RCA

Reference CCS Architecture

An initiative of the ERTMS users group and the EULYNX consortium

RCA System concept

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Version history

Gamma.1	31.01.2020	Bernhard Rytz	First release after review RCA core group.

1. Introduction

1.1. Overview

RCA (= reference CCS[1] architecture) is an initiative by the members of EUG[2] and EULYNX to define a harmonised reference architecture for the future railway CCS, with the main goal to substantially increase the performance / TCO[3] ratio of CCS in comparison with today's implementations.

Context of starting RCA

The reasons and main background for the RCA initiative are explained in the RCA white paper, accessible here: https://ertms.be/workgroups/ccs_architecture and here https://www.eulynx.eu/index.php/home2/37-reference-ccs-architecture-white-paper.

The background for RCA includes (quoted from the white paper):

- *in 1989, the European Union, together with the railway organisations, decided to develop a standard European System for Automatic Train Protection, the European Rail Traffic Management System (ERTMS);*
- *today, the specifications of ERTMS are mature enough to start the large-scale implementation of ERTMS;*
- *both members of EUG and EULYNX believe that it is the right moment to try to define a common, simple reference CCS architecture to support the step from installed base to ERTMS and to increase the capacity of the existing network, improve the deployment speed and reduce life cycle costs for CCS.*

Scope

The scope of the RCA work can be described by "command, control & signalling" or "everything needed to safely control movements and handle restrictions on the track". The architecture described by RCA focuses on the IMs perspective, while acknowledging that the command & control loops include the vehicles. For more detail, see the "Scope"-chapter in this document.

RCA in a nutshell

RCA…

- is founded on radio-based ERTMS/ETCS cab-signalling;
- defines standardised, evolvable interfaces for all major components of the future railway CCS;
- defines a clean target architecture without legacy systems, while providing a migration path[4];
- brings in new technology and ensures that technological progress from other sectors reaches the railways; this includes support for the ERTMS game-changers and for a geometric safety logic;
- uses the existing ERTMS standards for the interfaces to the vehicle according to the TSI CCS;
- integrates and builds on the standardisation work of EULYNX.

RCA main deliverable

RCA provides an architecture based on harmonised requirements. By definition, an architecture describes the decomposition of a system into components and the way in which these components are linked with each other. The main purpose of RCA is to define the interfaces of important (procurable) components of a CCS. RCA therefore focuses on well-defined interface specifications.

[1] CCS = command, control & signalling

[2] EUG = ERTMS Users Group

[3] TCO = total cost of ownership, i.e., including initial procurement and lifecycle costs, as well as direct and indirect costs.

[4] The migration path will, of course, include legacy systems in most cases.

1.2. Purpose of the document

This document presents the concept and scope of RCA. It describes the rationale for standardisation, the goals of RCA and introduces the modular system concept defined by RCA.

The RCA System Concept is a Phase 1 document according to [EN 50126]. While this document is free-form, documents addressing CENELEC phases 2 and beyond are based on MBSE (model-based systems engineering).

1.3. Applicable standards and regulations

A list of applicable standards and regulations used in RCA will be listed in the RCA Reference document list [RCA.Doc.42].

1.4. Other relevant documents

The RCA Documentation Plan [RCA.Doc.6] describes all published documents. The notation [Id] below refers to the document identifier in the documentation plan. The following documents are most relevant to get started with RCA.

- **RCA white paper**: the rationale for starting RCA (published in august 2018): available here https://ertms.be/workgroups/ccs_architecture and here https://www.eulynx.eu/index.php/home2/37-reference-ccs-architecture-white-paper [RCA.Doc.1].
- **RCA FAQ** (frequently asked questions): a short summary of important question regarding RCA [RCA.Doc.7].
- **RCA Process Overview**: how the RCA group works to prepare, maintain and communicate RCA [RCA.Doc.3].
- **RCA Concept: Architectural approach and Systems-of-systems Perspective**: Provides details and rationale of the architectural approach of RCA [RCA.Doc.13]
- **RCA System Architecture**: starting point for the model-based specification of RCA [RCA.Doc.35].
- Recommended read: Command and Control 4.0 by Josef Doppelbauer (ERA): https://www.era.europa.eu/sites/default/files/library/docs/command_and_control_en.pdf

1.5. Terms and abbreviations

The terms and abbreviations used in this document are listed in the RCA Glossary [RCA.Doc.14].

