting the dissemination of OCORA results to the benefit of stakeholders in the European railway community.

As a first step, OCORA aims at providing a comprehensive and coherent set of specification (architecture and interfaces) for a modular CCS on-board environment that will be published in consecutive OCORA releases. These specifications shall serve as a voluntary format for tender templates, supporting companies currently engaged in procurement activities or soon starting procurement programmes.

Additional, future deliverables include supporting material for IVV (Integration, Verification and Validation) and material helping to justify OCORA-based CCS on-board implementations (e.g. business case calculation templates). This will be done by developing prototypes for testing and demonstration purposes. These ultimately have to be industrialised for serial production. In Figure 1, the actual OCORA development phases are shown:

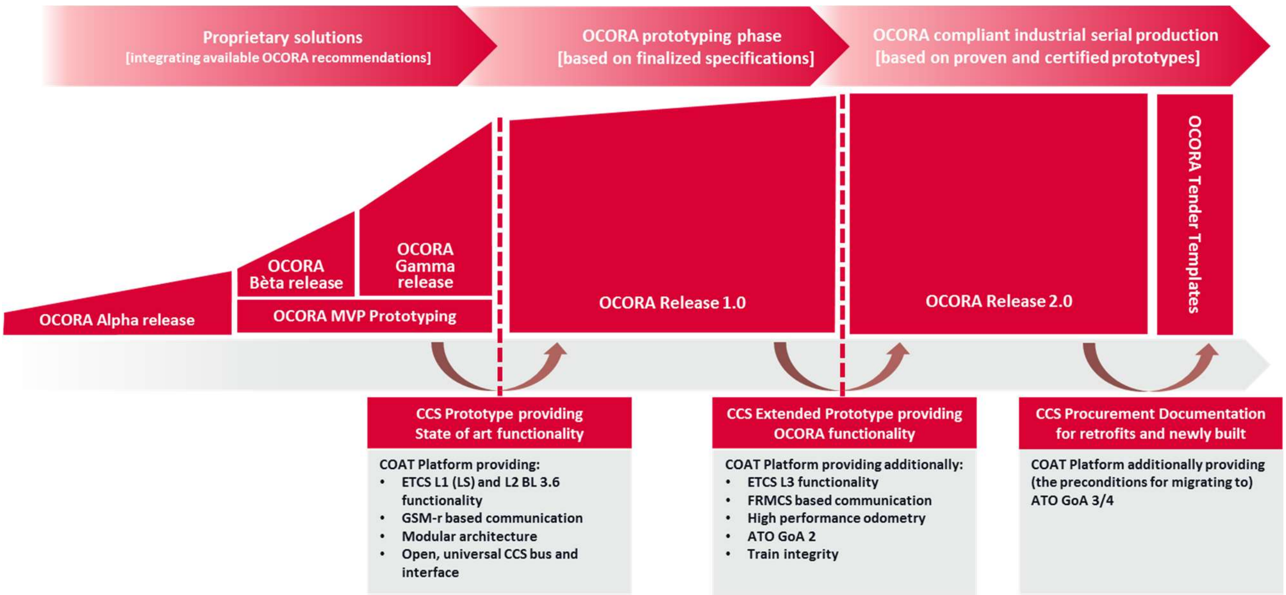


Figure 1 - OCORA Development Phases from initiation to full deployment

6.1 Minimum Viable Product MVP

The TSIs contain ambiguities, gaps and errors, resulting in vendor specific interpretations of what should be functionally completely identical CCS applications. Suppliers spend scarce R&D resources on the upkeep of routine products while hampering open competition. To break out of this deadlock, the current deficiencies of the specifications must be eliminated. The intention is to develop a model of the core functions of the CCS system – only those functions absolutely necessary to safely move a train over a rail network – using formal logic. This formal model should be tested in a laboratory environment and empirically in a prototype that performs the basic functions necessary for train operation. The prototype and its test environment is called, the Minimum Viable Product (MVP). A tentative planning for the OCORA MVP is depicted in Figure 2.

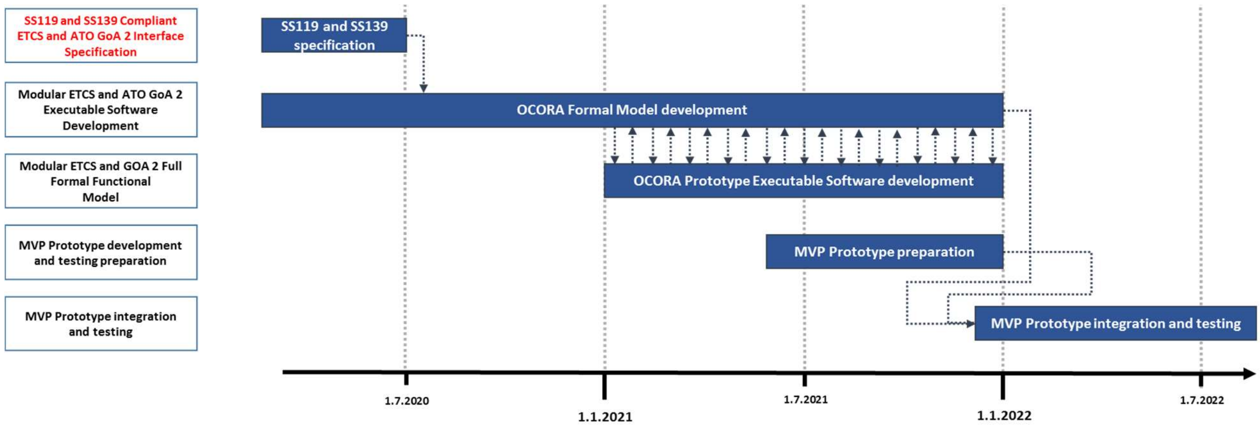


Figure 2 - MVP project planning phases

6.2 Roadmap

OCORA aim is to deliver quick value through recommendations that can be used in new build rolling stock, retrofit and CCS design projects.

Through OCORA releases, capitalising on industry partnerships, the set of recommendations will grow and should support the definition of tender templates for modular and serviceable CCS products.

