ERJU SYSTEM PILLAR

System Architecture Description-Railways_System_Architecture_Methodolo

System Architecture Description: Railways System Architecture Methodology

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Abstract	The System Pillar Task 1 “Railway System Architecture” proposes to improve the integration of the innovation and the technical changes in the existing system by using the concept of layered functional architecture, as deployed since several decades in many industries such as automotive, aviation, defence, energy, high tech, IT, software, telecoms, to frame the development of the rail system and harmonising this system architecture approach at European level, starting from radio-based ETCS without lineside signalling.
Config Item	System Architecture Description
Document ID	2024/Global Task 1 Architecture Report Methodology#724248 System Architecture Description-Railways_System_Architecture_Methodology
Classification	Public
Status	Open (educated draft, discussion in domain nearly finished)
Version	1.0
Revision	724248
Last Change Date	02.10.2025
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With contributions of all of Task 1:

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System Architect, Requirements Manager and Operational Design (respectively)
The REQ, OD and ARC roles have been assigned to the team by studied capabilities :

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	Jean-Marc Pourchier
	Werner Ried
	Hans Menschaert
	Piotr Chylinski
	Emre Teke
	Gerald Schinagl
	Aude Chailley

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System Architect, Requirements Manager and Operational Design (respectively)
The REQ, OD and ARC roles have been assigned to the team by studied capabilities :

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	Artur Rojek
	Artur Fojud
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	Hans Menschaert
	Aude Chailley
	Jean-Marc Pourchier
	Gerald Schinagl
	Oskar Gonzalez

Capability	Person
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	Zbigniew Jancewicz

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1 Preamble

1.1 Purpose

The activities conducted in Task 1 to determine the resulting architectures are based on a hierarchical approach.

Hierarchical design, or hierarchical approach, refers to a systematic and organized approach to structuring complex applications based on arranging elements in a parent-child relationship or tree structure. This method improves application architecture and enhances usability by breaking application components into smaller, self-contained modules that are easier to manage, maintain, and understand. As a result, hierarchical design contributes to a more efficient, scalable, and adaptable application development process.

The assumption made in Task 1 is that two or more architectures implemented following this approach communicate through channels connected only at the top of the architecture. No intermediate exchanges between the architectures are necessary.

This simplifies interactions between different geographical areas.

The presented hierarchical approach is applicable both between two geographical areas within a member state and between adjacent geographical areas within two different states.

Another important aspect developed inside the Task 1 is that, when possible, information and architectural aspects from some member states were collected. These was identified as best practices. We avoid indicating the country where these are coming from.

In some cases, in the Task 1 activities, the final As Is architecture it is the union of these best practices.

This also allows for simplification and the elimination of inefficient components.

In general, the approach followed allows for a more streamlined representation as well as an architecture that is, in most cases, easy to implement in each member country.

1.2 Intended Audience

1.3 Document context

The full content of the operational architecture is described in the following document:

System Architecture Description : Railways System Architecture Model Description - Main

1.4 Glossary

1.4.1 Terms

1.4.2 Abbreviations

2 Introduction

The System Pillar Task 1 “Railway System Architecture” proposes to improve the integration of the innovation and the technical changes in the existing system by using the concept of layered functional architecture, as deployed since several decades in many industries such as automotive, aviation, defense, energy, high tech, IT, software, telecom, to frame the development of the rail system and harmonizing this system architecture approach at European level, starting from radio-based ETCS without line side signalling.

In this innovative scenario, the goals assigned to the System Pillar Task 1 are:

- Conduct an as-is analysis of the railway system, considering operational, functional, logical & physical assets,

- Identify the pain points for selected operational interaction processes and derive a requirement set reflecting the Common Business Objectives,
- Specify the high-level Business Process Architecture and Operational Design (Organizational needs, Generic automation needs, …) for the (to-be) Railway System,
- Assess migration roadmap of the Tasks 2…n regarding overall Business Process Architecture and Operational Design consistency
- Assign high-level input requirements to lower-level tasks,
- Define requirements for reduction of total cost of ownership.

This document reports the achievements of the last **2 years of work** (2024 and 2025), which has been compiled by a multidisciplinary team of experts from EU-Rail.

