RCA Beta – Chapter on Architectural approach and Systems-of-systems Perspective

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1. Introduction

1.1. Purpose of the document

The publication of RCA Alpha has generated interest among railways and suppliers. Direct feedback and feedback from several workshops have provided insight, where clarifications or additional content would be helpful.

This document addresses two questions:

- What kind of architecture does RCA try to describe (functional, logical, physical…) and why?
- How does RCA fit into existing architectures or with on-going initiatives? Does RCA lend itself to be a part of a systems-of-systems approach?

This document complements chapter 4 "Description of RCA deliverables" of the "RCA Architecture overview" [1]. This is the very first publication on this topic from RCA and its main purpose is to establish the topic and get discussions with stakeholders in the sector going.

1.2. Relevance of architectural approach for RCA

If the goal of the chosen architectural approach in RCA is not well understood, RCA may be difficult to understand or may be lacking in content. Therefore, it is important to understand what issues the RCA addresses and what issues are (on purpose) left out.

1.3. Relevance of systems-of-systems perspective for RCA

Since RCA does not describe the complete architecture for an IM or the whole railway system, RCA will only be a “piece of the puzzle” and will need to be combined with other architectures. We will give a first overview, how this can be accomplished.

1.4. Concepts and Examples in other domains

- SESAR (single European Sky ATM research) JU has published in [2] an overall architecture for ATM, taking a very broad perspective.
- System-of-Systems Engineering is an established discipline (see https://en.wikipedia.org/wiki/System_of_systems_engineering).
- The discipline Enterprise Architecture offers a perspective of applying architectural thinking to enterprises including also non-technical concepts, see https://en.wikipedia.org/wiki/Enterprise_architecture. For an application of EA (Enterprise Architecture) to railways, see [7].
- Model-based systems engineering (MBSE) is a methodology of systems engineering focusing on (architectural) models and capturing more than technical implementation decisions https://en.wikipedia.org/wiki/Model-based_systems_engineering.

1.5. Reference material

- [1] RCA Architecture overview.
- [2] SESAR JU. “A proposal for the future architecture of the European airspace” https://www.sesarju.eu/sites/default/files/2019-05/AAS_FINAL_0.pdf.
- [3] ISO/IEC 42010:2011Systems and software engineering — Architecture description.
- [4] SysML is a systems modelling language (i.e. notation) derived from UML and the foundation for many system engineering methods. https://en.wikipedia.org/wiki/Systems_Modeling_Language.
- [5] Arcadia is a systems engineering method with a clear derivation process from need to solution. https://www.polarsys.org/capella/arcadia.html.
- [6] EULYNX Modelling Standard is available as part of the (public) documentation set of every EULYNX release. https://eulynx.eu/index.php/documents/documents-overview/published-documents/open-availability.
- [7] Network Rail “"Enterprise architecture within railway systems engineering" https://digital-library.theiet.org/content/journals/10.1049/iet-its.2018.5062?originator=ietauthorOffprint&identity=483079&timestamp=20200611101749&signature=397b95ccc00e2fca902d256f6a63d395&tinyUrl=http://ietdl.org/t/I9MA0.

2. Architectural Approach in RCA

RCA is a reference architecture, this leads to 2 important points:

- In [1], chapter 4 “Description of RCA deliverables” explains that RCA is not a complete system architecture but provides a reference i.e. a blueprint for building/procuring a concrete CCS for a specific IM.
- We will distinguish the architectural elements needed to define / develop RCA from the architectural elements needed when applying RCA.

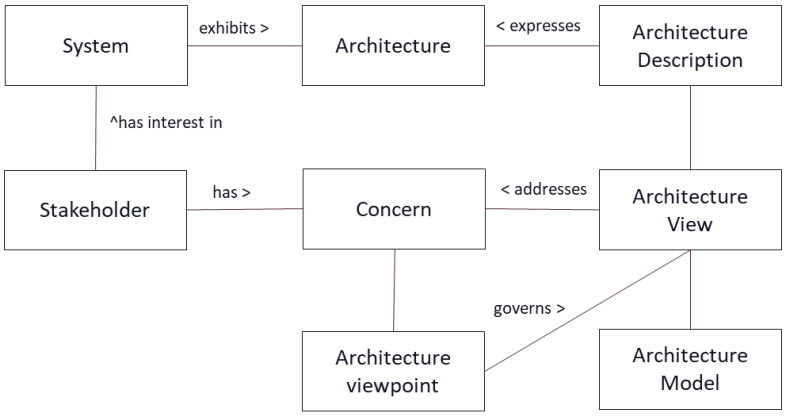
This chapter will describe the architectural approach of RCA including:

- What is the understanding of the term ‘architecture’ in RCA?
- What are the architectural definitions coming from the RCA process?
- Which architectural elements are necessary to define RCA?
- Which architectural elements are necessary to use / apply RCA?

