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An application of System Architecture in the Rail and Road Infrastructure

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Abstract. This paper describes the application of an Architectural Framework and System Architecture in the Rail and Road infrastructure. This is illustrated by addressing the state of the art of Systems Engineering in this domain, how the need for system architecture became apparent and finally what architecture framework was chosen and how that was applied in a real life rail example. The paper concludes with a view on the next steps to be taken to further mature the Architecture Framework and resulting system architectures.
The main focus of this paper is on architecture for Rail Infrastructure systems, with some references to road infrastructure system.

Current maturity of the application of Systems Engineering in the Dutch infrastructure domain

The Dutch Rail, Road and Waterways domain has been applying Systems Engineering since the late 1990's. At first it was the rail infrastructure manager experimenting with functional written supplier contracts. After first lessons learned and successes, the domain wide need for Requirements Engineering became apparent, followed by Verification & Validation, System RAMS and Lifecycle management. This led to a domain specific series called "Guideline Systems Engineering"; version 1 in 2007, up to version 3 in 2013. The guidelines define the level of maturity of Systems Engineering in the sector and are available in Dutch and English.

The need for System Architecture

With the current state of the art of applying Systems Engineering as described above, the need has become apparent to model the architecture of systems in the Dutch Rail, Road and Waterway construction domain. The main needs for doing so are listed below:

- Transparent link between the customer's organizational targets and the applied technology and solutions
- Explicit identification of critical design parameters and constraints
- Clear distinction of system elements
- Where feasible, standardization of system modules

Transparent link between the customer's organizational targets and solutions. When systems are being developed or upgraded, we want to make sure that the selected solutions do meet the customer's concerns, needs and requirements as well as the organizational targets. With continuous focus we can ensure that the project efforts and energy invested is in line with these customer relevant topics.

Explicit identification of critical design parameters and constraints. Architecture provides insight in the design drivers and constraints that are typical for a system and that drive the behavior and consistency of the system as a whole. Also the critical parameters and constraints from the stakeholder's and user's perspectives are captured and reflected in the architecture.

Clear distinction of system modules. This helps us to define a modular architecture of the system and its subsystems in order to optimize the interfaces between these subsystems, and with the objects in the context of the system. The optimization is regarding both the physical interfaces as the control levels of the system.

Standardization of system modules. Standardization of system modules shortens development cycles for future systems of a certain type, reduces variations of the needs and customer / user requirements and also characterizes the performance (RAMS, Functional and behavior) of the system.

System Architecture

Architecture. With architecture we establish between the Organizational Targets and the Design solution, by defining the needs, the Systems' assets management & operations, the System functions needed to fulfill the targets and operation and finally the System Concept. The "bridge" is illustrated by the figure below and based on the Architecture concept as published by James Martin.

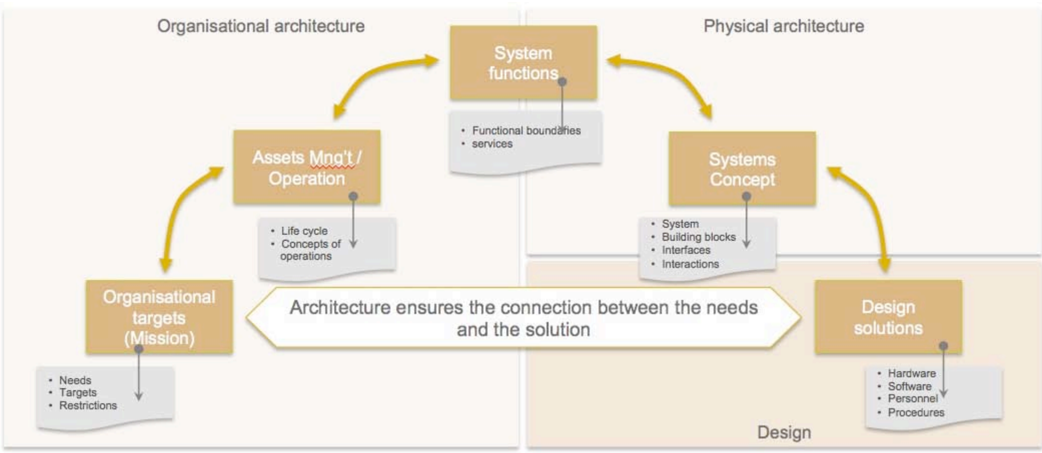

Figure 1. Concept of architecture

The System Architecture is the set of views and representations as shown above, including the relation between each of these representations. This relation is to be represented by the facts that:

The organizational targets leads to means of assets management and operational concepts, which leads to system functions that lead to a system concept, which leads to design solutions. Visa versa, each item fulfills its predecessor's characteristics.

