Integrating asset's object-type data in the Dutch railway industry

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Colophon

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Picture in Cover: Station Zwolle (Stefan Verkerk)

Abstract

The information management difficulties increase proportionally to the complexity of the infrastructure they are part of. In addition, the variety of experts and supply chain parties, adding the contracting schemes help to raise the complexity. Moreover, in the railway industry there are ever more demanding passengers on which the standards of service are set. To tackle this, governmental parties and infrastructure authorities started to promote Building Information Modeling(BIM) in order to enhance collaboration and improve lifecycle processes. Within the framework of BIM, initiatives like the IADD4UK(United Kingdom) and the CB-NL & OTL(The Netherlands) aim to set the basis for organising the infrastructure asset's data and standardise all the definitions used to name assets and systems throughout their lifecycle. Accordingly, organisation of asset's data faces complex challenges from the views of requirements, architecture and IT development. Moreover, within the Dutch railway industry there is still a strong traditional culture within ProRail –the Dutch railways asset's owner- and also in the supply chain parties. This pose important organisational challenges when introducing new technologies.

In this research insights were gathered out of thirty interviews and twenty-two surveys made to parties operating throughout the lifecycle of railway projects. The first were organised using a framework of five dimensions based on IT development and organisational theories. The surveys asked to rank specific purposes, contents and results. Besides, they also ask open questions about short-term priorities. In addition, they help to derive challenges to consider when trying to implement the roadmaps sketched in the last part of the research.
In addition, stakeholders -users of the platform- can bring unlimited wish lists with more and better features. Although, their interests must be taken in consideration they have to be aligned also to the government's vision. To give a proper alignment, roadmaps are considered which take many aspects into account. Based on literature study, a good roadmap helps to deal with the requirements management process, prioritizing needs, setting timeframes and ensuring that the needs of stakeholders are maximised.

Complementary, six use-cases were elaborated based on insights from experts working in ProRail and ARCADIS -the engineering bureau who funds this research together with TUDelft-. The use-cases elaborate on potential OTL uses for specific life-cycle phases based on experts' information needs. They also help to narrow down the scope for exemplifying an OTL implementation process in the roadmaps.
Thus, the interviews and surveys together with the use-cases constitute the base for defining the reference framework and content of the strategic and tactical roadmaps.
The roadmaps are based on existing theories and recommendations on technology road mapping for supporting managers' decision making. The aim of the roadmaps is to propose an structured implementation where the main parties' concerns are included and which provides value to the sector.
The overall validity and reliability of the roadmaps was discussed with experts from ProRail and ARCADIS. Although, a systematic approach has been aimed based on theoretical frameworks, the elements plotted within the roadmaps include personal interpretation and subjectivity. Therefore, it is advised to make a cross checking with all possible interested parties in order to assure agreements on the terms used, the scope of the roadmap's contents and timeframe.

Acknowledgements

This graduation research was started seven months ago in TUDelft after I found an internship query by ARCADIS on the BIMlab' board at the Civil Engineering faculty. However, my interest on railways awaked long before when living in my hometown Lima, Peru where the railway history has been abrupt and discontinued. With a rail corridor partly built in the early 80's soon after I was born; but not starting operations until recent times soon before I came to the Netherlands for doing a master of science.
In the second year of the master program I had the opportunity to make an exchange course in Munich, Germany where I became fascinated of the possibilities of BIM, GIS and remote sensing technologies.
Thus, when looking for a graduation topic I found in the OTL the opportunity to combine both interests: railways and IT infrastructure solutions.

In ARCADIS, this experience has brought me the opportunity to interact with highly skilled and experienced engineers from all sorts of backgrounds. This research would not have been successful without the help of my company supervisor Maarten Zanen who challenged and pushed me since the beginning when the scope and knowledge of the topic was barely clear. Besides, I would like to express my sincere gratitude to my TUDelft supervisors Sander van Nederveen for his availability and advice; Wijnand Veeneman for his critical and out-of-the box thinking; and Rolf Dollevoet for this oversight and help with contacting experts in ProRail.

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I also want to thank to all the stakeholders who participated in the interviews and took time to fill the surveys contributing their expertise and expectations. Ultimately, I want to thank my mother and girlfriend who supported me to stay focused and successfully finish this research.

Carlos Arguedas
Utrecht, September 21th, 2015

Reader's Guide

The structure of this thesis intends to be self-evident. Though, due to a lack of awareness in the Industry and because it is at an early stage of development, a variety of contents have been considered to help to introduce and understand the core content.
The research questions are answered chronologically and the chapters aim to elaborate on each subject in a coherent, systematic and structured way. The thesis, is broadly divided in four parts: problem identification, analysis, diagnosis of causes and roadmaps and conclusions.
To appreciate the complexity and interrelatedness of all the subjects readers are invited to read the whole thesis.

- Readers interested in the problem formulation and methodology focus on the introduction(section 1).
- Readers interested in theories associated with Infrastructure and data management focus on section 4.
- Readers interested in the Railway Industry context and Data Management initiatives in the Netherlands focus on sections 5,6 and 7.
- Readers interested in Data Management initiatives outside the Dutch railway industry focus on section 8.
- Readers interested in the interviews and surveys and their outcomes focus on sections 11 to 19.
- Readers interested in the roadmaps and conclusions focus on sections 21 to 25.

Contents

Acronyms

AIM	-	Asset Information Model
BID	-	Business Information Document
BIM	-	Building Information Modeling
CB-NL	-	Concepten Bibliotheek Nederland
CRS	-	Customer Requirements Specifications
COBie	-	Construction operation building information exchange
EAM	-	Enterprise Asset Management
e.g.	-	“Example given” – “For example”
GIS	-	Geographic Information Systems
i.e.	-	“that is”
IMS	-	Information Model Spoor
Infra	-	Infrastructure
IFC	-	Industry Foundation Classes
ISO	-	International Standards Organization
LC	-	Life-cycle
LCC	-	Life-cycle costs
O&M	-	Operation and maintenance
OTL	-	Object Type Library
RSE	-	Rail System Engineer
RWS	-	Rijkswaterstaat
SE	-	Systems Engineering
SOA	-	Service Oriented Architecture
SRS	-	System Requirements Specifications
XML	-	Extensible Mark-Up Language
PCA	-	Procescontractaanemer
PM&E	-	Project management and engineering
PPP	-	Private-Public procurements
PUIC	-	Project Unique Identifier
RWS	-	Rijkswaterstaat
WVS	-	Wisselverwarmingsysteem

PART A: IDENTIFYING THE PROBLEM WITH ASSETS' DATA

"If the concepts in the mind of one person are very different from those in the mind of the other, there is no common model of the topic and no communication"
— (Taylor and Fiske 1975)

1. Part A Introduction

PART A introduces the current information' problem faced by asset managers in the Dutch railway industry. Based on it, a formulation is made for the problem that is matter of this research. The Spoordata program is the main source from which elaboration about the problem is extracted. Accordingly, the research objective is stated stressing the importance of the time component related to both the lifecycle and the short and long-term implementation of the Object type libraries. Complementary, the scope is defined aiming to set the research alongside the knowledge provided by the master program in Construction Management and Engineering.
The main research question aims to answer directly the research objective whilst sub-questions bring the topics that are more relevant in order to come up with an answer and/or solution to the problem. Finally, the structure of the paper is schematized in the research methodology that shows how chapters are connected ultimately leading to the roadmaps and conclusions.

1.1. Problem description

In recent times the information management in construction projects is becoming more complex partly due to the more intensive involvement of multiple disciplines. Integrated contracts and public-private procurements result in a higher complexity, because of an increasing number of actors, interdependencies and requirements. This causes a substantial increase in the effort required to manage information that makes it hard to provide correct and unambiguous information. This can lead to less efficient and adequate work by the parties involved in a project (van Ruijven, 2014).

Over the past five years, the benefits of Building Information Modeling (afterwards called BIM) in use have been documented by numerous research studies providing data to support its positive value and encouraging wider adoption (Becerik-Gerber & Rice 2009). Value is more often associated with the ability of BIM to save project delivery time and costs that can then be directly translated into firm level productivity gains. (Jupp 2013)

In the Netherlands, Rijkswaterstaat(afterwards called RWS) -Ministry of Infrastructure and Environment- is responsible for the design, construction, management and maintenance of the main infrastructure facilities. This includes the main road network, the main waterway network and water systems. (rijkswaterstaat.nl). In response to a reduction of jobs planned by RWS for the coming years, strategies are needed(ProRail, 2013). They would aim to reduce the workforce without affecting the quality of the service. Lean practices and BIM can be useful techniques for improving efficiency in information matters. Accordingly, RWS has started initiatives that involve the adoption of BIM in the different sectors under its oversight.
Complementary, ProRail –asset owner of the rail infrastructure- has started the program “Lean Transformation” to get greater efficiency at lower costs. (ProRail, 2013). Within this aim, it is of major importance to keep quality of data throughout the Lifecycle in order to achieve an efficient maintenance. Additionally, in the Dutch railway infrastructure there are many assets and stakeholders involved at the different stages of a project’s lifecycle.
Although ProRail’s responsibility is to keep assets in good shape, this must overcome several difficulties due to a multi-party exchange of information.