2. Rationale for RCA

2.1. Overarching goals supported by RCA

The RCA enables IMs to modernise their systems by going beyond the currently available ETCS L2 implementations. According to the RCA white paper the goals of RCA are:

- *"Low LCC": The RCA shall allow the implementation and operation of a trackside CCS with a low number of standardised system components (simplified architecture), with the ability to procure these standardised system components in a competitive market with automated processes (this requires integrated data management);*
- *"A single modular framework": The RCA shall specify the generic design of trackside CCS with ability to select configurations within the modular framework to facilitate migration strategies and adaptations to specific business challenges;*
- *"Migratability": Low cost solutions for interfacing to existing systems in the environment around the RCA, protecting existing investments;*
- *"Adaptability": The RCA shall be a generic design, allowing different levels of requirements concerning safety, costs / LCC, availability, performance and other non-functional requirements by configurational parameters or component selection (plug & play). Software / hardware adaptions of the individual components are to be avoided[5];*
- *"Safe Investment": The interface quality of the RCA (in general Form, Fit, Functional Interface Specifications - FFFIS) shall aim to avoid incompatibilities to future developments by using well prepared mechanisms for upwards and downwards compatibility. Interfaces shall be defined on a formalised basis (and with real and early prepared reference systems for testing) for all communication layers to avoid vendor specific deviations.*

According to a survey conducted among participants of the RCA group, additional goals (such as higher capacity, increased safety, higher reliability, faster implementation speed) are also important for at least some modernisation projects. We will therefore enlarge the list of goals supported by RCA. In addition to the "wished-for" goals it is clear, that an architecture like RCA will have to address issues such as cyber security, performance and others, which will be treated in the category of non-functional requirements.

2.2. Targets for the RCA itself

The RCA supports the above-mentioned goals by providing the following enablers (excerpt from the white paper):

- *Significant reductions in the number and types of trackside assets;*
- *Optimisation of operational processes;*
- *Implementation of the game changers[6];*
- *Standardised and automated data preparation for open engineering and testing;*
- *Cost effective implementation and maintenance features for every interface and component (e.g., simple integration safety case by an automated impact analysis, remote updateability);*
- *Competitive procurement based on exchangeability of components;*
- *Open specification, standardised interfaces and use of mature industry standards;*
- *Components allowing independent industrial developments and deployments in a whole infrastructure or fleet ('components of the shelf')[7].*

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[5] This refers to IM-specific adaptions (variance). The RCA will support different target configurations (e.g., using or not using a component or using a fully vs a semi-automated implementation of a component).

[6] The ERTMS game changers include new technology such as ATO, satellite-based train-localisation or a 4G / 5G communication infrastructure.

[7] This includes supporting independent lifecycles of components, such that single components can be updated or replaced.

According to a survey conducted among participants of the RCA group, additional targets, such as "simple integration of / into safety case" are also important and will be incorporated.

2.3. How RCA will be applied by railways and by industry

The purpose of the RCA is to ensure that the architectural requirements concerning the main interfaces of the CCS architecture that are published in tenders are harmonised in detail and used in every tender in the same way. This includes all layers in the interfaces, such as the communication between applications, security and safety protocols, transport layers, carriers and standardised interfaces between applications and operating systems or hardware representation layers.

For this, the RCA defines a coherent set of references to specifications that make up the CCS architecture for the future railway system. These specifications may come from the TSI, from research projects, from industry projects, from railway projects or from other types of cooperations or bodies. Some of the important criteria for becoming an RCA-accepted interface specification are that the interface is openly usable, well-defined, stable, and has mechanisms for upwards as well as downwards compatibility. The components between these RCA interfaces are considered as "black boxes" coming from the product market. Specifying an RCA interface will allow the use of basic functionalities (always available, always the same), or the use of additional functionalities if they can be handled on both sides (runtime negotiation) and are accepted for the RCA architecture. This not only assures compatibility, but also allows product developers to generate USPs (unique selling propositions) for their products. Railways (IMs) committed to RCA will use the RCA architecture and its specifications in the planning and procurement ("tender templates") of their modernisation projects. Suppliers can use RCA to guide their product-development roadmaps. The following diagram shows the basic idea, going from heterogenous architecture (and, as a consequence, components) to an overall CCS architecture harmonised by important interface specifications.