2.1. Understanding of the term ‘architecture’ in RCA

The term ‘architecture’ is frequently used, but with different perspectives. We apply the definitions from ISO/IEC 42010:2011 “Systems and software engineering — Architecture description”.

The following concepts are central for the discussion (simplified from [3]):



Important points here are:

- The distinction between the architecture of a system and the architecture description of a system.
- Architecture: fundamental concepts or properties of a system in its environment embodied in its elements, relationships, and in the principles of its design and evolution.
- Architecture description: work product used to express an architecture.
- Architecture viewpoints are used to define architectural views which address certain concerns of stakeholder with respect to the system.

There are different contexts for architecting using quite different architectural modes. These contexts include enterprise architecture, systems engineering, software engineering.

RCA has a very specific target and therefore selects a small subset of architectural viewpoints for its description. We will therefore describe below which architectural viewpoints are important in RCA.

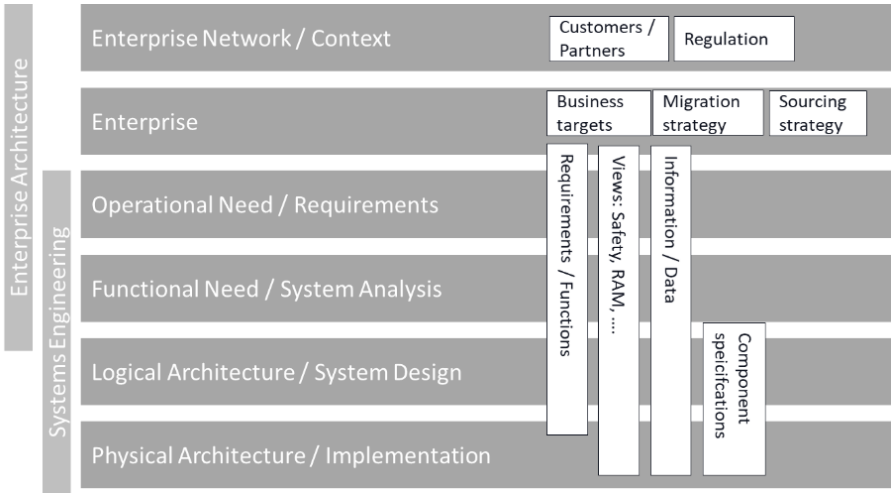
When integrating with other architectures (see also system-of-systems perspective), it will be important to take into the account the fact that architectural descriptions may be quite different.

2.2. Simple reference schema

We introduce here a simple reference schema (architecture framework) to be able to talk about which architectural elements are addressed by RCA. The diagram shows:

- commonly used “layers” used in the disciplines EA (enterprise architecture) and SE (systems engineering).
- topics (such as requirements, Safety-View, RAM-View) being refined & allocated from top to bottom.
- the solution design results in the rectangle “component specifications”.

Since terminology in architecture has not been standardized yet, we have re-used terms from SysML [4] and Arcadia [5].



2.3. Architectural modelling, methods and tooling

RCA is applying MBSE (model-based systems engineering) and a subset of SysML [4] as defined by the modelling standard of EULYNX [6]. Since the system scope and component complexity are different from EULYNX, some extensions to the modelling standard are being considered.

2.4. What are the architectural definitions coming from the RCA process?

The main purpose / result of RCA are specifications for RCA components. These RCA component specifications can be used:

- by IMs as building blocks in designing / building a CCS system.
- by suppliers as input to their product requirements.

The RCA components are not abstract functions, but buildable, procurable, runnable components (implementing, of course, the allocated functions). As is explained in [1], chapter 4.6. RCA components need not be physical boxes, but most components can also be implemented by “pure” software solutions (see also the topic “platform independence”).