An important RWS’ project is called Concepten Bibliotheek Nederlandse (afterwards called CB-NL) stands for a dictionary for the Dutch construction industry. It involves the definition of all objects used in the building, infrastructural and installation industries and aims for a single standardized language. (BIC 2014). This project includes both physical object and spatial object descriptions throughout the whole life cycle of a project from planning to maintenance. Thereby, integration is a complex task. In order to assist the CB-NL, an Object Type Library(afterwards called OTL) is being developed containing all asset-types with their aspects and functions. Whereas the CB-NL aims to provide a general description, the OTL goes more into details.
Similarly, the railways’ OTL aims to standardize the exchange of information in the railway industry and is part of the SpoorData.nl program initiated by ProRail. It is believed that an object database and a data-room can feed every stage of the life cycle of a project from the preparation of works to the maintenance. The OTL is the core of the Spoordata architecture (R. Nagtegaal, 2015) and it comprehensively includes all the subtypes, functions, and compositions of assets through the whole lifecycle. Therefore, in order to standardize the

OTL in the industry, a paradigm shift must take place regarding the current information management practices.

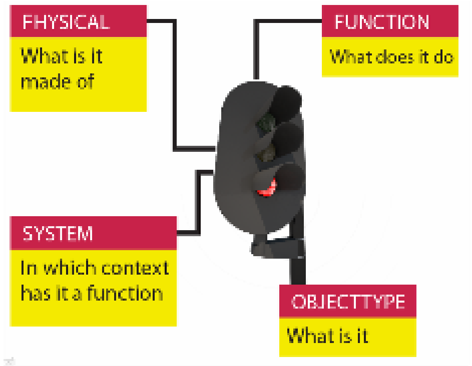

Figure 1: Asset attributes of an OTL object (Movares,2014)

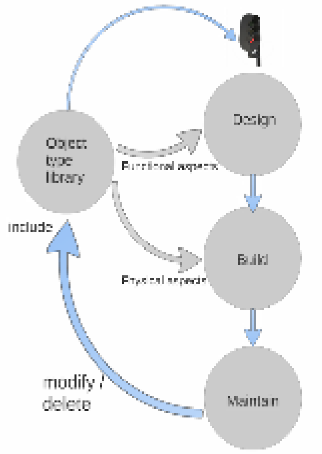

Figure 2:OTL interaction within the different project stages (Movares,2014)

1.2. Problem formulation

In the view of ProRail, the current problem with information management in the Dutch Railway sector is described by the Spoordata' Executive Management Report program(Schouten & Soeters 2014):

The information from current databases is insufficient to meet the needs of the value chain and thus it leads to considerable error costs and risks in the business. Some examples are:

- The function plans have no "functional photo" of the development of the infrastructure for more than two years.
- The Builders offers mediocre quality of data about the location of the underground infrastructure, leading to costs for cleaning up, ducts damages etc.
- Maintenance contractors have an insufficient reliable picture of its objects in their area, the condition of these objects and of the performed maintenance on these items.

In the case of the contractors, the problem can be related to their competitive stance in response to the integration requirements from ProRail. Consequently, the problem arises with the gap between two states of development: the current exchange between object-oriented-data systems; and the desired level of data integration aimed by ProRail for make the OTL useful. Thus, the challenge for the Asset Manager is how to show the parties the potential benefits of an OTL in order to narrow down this gap aiming for more efficiency and competitiveness in the industry.

1.3. Research objective

The Spoordata.nl program involves the uploading of data from all kind of components throughout a Lifecycle. Complementary, Virtual Spoor (joint project between ARCADIS and Movares) includes both the location aided by GPS and the object information fed by the CB-NL and the OTL. These initiatives however, are still at an early development phase and is not clear yet how an OTL can be best used.

The main objective is to find out what uses of the OTL may bring more added value in a lifecycle' phase and how current systems can be integrated over time.

For achieving this goal the potential uses of the OTL has been analysed based on the current developments, recommendations from experts and experiences of railway stakeholders through interviews and surveys. Out of the interviews and surveys, the perceived benefits of the OTL will be highlighted in the specific Lifecycle stages where more value is found. Ultimately, a Lifecycle Roadmap will be developed.

Short-Term vs Long-Term benefits

An important differentiation must be made between the potential short-term and long-term benefits. The first will be more likely to make the stakeholders practice more efficient and therefore "better" competitors. The second will add up to their existing activities and therefore it will expand them i.e. make their reach "bigger" towards future challenges.
Moreover, similar to the standardization of BIM, the OTL standardization takes more than merely implementing a technology, thereby the research will focus on two main components: people and process.

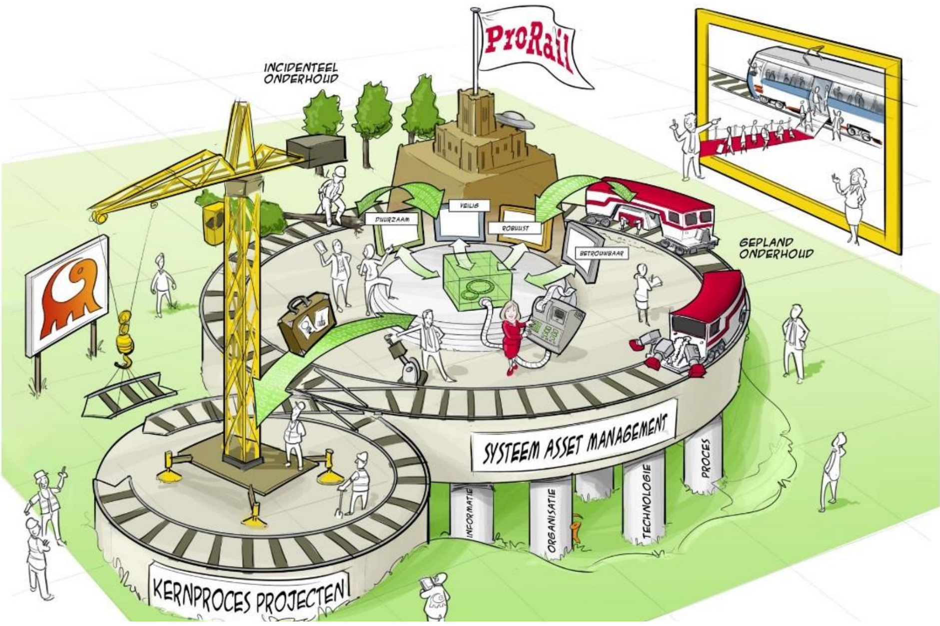

Figure 3: Representation of the data exchange within the Lifecycle Management in Railways. (Arcadis,2014)

1.4. Scope

This project focuses on those OTL uses that are feasible to implement in Short-term within the current systems of the stakeholders. Thus, current practices and the possibilities in a Short Term horizon will be explored more in depth.
Moreover, the research is done from an organizational perspective and not from a technical view (IT systems). Therefore, the focus is on people and processes, pointing to the interaction and feedback with/from the different stakeholders. In order to anticipate possible stakeholder clashes the research is made from the viewpoint of ProRail(The Client). In other words, the study is be framed within the predefined needs and requirements of ProRail. The underlying reason behind this approach is that even though the research is made for the

PM&E bureau (ARCADIS), is ProRail who initiated, demanded the implementation of the OTL and finally has the last word in a tender. A client oriented focus is therefore considered the logical approach. Besides, recommendations will be given and it will focus on the tactical level of the implementation, having connections with the strategic and organizational levels. Additionally, the research will define the aspects, which according to the Industry standards and the stakeholders practice, better measure the performance of the OTL.

1.5. Research question

Based on an organizational focus, the research aims to answer the following research question:

> **In which uses could an OTL add value to the lifecycle management of railway assets?; what is this value?; and how could stakeholders' systems can be integrated to the OTL over time?**

In order to answer the main question some sub-questions must be first addressed. They aim to clarify two types of problems: knowledge problems(questions 1, 3) and practical problems(questions 2,4 to 7).

Sub-questions:

1) What theories are relevant to understand an OTL?
2) What can be learned from other industries and/or previous railway experiences?
3) What is the current perception of an OTL in the railway sector? What are the main requirements to be addressed for using the OTL in Short-Term?
4) What can be learned from Use-cases?
5) Why is switching to an OTL a challenge for the stakeholders in the railway industry?
6) What are the pitfalls of switching to the OTL. How to prevent risk?
7) How to develop an optimal and coherent set of Roadmaps?

1.6. Research methodology

The research methodology is practice oriented rather than theory oriented because it tries to find solutions for practical problems rather than develop new theories. There are five stages for a practice-oriented research (Verschuren, et al., 2010): problem identification, diagnosis of the causes, design a plan(roadmap), intervention and monitoring of implementation, evaluation of the result

As the project objective includes both identification of causes and developing a roadmap(plan), this research cannot be structured around one research type, but rather it uses both the diagnosis of causes and the roadmap frameworks. Considering the scope and the time constraint of this research project, it does not go further than creating recommendations for an implementation plan and therefore it does not reach the stages of monitoring and evaluating the actual implementation process. Accordingly, after identifying the problem the following steps are taken:

PART A introduces the problem, research objective, scope, research questions and methodology. PART B starts from a broad research on different theories that help for a

better understanding of the OTL and its context in the industry. More in deep, the collaboration framework within the railway industry is introduced and then the latest initiatives in dealing with asset data are briefly described. Complementary, experiences outside the Dutch railways are assessed in order to learn lessons that can be included in the OTL implementation. The problem is revealed based on The Spoordata Executive Management Report (Schouten&Soeters,2014). PART C depicts to diagnosing the problem' causes and it comprises interviews and surveys that provide insights about what the OTL represents for each stakeholder. The interviews represent a qualitative assessment whilst the survey forms aim for a more quantitative assessment. Insights from the interviews and surveys are then organized in five dimensions based on literature. The previous steps help to know what is the perception of the stakeholders about the causes of the problem. The insights are elaborated under the following: a stakeholder mapping; a risk assessment matrix; a value system design, performance indicators and use-cases.
PART D is where the research condenses all the previous information in the form of a graphical tool. Accordingly, Roadmaps balance and calibrate the process towards an infinite "wish list" of requirements(Jandourek,1996). They focus on the necessary activities to implement the OTL considering the main challenges and their causes identified in prior phases, and it does not focus on costs and schedules for these activities.