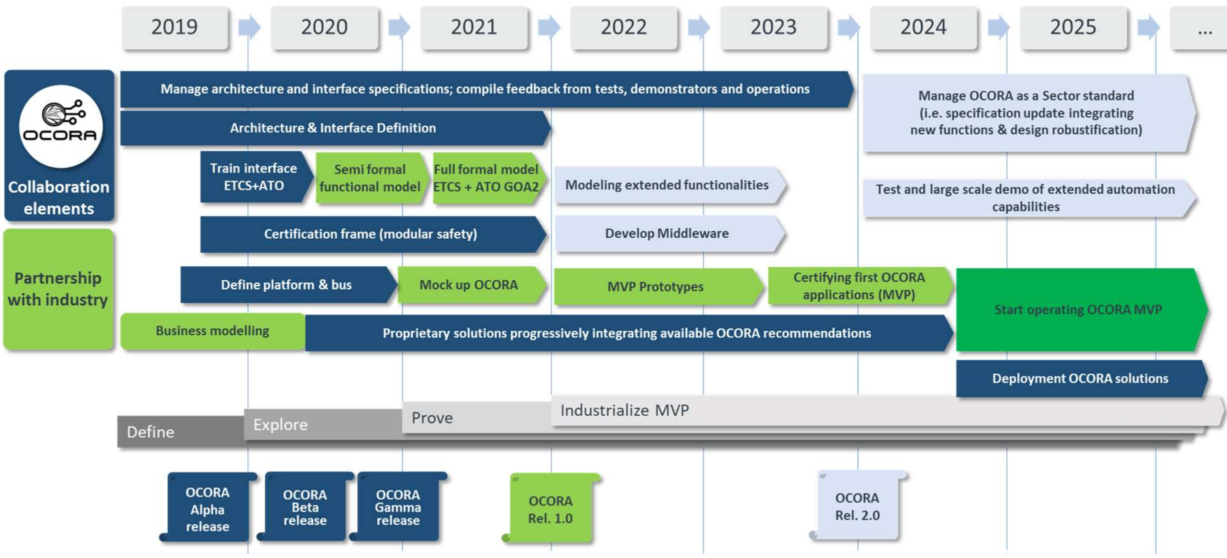


Figure 3 - OCORA Roadmap

7 OCORA business rationale

To keep up competition with modal competitors, investing heavily in digitalisation and automation, railways rapidly have to embed innovative technologies in their physical assets, planning systems and operations. Digitalisation and automation are the prerequisites for boosting productivity, controlling cost and risk levels, and improving performance. That is why OCORA deems the fast integration of the game changers in the CCS domain of imperative importance and intends to gradually extend the grade of automation of heavy rail to the domain of fully automatic, unmanned operation (since decades business as usual in light rail).

The European railway community has identified ATO over ETCS to be the preferred solution for implementing ATO in heavy rail environments. At the same time, it recognizes the drawbacks of the current ERTMS implementation process which encompass high development and investment costs for suppliers and customers, performance issues and considerable technical, operational and financial risks. EC and ERA already acknowledge that a modular architecture is one of the prime prerequisites to boost the roll out of ERTMS over the European rail network, improve the market dynamism in and to enable the successful adoption of the game changers.

> *DG MOVE in its end of May, 2020 version 'CCS framework: governance and arrangements at EU level':*
>
> *The current typical CCeeS on-board configuration includes multiple proprietary and Class B driven interfaces between the main train on-board building blocks. This induces low on-board upgradeability and dependency on the initial suppliers (CCS and rolling stock) when on-board upgrades are necessary and, consequently, increased cost and complexity.*
>
> *[…]*
>
> *This situation significantly increases CCS complexity and reduces the opportunity for more open and competitive markets across Europe. It also creates a system that is not conducive to harmonised evolution and innovation.*
>
> *Hence it has been agreed in the CCS Framework vision that there should be: one European CCS system: There should be a genuine integrated European CCS system, beyond the current specifications in the CCS TSI, with much greater standardisation and much less variation than at present. This integrated CCS system shall on the one hand deliver unrestricted movement of trains, on the other hand, it shall create a larger market for components.*
>
> *[…]*
>
> *As a key enabler of the Single European Railway Area, technical interoperability needs to be ensured in the sense that:*
>
> - *A vehicle fitted with a compatible ERTMS on-board unit can safely operate anywhere on the European network with acceptable performance.*
> - *The implementation and consistent application of CCS is made sustainable for users by allowing for cost effective implementation, updating, upgrading and replacement of CCS systems and single parts thereof.*
>
> *Considering the intrinsic nature of rail as on integrated complex system, a harmonised functional and technical CCS architecture on a systems level is a prerequisite to master complexity and ensure enduring coherence. Managing the complexity requires a common harmonised functional CCS approach between the different CCS components, with a clear separation of safety-related and non-safety-related layers with non-safety functions.*
>
> *The role of customer in defining services, requirements and specifications supplier in designing and developing the technologically and operational enablers of the functional system architecture is recognized.*

The benefits the OCORA initiative expects to harvest are:

- Reduction of CAPEX: amount of capital expenditure reduced for a CCS on-board solution. This includes also the non-recurring engineering costs for development, integration engineering, certification, and even baseline upgrades.
- Reduction of OPEX: amount of operating expenditure reduced for a CCS on-board solution. This includes operation, maintenance, updates, as well as the life-cycle exchanges at least over a full vehicle lifespan.
- Fast and flexible migration: capabilities supporting functional evolution and simplified integration in existing vehicle and infrastructure.