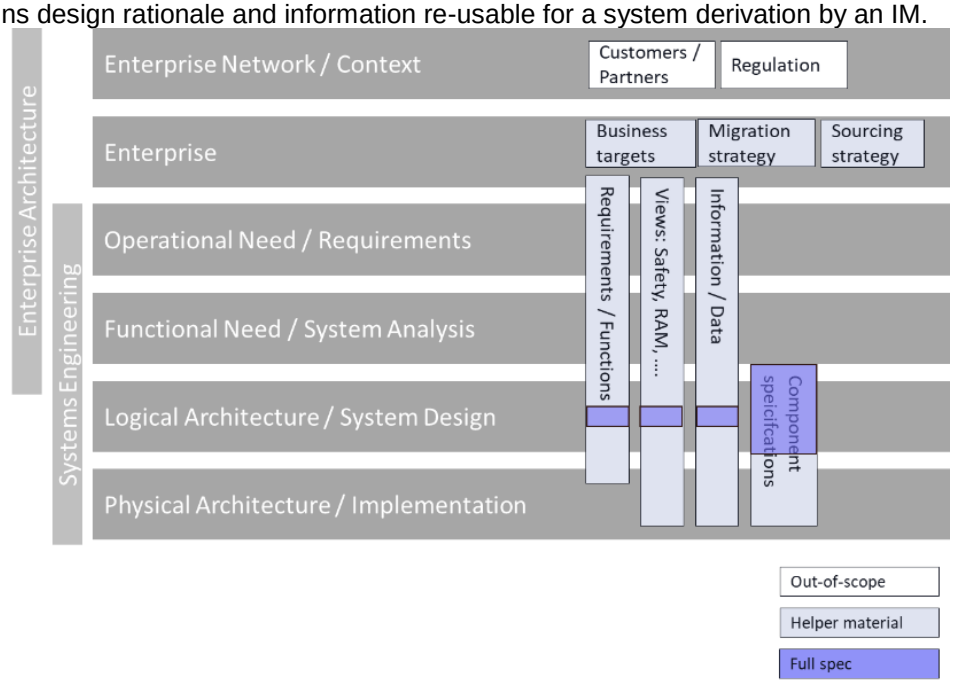
The RCA components specifications consists of two (largely) orthogonal aspects:

- Interface architecture of RCA, see [1] chapter 4.2.
- Technical architecture of RCA, see [1] chapter 4.3.

The interfaces architecture includes the following elements:

- component decomposition
- component behaviour definition
- component interface definition, including information modelling

The parts marked “”Full spec” in the following diagram are the core of the architectural deliverable of RCA. Additionally, RCA will contain “Helper material”. Helper material is not necessarily complete to derive a system but contains design rationale and information re-usable for a system derivation by an IM.



2.5. Which architectural elements are necessary to define RCA?

In the design / specification process for RCA we use existing requirements and design inputs form several IMs.

Regarding the “RCA components specs”, the RCA process works in 2 directions (see diagram below):

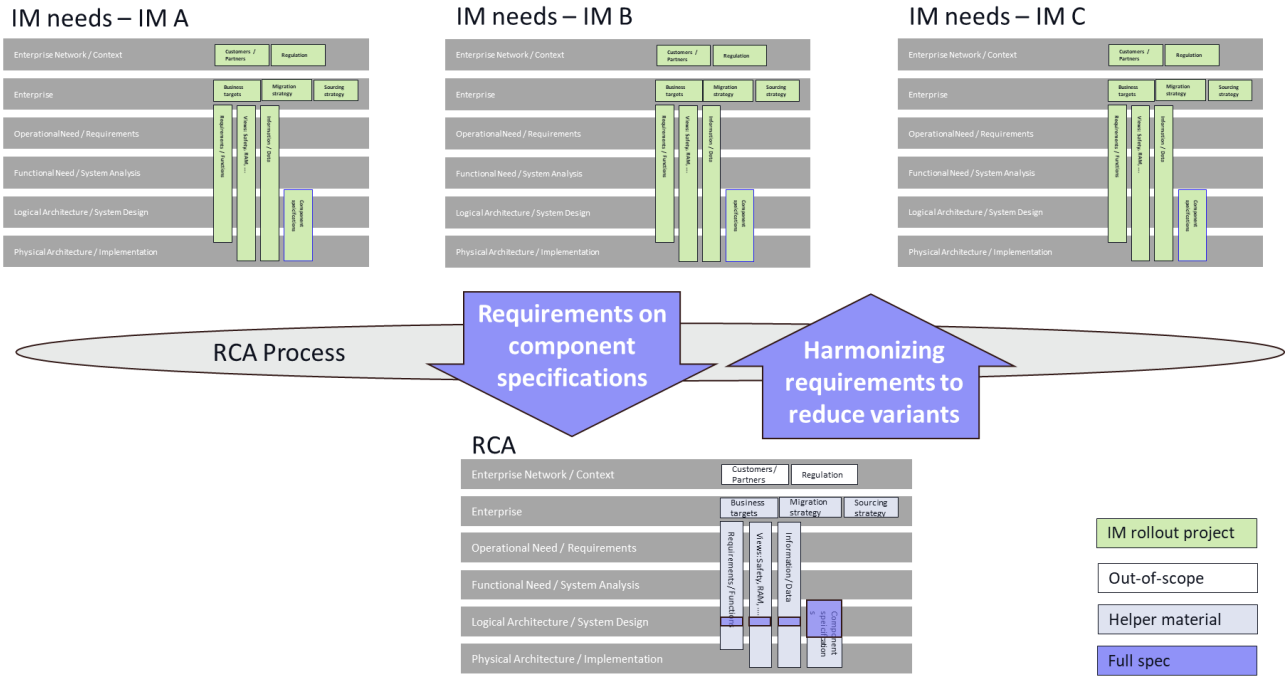
- “top-down” - from need to solution:
  The RCA component specification is checked against the needs / design constraints. A new / different need may lead to an extension of the RCA component spec.
- “bottom-up” – from solution to need:
  If an RCA component spec would be required to cover the sum of all existing needs / design constraints, the spec would become too complex, the opportunity for harmonization would be missed and the cost of products may be too high. Therefore, before considering an extension of the RCA component spec, an attempt at harmonizing the requirements among IMs is necessary.