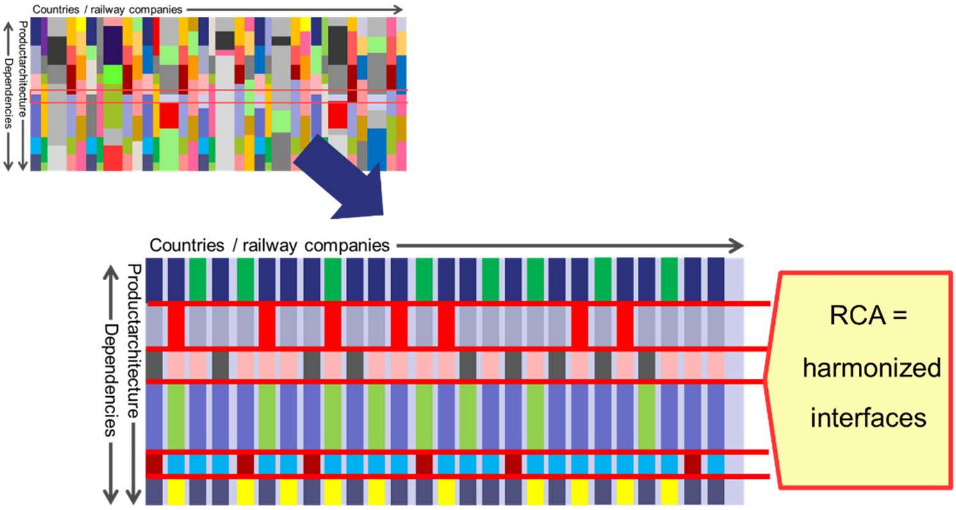

Figure 1: Harmonising proprietary CCS architectures

Note: The RCA development process is described in the document "RCA Process Overview" [RCA.Doc.3].

2.4. Why is RCA useful?

RCA is important for the future of the railway system because:

- by using shared specifications, we create a more attractive system / component market with larger scales, we reduce the integration effort and lifecycle complexity;
- by designing a system with built-in upgradability, we allow the railways to integrate innovations faster;
- this increased performance / TCO ratio will help increase the competitiveness of the railway sector and, in the longer run, the market share of rail.
- The ERTMS rollouts face the dilemma of "stability vs evolution": RCA contributes to reducing the consequences of this trade-off by providing the foundation for a more upgradable CCS system.

This is beneficial for the railway customers, IMs, RUs and suppliers.

2.5. Role of existing standards / architectures

RCA will use already elaborated standards:

- ERTMS: RCA is based on the existing ERTMS architecture and reuses the TSIs. To fully use RCA, some change requests to the TSI will be necessary, which will be submitted in due form and will go through the official change process (requests were submitted at the end of 2019);
- FRMCS: RCA is based on the availability of the successor to GSM-R;
- EULYNX: RCA reuses the EULYNX-defined interfaces (and object controllers) for trackside objects. RCA will also reuse other EULYNX elements (such as modelling standards, and other concepts);
- ATO: RCA will incorporate the results of the ATO-over-ETCS specifications.

RCA will take the existing standards / procedures for designing, building, integrating systems in a railway environment (CENELEC, etc.) into account.

2.5.1. ERTMS

RCA is based on the architecture of radio-based ERTMS/ETCS and reuses existing ERTMS/ETCS specifications / protocols. Major building blocks include: possibility for inclusion of new localisation methods, a geometric safety logic, fully supervised shunting, ATO GoA1-GoA4, FRMCS, and new options for fallback systems. Some of these are already known as “game-changers”.

2.5.2. EULYNX

Relation to EULYNX on content level:

- RCA integrates EULYNX interface definitions for trackside assets into the overall RCA;
- EULYNX object controllers will be part of RCA-based systems.