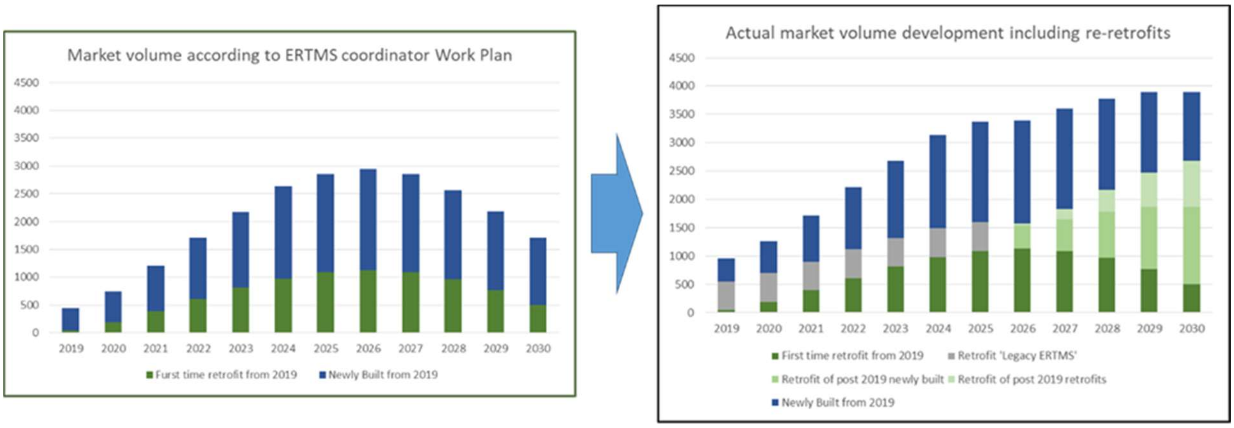
- Shorter time-to-market: amount of time reduced to introduce new or adapted CCS functionalities and/or technologies into a vehicle. The time to fix an issue is also relevant when it comes to adaptations related to error correction or security patching.
- Increase performance: for the CCS on-board solution, an increase in reliability is expected, the availability and the maintainability, while maintaining the current level of safety.

OCORA intends to provide a quantitative and qualitative economic evaluation in the gamma release where OCORA member corporate objectives, business objectives, design goals and architecture design will be analyzed and modelled.

7.1 Market dynamics

An important general notion underpinning the necessity of the OCORA collaboration is the expected growth of market demand in relation to the financial burden for the treasury of the European Communion. Recently, the draft Work Plan 2020 of the European Coordinator for ERTMS was made available. This document provides an estimate of the number of newly built and existing vehicles to be equipped with ERTMS up to 2030 in a “low bound” and a “high bound” scenario. These scenarios appear to be based on the assumption that trains need to be equipped only once during their life time and that demand is distributed evenly and balanced over the period under consideration. Experience teaches, however, that the ERTMS On-board has to be replaced once every 5 to 15 years, on average 10 years at the moment (OCORA assessment). Moreover, it is quite conceivable that shockwave changes like the introduction of FRMCS and the decommissioning of GSM-R will result in peak demand in relatively short time windows.

Taking account of the fact that approximately 3600 vehicles have been (retro)fitted already with an estimated average residual life expectancy of 15 years and a (conservative) average replacement rate of 10 years (7 years expected in the futureless to be foreseen, the annual demand for on-board CCS installations would be as depicted in the graph below.



Mr Ruete Draft Workplan 2020 (§ 3.3, p. 27) low bound 2019 – 2030 demand estimate:

Mr Ruete Draft Workplan low bound 2019 – 2030 demand estimate inclusive of pre and post 2019 ERTMS fleet retrofit requirements:

Figure 4 - Market volume trends

Market volume trends are extrapolated from Work Plan 2020, European Coordinator for ERTMS. As can be seen from this graph, the demand (and expenditure) for fitting and retrofit capacity will increase considerably in the next decade, resulting in a continuous high demand that will stretch the supply industry production capabilities. The demand for retrofit capacity will ultimately become the dominant factor in the CCS market, indicating also a considerable need to develop prototypes.

Table 1 - EC CEF Unit contribution overview is an abstract from the EC publication ‘Decision Authorising the Use of Unit Contributions to Support ERTMS Deployment under the Connecting Europe Facility – Transport Sector[1]. It defines the actual reimbursements for the retrofit of rail vehicles and the level to which EC compensates RU’s for their investments.

[1] https://ec.europa.eu/inea/sites/inea/files/ertms_decision-annex_i_unitcontributions.pdf

Activities	Cost category		Scenario	Sub-scenario		Amount identified in report (K€)	Unit contribution after application of the differentiated co-financing rate (K€)	Co-financing rate applied (%)
On-board ERTMS B3 equipped vehicle	Retrofitting	Prototype	International	/	/	2.509	900	36%
			National	/	/	1.352	450	33%
		Serial	International	/	/	255	110	43%
			National	/	/	273	80	29%
	Upgrade	Prototype	International	/	/	1.683	600	36%
			National	/	/	907	350	39%
		Serial	International	Software	/	41	18	44%
			National	Software	/	44	15	34%
			International	Software	Hardware	130	55	42%
			National	Software	Hardware	139	55	40%
	Fitment					100	25	25%

Table 1 - EC CEF Unit contribution overview

Although recent experiences demonstrate that the actual expenditure is significantly higher than anticipated by EC (bills for prototyping run into tens of millions and the average retrofit cost is nearing € 1 million per vehicle), even at the rates indicated in the Table, the structural compensation of RU's will amount to hundreds of millions of Euro's annually in the – from the financial point of view –most optimistic scenario. And the expenditure for the RU's themselves, paying the majority of the investments needed, will rise beyond what is economically viable. The advent of the game changers which drive CCS On-board system complexity, threatens to increase cost levels even further.

At the same time, developments give a glimpse on the opportunities that offer themselves to the railway community. Market volume is on the rise, even in a conservative scenario. In the do-or-die scenario that is now unfolding, releasing the market potential by ensuring the availability of cost effective solutions for the on board CCS will trigger a vast and swift transformation from the current, fragmented railways to a fully interoperable European Network. Because it's i affordable and offers a value proposition that it now doesn't o have.

It is the prime objective of OCORA to provide the preconditions that allow to effectively accelerate development towards an affordable on-board that drives market expansion while ensuring a positive business case for RU's at the same time. This has to be done in close collaboration with authorities, institutions and especially the supply industry. Expanding market volume, while at the same time harnessing cost and performance levels have to be actively and jointly managed from both the demand and supply sides.