The key results are the development of existing high-level business architecture model and operational design for the High-level Railway System Architecture in version **'AS-IS' for 5 capabilities**:

- Manage Energy
- Maintain and monitor infrastructure
- Upgrade or renew infrastructure network capabilities
- Operate Train
- Maintain and Monitor rolling stock

As well as the High-level Railway System Architecture in version **'TO-BE' for 2 capabilities**:

- Operate Train
- Manage Energy

A structured method was adopted to describe and manage all the results. These results were derived using the ARCADIA methodology and following the SEMP rules. This document provides more details on the methodology.

Finally, as output of Task 1, are outlines the **next steps for the second period (November 2024-October 2025) and beyond**:

- Develop the 'TO-BE' architecture of the Operate Train capability
- Develop the 'TO-BE' architecture of the Manage Energy capability
- Develop the 'TO-BE' architecture of one additional capability [*either "maintain and monitor rolling stock" or "maintain and monitor infrastructure" (To be defined after vote by Task 1 participants)*]
- Work to integrate the models output from Task 1 and Task 2 in the architecture reference model.
- Continue to align the deliverables with best practice described in the SEMP.

3 Description of Task 1 Architecture

Specifically, the **responsibilities of System Pillar Task 1** include:

- Conduct an "As-Is" analysis of the railway system, with a focus on certain capabilities
- Identify the pain points for selected operational interaction processes and derive a requirement set reflecting the Common Business Objectives,
- Specify the high-level Business Process Architecture and Operational Design (Organizational needs, Generic automation needs, …) for the "To-Be" Railway System,
- Assess migration roadmap of the Tasks 2, 3, … n regarding overall Business Process Architecture and Operational Design consistency,
- Assign high-level input requirements to lower-level tasks,
- Define requirements for reduction of total cost of ownership.

3.1 Methodology

The building of the Railway System Architecture relied on a methodology called **ARCADIA,** for **ARChitecture Analysis and Design Integrated Approach, as stated in the System Pillar SEMP -** see *SPPROCESS/10 SEMP V 01_01/SEMP Systems Engineering Management Plan : 724248* .

ARCADIA relies on several layers, presenting possible viewpoints of the system under study, as described **Figure 1.**