So, for a given existing requirement on which 2 or more railways diverge, 3 outcomes are possible:

1. The requirement is harmonized among railways (preferred)
2. The requirement can be handled by functionality / processes outside RCA components, the RCA components implement a “superset” of functionality to support the requirements.
3. The RCA component spec implements the sum of the requirements (expressed as variants).

The process needed to manage the 2 directions “top-down” and “bottom-up” will involve constant trade-offs and will require a clear governance.

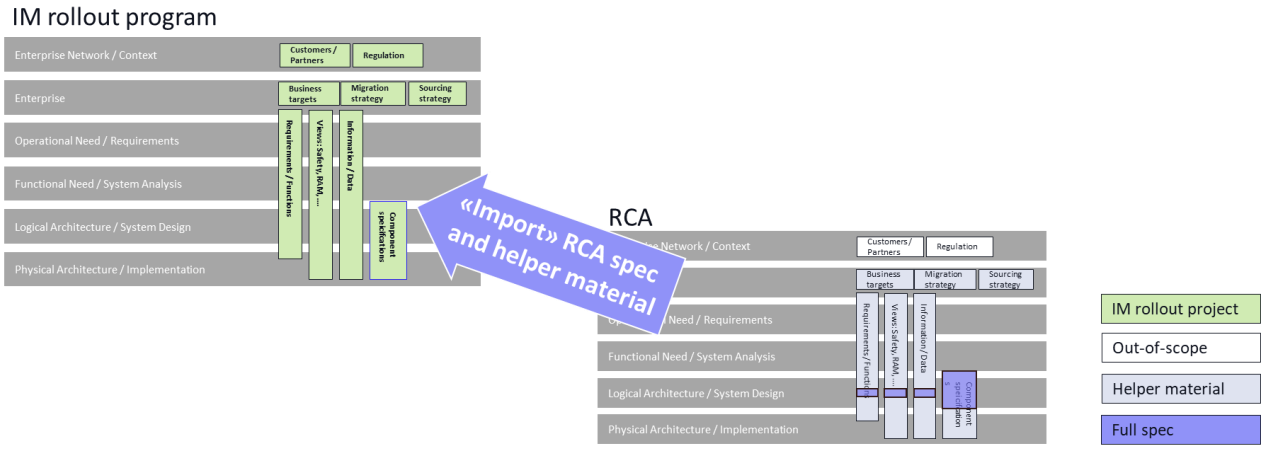
Regarding the helper material, the RCA process will document needs and design constraints that provide the rationale for the RCA component spec and which may be material for re-use in IM rollout programs.



2.6. Which architectural elements are necessary to use / apply RCA?

The following diagram shows, how an IM rollout program will "import" RCA deliverables into their overall architecture and program. The RCA deliverables come in 2 categories:

- RCA components specs:
  RCA specs are to be used as tender templates to procure components and the RCA specs will also be used to plan integration, acceptance, linking to existing systems etc.
- RCA "helpers": this is requirement and design material that can be re-used in the IM rollout program but will have to be extended and merged with the specific requirement material of each IM.