8 OCORA scope and collaboration with other groups

OCORA is an open CCS reference architecture for an on-board software and hardware platform, providing hardware abstraction interfaces and services primarily to CCS on-board applications and eventually to other on-board applications. OCORA covers only the train borne part of the overall control-command and signalling infrastructure needed for safe and automatic railway operation (Automatic Train Protection and Automatic Train Operation). A good integration in the overall CCS environment is therefore essential and requests a good collaboration and liaison with related activities, in particular with the following:

- RCA (Reference CCS Architecture): ERMTS Users Group and EULYNX
- Localization: EUG working group "Localization"
- FRMCS: UIC working group “Telecom On-Board Architecture”
- ERA CCS architecture group through CER CCS SG
- Shift2Rail: Connecta, Linx4rail

Prior to this OCORA Alpha release, alignment with some key stakeholders have been discussed. As a result, it can be said that a common view is shared, and the identified Problem Statements are aligned. Collaborative meetings and joint alignment groups are in preparation to reach a pragmatic an efficient cooperation.

OCORA is aiming at close and efficient liaison with other stakeholders in order to help consistency and complementarity between sector initiatives affecting the definition of CCS onboard subsystem. However it is also no secret that the collaboration between the railways and their supply industry on the issue of CCS in general and ERTMS in specific, have not been optimal during the last decades. Especially the relations between RU’s and the industry have to be intensified to ensure a successful roll out of ERTMS and the upcoming game changers. EC actively drives mutual cooperation forward jointly with ERA and S2R. It recently formulated its intentions in a number of papers on the future framework for CCS development, intentions that come very close to those of the OCORA collaboration.

The OCORA partners believe that the European railways cannot do without a viable and, therefore, profitable supply industry, just as much as the supply industry cannot do without a viable and therefore financially sustainable rail transportation sector that provides for a healthy and profitable demand for their products. Resources and expertise are scarce in the railway domain, especially with respect to CCS, and a productive cooperation between RU’s and Industry is vital to safeguard the future for both parties. One of the prime preconditions to achieve such equilibrium, is that the supply industry provides for a cost effective and innovative range of products and services that meets user requirements. On the other side, railways can accommodate the industry by improving the predictability and stability of demand, especially rationalizing the number of specialties.

> *DG MOVE in its end of May, 2020 version ‘CCS framework: governance and arrangements at EU level’:*
>
> *The business needs of customers and suppliers are not necessarily aligned at the “design phase”. Customers do not believe that suppliers have the appetite to move to a different model – away from tied-in national solutions. Indeed, through initiatives such as RCA EULYNX and OCORA, significant resources have already been invested by many IMs and RUs to develop an architectural view on rail system level. Suppliers do not believe that customers have the discipline to move towards a “single uniform architecture”, with the danger that the evolution would end up being as fractured and diverse as today.*
>
> *In order for the European Union to effectively manage and direct funding for rail research and innovation activities within the S2R JU and its successor, coherence at European level to make best use of financial and human resources and obtain the best result is required. This will bring a clear return on taxpayer money, i.e. improved services for passengers and shippers, i.e. maximising the logistic value*

OCORA believes that a productive collaboration with its industry partners would accelerate the evolution of the CCS system and provide for the universal and open CCS configuration it is looking for. That would boost the RU confidence in the ability of the industry to deliver according to OCORA requirements and, ultimately, market volume. ‘Confidence’ being a pivotal theme, OCORA assumes that a frequent, well-structured and open, unbiased exchange of views and ideas with its suppliers is fundamentalto initiate customer oriented product and service development. OCORA believes that as a rule of thumb, it should target reasonable cost to benefit ratio’s that support the business requirements of both customer and supplier.

9 Evolution of the OCORA architectural framework

The on-board CCS system is currently “only” ensuring the safe movement of the vehicle over the railway infrastructure. Except for the emergency brake intervention in case of supervised speed threshold overshoot, it is up to train staff, especially the driver, to manage all facets of train operation. This will change with the advent of digitalisation and automation in train operation, supported by innovation in computing and telecommunications. Currently, ATO projects are being developed by a number of RU’s, for the moment targeting GoA 1 and 2 levels. But increasingly also GoA 3 and GoA 4 experiments are started with the express intention to start operations as soon as possible, e.g. for automatic shunting.

9.1 Requirements for an adaptive architecture

OCORA follows an evolutive, stepwise approach that targets testing and approval of the core functions of an OCORA proof on-board prototype, the so called ‘Minimum Viable Product’ as a first stage. The main characteristics of the MVP are plug and play interchangeability within the CCS domain through isolation of specific functions in combination with the specification of a generic and open communication backbone, the Universal Vital Control and Command Bus. Furthermore, the integration of the control-command and signalling system in the vehicle is supported by a generic gateway interface specification. **Error! Reference source not found.** depicts a simplified high-level view of the envisioned stage one OCORA CCS on-board system architecture as presented in the Alpha Architecture. Please note that the number of functions or devices is not limitative and includes e.g. train positioning, train integrity management, etc. These are not specifically made visible, since it is a matter of the detailed architectural design to allocate such functions to either the CCS on-board or train domain.