The table below illustrates the research methodology.

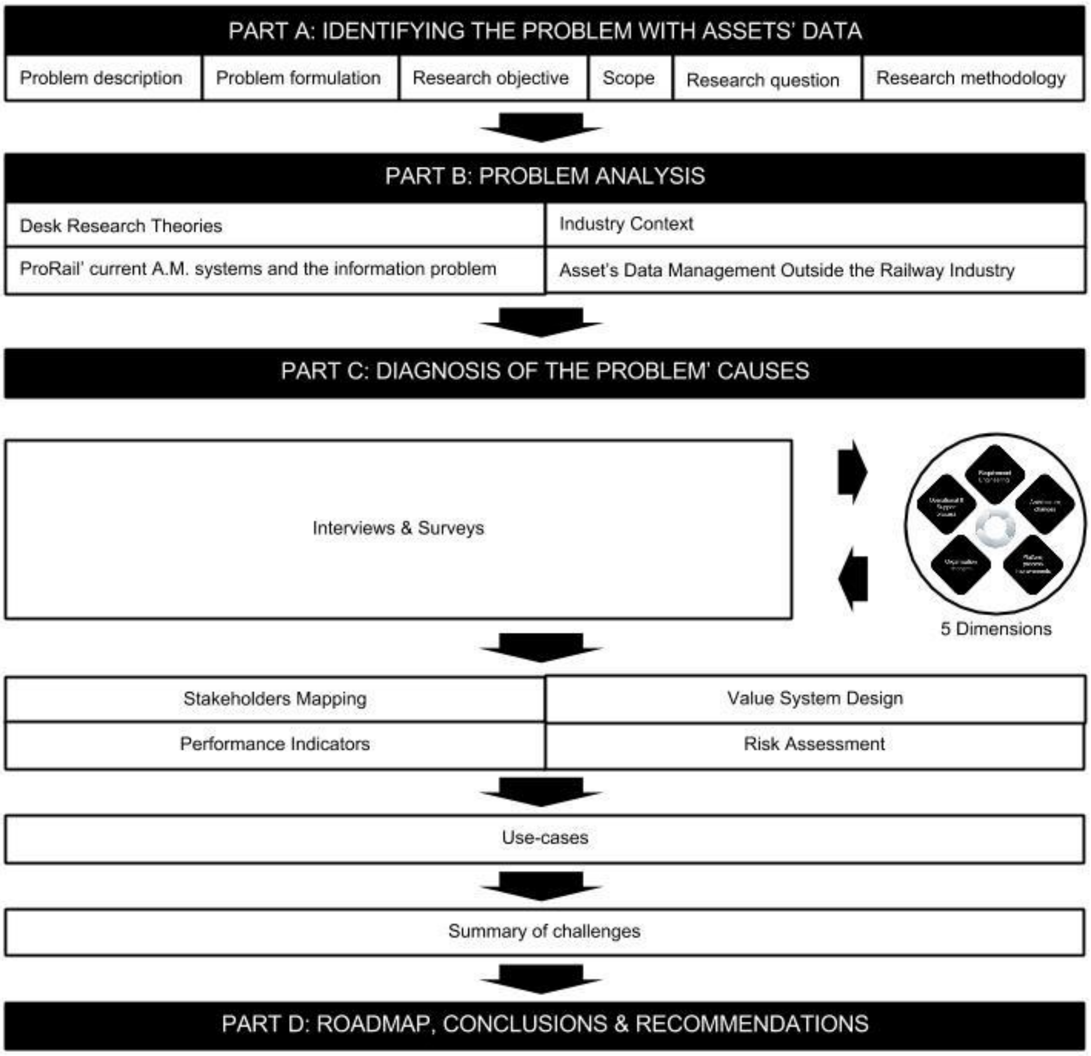

Figure 4: Methodology framework. (Own creation, 2015)

2. Part A Conclusion

There is a current problem with asset's information management affecting specially large projects in the construction sector. Information problems are likely to lead to time and cost overruns. Railway projects in the Dutch railway industry are not exempted from this kind of problems. In the Netherlands the root of the problem is mainly the lack of efficiency in information exchange between the Asset Manager(ProRail) and supply-chain parties as stated in the Spoordata program.

In response to the problem this research aims to investigate what are the possibilities of using Object type libraries(OTLs) in order to tackle the problem. In other words, the goal is to find out if there is added value for certain stakeholders. The reason for choosing the OTL is that it is considered the core of the Spoordata program and is likely to become a standard register of all the railway assets in the country. The methodology is divided in four parts starting with the problem identification and finalizing with roadmaps and advice on the OTL implementation.

Being a new technology, the OTL itself poses challenges regarding being accepted by different engineering cultures forming part the Dutch rail sector. Thus, a cornerstone in this research are interviews and surveys assessing all possible perspectives from different chain parties throughout the lifecycle and supply-chain. They are analysed based on advise extracted from a literature study. In addition use-cases help to narrow down the applicability of the OTL in order to come up with real solutions according to the current needs of stakeholders.

PART B: PROBLEM ANALYSIS

"If you wish to converse with me, define your terms."
— **Voltaire**

3. Part B Introduction

Part A introduced the current information' management problem in the railway industry based on the Spoordata program. The OTL is likely to help to tackle this problem and thereby it is considered as the core of Spoordata. As this research aims to set OTL within BIM, some literature must be studied as well as the industry context where parallel IT initiatives take place. Accordingly, Part B is divided in five sections: desk research theories, industry context, ProRail's asset management systems, recent IT sector' initiatives and experiences outside the Dutch railways.

The first, section 4 provides a brief description of the topics that build up the theoretical framework that helps for a better understanding what Object type libraries are. Thus, the focus is on asset management, BIM, system's integration and the semantic web. Besides, a theoretical approach is designed based on software platform and organisational literature in order to organise the challenges posed by the OTL.
Section 5 provides relevant insights on the Industry context in terms of the stakeholders and the collaboration between them. The chosen aspects are Systems engineering, the Core Process, the procedure fifty-five and the Business Information document.
Section 6 briefly lists the main ProRail's information management systems and section 7 comments about the most relevant recent IT initiatives in the sector as Semmtech, Dataroom, Spoordat.nl and OTL Spoor.
Section 8 goes through different initiatives to tackle assets' data management problems developed by national and international organisations outside the Dutch Railway industry.

4. Desk Research Theories

4.1. BIM in Asset Management

4.1.1. Asset Management and Information

ISO 55000 defines Asset management as the "coordinated activity of an organization to realize value from assets". In turn, Assets are defined as follows: "An asset is an item, thing or entity that has potential or actual value to an organization". Purposely the IAM provides a vague definition of Asset Management aiming to let the organizations to choose their way in providing value. The modern concepts of Asset Management come from three main sources: the financial services, focused in optimizing risk within the last 100 years, the north sea oil & gas, who since the price crash in the 80's started to improve interdisciplinary collaboration throughout the Lifecycle, the Australian and New Zealand public sector who was forced to improve its level of service, strategic planning and value-for-money thinking. Thus the lessons learned from these experiences helped to define the main characteristics of good asset management which are captured in the ISO 55000: multidisciplinary, systematic, systems-oriented, risk-based, optimal, sustainable and integrated. (IAM, 2014)

Assets have different levels of granularity(Figure 6) and yield functional performance when included in a systems context - network, production line, infrastructure facility. Therefore, when aiming to maximize value it is important to consider the inputs, costs and risks for the different levels of assets from the unit level to the top systems level. (IAM,2015)

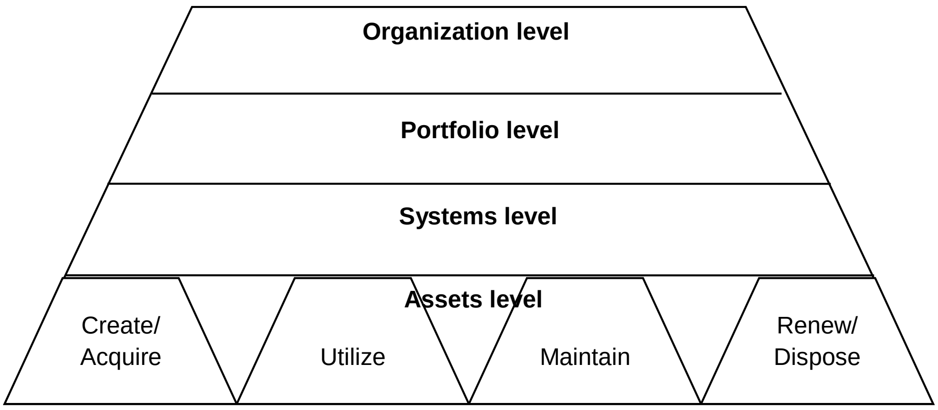

Figure 5: Levels of an Asset Management System (based on IAM, 2014)

According to the IAM asset intensive organizations rely on the following key enablers: asset data, information, knowledge(experience, values, information in context, insight) and wisdom. A good management approach can improve data and can be set out in an Asset Information Strategy. Based on the IAM(2014) the following aspects and definitions have been found to be the most relevant for this research:

- **Main information' components**: an asset inventory or register; asset's attributes (make, model, serial number, age, rated capacity); asset system's attributes(capability); location, spatial information – especially in Geographical Information Systems (GIS); logical groupings e.g. systems, equipment types, zones, etc.; access requirements(permits, right of way requests, safety related information); performance information about the asset, historical records and others.