Relation to EULYNX on a formal level:

- Whenever feasible, RCA reuses concepts, processes and techniques developed for EULYNX;
- The functional, non-functional, and implementation architecture are used similarly;
- The physical architecture of EULYNX is a part of the technical architecture of RCA.

2.6. Summary of Goals and Enablers for RCA

The following diagram shows the most important goals that can be achieved with an RCA-based architecture and the enablers that RCA provides. A more detailed explanation of the effects can be found in "Concept: RCA effects overview" [RCA.Doc.37].

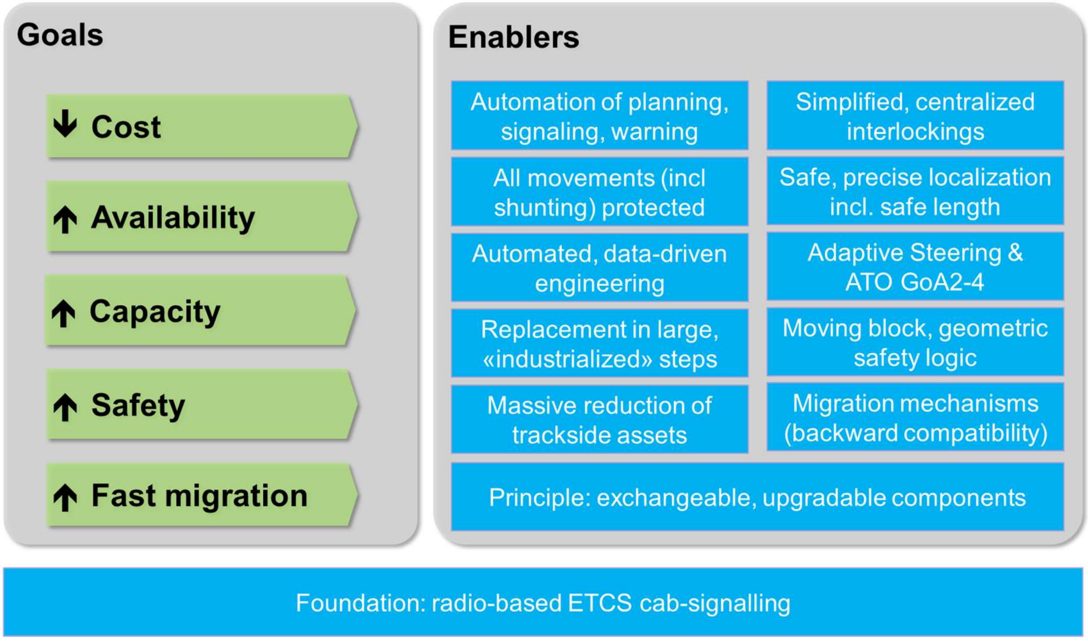

Figure 2: Overview of RCA goals and effects

3. System scope

RCA provides a generic reference architecture for CCS, i.e., for all functions needed to safely and efficiently control movements and restrictions on the tracks.

The reference architecture applies throughout the whole lifecycle of the system according to [EN 50126].

3.1. Functions in scope

In scope are the following functions / systems:

- All CCS functions needed between a TMS (traffic management system), providing an operational plan and the physical actors (vehicles, trackside objects and devices for personnel working on or near the tracks).
- All ATO functions between a TMS and the vehicle.
- Data preparation processes and systems for the above systems.
- All configuration, diagnostics, monitoring functions to support the above systems.
- ICT-Security.

3.2. Functions / systems out of scope

Out of scope are the following functions / systems:

- the long-term planning, the booking and financial book-keeping of slots for the RUs;
- the short-term planning;
- the planning of resources like people, trains or construction equipment;
- distribution of customer information (customers of the RUs);
- trackside assets like point machines, train detection devices, etc.;
- the technical implementation of CCS equipment on the vehicles; however, the functional CCS behaviour of the vehicles (interoperability) is in scope for RCA;
- other devices such as warning devices for track workers;
- braking curves are an important driver for safety and capacity; RCA does not work on this topic but welcomes initiatives to optimise braking curves;
- implementation of communication or computing infrastructure (e.g., datacentre design), except the interfaces of an CCS application to its runtime environment.