2.7. Architectural FAQ

2.7.1. What kind of architecture does RCA provide?

In a nutshell:

- Component spec:
  - RCA interface architecture: consists of a logical architecture of components, with defined interfaces, including: component behaviour, component states, message behaviour (sequences), message payload, data model for the message payload.
  - RCA technical architecture: consists of logical/physical architecture describing the interaction of applications (the components of the interface architecture) with a platform (a component including physical aspects) over a well-defined API (see also “Platform Independence”).
- Helper material: includes material providing the rationale for the component spec and focusing on the architectural aspects on the level of “functional need / system analysis”. This includes the definition of end-to-end functions and their allocation to components.

2.7.2. Why does RCA start at the “bottom” (components)?

As shown in 2.5 ”Which architectural elements are necessary to define RCA?” the process does not start at the bottom, but goes back and forth between needs (top) and solution (bottom). Long experience in IT has shown that “top-down / waterfall” approaches (e.g. do a full requirement & functional analysis before thinking about the solution design) is wasteful and often leads to over-generic, unworkable architectures.

3. System-of-systems perspective in RCA

This chapter will describe the system-of-systems perspective of RCA including:

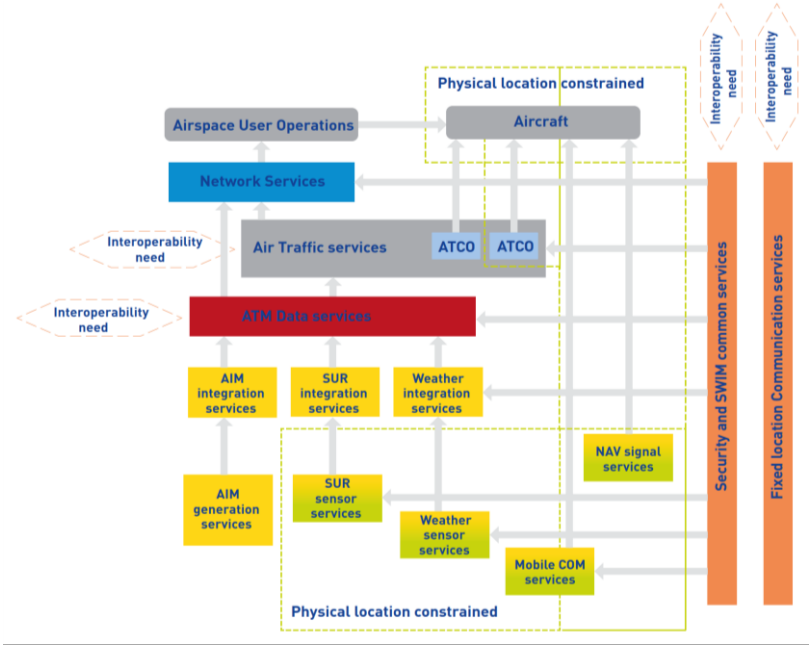
- How do we use the system-of-systems perspective in this document?
- How can an RCA-based system be integrated in a systems-of-systems perspective of the railways?

3.1. System-of-systems perspective in this document

The concept “system-of-systems” is very broadly defined (see https://en.wikipedia.org/wiki/System_of_systems). In the context of RCA, the components of RCA can be seen as systems and thus RCA is a system of systems. In this document, however, we take a higher-level perspective, looking at the “railway system” as a system-of-systems, in which the RCA may be a part (i.e. a system).

Relation to “Enterprise Architecture”: EA is a form of system-of-systems approach, often focusing on one enterprise (including its interfaces). Enterprise Architecture does not only deal with technical systems but also with “soft systems” such as goals, organisations, processes, capabilities.

As an example from another domain, in [2] the SESAR JU proposes an overall architecture for the European airspace, including governance, regulatory, organization and technical systems issues. The following picture show the proposed services in this context.



In the telecom sector there are models (such as eTom[1]) which provide a shared reference architecture (without being binding).