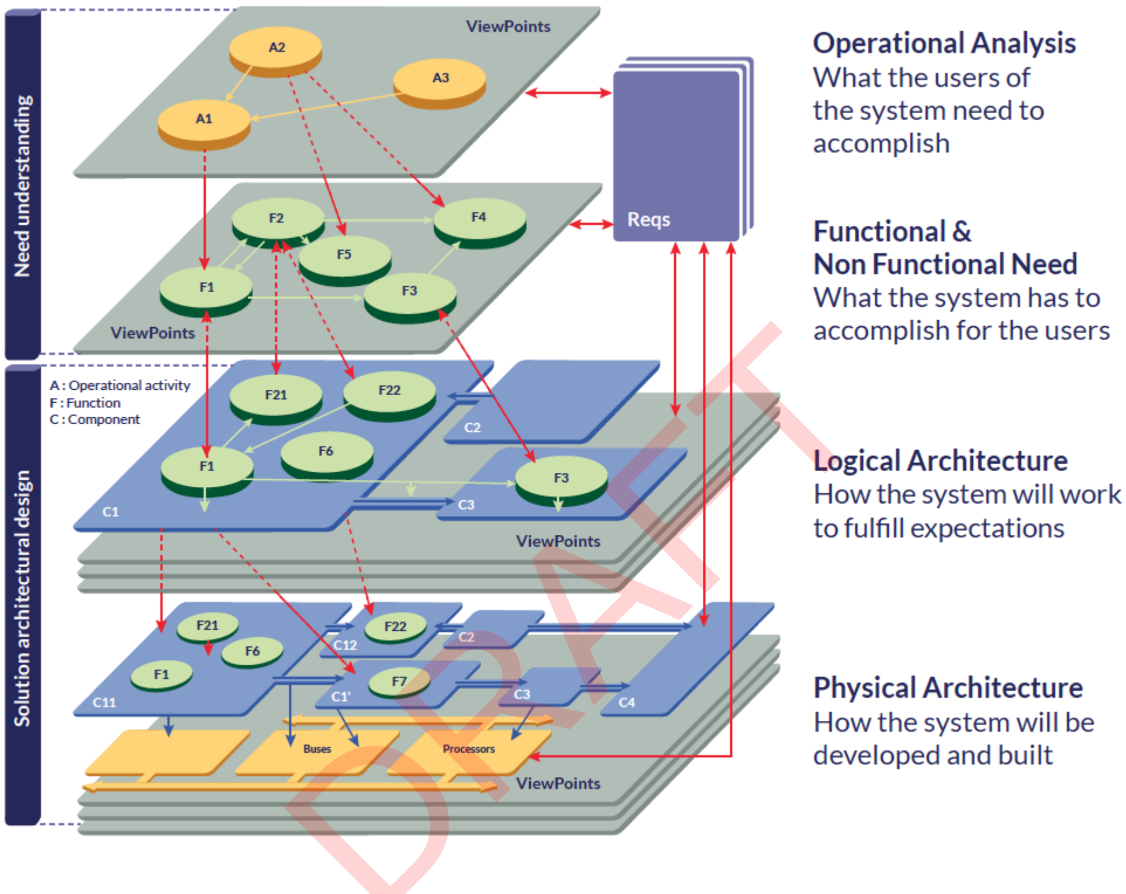

Figure 1 : ARCADIA Layered approach

For Task 1, the objective is to inform the **Operational Layer** of the **Railway System**.

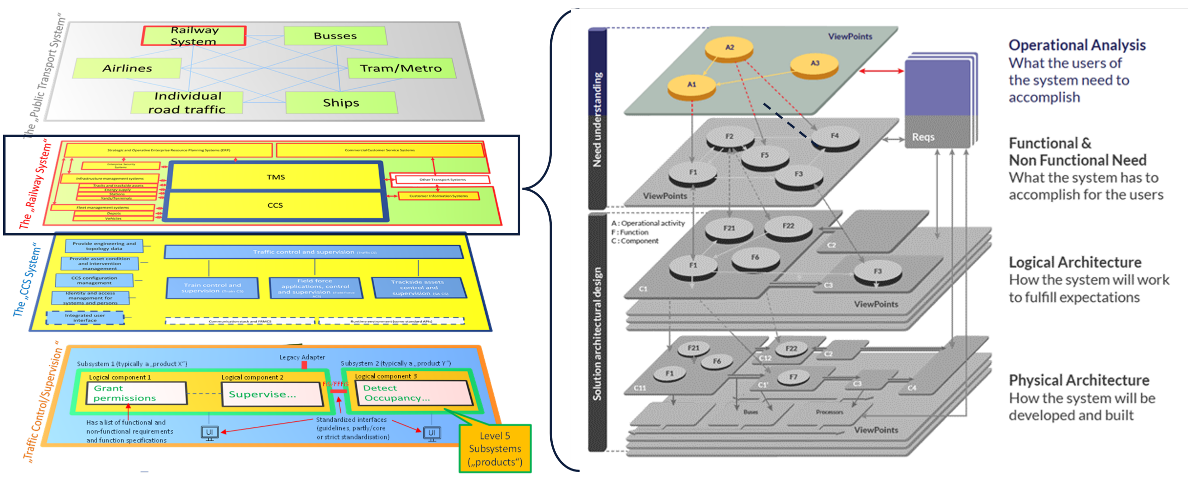

Figure 2 : Scope of Task 1

The European Railway System is a complex System with many actors, sub-systems, sub-enterprises, and having many missions. The goal of System Pillar Task 1 is to define a “To-Be” Railway System. Thus, there is no use spending time on the Logical and Physical Layers, with a very precise granularity, so the study focuses on the first layer presented by ARCADIA, called the **Operational layer (Figure 3).**