Reasons for excluding functions / systems:

- existing (trackside) devices have been excluded, as RCA is supposed to be able to use them “as-is” (as long as they are needed);
- the “upper-level” of the TMS (including long/short-term production plan) has been excluded, since the automation goals are quite different among IMs and this part serves as a “hub” into the different existing information systems of each IM; however, the execution of the production plan is in the scope of RCA.

While the functions / systems corresponding to these topics are out of scope, interfaces from RCA to these functions / systems are in scope. In particular, the interface to short-term planning and dispatching (the operational plan) plays an important role in RCA.

3.3. Depiction of scope

The following diagram shows a simplified system scope. A more detailed system scope, including interfaces to the surrounding functions / systems, is described in the chapter “High-level architecture”.

Note: The current version of the architecture covers ATO GoA1 / 2 but is not yet complete with respect to ATO GoA3 / 4.

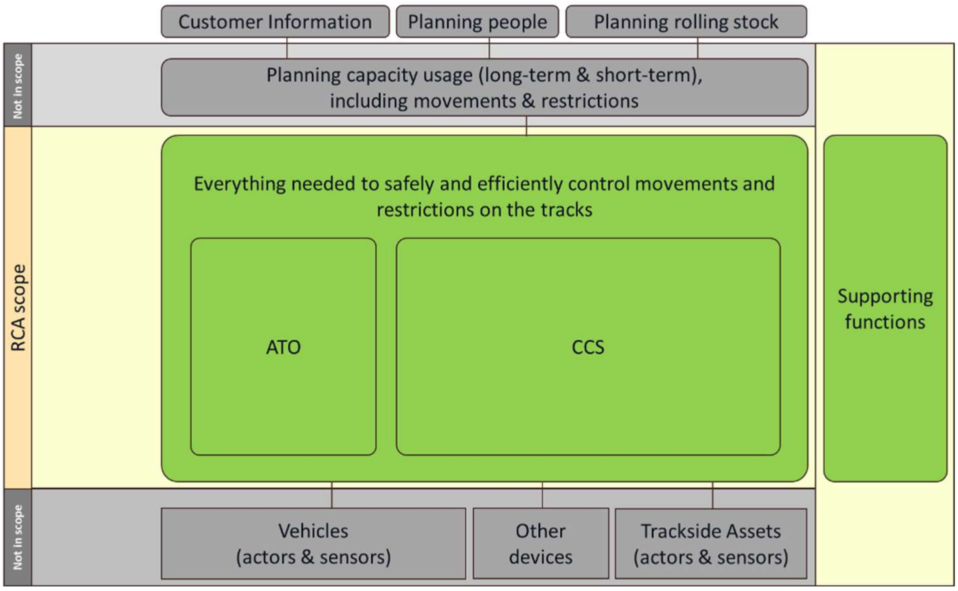

Figure 3: Scope of RCA

Notes:

- The interfaces that are in scope is more precisely defined in the “RCA System Definition and Systems requirements” [RCA.Doc.16]
- Even though functions / systems such as “Customer information” are not directly in scope of RCA, an RCA-based system will be able to provide more up-to-date and precise information which can also be used in a customer information system.

3.4. Stakeholders in scope

The reference architecture addresses the needs and concerns of the following stakeholders:

- infrastructure managers;
- suppliers of signalling systems and subsystems;
- train operators;
- safety authorities;
- the European Railway Agency;
- others (users, notified bodies, independent safety assessors, engineering bureaus, further standardisation organisations, contractors, etc.).

4. System concept

4.1. Reference architecture - Distinguishing RCA from an RCA-based system.

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. When we talk about goals, features, etc., of RCA, we often mean the goals, features, etc., of an actual system implemented based on RCA. When we want to make this explicit, we use the expression “RCA-based” system.

The standardisation level does not encompass a fully harmonised operational concept. However, requirements are provided about how the system operates, where in the operating environment the system will be distributed, how long the system must operate and how effective the system’s performance must be.

See also the document “Concept: Architectural approach and system-of-systems perspective” for more details.