- **Asset information systems:** applications, software systems and other systems that collect, store, process and analyse asset's information throughout the Lifecycle.
- **Asset data quality:** covers the following specific data quality measures: accuracy, completeness, consistency, validity, timeliness and uniqueness.
- **Asset knowledge:** is based on subjective concepts such as values, experience and insight. Thus, organizations must try to make this available for future decision making and avoid knowledge loss.

4.1.2. Building Information Modeling (BIM)

The concept of BIM was created in the 1970's. The first implementation of this concept was the virtual building concept by Graphisoft's ArchiCAD launched in 1987. Since then, other software companies (Autodesk, Bentley Systems) developed alternative BIM design software. The actual term "Building Information Modeling" first appeared in 1992 in a paper by van Nederveen et al. and has been progressively spreading throughout the Infrastructure Industry. The British National Building Information Model Standard Project Committee defines Building Information Modeling as follows:

> **BIM is a digital representation of physical and functional characteristics of a facility. A building information model is a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life-cycle; defined as existing from earliest conception to demolition. (Buildingsmart, 2014)**

BIM software is based on parametric objects. Each of them has boundaries in the form of the objects that border it. These shared parameters are a characteristic trait of BIM in respect to traditional CAD and 3D objects. Modeling based on parametric objects is a major change in the industry that facilitates the change of the workflow in design from drawing based towards digital models able to create consistent drawings, schedules and data. (Watson, 2011)

Eastman, et al., (2011) states the main traits of a parametric design. Among them are:

- Different levels of aggregation. Modifying subcomponents affects higher hierarchical levels.
- Rules for objects identify when a change violates object feasibility(size, manufacturability).
- Objects have ability to link to, receive or export sets of attributes to other applications.
- Material specification – name and texture
- Location of connections and requirements for: structural, electrical, plumbing, telecommunications, and ventilation systems.
- Performance specifications, operating life, maintenance cycle and other specifications.
- Product distribution links.

4.1.3. BIM in ARCADIS

ARCADIS is an international design & consultancy firm/bureau that works with natural and build assets. Regarding information management, the firm has been working intensively in a BIM development plan that aims to reach all the different industries in their scope. The firm's BIM principles are elaborated on the guidelines called "BIM according to ARCADIS" internally known as the BIM White paper. In the bureau's view, BIM is a disruptive technology which might bring major changes into the industry. This pose a challenge when working with contractors and clients. Therefore, a BIM Maturity Model helps to clarify the way to introduce BIM considering its early stage of development. (ARCADIS,2014)

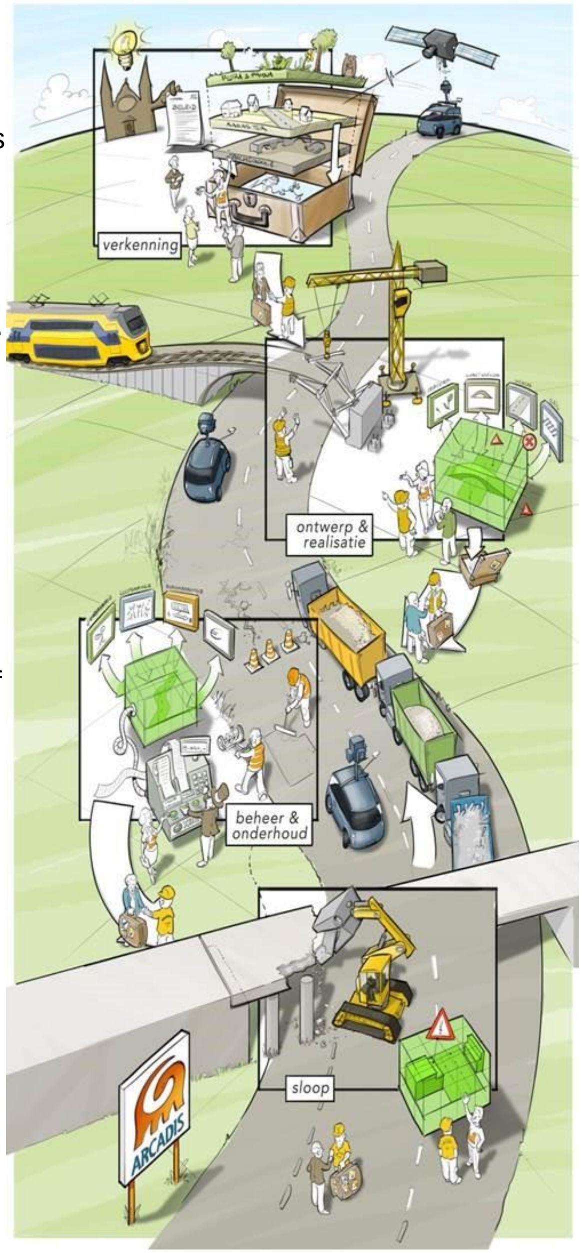

Figure 6: "The journey of the suitcase" (ARCADIS, 2014)

BIM Maturity Model

This model considers the fact that every user of BIM will focus on a specific part of their interest and a different life cycle stage. For example a Project Manager would focus on bundling the designs whilst an Engineer would focus in importing information into analysis software. Thereby, putting this picture into several levels of integration allows to gain insight on how and when BIM can be used. Thus, the Maturity model has in its least developed stage the 2D CAD drawings and in the other side -the most developed stage- one source of Information for all. Figure 7 exemplifies a metaphor for the BIM ' collaboration. Additionally, the following phases are part of this model(ARCADIS,2014): CAD drawings, object oriented models, federated and integrated BIM and collaborative BIM

ARCADIS' BIM Menu

In order to explain the potentialities of BIM, ARCADIS developed a "BIM Menu" in which concrete uses for the business are stated. The parallel with a "menu" comes from the firm's ideology where every BIM use has its own "recipe" for success. This recipe includes an specific purpose and benefit which can add value for clients. The uses are classified into five main goals: gather, generate, analyse, communicate, realize. (ARCADIS,2015)

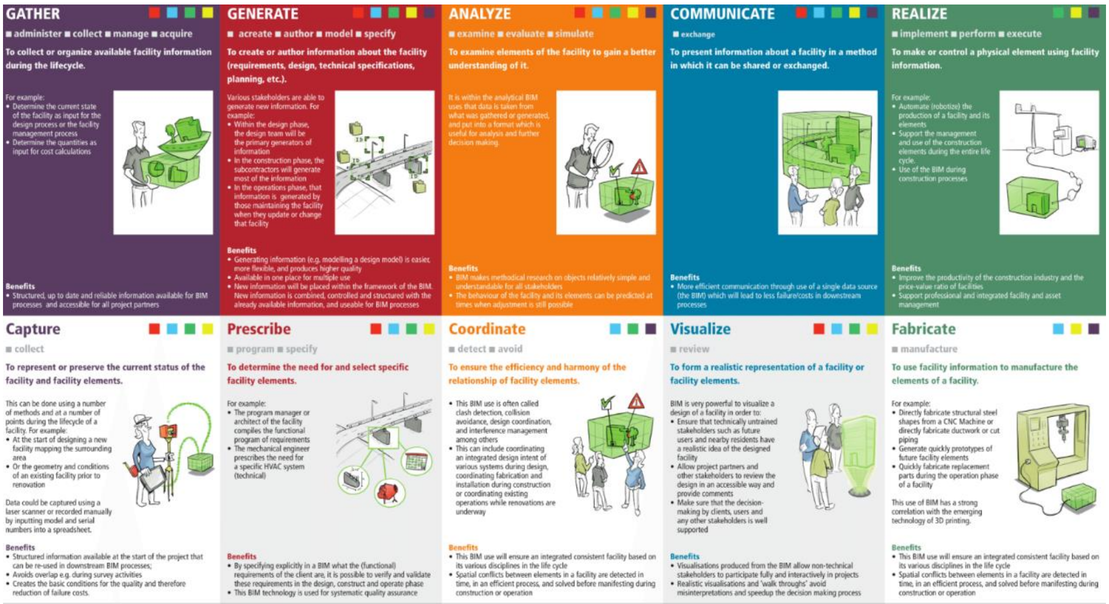

Figure 7: Extract from the ARCADIS BIM Menu. Complete graph in the Appendix. (ARCADIS,2015)

The main goals are break down into 18 sub-goals. Every sub-goal has a title and synonyms for it, an objective, a description, and specific benefits. Moreover, every sub-goal is linked to the stakeholder whom benefit from it. As an example sub-goals like “validate”, “draw” or “regulate” bring benefits to the whole range of stakeholders(client, designers, contractors, suppliers, asset managers). Conversely, the sub-goal of “control”(manipulate, operate) only bring direct benefits to the contractors.