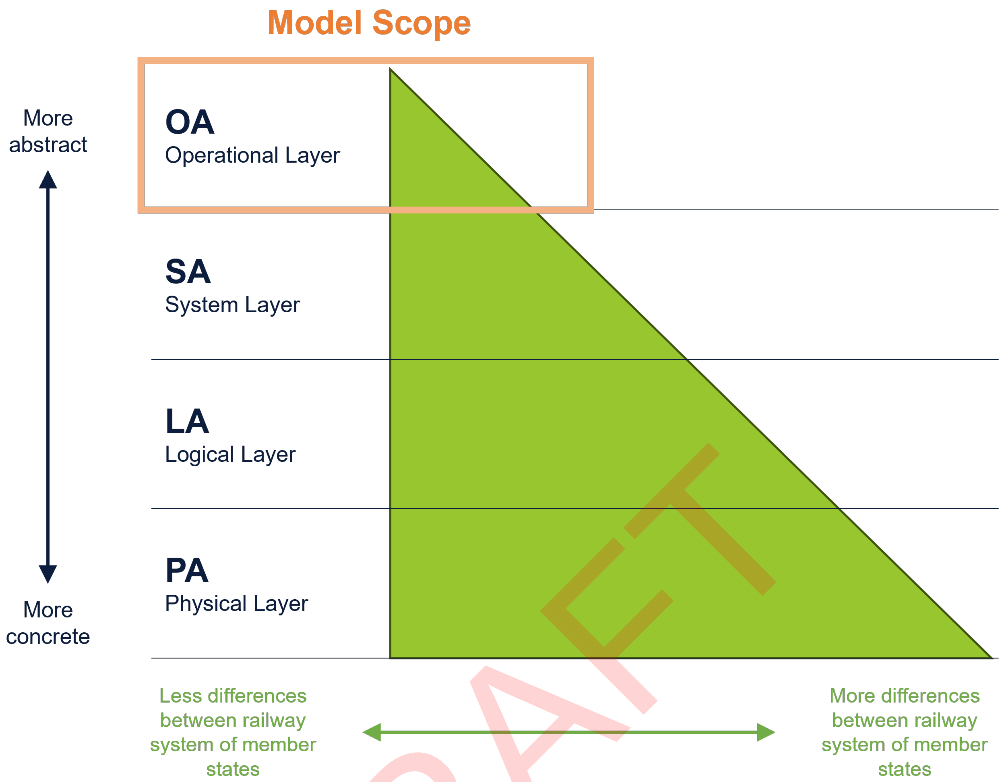

Figure 3 : Model scope

The **Operational Layer** intends to create a model independent of the system being created. The idea behind it is to create a level of abstraction from the system under study, in order to focus on the **needs of the stakeholders.**

The ARCADIA framework defines a list of **concepts applicable to the operational layer** as follows:

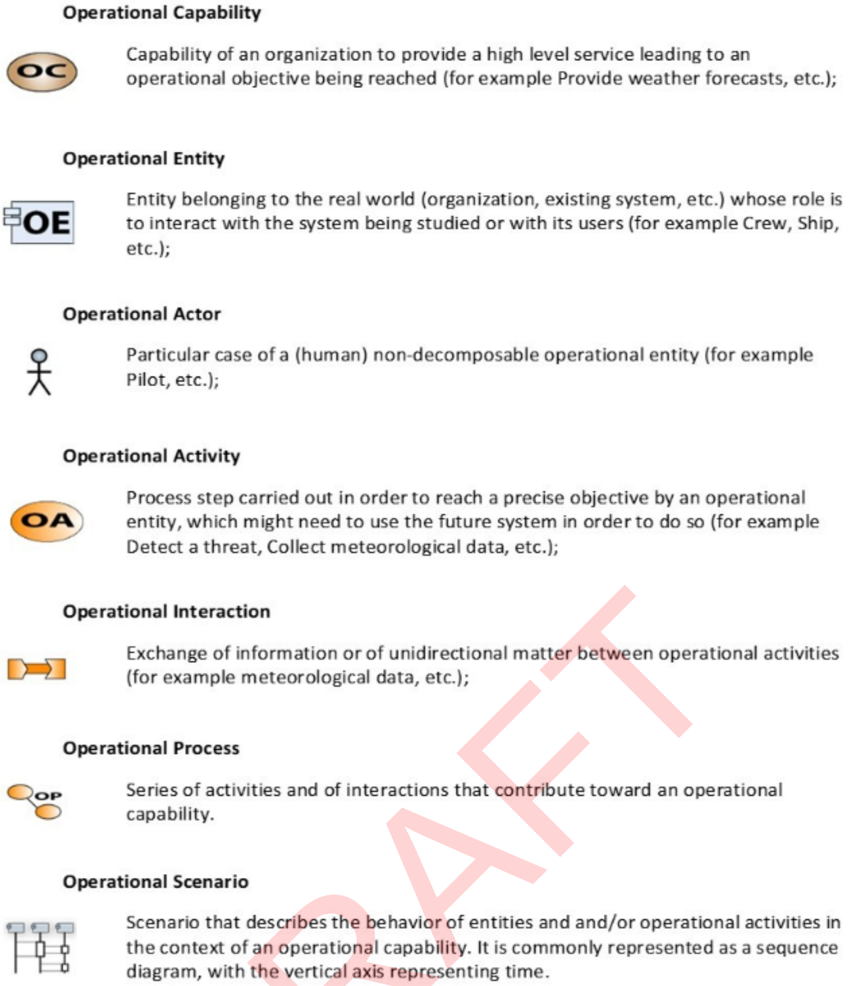

Figure 4 : ARCADIA Operational Concepts

ARCADIA suggests a variety of **activities (or diagrams) to inform the operational layer**, of which:

- **[COC] Capability Operational Context**: Identifies the capabilities and their associated entities.
- **[OEBD] Operational Entity Blank Diagram**: identify Operational Entities and Actors that will interact with the future system, and their hierarchy
- **[MSM] Modes & States**: capture the modes and states relevant to the system Life Cycle, in order to fully capture the activities carried out by each entity
- **[OAB] Operational Architecture Blank**: identify and allocate Operational Activities to Actors and Entities, and define the Operational Interfaces between these activities.

Therefore, In Arcadia terms, the objective of the Task 1 can be written as:

Define the “As-Is” and "To-be" **Operational Activities**, and the necessary **Operational I**nteractions between them, which are mandatory in order to fulfill the **Operational Capabilities**, using the [COC], [MSM], [OEBD] and the [OAB] diagrams. **[**SPT1RS-879 **]**

The System Pillar Participants worked together through **online meetings and 4 in-person workshops** in Paris (UIC premises) and Brussels (UNIFE premises) towards this objective. These workshops were facilitated by the CESAMES team using Klaxoon, Capella and Polarion.

3.2 Methodological principles

From the position and methodology described for Task 1, modelling principles have been derived:

The "As-is" and "To-be" models produced in the scope of Task 1 should be representative enough for all the railway systems of the member states. **[**SPT1RS-881 **]**

The "As-is" and "To-be" models produced in the scope of Task 1 should be agnostic of technological choices. The operational layer's objective is to define the problem and not the solution. **[**SPT1RS-880 **]**

The "To-be" architecture should be focused on standardizing key interfaces in order to modulate the architecture. Standardizing the interface is a means of decoupling (removing inter-dependencies) between systems and hence allowing for greater innovation. **[**SPT1RS-888 **]**

These principles are applicable at all scales of Task 1 deliverables and have been adopted as a doctrine throughout the process.

3.3 Team

The team and organization within Task 1 is described in the document Team Role assignment table .

3.4 Deliverable Structure

The Deliverables for Task 1 have been organized in several reports to facilitate the reading:

- Stakeholder Requirement Specification : Operate Train Capability
- Stakeholder Requirement Specification : Manage Energy Capability
- Stakeholder Requirement Specification : Maintain and Monitor Infrastructure Capability
- Stakeholder Requirement Specification : Maintain and Monitor Rolling Stock Capability
- System Architecture Description

In the future, as more capabilities are developed, then new capability architecture reports may be added.