The core of the RCA specification consists of the

- specification of the interface architecture
- specification of the technical architecture

4.2. Modularity

The RCA reference architecture defines a modular system with subsystems and interfaces to be specified and standardised.

Components shall be fit for integration into the signalling system solely based on interface and function specifications provided by RCA.

The overarching standardisation goal is exchangeability of components (e.g., switching supplier or upgrading). The standardisation elements (see below) needed to achieve this are component specific.

RCA considers the following standardisation elements, listed according to priority:

- Functional requirements which are visible at the interface
- Technical requirements of the interface, data structure
- Identification of the subsystem and the configuration data
- Requirement for maintenance and diagnostics
- Physical requirements of the subsystems
- Environmental requirements
- Power supply

Maintenance efficiency and system optimisation shall be improved by providing a modern architecture and standardised diagnostic system.

The modular architecture shall also support modular safety, to reduce the safety case workload when integrating the RCA components.

4.3. Purpose of the RCA interface architecture

The interface architecture specifies well-defined interfaces for all components in the scope of RCA. For these components <u>all</u> interfaces need to be well-defined by RCA to ensure exchangeability and upgradability. In addition to the interfaces defined between components, we also define interfaces to the runtime environment and to the communication stack (see technical architecture).

For components outside the RCA scope, but having an important interaction with RCA, we specify well-defined interfaces for the interaction only.

An IM can use these specifications to build or procure exchangeable and upgradable components. An IM is free to procure components independently or to group them (see procurement option).

4.4. Purpose of the RCA technical architecture

The components of the interface architecture can be thought of as “boxes”. The components in RCA are, however, not necessarily “physical boxes”. Adopting successful architectural thinking from the IT domain, we use the following decomposition:

1. The input- / output-behaviour (“function”) of a component (mostly implemented by software).
2. The platform or runtime environment providing
   a) fundamental resources such as computation or storage to the “function” and
   b) mechanism for common concerns like fault tolerance, application management, persistence (defined by APIs and implemented by software and (maybe virtualised) hardware).
3. The communication stack providing the communication channel. On one level this is the “virtual” channel from the point of view of the different (functional) components; on another level, this includes the “physical” channel between the platform the functions have been deployed to. The stack is defined by APIs and protocols; implemented by soft- and hardware, over several layers.

Thus, points 2 and 3 above are defined by the technical architecture of RCA, while point 1 is defined by the RCA interface architecture.

4.5. The purpose of additional (“helper”) material in RCA

In addition to the “specification core” consisting of the interface architecture and the technical architecture, RCA will provide additional material to help IMs apply RCA, see [RCA.Doc.13].

4.6. What needs to be specified to “sufficiently” define a component?

A building block (component) is normally described by the following aspects:

- External interfaces: Input, output, transactions, communication layers, non-functional requirements (NFRs, e.g., RAMS);
- Internal state(s);
- Internal events;
- Internal memory and data storage;
- Internal operations and algorithms.

For a freely usable architecture only the external interfaces are relevant. They describe the complete behaviour of the function at its external interfaces. Behaviour has to be qualified by NFRs (e.g., availability, hazard scope or hazard rate of a behaviour). If all interfaces of a block are specified this way, the functional requirements for the block are complete from the perspective of the RCA[8].

Need for FFFIS

Many building blocks of an RCA are SW-based and don’t need a “physical incarnation” and, therefore, don’t need a full FFFIS. For the SW-based blocks the “physical” connection is sufficiently specified by their interface to the runtime environment and to the communication stack (see also “technical architecture”).

Other important qualities for RCA interfaces include:

- Providing mechanisms for upwards- and downwards-compatibility;
- Being independent from the communication stack;
- Being free of IPR that may be an obstacle to the exchangeability or upgradability of blocks / components (the products or component implementations may, of course, still be protected by IPR).

[8] While this is true, once a high-quality specification exists, the process of defining such a specification must include building models / prototypes for the internal working of the components to be able to “test” the specification and the resulting end-to-end behaviour of the system. There may also be specification elements for overarching behaviour, including several interfaces (e.g., the safety rules).

5. System development process

The responsibility of the Infrastructure managers in the system development process is within Phases 1-4 and Phases 9-10 according to [EN 50126], with a shared responsibility with the industry in Phase 5.