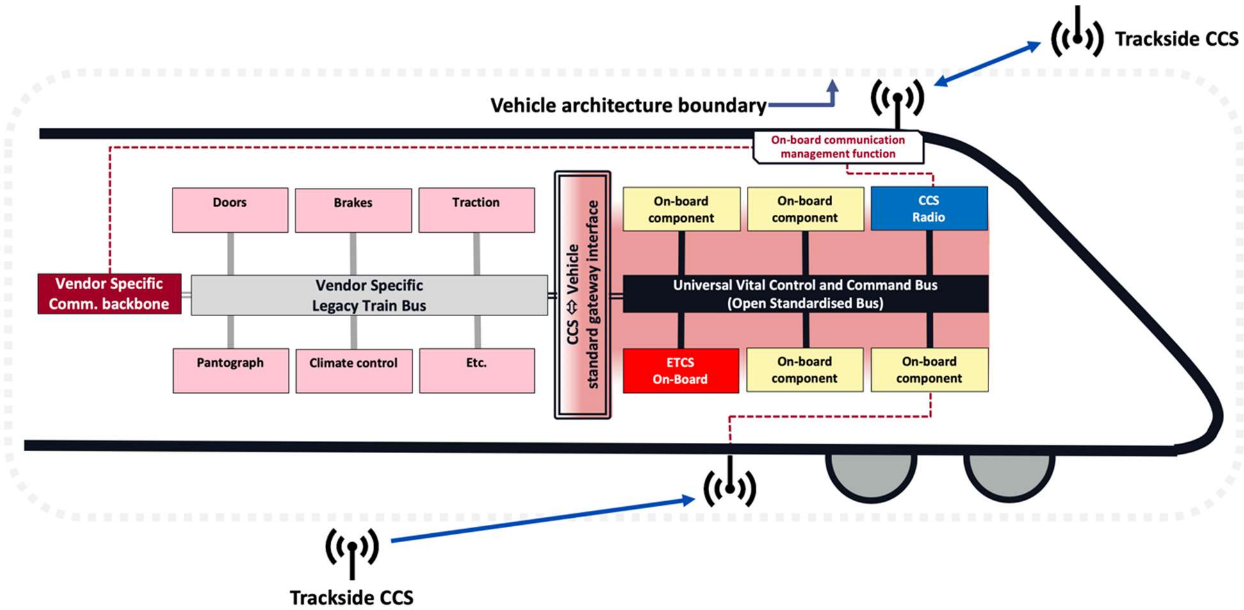


Figure 5 - High-level simplified vision of OCORA stage one vehicle architecture

Obviously, this architecture retains a number of the drawbacks of current vehicle design and stops short of the complete modularisation of the vehicle inclusive of the CCS system that will be required for commercial operation under GoA 3 and GoA 4. Therefore OCORA foresees that further development on the overall vehicle architecture will be necessary in order to ensure technology convergence and standardisation for buses on the vehicle side. Indeed, OCORA is already in the process of probing the options with industry partners in the frame of S2R-LinX4Rail discussions on CONNECTA.

With the advent of automated train operation in heavy rail, notably through GoA 3 and 4, the option of unmanned rail traffic – for decades of “business as usual” in light rail – becomes feasible. The introduction of ATO and FRMCS in TSI 2022, supported by improvements of e.g. braking curve calculation, are a first step in that direction. The imperative of cost reduction and productivity improvement allowing rail transportation to keep up with modal competition, will inevitably drive the development of further automation and digitalization.

The on-board CCS domain is at the moment defined by the need of safe movement of the individual (combination of) rail vehicle(s) over the railway infrastructure. It essentially requires an ATP system (ETCS core) and supporting functions to feed the ETCS core with the necessary data. Except for the emergency brake intervention in case of supervised speed threshold overshoot, it is up to train staff, especially the driver, to manage all facets of train operation.

The reduction of the human element in train operation requires that an increasing number of vehicle systems be effectively controlled by technical system. Traction, doors, climate, etc., have to be automatically controlled when human control is absent. On the long term, OCORA envisages unmanned train operation on, at least selected, sections of heavy rail networks or for specific transportation functions like shunting, especially high traffic density lines. Obviously, this requires a progressive adaptation of the railway system architecture, infrastructure and rolling stock, along the definition of the CCS architecture.

9.2 OCORA architecture development stages

To accommodate the gradual evolution of the OCORA on-board architecture, a number of development steps are identified that allow the OCORA members to consecutively address actual topics.

9.2.1 Preparing imminent retrofit projects

In this step, the interface between proprietary CCS system and fully integrated proprietary vehicle environment is isolated, enabling exchange of the CCS environment without affecting the vehicle and vice versa, simplifying obsolescence issues

OCORA members are already engaged in retrofit projects that are, or will be, well under way. It is not realistic to expect all OCORA requirements to be fulfilled in these implementations. In this phase, the first objective is to establish exchangeability and modularity on a CCS system level, enabling replacement at end of life cycle without any residual artefacts having an impact on the selection of suppliers for successors or the implementation of the OCORA platform. The first objective is, therefore, to specify an unambiguous and open interface between the CCS system and the vehicle, including ATO functionality. OCORA aims at eliminating existing ambiguities from the subsets 119 and 139 and closing the gaps in these specifications. The result will be a generic and open interface between vehicle and ETCS system as depicted in Figure 6.

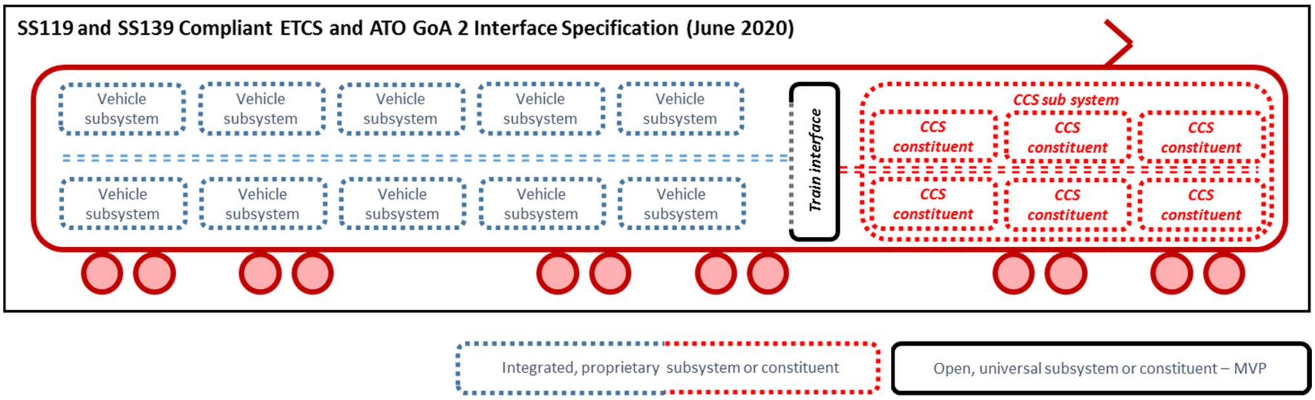


Figure 6 - Decoupling of the interfaces between the CCS sub-system and the vehicle

OCORA intends the output from its subset 119 and 139 development work to be integrated in the TSI Revision of 2022 to complete and enhance the existing specification.

As a further preparation for the OCORA platform development, OCORA formulated the following problem statements as an incentive to improve the current TSI's:

- Modular Architecture
- CCS new open Bus
- CCS – Vehicle Adapter/Gateway

- Hardware/Software independence
- Acceptance of global standards
- Non-Functional Requirements

These problem statements will be worked out in detail to provide input for the TSI revision. OCORA will make use of existing channels (e.g. CER, EUG) to infuse its proposals into the regular framework for TSI updates.