Systems Aspects. In Systems Engineering terms like System, Subsystem and system elements are quite commonly used. Typically, a system is a combination of interacting system elements organized to achieve one of more stated purposes [ISO/IEC/IEEE 15288]. A subsystem is defined as a system element comprising an integrated set of assemblies, which performs a clearly separated function, involving similar technical skills, or a certain supplier. Ref. SE Handbook 3.2.2

In the system definitions by Prof. in ‘t Veld, the phenomena he calls “aspect systems”, is defined as a sub-set of relations between elements. These elements of an aspect system are part of multiple subsystems. An aspect system can be seen as a sate skewer representing a certain relation, between multiple subsystems. Thus, the allocation of aspect systems depends on the division of subsystems defined for a certain system. In case of a car system, which consists of for instance a drive system, steering system, interior system, electronic system and the car body, an example of a system aspect is the Car Safety that is instantiated through components / mechanisms in most of the subsystems. The figure below illustrates three views of a system. The first is a system with 6 (arbitrary) subsystems in variations of yellow. The second illustrates the aspect systems (varieties of green) that interact with multiple subsystems. The third additionally illustrates the differentiation by multiple control layers.

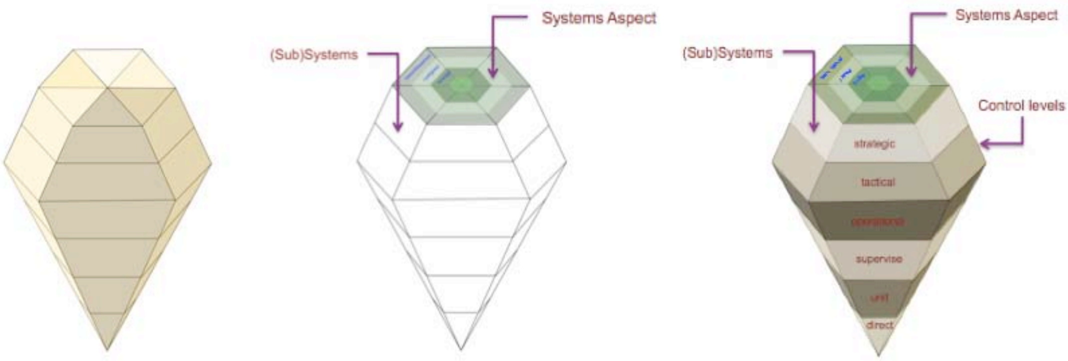

Figure 2. System decomposition in sub-systems, aspect systems and control levels, illustrated by a 3 views on a diamond shaped system

In the domain of the rail, road and waterway infrastructure these system aspects have proven to be very valuable for managing and understanding the system and its design. This is especially the case because this industry has a strong tendency of creating subsystems that are discipline oriented. So in the case of a road traffic tunnel, the tunnel typically is split-up into a civil construction system, the road layer system, tunnel installation system and software system. *Note: this is all but smart to do. However, the domain seems to be very hardheaded and persistent in doing so.*
An example of an aspect system that interacts with all subsystems is the water management of the tunnel. It requires a chamber for the pump as part of the civil system, pumps as part of the tunnel installation system, power supplies (external), control software in the software system, connection to the sewage system (external), etc..
As an example of a project where the differentiation is made between the physical and aspect systems, the Oosterweel Link (Oosterweel Verbinding, OWV) project in

Antwerp (Belgium) is shown below. The OWV project is both an upgrade and closure of the circle-shape highway surrounding the city of Antwerp. The LO subsystem is at the Left Bank of the river Schelde including a tunnel connecting the LO to the RO at the Right Bank of the Schelde. The LO has two major subsystems and the RO has three. Each of these subsystems consists of many systems and elements, which are not shown in this illustration.
For OWV several Aspect systems have been recognized. The ones illustrated here are the Traffic control system, Tunnel Installations, Energy, Water Management, Maintenance and Safety.