3.5 Overall Architecture description

By following the described methodology, workshops were able to describe,

- The **modelling of the Operational Railway Architecture** in CAPELLA, compliant with System Pillar framework, including:
  - The identification of the High-level **Capabilities,**
  - The refinement of the **Operational Entities,**
  - The **Lifecyle** diagram (the lifecycle diagram has not been updated as part of the work in 2024),
  - The refinement of the **Operational Activities** and their associated **Interactions.**

3.5.1 Capabilities

By following the described methodology, workshops were able to describe, the detailed description of **5 key Capabilities** of the Railway System:

- **Manage and Maintain Infrastructure**
  - A detailed architecture report of the As-is architecture of this capability is described in *SPT1RailwaySystem/Operational capabilities/Maintain _ Monitor Infrastructure Architecture Report : 724248* .
- **Manage and Maintain Rolling Stock**
  - A detailed architecture report of the As-is architecture of this capability is described in *SPT1RailwaySystem/Operational capabilities/Maintain _ Monitor Rolling Stock Architecture Report : 724248*

- **Manage Energy**
  - A detailed architecture report of the As-is & To-be architecture of this capability is described in *SPT1RailwaySystem/Operational capabilities/Manage Energy Architecture Report : 724248*
- **Operate train**
  - A detailed architecture report of the As-is and To-be architecture of this capability is described in *SPT1RailwaySystem/Operational capabilities/Operate Train Architecture Report : 724248*
- **Upgrade or renew Infrastructure network**
  - A detailed architecture report of the As-is architecture of this capability is described in *SPT1RailwaySystem/Operational capabilities/Maintain _ Monitor Infrastructure Architecture Report : 724248*

The following capabilities have been identified but have not been developed to date in the Operational architecture of the Railway Network.

- Manage passenger commercial service
- Manage freight commercial services
- Management of railway stations
- Manage the reliability, processes, and security chains resilience to external factor

3.5.2 Operational Entities

Throughout the collaborative architecture exercise on the listed capabilities. The following Railway System entities have been identified:

[OAB] Operational Entities [Operational entity definition]