The responsibility of the infrastructure managers encompasses:

- requirements management;
- formal modelling;
- tooling selection;
- configuration management;
- variability management;
- verification and validation;
- change management.

The RCA development process is iterative and includes the overall system (according to the defined RCA scope) as well as the system decomposition in RCA components and interfaces:

- The architectural design process is performed in MBSE. For consistency, one shared model is used for the system and the components;
- End-to-end use cases and cross-cutting requirements (from all involved partners) define the system requirements;
- Design principles and decomposition principles (including a layer-architecture) [RCA.Doc.13] are applied to identify / define components and their interfaces; functions are then allocated ("apportioned") to components and interfaces.
- The development of RCA interface specifications is performed based on the requirements derived from the system level.

NFRs dominate the complexity and cost of an architecture for systems where safety and availability are critical. For RCA, the following points are essential:

- Missed critical NFRs may invalidate architectural choices;
- Critical NFRs have to be sensibly propagated and / or allocated to the components and interfaces;
- NFRs may lead to the need for additional "technical" functions (such as a monitoring system);
- NFRs may lead to the need for additional interface specification (such as an interface from each component to a central monitoring system).

The following list can help cover all types of NFRs: Safety, RAM, Physical robustness, Security, Capacity, Time Behaviour, Scalability, Reusability, Portability, Adaptability, Modifiability, Testability, Exchangeability, Monitoring & Diagnostics, BCM, Interoperability, Usability, Form and fit, EM radiation / robustness, Environmental protection

For RCA we will have to a) identify critical requirements, b) have a top-level strategy for dealing with these requirements and c) ensure requirements are propagated to the Working Groups.

The following diagram shows the iterative nature of the development process:

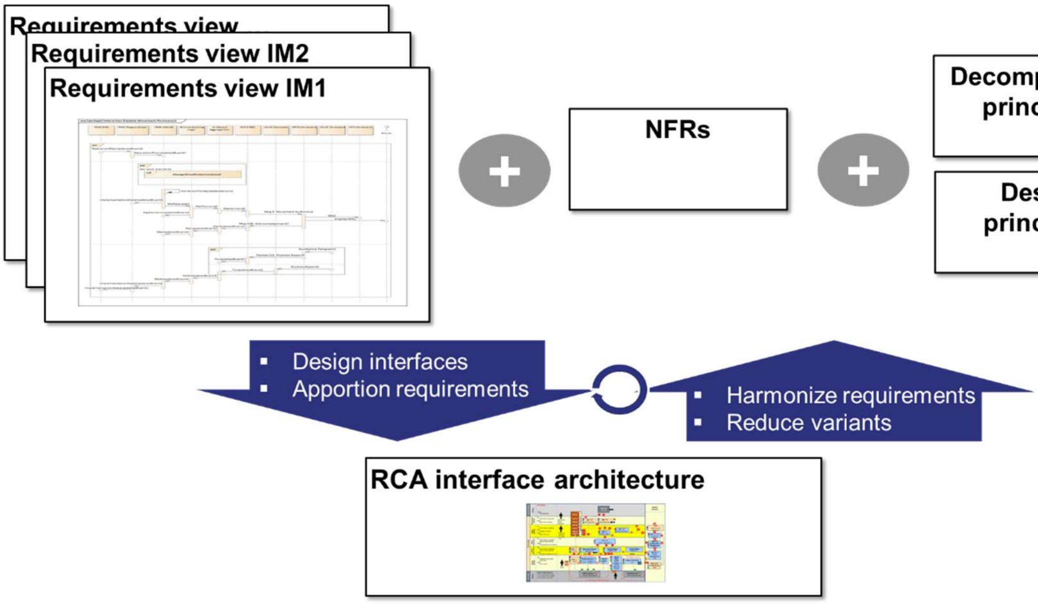

Figure 4: Specification development process

6. Variability

Variability is due to the fact that not all features of an RCA-based system will be needed by all IMs with the same functionality and / or at the same time. Variability introduces complexity, increases cost, and may reduce overall performance. An important principle is: RCA specifies a toolbox of components. Necessary differences among IMs should be expressed as:

- a difference in how the components are assembled or if they are used;
- a difference in how the components are used (manual process);
- a difference of how much redundancy is applied;
- a company-specific add-on (automated process) outside of the RCA scope;
- the parametrisation of components.