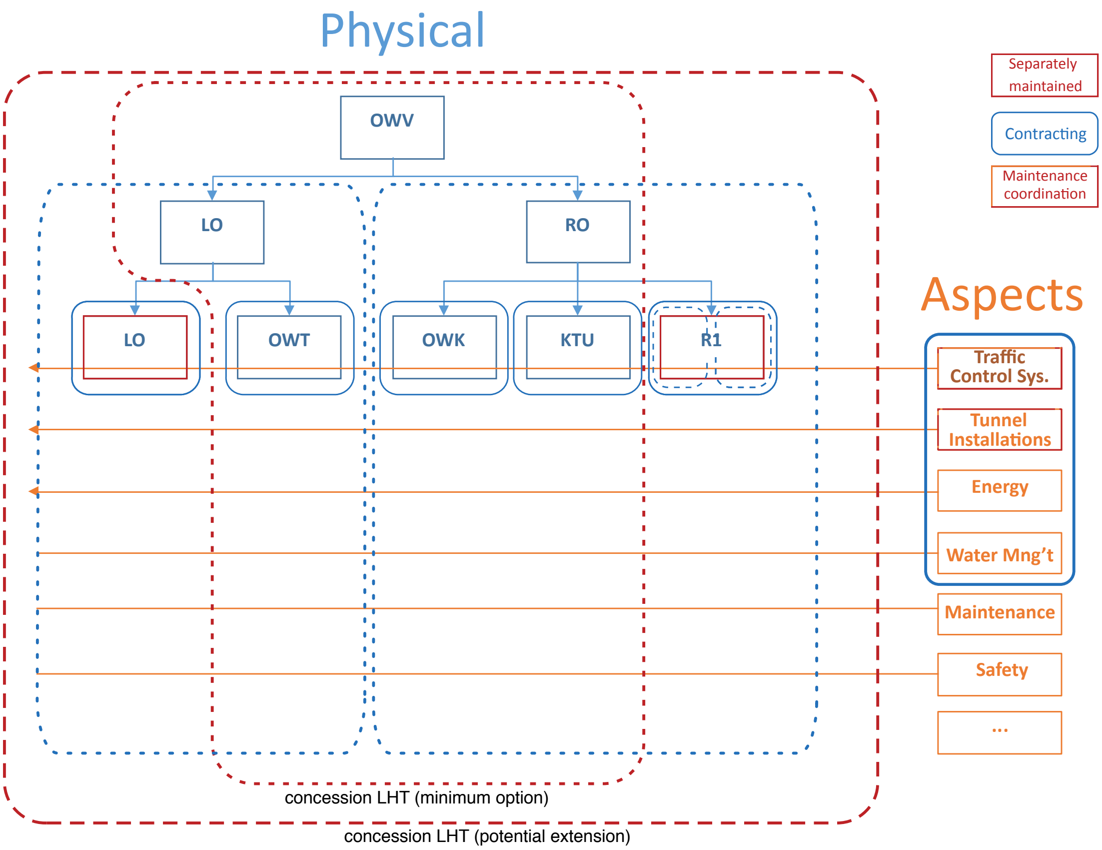

Figure 3. The OWV Physical and Aspects system decomposition

Architecture Frameworks

In other domains than the rail, road and water infrastructure, Architecture Frameworks (AF) are being increasingly applied in various domains.

Typically, the benefits of using these AFs:

- An Architecture Framework provides:
  - Standard approach for defining the architecture
  - Standard views and view descriptions
  - Standard information structure

- An AF should lead to effective development of architecture
  - Shorter development time by uniform application
  - Provides project teams with uniform images
  - Ensures the uniform exchange of project information

- The AF supports the evaluation of the system architecture
  - It emphasizes on differences between alternative product families
  - Supports the decision making for both management and the project team working on a system architecture

Architectural Frameworks (AF) describe the generic information that is to be provided, each time when creating a system architecture for that domain or organization. The Architecture Framework is a stable factor for that specific domain or organization.

Some examples of existing Architectural Frameworks:
DODAF: Department of Defense Architectural Framework (US)
MODAF: Ministry of Defense Architectural Framework (UK)
TOGAF: The Open Group Architectural Framework
ZACHMAN: Enterprise Architectural Framework, by Zachman
TRAK: The Rail Architecture Framework, based on MODAF (by London Underground)
A3AF: This Architectural Framework focuses on limiting the views presented to a paper format of the size A3 (M.Bonnema, Twente University)
CAFCR AF: Customer objectives, Application, Functional, Conceptual Realization Architectural Framework by Gerrit Muller

Overview of the evaluated Architectural Frameworks

Various non-defense related AFs have been evaluated for application in the Rail infrastructure. The obvious candidate to evaluate was TRAK. However, TRAK has a strong focus on UML / SysML modeling concepts. The team working on the development of the ProRail Rail Architecture choose to focus on defining the for ProRail relevant views and critical parameters, rather than using the 20 views defined for TRAK.