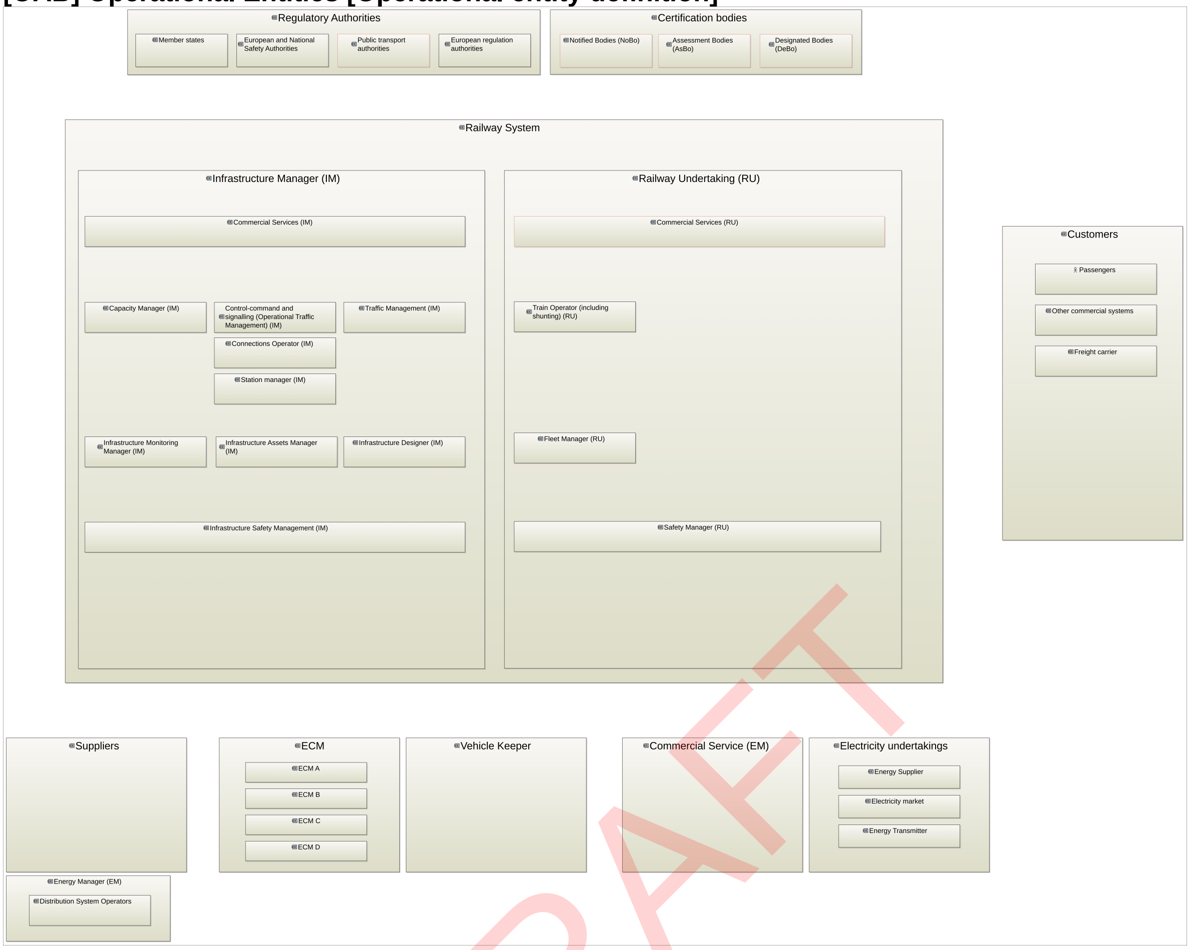

Figure 5 Diagram [OAB] Operational Entities [Operational entity definition]

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3.5.3 Operational Activities

Throughout the collaborative architecture exercise on the listed capabilities. The following Railway System activities, allocated to the entities have been identified:

[OAB] Operational Entities [Consolidated operational activity allocation]

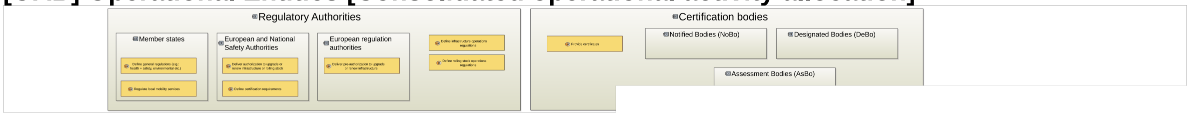

Figure 6 Diagram [OAB] Operational Entities [Consolidated operational activity allocation]

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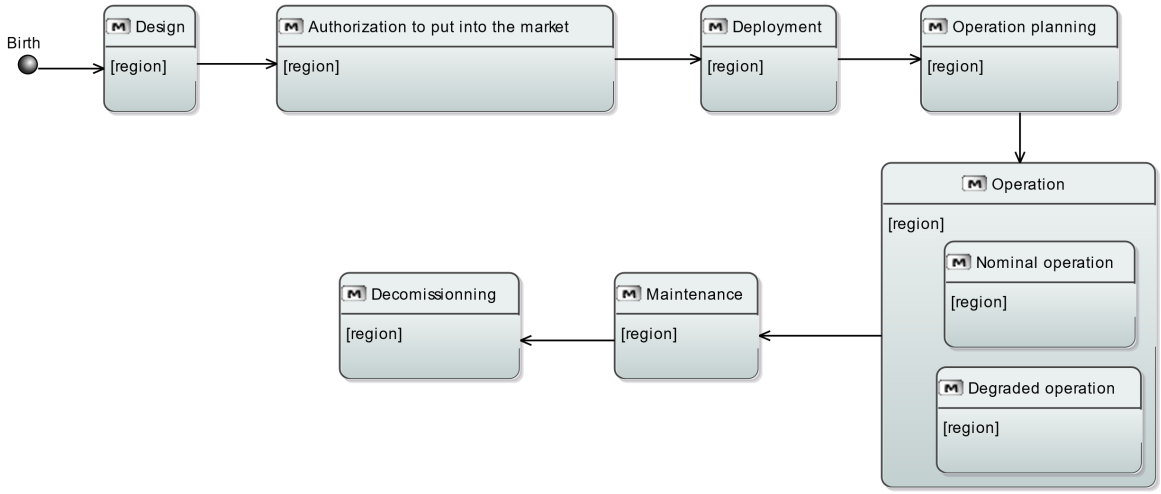
3.5.4 Lifecycle

The lifecycle diagram of the overall railway system was determined as part of the remit of 2023.