Within he BIM Menu, the contractors are the most benefited parties as they are plenty benefited by the improvements in gather, generate, analyse and communicate the project-related information. They are also benefited in the realisation goal being the fabrication sub-goal the only without direct benefits. Following the contractors, the designers are also greatly benefited by achieving the goals of generating, analysing and communicating the information. They do not perceive benefits only in the monitoring, assembling and controlling. The third most benefited party results to be the suppliers whom are totally benefited in the goal of gather the information. They do only do not benefit from the coordination, transformation, assembling and controlling sub-goals. The Client is mostly benefited when using BIM helps the project organization to attain the goal of communication. Besides they will be also benefited if BIM supports to quantify, qualify, prescribe, arrange, validate the project-related information. Ultimately, if well implemented the asset managers can seize the benefits of better coordinate, validate, transform, draw, document and fabricate infrastructure elements in a consistent and integrated way.

4.1.4. Link Between BIM & Asset Management

Pocock(2014) states that by providing a structured framework for the creation, collation and exchange of information about assets, BIM supports effective asset management. However, to enable this, BIM must provide information that covers the whole life cycle of assets. The benefits from an integrated life cycle approach will include(Pocock 2014):

- Greater clarity on long-term in-service performance.
- Consequences of design decisions over lifecycle performance and cost.
- Reduced project start-up costs due to availability of better information early.

- Reduced construction and operational costs as a result of reduced construction defects.
- Better life cycle management resulting from more readily available consolidated design and construction information as a single source of data.
- Reduced management process costs arising from incomplete data.

However, steps need to be done before firms can be able to seize the BIM benefits as stated in a study of inefficiency in the activities of Dutch semi-public and public clients.

> **The current added value of BIM in the operations stage is marginal. The main reasons for this are a lack of alignment between the supply of and demand for information and the context-dependent role of information. (Bosch et. al.,2015)**

Nederveen et al.(2013) stress the importance of good information quality in infrastructure management. They state the following advantages of an ICT-based integration over the Life cycle and supply-chain for infrastructures: better information management, less failure costs, better handover to commercial parties for realisation and maintenance, improved asset management and more traffic management

In addition, maintenance and renewal at the right time are important responsibilities. Availability of the infrastructure network is a key parameter specially for roads, railways and telecom. Therefore, planning demands good knowledge of the network that includes: objects, characteristics, status, eventual problems. In practice, this knowledge is scattered and thereby the challenge is to retrieve all the information needed at the right place and time. Consequently, a first step is to make an inventory of information that will be commonly stored and managed in different Lifecycle phases (Nederveen et al.2013).

4.2.Data Exchange and Integration approaches

Data exchange is about the re-use of data and information with the purpose of cost savings and quality improvement(Du et al. 2012). Before any dataset can be re-used, it must be exchanged first. The exchange of data can be compared with the human communication process that always consists of three components, i.e. a sender, a receiver and a message (Schramm, 1971; Brodeur et al. 2005). It often happens in direct data exchange, that problems arise in the communication between two (intra-inter-organizational) systems. This kind of problems is often referred to as interoperability (Naudet et al. 2010). To understand the problems of interoperability it is important to know that a system is seen as one or more interacting elements (Naudet et al. 2010). Within a system, it is also important how subsystems are integrated. Vernadat (2010) dist(inguishes three levels for system integration, i.e. “loosely coupled”, “tightly coupled” and “fully integrated”.

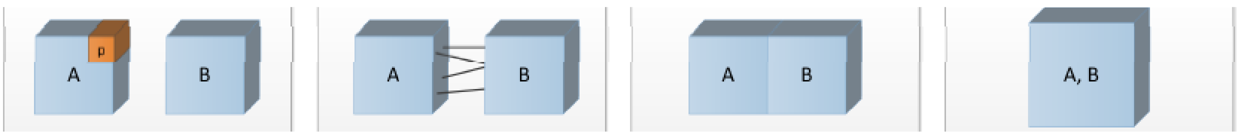

Figure 8: Overview of different integration levels (Succar, 2009)

Nederveen(2015) elaborated on three integration approaches based on case studies:

- the vendor suite approach(London Crossrail, UK).
- the open standards approach(EU V-Con project).
- the use of advanced information retrieval technologies(Volker experimental project).

The first-the vendor suite approach applied in the London Crossrail project is based on the British standard BS 1192 and implemented in cooperation with Bentley systems. Thus, is mainly based on the latter's offered software platforms. This single-vendor bypassed the standardization processes and therefore a high-level of Lifecycle integration was reached e.g. including configuration management of assets earlier defined in BIM. Although the stated advantages, this approach does not meet the 'open' principles and cannot be applied in open environments.

Contrastingly, the second project - the EU V-Con has been based on open standards. This has been reached based on new technologies and concepts such as the semantic web and distributing Modeling respectively. In this case, the project bet for a long term solution based on an ontology approach. Although it has promising results, its full potential will not be revealed until further work is done.

The last case -advanced information retrieval technologies- does not use predefined information structures. It uses however, advanced information retrieval technologies for data collection and developing of structures.

4.3.The Semantic Web, Ontologies, Concept library and limitations

4.3.1. The Semantic Web

Ahmed(2010) defined semantic web as: A mechanism of presenting information over the web in a format so that human being as well as machines can understand the semantic of context. Semantic web is a mesh of information which can be linked up in a way, so that it can easily be processed by machines and aim to produce technologies capable of reasoning on semi structured information. The predecessor of the Semantic Web is The World Wide Web (WWW). The WWW is a collection of interlinked documents, which might be written using the (X)HTML[1] format, accessible over a standardized protocol (e.g. HTTP), and each document is identified by a Uniform Resource Identifier (URI) (de Bruijn, et al., 2008). Although HTML has been the dominant format, recently more formats have become more used such as XML[2]. The latter allows to exchange structured data over the Web. In fact, it forms the basis for the formats typically used in the context of Web services as well as the Semantic Web (de Bruijn, et al., 2008).

Semantics is machine-usable content, and the Semantic Web as based on the World Wide Web includes such content (Fensel & Hench, 2008). The Semantic Web allows the representation and exchange of information in a meaningful way, facilitating automated processing of descriptions on the Web (de Bruijn, et al., 2008). The Semantic Web express links between information resources on the web and connect information recourses to formal terminologies. These connective structures are called ontologies (Fensel et. al. 2002).

An ontology is the backbone of the Semantic Web and can also be defined as a Semantic Model. They allow the machine understanding of information through the links between the terms in the ontologies (de Bruijn, et al., 2008). Doan(2012) et al. stressed the importance of develop automated techniques for ontology matching as crucial for the success of the Semantic Web. In his research he described an approach that applies machine learning techniques to propose semantic mappings. His approach is based on semantic similarity and multi-strategy learning for computing concept similarities.

1 HyperText Markup Language. A format for representing documents and their inter-linkage on the Web.
2 Extensible Markup Language is a language for the representation of (semi-)structured data.

4.3.2. Concept library as an ontology

Van Thiel(2014) states that Concept libraries like the CB-NL and OTL are modelled in a Semantic Web language, or ontology language. Concepts are the content of the library. Also known as classes, they are used in a broad sense. They can be abstract or concrete. They can be anything about which something is said, and, therefore, could also be the description of a task, function, action, strategy, reasoning process, etc.(Corcho & Gomez-Perez, 2000).
Concepts form the subject-matter of ontology (Smith, 2004). They can serve as a substrate for rich metadata descriptions, and thus can be viewed as 'ontology like' artefacts. This can be illustrated from an information perspective as in the Figure below.

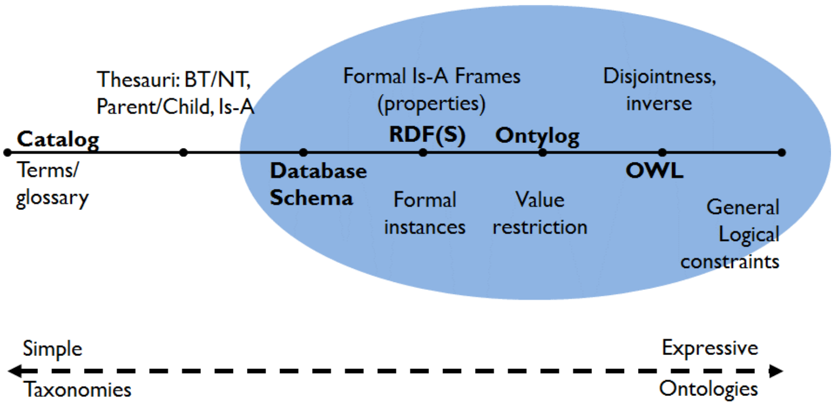

Figure 9: Ontology characterization (Kashyap, et al., 2008)

4.3.3. Limitations of ontologies

Limitations of OWL are (Meditskos et al. 2013 and van Thiel,2014):

- OWL provides no support for temporal reasoning[3].
- The schema-level axioms in OWL can model only domains where individuals are connected in a tree-like manner. In the activity interpretation domain, however, there is a need to model general relational structures among individuals, i.e. relations among individuals that are not connected.
- In most cases, the derivation of composite activities requires the assertion of new individuals. With OWL, such assertions are only feasible by external reasoning services
- It has no database backend and Multi-user support; and
- Some language features are missing.

[3] The ability to reason over the temporal extensions of activities is crucial for the successful identification of activity correlations(Meditskos et al. 2013).

4.4. Five Dimensions for IT innovation in organizations

Since the Dutch OTL is unique in its type[4] (Mommers,2015) there is not much specific literature to reference. However, previous research about new technological developments can provide useful insights(Baggen,2015). The latter is not only more abundant but also it helps to clarify what dimensions can be used for expected challenges when introducing a new technology. Complementary, a look into organisational science literature provides guidelines to better understand people's motivations and expectations towards new technologies.