Two much more appealing concepts were the A3 and CAFCR Architectural Frameworks. The benefit of the A3AF is that the entire Architecture needs to fit on an A3-size paper, to encourage the architecture team to only present relevant information of the right level of abstraction. In itself, this is a powerful approach, as described by Bonnema. The A3AF was recently successfully applied to model the architecture of rail switches. However, for the complex rail infrastructure that is the focus of this architecture, the A3 size is perceived as physically too limiting for the amount of information needed to represent the architecture.

The CAFCR is developed by Gerrit Muller (www.gaudisite.nl). This framework is quite similar to the A3AF, but doesn't limit it's size to the A3 page size. It consists of the following five groupings of views: Customer objectives, Application, Functional, Conceptual and Realization, hence the name CAFCR. For each view a number of dedicated methods can be applied to create a consistent set of representations that lead to a complete view. The views become more powerful by the integration of quantified relations throughout the views as well as by the reasoning of the interaction of critical parameters between each view.

Actually, the approach of integration via qualities has a lot or resemblance with the earlier described phenomena of Aspect systems. Where the aspect systems are an integration of specific qualities of system element, the CAFCR integrates the qualities between the 5 main views of the architecture.

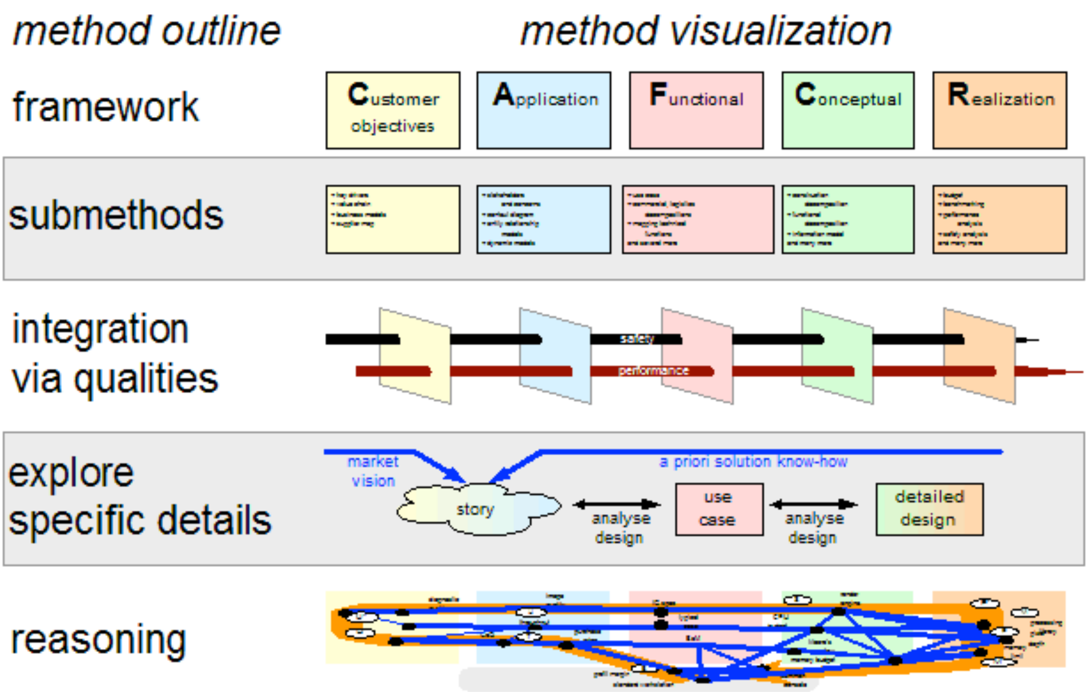

Figure 4. Graphical representation of the CAFCR

ProRail Architecture Framework

After a first experiments with the A3 Architecture Framework, the team wanted to first define the relevant views that represent the rail infrastructure in a consistent and coherent manner. As a result, the ProRail Architecture Framework has been based on the CAFCR Architectural Framework .with the following set of relevant views:

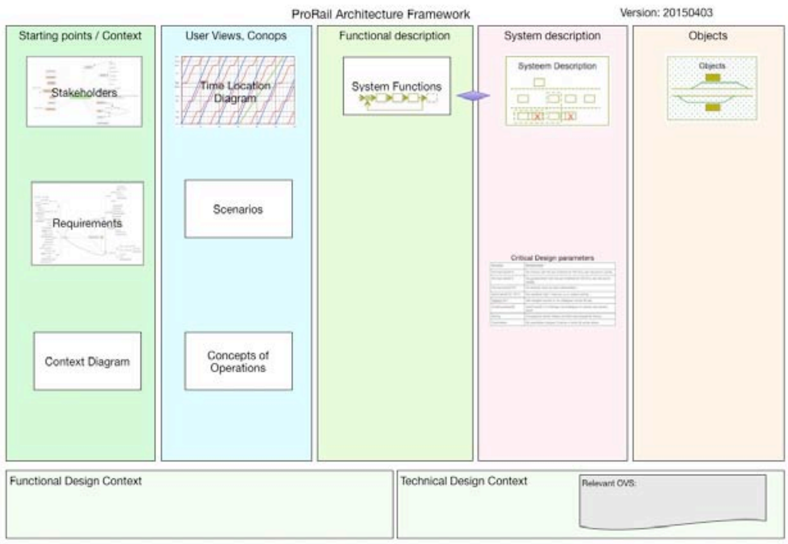

Figure 5. ProRail Architectural Framework

Aside of the views as defined in the CAFCR, the so called Functional Design Context as well as the Technical Design Context were added. Both of these representations form the legacy of the ProRail organization and are very familiar terms for ProRail employees.

Functional Design Context. Represents typical functions of the Rail infrastructure and their interaction.

Technical Design Context. Represents the regulations, guidelines and design constraints for objects, called OVS (example; allowed types of switches).

Example of architecture for a Rail System

As an example, this Architectural Framework was applied to model a section of the Dutch rail infrastructure that, in the near future, will be densely used. The rail infrastructure network in the Netherlands has been split in 5 rail infra concepts. See the figure below for an overview of the five (infra) concepts, projected on a map of the Netherlands.

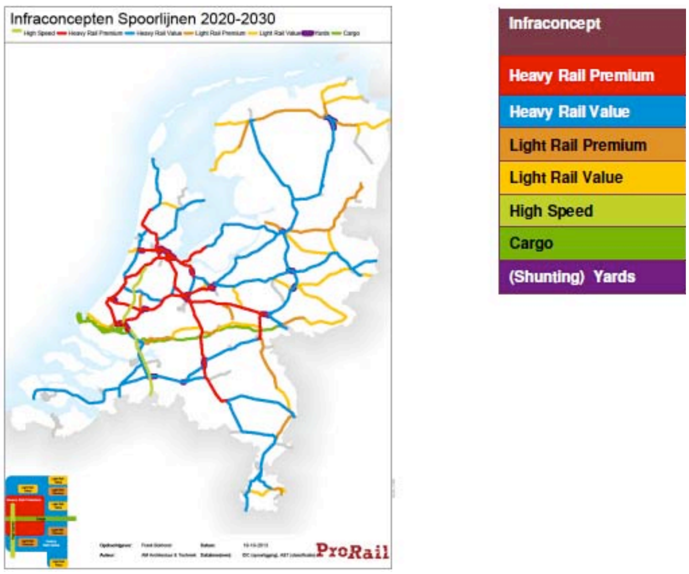

Figure 6: Rail infra concepts in Netherlands

The subject for the architecture modeling activities in this paper is Heavy Rail Premium (HRP) between the cities Eindhoven and Den Bosch. This is a representative section of the Dutch HRP track.

Some of it's key characteristics are:

- the corridor has 2 node stations, 4 local stations (between nodes)
- two parallel tracks
- each hour, in each direction, will run 4-10 intercity trains, 3-6 local trains and 0-2 freight trains
- track speed between 140 and 160 km/h (Freight train is max 80 km/h)
- maximum maintenance windows of 4 hours, each night

- strong reduction of delayed or canceled trains (>90% runs in time; trains with a delay of less than 3 min.)
- Various types of rolling stock shall be able to run.