To express these conditions in one sentence: If an interface exists in a CCS architecture (RCA scope), it shall be an RCA interface, everything else can be freely designed. The design process / requirements model of RCA must include explicit links to requirements of IMs, leading to the need for variability (e.g., operational rules).

7. Data Management

Although mostly “invisible”, efficient handling of data plays a crucial role for the success of RCA-based systems.

7.1. “Runtime” data

An RCA-based system will collect data at a new granularity and precision:

- At any moment in time (with a temporal resolution of one second to a few seconds and a spatial resolution of a few metres) the position and speed of trains (and other objects) will be reliably known in a central system. In addition to its use within the CCS system itself, this data can be very valuable for customer information, logistics, optimising the system, usage pattern (for condition-based maintenance), etc.;
- When going for ATO GoA3 or GoA4, a lot of additional sensor data will be needed and made available. Note: GoA3 / 4 has yet to be integrated in RCA.

7.2. Data for construction and maintenance phases

With RCA the following data-driven automation potentials can be achieved:

- Automated topology recording: create a safe topology data base with a high degree of automation (using automated object acquisition and mapping technology);
- Automation of the project management and documentation steps for CCS projects, including data exchange with authorities and suppliers.

These automation / efficiency opportunities rely on mastering data-management processes. To make the process manageable, the RCA must clearly define the needed data items and the required data quality, which includes attributes such as completeness, consistency, timeliness and accuracy.

7.3. Need for a shared data model

A shared data model facilitates communication between people, processes and systems. On the other hand, attempts to create “global” data models typically fail. Priorities for the data model in RCA are:

- Identifying, describing and ultimately specifying data items appearing in several RCA interfaces;
- As a special case of the above: how to reference geographical, topological data.

In RCA this is even more important than for EULYNX, since RCA has conceptually new interfaces, a richer information model (e.g., positioning information) and more complex (cascading) interactions.

The scope of the data model in RCA will go beyond the scope of EULYNX but will reuse existing EULYNX assets. RCA will define its data model considering existing efforts.

7.4. The role of Data preparation (“Dataprep”)

The importance of data modelling and data preparation has already been noted in EULYNX:

> EULYNX also standardises data preparation. This consists of designing the data structures that capture the information a supplier needs to build a signalling system from the ground up. This is a radical improvement from the present where the parties involved in (re-)signalling projects exchange heterogeneous and proprietary datasets, often on paper. In the future, the signalling industry ingests standardised EULYNX data into their proprietary design toolset. As before, the signalling industry processes the data and then returns the enriched data, in EULYNX format, to the IMs who absorb this as-built data into their asset management systems. IMs and signalling industry retain their proprietary formats and tooling but EULYNX harmonises data exchange. […] The case for automating the data transfer process through well-defined standard data structures is obvious.

The RCA includes explicit components and interfaces for Dataprep (components EDP and Topo4) and will address Dataprep through the specification of the components.

8. Assurance

The RCA assurance activity consists of (based on EULNYX approach):

- independent confirmation that the architecture and the modelling process are adequate and complete;
- a generic safety assurance process, applied in each EULYNX cluster, demonstrating that both the work process followed and the outputs of that work are complete and adequate for use by each of the partner members;
- independent review of the assurance plan and process;
- independent audit of the assurance outputs.

RCA encourages the reuse of previous experience from reference implementations (CSM reference system path [CSM]).

The reference architecture and the system-engineering process shall be created using expert judgement by the respective cluster members. The independent review of the outputs of these clusters will be carried out by both inspection of the documentation and by review of a career description of the cluster project members.

Assurance of the interface cluster project outputs will be facilitated by a checklist to allow the cluster leader to record successful completion of each step. Each cluster will be subject to independent audit to ensure correct application of the process.

The outputs to the supply industry are complete in terms of requirements and can be used as a valid input to safety cases for equipment created with RCA compatible interfaces.

In RCA, assurance activities will be started for the preparation of Baseline 1.0.