The main dimension influencing challenges for the platform products is "origins of requirements related to characteristics of requirements engineering" (van de Weed et al.,2006).

Another determinant that influence challenges are the Architecture changes (Brinkkemper,2007). Moreover, challenges faced by the software platforms are influenced by three forces "Requirements engineering, architecture changes and operational & support process". (Bosch,2002 & 2007)

Additionally, Adriaanse (2007) proposes a theoretical model specific to the implementation of ICT in construction projects. It aims to find the key mechanisms that influence the way actors use inter-organizational ICT and solutions for the barriers of successful use of ICT in construction projects. The theoretical model set up by Adriaanse addresses technological, organizational and individual aspects that result in barriers or drivers to a successful use of ICT.

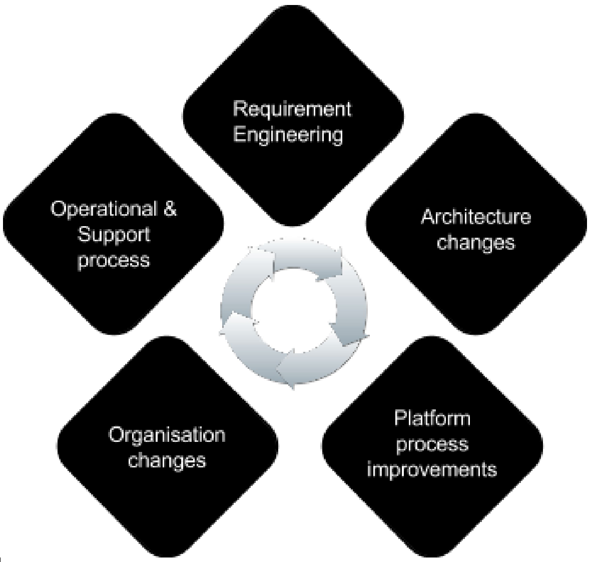

Figure 10: Five dimensions of IT platform development (own creation, 2015)

4.4.1. Requirements engineering

Khurum et. al. (2010) points to requirements engineering as an essential phase in the lifecycle of the platform development. Besides the conventional requirements a software platform has to deal with a continuous inflow of requirements from various parties. Moreover, it strives for balancing the new needs and features with the previous legacy systems. Additionally, Implementing a standard mechanism of communication between the applications that use the platform and the platform team reduces requirements ambiguity.

4.4.2. Architecture changes

Three main aspects related to architectural problems at early development stages are (Bosch, 2002 & 2007 and Meyer et. al. ,1998):

[4] According to Bram Mommers the closet is the UK asset dictionary which has a Taxonomical level.

A. **Implicit dependencies.** In early approach, to increase the short term developer productivity, a high degree of connectivity between components in platform is accepted, as there are few disadvantages at this stage. However, later when the increase of the scope, implicit dependencies between components becomes a significant problem.
B. **Incorporation of immature functionality.** In the initial scope there is a tendency to incorporate a product specific functionality useful for one product and likely to become relevant for other products over time. Sometimes this further extends to early incorporation of product specific functionality before it is used in the first products. Disadvantages become apparent as the scope of the product family increases.
C. **Dependencies on external software.** Software platform does not have control over the release cycles, development process and roadmap if it is integrating external software. This leads to number of difficulties and makes it more challenging to develop an architecture which suits all the application products and external software.

4.4.3. Platform process improvements

The need of a well-coordinated and executed process lies on developing a reliable, high quality, in-budget and on-time platform. Therefore investing in process can improve the future-proof trait of a platform. Nevertheless, external market and business demands create disturbances in the software process. This may disturb the process resulting in time and costs overruns. (Jiang et. al. 2000). Relevant disturbances found in the literature are:

A. Uncertain customer requirements. It depicts to the problem to formulate the requirements (even if they are known) leading to uncertainty. Efforts cannot bring value if requirements are not rightly prioritized. Formal requirements specifications are important for these cases (Chandrashekar et al., 2006 and Regnell et al.,2005).
B. Non – official releases. The quality of the product can be comprised more than once to meet the release date. Before the official date unofficial releases are generated. Thus, soon after the release date, a service pack with patches is released. (Jiang et al. ,2000)
C. Tao Management. Testing takes place usually at the end of the platform development. Reducing the testing time due to development delays and reverse engineering[5] are likely to cause problems. (Chandrashekar et al.,2006 and Jiang et al., 2000)

4.4.4. Organization changes

Adriaanse' "actor's use of inter-organizational ICT in construction projects" describes four main mechanisms that determine the way actors use ICT in construction projects. They are (Adriaanse,2007):

A. **Personal motivation.** The extent to which actors are willing to use inter-organizational ICT themselves. It influences both the willingness of the actors to use ICT and their willingness to invest resources to overcome barriers to the intended use of ICT.
B. **External motivation.** The degree to which actors are forced by other actors to use ICT. External motivation influences both the use of ICT and the efforts made to invest resources to overcome the barriers to the intended use of ICT.
C. **Knowledge and skills.** The degree to which actors know how to use ICT. When knowledge and skills are limited, actors themselves can be restricting the use of ICT.

[5] First setting the release date and then defining how to make it.

D. **Acting opportunities.** The extent to which actors are able to use ICT in the intended way. When the acting opportunities are limited, ICT is not able to support actor's actions.

The four mechanisms are broken up into subcategories as illustrated in the Appendix. Additionally, London's "from impediments to drivers in e-adoption" was developed after analysing e-adoption in the Australian AEC Industry. It proposes patterns grouped in three inter-related pathways (London et al.,2006): Perceptions, Compatibility and Communication.

A. **Perceptions Pathway.** It starts with high levels of inconsistent adoption patterns internally & across supply chains and firm highly reactive to market economics**.** The primary impediment is the underlying negative attitudes towards e-adoption by management and staff and minimal or no apparent perceptions of economic advantage of e-adoption by management. There are high levels of hemophilic communication and attitude of resistance to e-adoption, low levels of diffusion of e-adoption. High resistance to heterophilic communication[6].
B. **Compatibility Pathway.** It starts with inconsistent adoption patterns internally and across supply chains and firms reactive to market economics. The primary impediment is the perception of e-adoption as complex and difficult. There is incompatibility of e-adoption across organizations and lack of accurate information transfer and frustration and negative attitudes. Besides, there are low levels of perceptions of economic advantage and market economic impediments linked to incompatibility.
C. **Communication Pathway.** Although it starts with inconsistent adoption patterns internally and in supply chains, the compatibility issues are solvable. Firms are responsive to market economics but can see competitive advantages to e-adoption or may have experienced competitive advantages. Attitudes and perceptions towards e-adoption are positive. The primary impediment is related to communication in 'hard' and 'soft' forms. There is a general resistance to heterophilic communication and a generational problem. Additionally, there is a duplication of various systems e.g. paper based and electronic; and a general level of underutilization of a communication network between organizations.

4.4.5. Operational and support process: The Need of a Roadmap

The release of new functionalities and upgrades with the right amount of features and quality within an open market window determines the success of the software platforms. Therefore, a systematic approach is needed for managing the content, roles of platform architecture and future product releases and timing as described below(Meyer et al.,1998).

A. **Content** is about what and when to release features. It links product features to business requirements and technology availability.
B. **Timing** refers to making trade-offs between quality, functionality and time, identifying and exploiting a window of opportunity. The product must be assessed based on business needs.
C. **Roles** is about intended business implications for the company, planned audience for the releases.

[6] Hemophilic communication: between individuals in groups with common beliefs
Heterophilic communication: between individuals with different beliefs and education.

A Roadmap balances and calibrate the process towards an infinite “wish list”(Jandourek,1996). Besides, it enhances a faster delivery while providing a streamline. Moreover, the Roadmap will align and help to keep track of the process activities throughout the Lifecycle. It also shows the interaction of the activities with all the interested stakeholders. Additionally, both external reference and internal development can be reached with technology Roadmaps. (Jiang et. al. 2000). Complexity can be reduced by showing the different types of features at an early stage. (Elbert 2005). Last but not least , in a Roadmap customer expectations are set and the requirements specifications are formalized, thus it lowers later external pressure from business demand(Chandrashekar 2006).

4.5.Literature review on technological road mapping

Even though, technology roadmap is a useful and flexible approach, an important starting point is that there is no commonly agreed technology road map and process(Lee & Park, 2005). Technology road mapping (TRM) can defined formally as a flexible technique that is used within the industry to support strategic and long range planning(Phaal et al.,2001). Motorola, developed technology roadmap more than 2 decades ago, from where it has been spread to other firms widely. In 1998, its CEO Bob Galvin stated(Beeton et al. 2008):

> **“A ‘roadmap’ is an extended look at the future of a chosen field of inquiry composed from the collective knowledge and imagination of the brightest drivers of change in that field”.**

Technology roadmaps will seek to answer three simple questions even though they can take various forms(Phaal et al. 2001): Where are we going?; Where are we now?; How can we get there?.

A multi-layered roadmap can be constructed from a market pull and technology push perspective. The roadmap defines the most important requirements needed by customers from market pull perspective and from technology push perspective; it defines the key new innovations and technologies (Phaal et al.2006 & Groenveld,2007).
The road-mapping activity can be both goal oriented – by defining strategies to realize clearly defined targets and exploratory – surveying future possibilities(Kappel,2001 & Phaal et al.,2004). Phaal states that roadmap structure needs to be considered in parallel with the technology road mapping process(Rinne,2004). That is why it is essential to make the conscious decision to focus on a certain type of roadmap fulfilling a certain purpose.