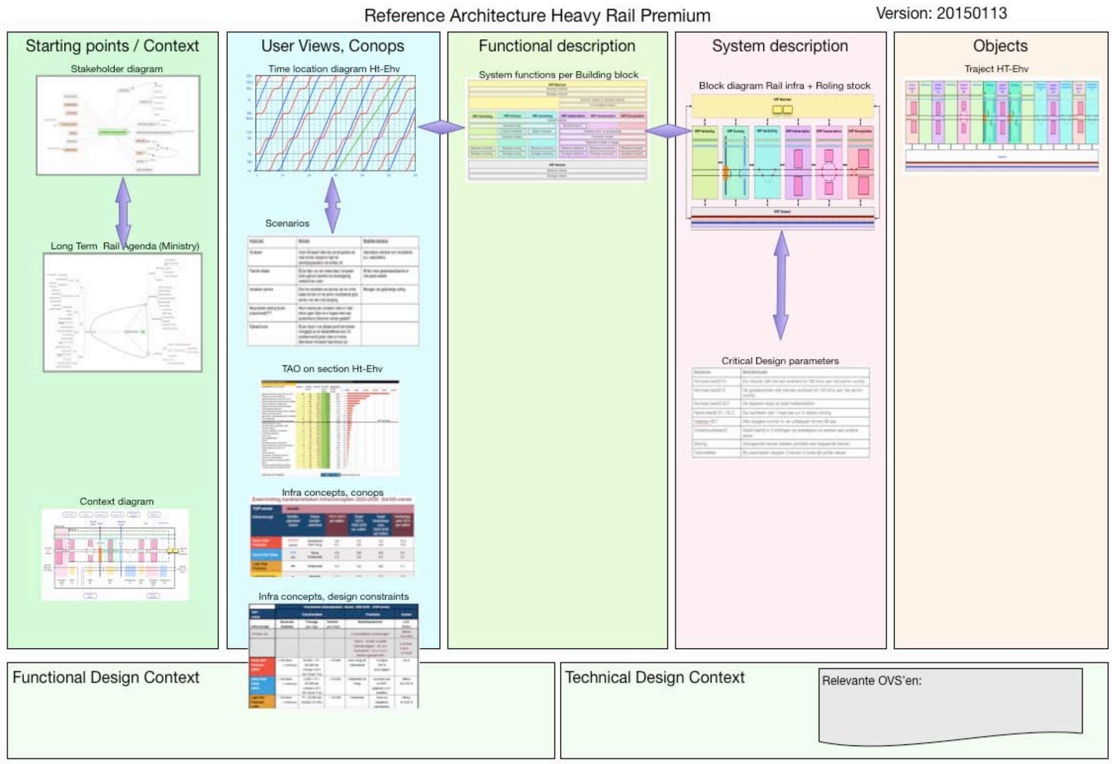

Figure 7. Heavy Rail Premium Architecture

Some of the views generated for the HRP architecture are:

The Context Diagram illustrates the main parts of the system, their primary interaction and of course the interfaces towards the context of the system. The detail of the Context diagram is sometimes perceived as strange. However, the vast majority of projects in the rail infrastructure are developed and executed in a 'brown field' environment. In most cases existing rail infrastructure is maintained, rearranged or upgraded. Only very few projects concern 'green field' projects with completely new infrastructure. Another reason why the context diagram is up front is that the majority of rail is located in heavily populated areas with lots of surrounding infrastructure and other rural applications. All of these have a large influence on the rail infrastructure. The System of Interest is marked with the dotted line and clearly indicates what is within and out of scope of HRP.