Birth
Design
[region]
Authorization to put into the market
[region]
Deployment
[region]
Operation planning
[region]
Operation
[region]
Nominal operation
[region]
Degraded operation
[region]
Maintenance
[region]
Decomissionning
[region]

4 Conclusion

4.1 EXECUTIVE SUMMARY OF S.C 2.3

The methodology section clarifies the role of Task 1 relative to the overall System Pillar and relative to the other tasks. The implementation of this methodology will eventually guarantee a complete and coherent description of the overall Railway System architecture. The key achievements this year has been to integrate the Task 1 model into the Reference Model within System Pillar which enables much easier collaboration and integration with the other tasks during the next remits. Task 1 has also conformed to SEMP rules and hence made it easier for readers to use and interpret their outcomes.

This global report provides a view of the progress achieved in the description of the architecture of the railway system. More detailed views are then developed in the capability reports. However, as the detail is being developed at the capability level, a global architecture for the Railway System is automatically coming together and will eventually provide a holistic view of the global system. This holistic view in development is key to thoroughly understand the impact of changes and modulating the architecture in a way that enables continuity in the working principles while enhancing innovation.

Technically, a key finding has been that at the capability level, there are few changes that will have a tangible impact on To-be activities and interactions. However, many changes will incur different levels of performance associated to the architecture elements. A more focused development of this aspect in future remits will allow to identify and measure these changes.

4.2 EXECUTIVE SUMMARY OF S.C 2.4

Operate Train

This section provides a summary of the activities carried out under Task 1 – Operate Train Capability

In line with the defined milestones, during S.C 2.4 the Operate Train Capability focused on consolidating and further maturing the To-Be architecture developed last year. The Operate Train Capability primarily interfaced and interacted with Task 3 and took into account the Task 3's suggested Federated approach in the To-Be architecture.

With the involvement of Werner Ried (Task 2 OD) , Operate Train Capability also established interactions with Task 2 OD and Task 2. It was jointly agreed that interactions with Task 4 would be addressed in the following contracts.

In addition, studies were undertaken to consolidate the architecture based on the defined operational scenarios to validate the To-Be Architecture.

As a result of these activities, the Operate Train To-Be architecture was further matured, incorporating the Mirror Group's comments on last year's deliverables. The To-Be architecture has been integrated into Capella to enable interactions with other tasks in alignment with the SEMP.

Manage Energy

This section provides a summary of the activities carried out under Task 1 – Manage Energy Capability.

In line with the defined milestones, during S.C 2.4 the Manage Energy Capability also focused on consolidating and further maturing last year's To-Be architecture. The Manage Energy Capability principally interfaced and interacted with Task 3, through the outcomes of the interactions between Operate Train Capability, Task 3, and Flagship Project 4.

As a result of these activities, the Manage Energy To-Be architecture was further matured, again incorporating the Mirror Group's comments on last year's deliverables. The To-Be architecture has been integrated into Capella to support interactions with other tasks in line with the SEMP.

Maintain and Monitor Infrastructure (MMI)

This section provides a summary of the activities carried out under Task 1 – Maintain and Monitor Infrastructure

According to the defined milestones, during S.C 2.4 the MMI Capability aimed to create the To-Be architecture based on the already agreed As-Is architecture, addressing the identified CBOs and Pain Points.

As requested in the remit, interface and interaction activities were carried out with Task 5 and TCCS. The outcomes of these tasks were exchanged, and the MMI Capability shared the As-Is architecture in the Klaxoon environment with other tasks to collect their feedback. The high-level approach of Task 5 was analyzed by MMI. It was jointly agreed that once the Task 5 architecture is further developed, interactions with MMI will be consolidated in the upcoming contracts.

The created To-Be architectures were validated by the Task-1 Members during the In Person Workshop in Frankfurt DB Infra Go Premises on 26.09.2025.

I**Interaction between TASK1 and TASK3**

The convergence work between Task 1 and Task 3 was carried out through the Operate Train capability. The analysis results made it possible to establish traceability between the operational elements defined in Task 1 and the functional elements defined in Task 3. This traceability was defined textually in the deliverables produced this year. Traceability between the dedicated Capella models is expected as part of next year's contract.

The feasibility of performing model traceability with other tasks will also be studied as part of next year's contract.