The general and most common road-mapping format derived from its technical origins in firms such as Motorola and Philips comprises a time-based multilayer dynamic systems framework. However, this format is not necessarily suitable for communicating strategy to other Stakeholders. Other less complicated formats are appropriate for this purpose, to highlight key strategic objectives. (Phaal&Yoshida,2014)

As illustrated below, the design-driven approach consists of four process steps(Phaal,2015): defining the frame, establishing the structure, depicting the relationships and articulating a narrative' direction.

Step	Tasks	Key Questions
Frame	• Agree on the unit of analysis • Identify the target audience • Determine the audience's information requirements	• What is the unit of analysis? • Who needs to see the roadmap? • Who are the key stakeholders? • What are their lenses of interpretation? • What perspectives/dimensions are to be included? • What is the most important information?
Structure	• Develop an appropriate layout for each key audience	• What form should the representation take? • How much physical real estate is available? • How much of the page should be dedicated to outlining a sense of context/vision/action? • What are the key axes? • What is the appropriate information hierarchy? • What is the logic driving the layout?
Relationship	• Elicit a dynamic systems model • Distinguish the important pathways	• How can the dynamics of the situation be depicted? • What is the best way to articulate linkages? • How should relationships be shown? • How can cause–effect pathways be made visible? • What are the pertinent connections?
Direction	• Establish the narrative sequence • Emphasize the narrative	• How can the overall direction be best depicted? • What are the main narrative threads? • What is an appropriate narrative sequence to reflect the strategic dialogue? • How can the narrative be emphasized?

Figure 11: Design-driven methodology for developing Roadmaps visualizations (Kerr&Phaal,2015)

A simplification process based on the general multilayer systematic roadmap structure is presented in the Appendix. Among this formats, a simplified communication roadmap (left Figure below) is closely related in structure to the multilayer systematic format. This is illustrated with the example of the camera' technology development(right Figure below).

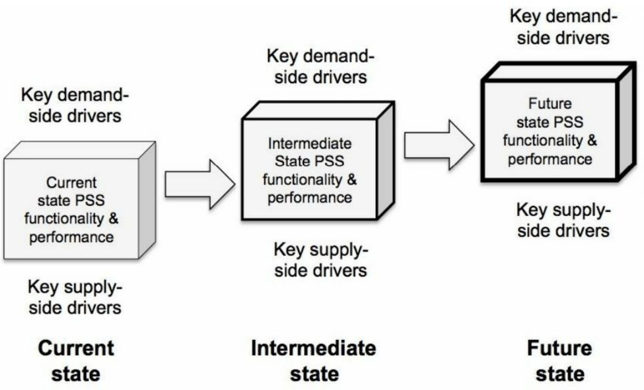

Figure 12: Geometric simplified communication roadmap framework(Phaal& Yoshida,2014)

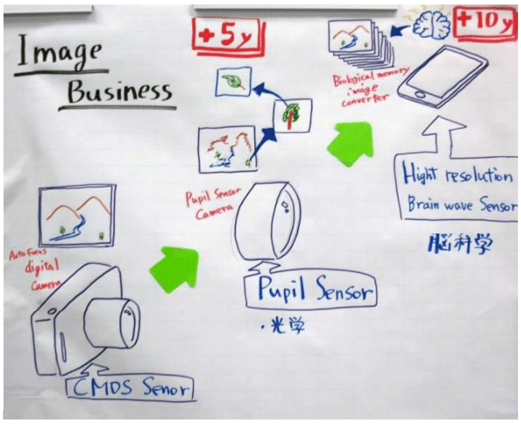

Figure 13:Communication roadmap design sketch (Yoshimoto,2013)

5. Industry Context

5.1. The Dutch Railways and stakeholders

The Netherlands has a tradition of innovating in public transport. Some directional innovations on public transport include: the national, fixed and symmetrical rail transport timetable (1970); the national ticket and fare system for local and regional public transport (1980); the broad application of traffic signal pre-emption in favour of public transport; the national public transport season ticket for all students aged 18 and over (1991); one national telephone number for all public transport travel information (1992). (Rijksoverheid,2010)

Responsibilities are decentralized in regional authorities as they have better understanding of regional needs. Central government sets the framework and provides a budget to the regional public transport authorities. The regional authorities have great freedom of how to spend the budget. Decentralization does not have functional benefits but it strengthen ties between the populations and local public transport. (Rijksoverheid,2010).

5.1.1. The Dutch Railway System

The Netherlands has one of the most densely spread railway networks in Europe and a strong railway culture (Rijksoverheid,2010). The Dutch railway system is very complex due to its heavy utilization and network design, organizational and institutional arrangements, and number of stakeholders (Mannaerts, 2013).

Statistics		System length		Track gauge	
Ridership	438 million/year	Total	2886 km	Main	1435 mm
Passenger km	15.5 billion/year	Double track	1982 km	High-speed	1435 mm
Freight	36.5 million ton/year	Electrified	2159 km		
		Freight only	158.5km		
		High-speed	125km		
Features				Electrification	
No. tunnels	13			1.5 kV DV	Main network
Longest	Groeneharttunnel, 1760 m			25 Kv AC	HSL Zuid, Betuweroute
No. bridges	4500 (76 movable)				
No. stations	408				

Table 1: Some figures about the Dutch Railway sector. (own creation based on wikpedia.com, 2015)

A lot of train movements take place on a relatively small network within the Dutch railway system. On top of that, the rail network also has a high ratio of track length to line length (ECMT, 2005). On average a line contains 2.3 tracks. Multiple tracks per line increases the complexity of the network because of the need for switches, signalling, safety systems and a more complex schedule with trains overtaking each other.
Moreover, Mannaerts(2013) states that because of the separation of operations, management and oversight in the Dutch railway system, decision making requires a high level of collaboration by all parties.

5.1.2. Stakeholders

The Railway environment has many stakeholders being the most relevant: the government authorities, operators, contractors, travellers and neighbours of rail infrastructure (Mannaerts, 2013). Information about operators, passengers, neighbours and government regulators can be found in the Appendix.
ProRail is responsible for the capacity, reliability and safety on Dutch railways, focusing on: capacity management, supply of safe tracks, maintenance and control, construction, travel information. In addition, ProRail oversees four types of activities (Doorhof, 2009):
(1) Maintenance; (2) Modifications; (3) Third parties/work environment; and (4) MIRT (Multi-annual program of spatial infrastructure and transport). The figure below shows the stakeholders interfacing with ProRail.

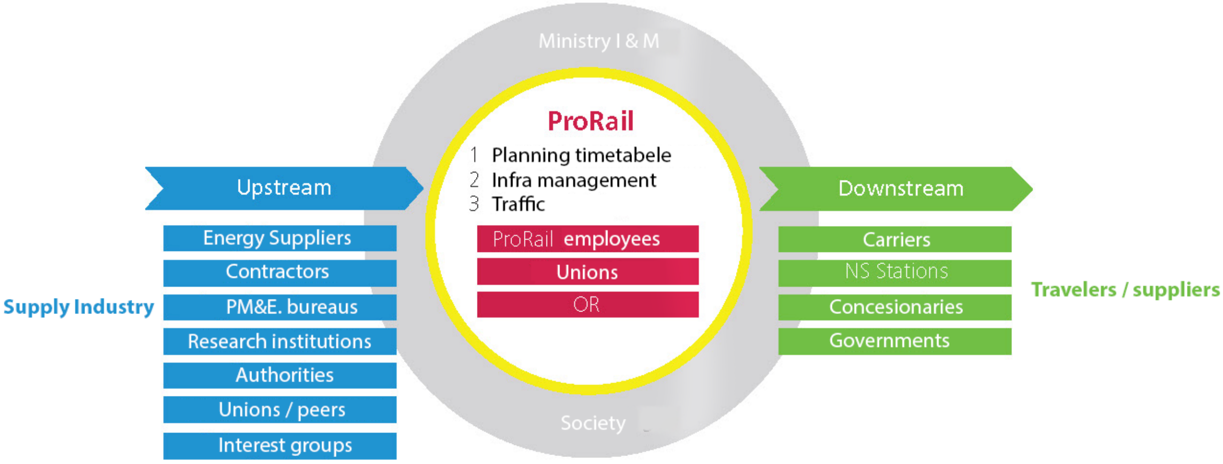

Figure 14: ProRail value-chain and stakeholders (ProRail, 2014)

In the case of maintenance or modification works ProRail's function enforcement is made assuring the lifetime of objects, inspecting contractor's reports and consultation between inspectors. The most common contract types used by ProRail can be classified in two main categories: output-based and performance-based contracts (Doorhof, 2009).
In an Output Based Contract (OPC) ProRail steers the output of potential contracts. Thus, there is a transfer of inputs including: units, work package or turn and a maximum fee per year is pre-set. However, this modality does not offer incentives for efficiency and hinders innovation (Doorhof, 2009). On the other hand, Performance-based Contracts(PBC) entail specifying service performance and linking that to payment, effectively transferring risk to the provider (Kim et al., 2007; Doerr et al., 2005). PBC emphasizes the specification of performance or results for the customer rather than inputs and processes of the required service (Martin, 2007). Its implementation in the Netherlands started the year 2008 and since then, ProRail has tendered several contractors under this modality.