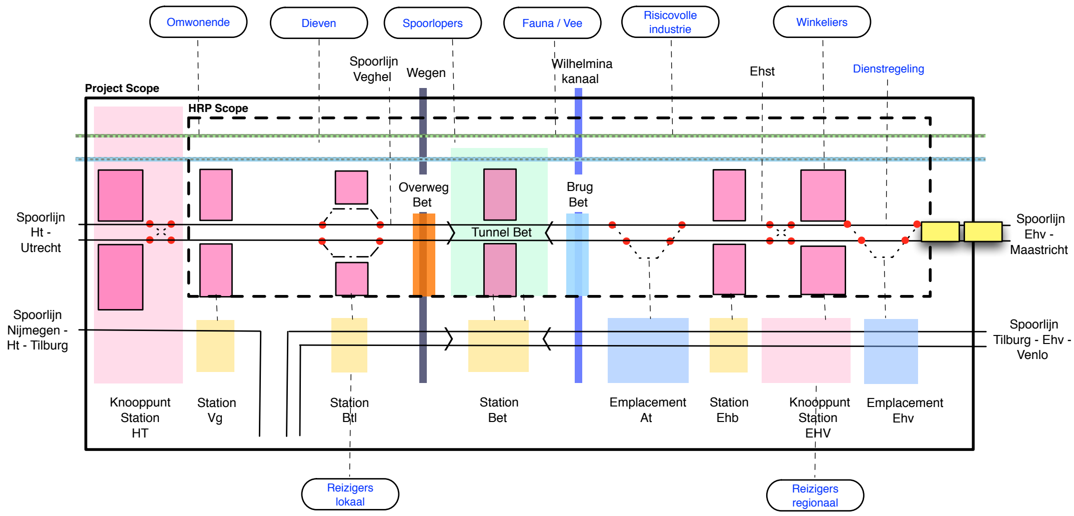

Figure 8. HRP Context Diagram

The Time Location Diagram represents the location of types of trains along a track, during one hour. This is one of the views of the operation of the rolling stock, illustration when faster trains need to pass slower trains on the track. The rolling stock owners require certain time table for trains operation, as input for this pattern.

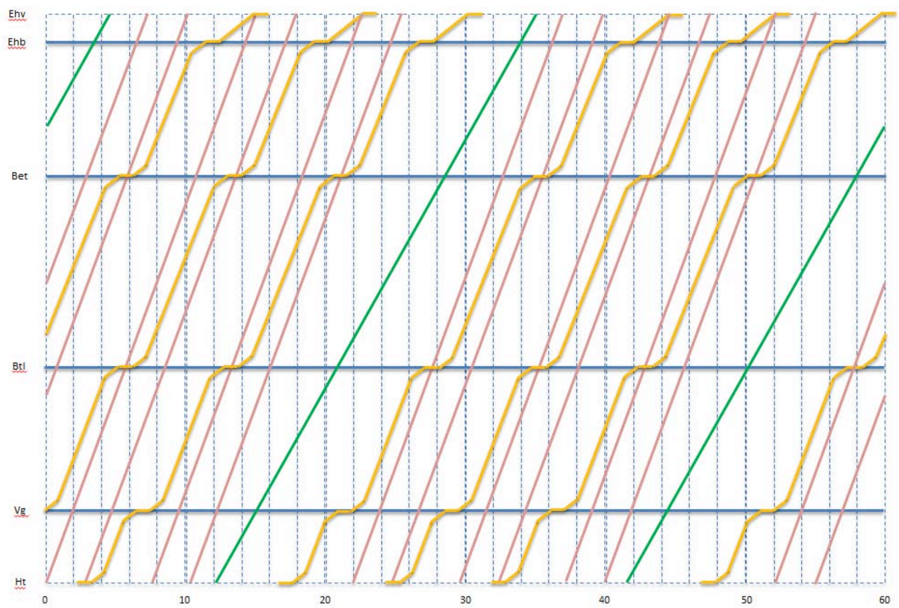

Figure 9. Time Location Diagram

The Building Blocks View represents the higher abstract building blocks that can be applied to assemble a physical stretch of the track. The separation between building blocks is driven by the minimization of interfaces. The advantages of the building blocks are:

- Identification of typical capabilities of each building block
- Creates a standard set of user and client requirements for each building block and the HRP system as a whole.
- Standardization of solutions used

- Will lead to better insight in the RAMSSHE performance of the building blocks and the whole system.
- Differentiate between location specific (Open track, Crossing, Node station, etc.) as well as generic (Network, Rolling Stock) needs, functions and solutions.