9.2.2 Modularisation of the CCS subsystem

In this step, the CCS domain will be decomposed in single building blocks, connected by open interfaces and an open bus system allowing exchangeability between the building blocks without affecting either the vehicle or other CCS constituents. Obsolescence management and migration issues can be simplified; approval and certification can be confined within the boundaries of the building blocks instead of the CCS system or the whole vehicle. This step implies development of the specifications for the Universal Vital Control and Command Bus and the interfaces between the single building blocks. Furthermore, the core functionality of the CCS, involving the safe movement of vehicles over a rail network, will be modelled using formal methods. Based on this development software will be generated, a test environment established which will eventually result in a prototype that can be empirically tested in an operational environment. The objectives include the approval of the prototype as a first step in industrialisation.

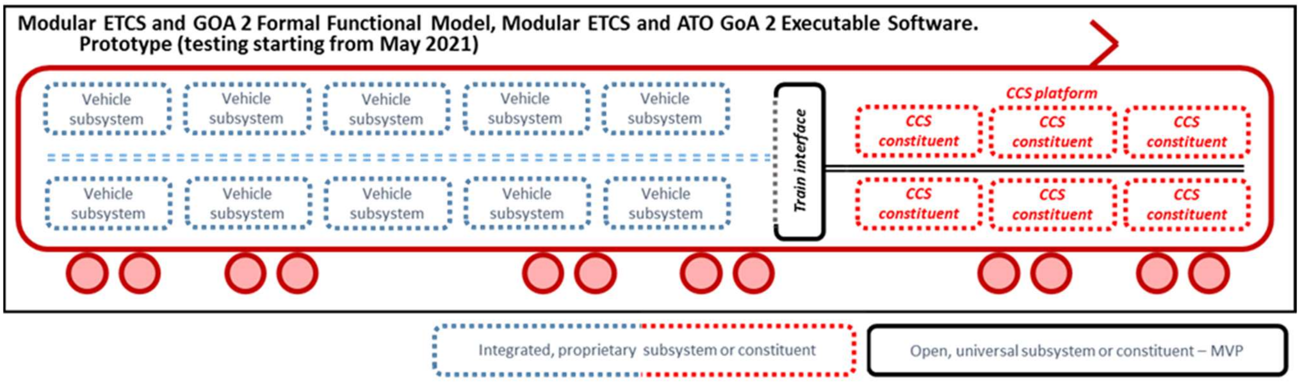


Figure 7 - Modularization of the CCS system proper - UVCCB introduction

OCORA intends, with the output from this modularisation exercise to challenge the TSI Revision of 2022 in order to prepare the path for the long term CCS evolutions. The definition of modules should help to shape an adequate level of granularity for TSI options, which will facilitate both standardisation of product supply and smoothen the migration from existing and future CCS building blocks.

9.2.3 OCORA CCS platform

In this step, the core CCS functions will be organised on a generic platform that enables adding, removing or changing software without affecting the hardware and computing platform on which they are installed or the state of approval of non-affected parts of the system. This will facilitate fast and easy software updates and upgrades of only those applications for which that is necessary, necessary e.g. when requirements demand frequent updates of security software. Authorisation issues can be further simplified and contained.

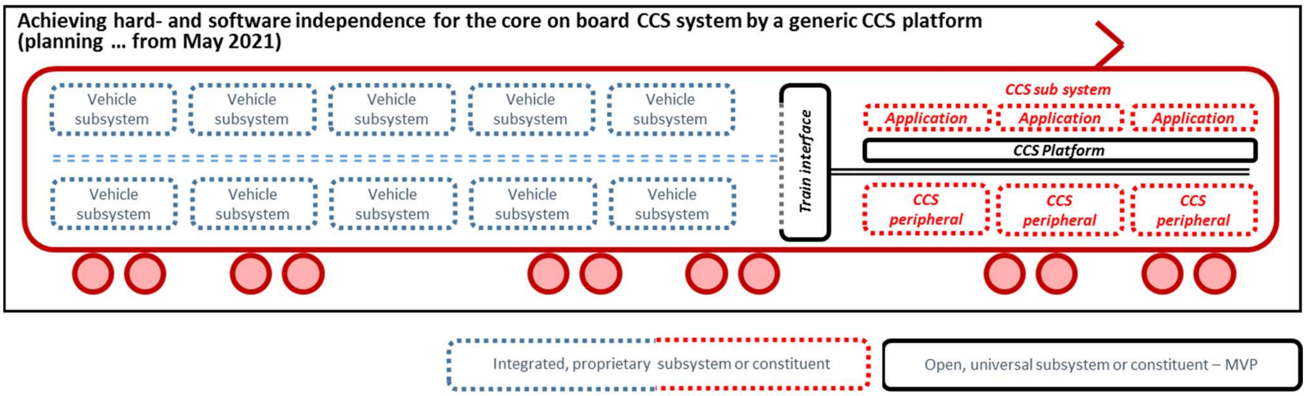


Figure 8 - open CCS system with full plug&play capabilities for application, hardware and peripheral

On the longer run, but already under scrutiny of OCORA and Shift2Rail Connecta, is the convergence of vehicle networks, consisting of one or multiple bus systems that integrates the CCS and vehicle bus systems.

Developments like GoA3 and GoA4 will demand for remotely access and automated control of an increasing number of CCS and vehicle functions. Evolution of the CCS domain and the vehicle will become inevitable at some point in the future. Such development will have a considerable impact on vehicle design, performance and cost structure and will give a strong impetus to improved management of cost, risk and performance for both users as well as suppliers. The train interfaces allowing to connect legacy bus may disappear but standardised secured communication interface, being a physical or virtual building block, must be anticipated in order to decouple issues. This would ease safety approval, non-regression, cyber security and maintenance management, while allowing for innovation and fair competition.