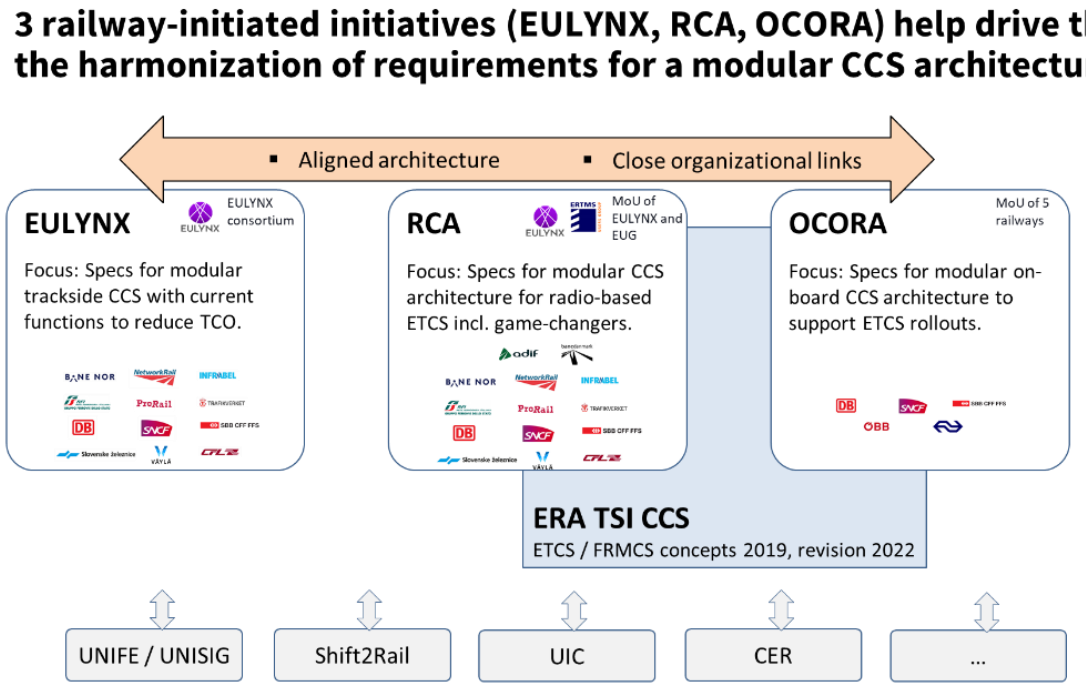
In the railway sector there seem to be no widely adapted, shared, over-arching reference architectures (yet). It is not the purpose of RCA to provide such a model. From the RCA perspective it would be helpful to have such models and RCA will help map / integrate RCA into such an overarching architecture. There is a proposal in Shift2Rail IPX to start working on such an architecture.

[1] https://en.wikipedia.org/wiki/Business_Process_Framework_(eTOM)

3.2. Combining RCA with other systems into a system-of-systems of railways

The following diagram (from the standards slide set) shows that RCA is already preparing integration into a system-of-systems:

- EULYNX, RCA and OCORA have each a clear specification scope which is complementary among the 3 initiatives (no overlaps). To efficiently implement the overall CCS functionality, functionality has to be apportioned and some concepts and interfaces have to be jointly prepared.
- The ERA TSI CSS is shown behind RCA and OCORA, since RCA and OCORA act on the foundation / background of the existing TSIs to ensure interoperability. When needed, CR (change requests) will be submitted to the defined process.



3.3. Important criteria for integration into a system-of-systems

For architectures / systems to be integratable easily, these characteristics are important:

- Very clear and explicit scope:
  - what elements (needs, functions, component) are in-scope and will be defined by the architecture?
  - dealing with the system border: ownership of interfaces (definitions, exported conditions, assumptions)
- Explicit (and mostly shared) architectural principles: what are the architectural goals (modularity, re-use, evolvability, …) and what criteria drive the architecture process.
- Clean and precise modelling: applying a well-defined modelling standard, using tools supporting an open process.
- Open process: open availability of all architectural artefacts, easy access to the artefacts (tools), transparent change management process.

RCA adheres to these criteria in its development process.

4. Summary and outlook

The focus of RCA is to provide component specifications based on harmonized requirement for use as tender templates by IMs planning ETCS rollouts.

RCA is therefore only an (important) piece of the overall system / architecture puzzle: in the CCS domain it covers most logical component aspects on the trackside. Other architectural aspects of the CCS domain and architectural aspects of other railway domains must be integrated in a system-of-systems perspective.

The current approach of RCA with a clear scope will facilitate the integration of RCA.

Next steps:

- The EC and ERA are working on how to address the overall CCS architecture and its evolution.
- RCA, OCORA and EULYNX will continue to align their respective architectural scope.