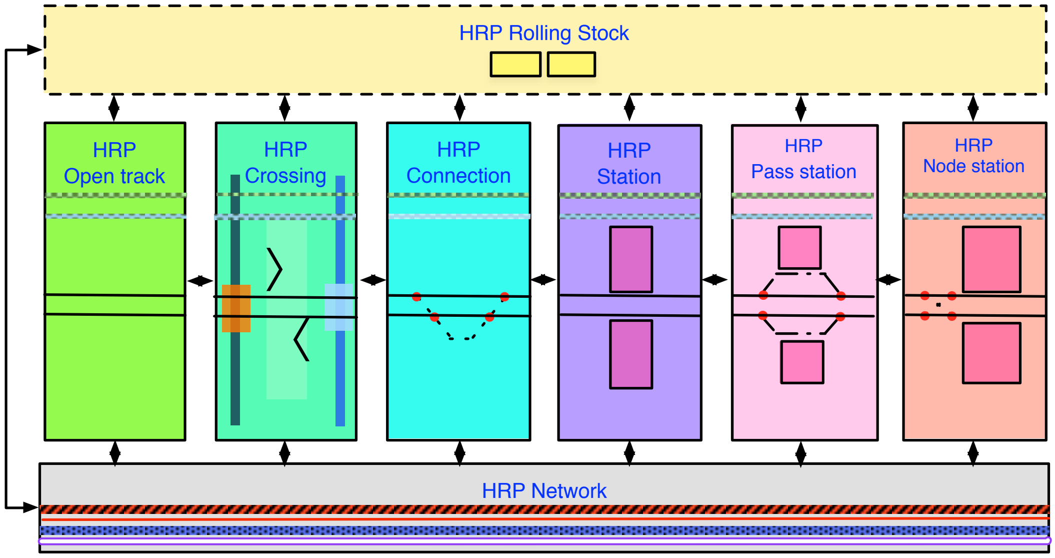

Figure 10. HRP Building Blocks

Next steps for the Architecture of Rail and Road Systems

Assumptions made by the team working on the HRP architecture, need confirmation by the relevant stakeholders.
Another action to take is to further connect the dots between the views defined, so the interconnection between the views becomes explicit. This ensures integrality of the architecture and the items it consists of. With the definition of the views and their interconnectivity, the step towards MBSE becomes in sight.

After HRP, other rail concepts as 'Light-Rail' and 'High Speed Rail', may be modeled as well, with re-use of HRP information where applicable. To make these targets happen, significant workforce is required, the relevant stakeholders need to be constantly or regularly involved in the solicitation and confirmation of critical parameters. The other critical success factor is that the organization managers are explicitly involved in decisions regarding fundamental design drivers and solutions. This might even involve governmental stakeholders in the rail infrastructure.

A challenge while further developing the architecture, are the constraints implied by regulations regarding existing components of rail systems, sometimes "tightening the hands to the back" of the team working on the architecture of the rail system as a whole and in its context.

For the architecture, as discussed above, for road infrastructure systems is currently limited to the so called Tunnel Technical Installations. System architecture will also for the application of road infrastructure help to secure the system integrity and consistency over the total set of system elements and disciplines involved

Conclusions

The application of system architecture helped the rail infrastructure manager to map and better understand:

- the customers worries, needs and requirements
- the transparency of the links between the customer's organizational targets, requirements, operation, functionality and the applied technology and solutions
- the critical design parameters, drivers and constraints
- at what level to create clear distinction of system elements, with optimization of interfaces between these elements
- to what extend the feasibility of standardization of system modules

The architecture has proven to be a powerful means to provide insight in te integrity and consistency of rail infrastructure systems.

A ProRail specific Architecture Framework based on CAFCR was developed to represent and clarify the views and links between them. This framework is to also to be used for future architecture activities.
Further development for the HRP architecture is currently progressing, especially further 'connecting the dots' between the architecture views and by creating the architecture for the Building Block "Passing Station".

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Biography

Paul Schreinemakers holds a Bachelor's degree in Fine Mechanics and is a Master of Science in Engineering Product Design. He has almost 25 years experience in product development in various domains. Paul started his career as a mechanical engineer with SRON, the Netherlands Institute for Space Research. During his 10 years at SRON he learned to apply Systems Engineering. Than Paul moved to Thales, being in the frontier of implementing CMMI in a hardware development environment.

Since 2003 Paul Schreinemakers runs his own consultancy companies, called SEPIAdvies BV and How2SE BV. In addition to activities for customers in the traditional domains of Space and Defense, he now mainly applies Systems Engineering in the transportation and civil construction industries. Many of the projects Paul is involved in consist of interdisciplinary and multi-cultural project teams in the Netherlands and Belgium. He has coached projects in different organizations operating in various domains.

Paul became involved in INCOSE in 2000, and served for 3.5 years on the board of directors of the Dutch chapter, of which he is a former President. Over the years he has been member of various Chapter and Int'l working groups. As general chair Paul was responsible for the 2008 INCOSE International Symposium in the Netherlands and served as the Associate Director for Events in the years 2009 to 2012. At IW 2015 Paul Schreinemakers has become the INCOSE Technical Director.