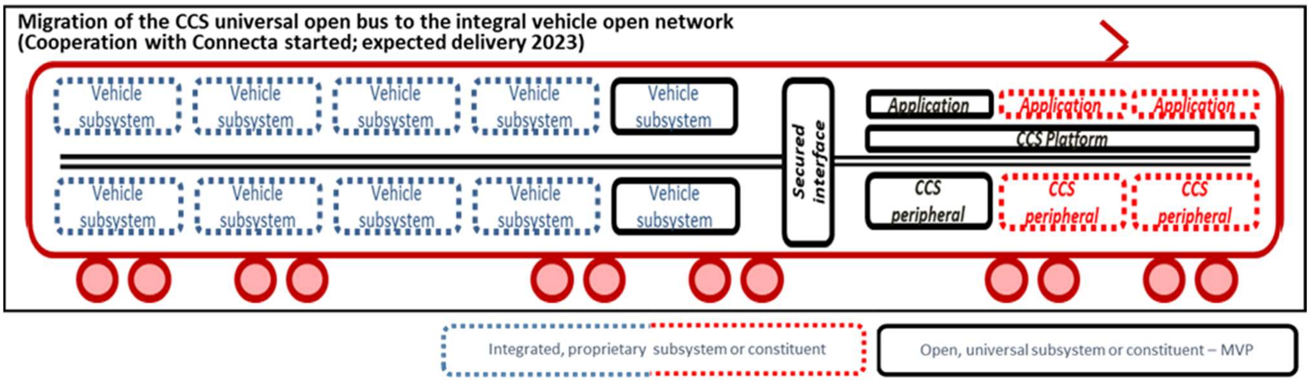


Figure 10: prospective view : CCS building blocks integration supported by vehicle standardisation

10 OCORA architecture design principles

OCORA defines the principles along which it intends to develop its platform in terms of:

1. Architecture design principles, determining coherence and consistency of the functional and technical building blocks that together define role and value of the on-board CCS system in its institutional/sectoral, commercial, functional and physical environment (rail vehicle, railway operations), providing an answer to the question: **why** (decomposition) design choices are made?
2. The principles governing the logical and physical structure of data communication between the (sub)systems of the on-board CCS system and between the on-board CCS system and external systems that define how these building blocks and their environment interact, i.e. the transformation of OCORA design principles into the **behaviour** of the OCORA platform. OCORA uses the OSI Model for this purpose.

OCORA also uses architecture design quality criteria that are further explained in [3], i.e. product quality characteristics and sub-characteristics for the OCORA platform as defined by ISO 25010. These explain **how** design choices are to be implemented in the OCORA platform. Please note that ISO 25010 in some cases makes use of the same terms as usually applied in railway design, notably ‘modularity’ and ‘interoperability’, but with a different meaning.

10.1 OCORA architecture design principles

10.1.1 Context and coherence

Architecture design principles explain how and why system design enables RUs to achieve business objectives and, therefore, always have an economic rationale. They are not necessary to explain how or why a system works or performs, but how a system supports the corporate goals of its users.

CCS systems, especially ERTMS, have become important drivers for the life cycle costs of rolling stock, operational performance and transportations capabilities. Defining architecture design principles is of paramount importance to manage financial, operational and performance risks by design. This requires moving away from monolithic CCS architectures that result in any (minor) change almost automatically affecting the integrated whole. The subsequent need to replace entire systems, repeated authorization processes and persistent complexity and performance issues, in the end damages the economic viability of both users and suppliers while it prevents early adoption of innovations and slows down the automation of railway processes.

OCORA architecture aims at breaking down the CCS on-board in building blocks that provide an optimum between economic value and technical feasibility. In economic terms: the upper limit of granularity, is the first level of decomposition where it is more cost effective to exchange single building blocks than to replace the monolithic system they are part of. For example: if the total cost of ownership of a monolithic system exceeds that of the coherent and integrated whole of the sum of its independent building blocks, then the user should opt for decomposition of the system. And vice versa. This rule also applies to the question whether to further decompose single building blocks, defining the lower limits of decomposition. When it is more cost effective to replace a subsystem or component than to repair it, the lowest level of granularity is reached. When it is more cost effective to repair it, it is worthwhile to decompose it since that will allow the level of modularity needed for maintenance.

OCORA has defined a number of core design principles pertaining to the breakdown and clustering of functional building blocks that are to be perceived as mutually related and dependant and can be both cause and effect of the others:

1. **Openness:** the property that design, contents, operation of a system and any information hereon is fully transparent and accessible to users and stakeholders.
2. **Modularity:** The property of being composed of a coherent whole of single, independent building blocks or modules. This ‘whole’ could also itself be monolithic system, so to make effective use of this property, OCORA also requires an approach to product (e.g. functional vehicle adapter module) and services (e.g. testing, insurance) allowing to integrate the CCS onboard subsystem with the rest of the vehicle building block.

3. **Exchangeability**: The property that individual modules can be replaced by others without affecting the integrity of the whole system. This property implies that provisions have been made regarding the connection between discrete modules which should enable the system to retain its integrity in case building blocks are replaced.
4. **Migrateability:** The property allowing to add or remove independent building blocks to the system or exchange existing building blocks by alternative ones without compromising the integrity of the system as a whole, and
5. **Evolvability:** The property of enabling new technologies to be integrated into existing building blocks (or the mortar between them) while retaining at least the necessary functions of the integral system.
6. **Portability (Platform Independence):** the property to exchange modules or their functions between systems. A good example is regular office software that can be used on laptops from multiple manufacturers using different operating systems., e.g. software
7. **Security:** the property that a system cannot be used or its correct functioning compromised by an unauthorized source.

These and supporting principles are further described and defined in the next paragraphs.

10.1.2 Openness

As the most important principle for collaboration within OCORA, the concept of ‘openness’ certainly also pertains to the architectural level. Here, OCORA has adopted the interpretation of ‘open’ as proposed by the OSI DARTS open spectrum[1]. DARTS stands for data and information being discoverable, accessible, reusable, transparent and sustainable. These words indicate in short that information can be found, used, shared, easily understood, analysed, validated and verified and applied without the user being hampered by financial, legal, technical or ethical barriers or constraints.

10.1.3 Modularity

As a design principle, the concept of ‘modularity’ should target Coupling & Recombination, Fitness and Adaptation and Migration Equilibrium and . This makes one of OCORA prime design principles to something that is secondary to maintenance. Our point is that modularity by design affects maintenance (costs), not the other way around. But also the ability to achieve and increase performance, etc.

Modularity is expressed by the degree to which a system or computer program is composed of discrete building blocks. A good architecture must anticipate the need that a change to one module has minimal or no impact on others. As per definition, modularity is one of the main drivers for maintainability, performance and capabilities and, therefore, expenditure and risk. OCORA aims at managing RU’s financial, operational and performance risks through improved exchangeability. In the OCORA context, modularity is defined as follows:

> Modularity is a prerequisite for having “plug & play”-like exchangeability of an on-board CCS system or its subsystems without the need to involve either the original supplier of the vehicle, of the CCS system or one of its subsystems.

While the main target of modularity for OCORA based systems is to achieve “plug & play”-like exchangeability as defined above, modularity brings along other advantages:

1. Life cycle orientation on building block level. Where now monolithic systems often need to be replaced while only specific components or subsystems have become (technologically or economically) obsolete, life cycle management can decentralise from systems’ level to the single building blocks of the system. Life-cycle costs of the CCS on-board system can be improved, since subsystems at the end of their life-cycle can be replaced individually.
2. Decomposing a system into subsystems reduces the development time for the overall system, since it improves the possibility for parallel development and specialization of the different development teams.
3. Decomposing a system reduces complexity during development and maintenance of the overall system. For example, single subsystems and components can be easily isolated, exchanged, or replaced for

[1] http://osiglobal.org/2018/11/15/osi-brief-what-do-we-mean-by-open/

trouble shouting purposes. Testing and acceptance efforts can be concentrated on the respective subsystem. As a result, life-cycle costs and implementation time can be reduced.

4. If the interfaces of the subsystems are well-designed, introducing new functionality to the CCS on-board system is greatly simplified and the system can evolve rather than be replaced as a whole.
5. If safe functionality is encapsulated and separated from non-safe functionality, the likelihood of having the need to modify, test and accept safe subsystems decreases. At the same time, it increases the capability to easily introduce changes to non-safe subsystems.

Modularity not only comes with the advantages pointed out, but also has its downsides. Usually, the integration testing effort increases when building the system for the first time. Modularity with the purpose of having "plug & play"-like exchangeability as defined in the OCORA context (see red box), requires very detailed interface descriptions as well as harmonized requirement specifications (functional and non-functional) for all subsystems. Defining these interfaces and requirements to the level needed for the OCORA desired "plug & play"-like exchangeability, requires a substantial deployment of scarce human resources. Therefore, the granularity of the decomposition needs to be a result of a well-balanced analysis of the effort against the business needs (expected benefits). A relevant size for standardised modules is also essential to avoid that the workload to update interface specification will at the end become a new bottleneck for evolutions.

10.1.4 Exchangeability (Interchangeability)

In the OCORA context, exchangeability is often also referred to as interchangeability. The OCORA definition for exchangeability is as follows:

> Exchangeability (Interchangeability) is the ability to replace one or multiple OCORA defined subsystems with (a) respective subsystem(s) of (an)other supplier(s), without affecting other subsystems of the train or the overall CCS on-board system.

Exchangeability (interchangeability) is an important driver for maintenance as it should allow OCORA defined subsystems to be fitted in various type of rolling stock (e.g. generic spare parts that are configured automatically when plugged in a specific train).

10.1.5 Migrateability (Upgradeability)

In the OCORA context, the terms migrateability or upgradeability are often used as alternatives. The OCORA definition for migrateability is as follows:

> Migrateability (Upgradability) is the ability to introduce changes to one or multiple OCORA defined subsystems, without affecting other subsystems or the overall CCS on-board system.

10.1.6 Evolvability (Flexibility)

In the OCORA context, the words evolvability, evolutivity, and flexibility are often used as alternatives. The OCORA definition for Evolvability is as follows:

> Evolvability (Flexibility) is the ability to easily adopt to new technologies or to extend the functionality of an on-board CCS system without the involvement of the original supplier.

10.1.7 Portability (Platform Independence)

Portability is the degree of effectiveness and efficiency with which a system, product or component can be transferred from one hardware, software or other operational or usage environment to another. Portability is a main characteristic and includes the sub-characteristics: adaptability, installability, and replaceability (ISO 25010). Portability in the context of OCORA focuses on platform independence of functional applications: the fact of using a "generalized abstraction" (API) between the functional application logic and the underlying (Computing) Platform. The OCORA definition for portability is as follows:

Portability (Platform Independence) is achieved when a functional application, based on the generalized abstraction, runs un-changed on different (computing) platform implementations. For this, the functional application shall only use external functions through a defined application programming interface (API).

10.1.8 Security (Cyber Security)

Security is the degree to which a product or system protects information and data so that persons or other products or systems have the degree of data access appropriate to their types and levels of authorization. Security is a main characteristic and includes the sub-characteristics: confidentiality, integrity, non-repudiation, accountability, and authenticity (ISO 25010). In the OCORA context, the focus is on cyber security. Therefore, this term is often used to express this product characteristics. The OCORA definition for security is as follows:

Security (Cyber Security) is the protection of (especially safety related communication and data used in) on-board CCS systems against threats (in particular cyber-attacks and hacks). To achieve this, all main security functionality like identify, protect, detect, respond and recover are considered.

10.2 Data communication design principles (OSI)

OCORA follows the OSI reference model for data communication design. The model provides the 'mortar' that enables modular exchangeability as referred to in paragraph 2.1.1. The OSI, or Open System Interconnection, model defines a networking framework for implementing protocols in seven layers. Control is passed from one layer to the next, starting at the application layer in one station, and proceeding to the bottom layer, over the channel to the next station and back up the hierarchy[1]

Since OCORA applies the OSI reference model, the design principles applied are given here for reference purposes:

1. A layer should be created where a different level of abstraction is needed.
2. Each layer should perform a well-defined function.
3. The function of each layer should be chosen with an eye toward defining internationally standardized protocols.
4. The layer boundaries should be chosen to minimize the information flow across the interfaces.
5. The number of layers should be large enough that distinct functions need not be thrown together in the same layer out of necessity, and small enough that the architecture does not become unwieldy.

[1] Source: https://www.ukessays.com/essays/information-technology/explain-the-principle-of-network-osi-layers-information-technology-essay.php