5.2. Collaboration Framework: SE, KP, PRC-00055 and BID

5.2.1. Systems Engineering (SE)

According to INCOSE[7] (consistent to ISO 15288:2002[8]), SE is an interdisciplinary approach and aims to enable the realisation of successful systems. SE considers both the business and the technical needs of all customers with the goal of providing a quality product that meets the user needs (Haskins, 2006). A system is an integrated composition of persons, products and processes which achieve a specific goal by features need (Department of Defence, 2001). A system-of-interest is a part of the scope of a bigger total system. It is dependent of the project level. A life cycle model for a system of interest defines six main stages (ISO 15288). They are: Concept, Development, Production, Utilization, Support, Retirement. The purpose in defining the system life cycle is to establish a framework for meeting the stakeholders' needs in an orderly and efficient manner. This is usually done by defining life cycle stages, and using decision gates to determine readiness to move from one stage to the next (Haskins, 2006). The Vee model is used to visualize the system engineering focus. The "V" stresses the need to define verification plans during requirements development, the need for continuous validation with the stakeholders, and continuous risk and opportunity assessment (Haskins, 2006).

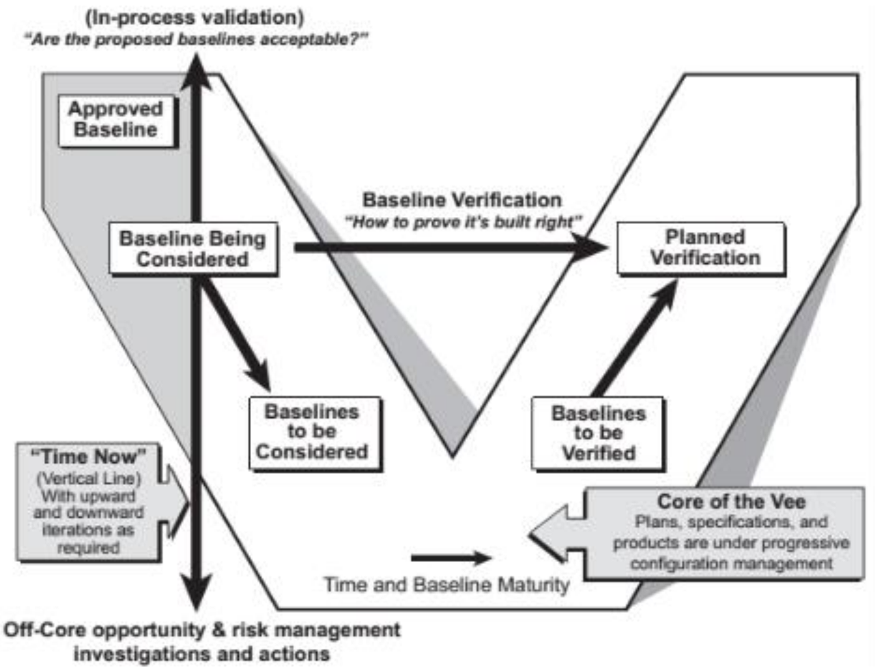

Figure 15: Vee model(Haskins, 2006)

In the Netherlands several parties collaborated in making the "Guidelines for Systems Engineering within the civil engineering sector" (ProRail, RWS et. al., 2013). Based on them, Pro Rail links the activities to the Lifecycle phases using Systems Engineering(SE). The customer need can be understood as the set of needs and preconditions of these customers with regard to the system. It starts with the system specifications. Customer needs are specified as

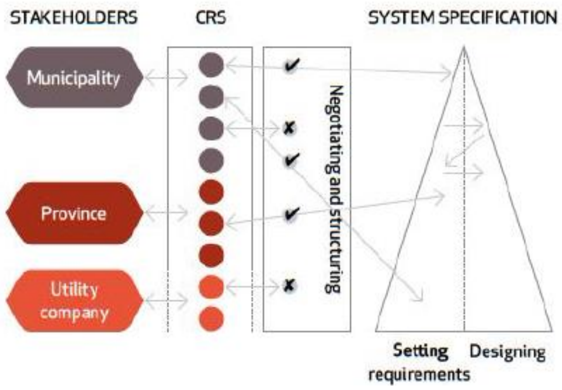

Figure 16: Traceability input from stakeholders to system specifications (ProRail et al. 2013)

7 International Council on Systems Engineering. INCOSE is a not-for-profit membership organization founded in 1990. Their mission is to promote systems engineering across the globe.

8 ISO 15288:2002(E) – Systems Engineering – system life cycle processes. An international standard that is a generic process description.

requirements. The same happens with preconditions e.g. time and money. All these are laid on the Customer requirement specifications(CRS).

It is important to keep the traceability of customer needs into system requirements. The system specification can be subdivided in for example system requirements specification and system design specification (ProRail et al. 2013).

5.2.2. Core Process (KP)

ProRail's core activity is about the realisation of investment projects for which a joint effort and collaboration with partners is necessary. This goal is supported by a Core Process("Kernprocess") which has two main objectives: to provide understanding of ProRail towards stakeholders and to make clear agreements for every step within the life cycle of a project (ProRail 2013). Below, each of the seven stages of development is briefly described(ProRail, 2015):

- Pre-phase: It defines the concept of the project required by a client.
- Concept Exploration: Its focus is on collecting all stakeholder needs and objectives.
- Concept definition: Where the balancing concepts is made.
- Elaboration of Adopted Concept: Is made by identifying and reducing risks.
- Detail Development: It is directed to the full development of the design.
- Realisation: It involves the merging of components into a working whole.
- Operations & Maintenance: The system is then put into use. The knowledge should be shared from the development process.

The Appendix elaborates on each phase. The figure below illustrates the seven phases.

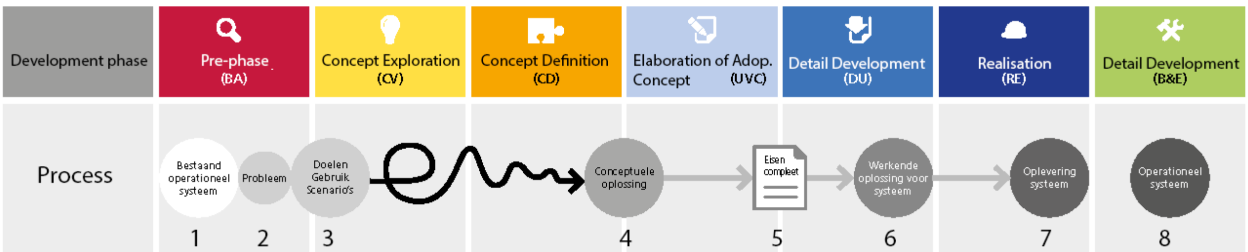

Figure 17: Development phases of a System (Translated from ProRail,2015)

Process legend: 1)Existing operational system; 2)Problem; 3)Use scenarios; 4)Conceptual solutions; 5)Complete requirements; 6) System' working solutions; 7)Delivery system; 8) Operational system.

Whilst the seven SE-development stages structure the development, decision-making and decision points within ProRail; the Core process has four major decision-making stages coupling the SE-development process and the Kern process steps.

- Preliminary phase : identify customer demand and capture.
- Alternative study phase : selecting the optimal solutions for transport demand.
- Plan development phase: set a clear scope of the project and other partial solutions.
- Implementation phase : preparing and executing construction.

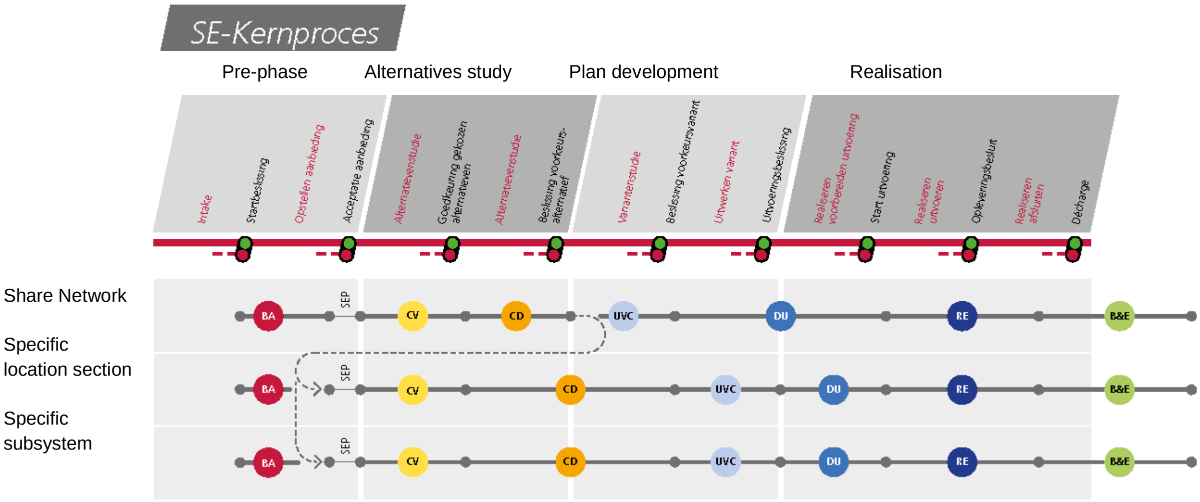

Figure 18: Development phases in the Core process. (Translated from ProRail,2015)

Finally, when choosing a preferred system the process starts at a high level of abstraction e.g. fly-over vs. drive-under railway. This phase comprehend the following steps (ProRail 2013): (1) Structuring the project organization; (2) In-depth study questions (CRS update); (3) Partial exploration of solutions; (4) Underpinning selection and description of alternatives; (5) Approval of chosen alternatives ; (6) Study of the preferred alternative; (7) Plant development; (8) Realisation phase; (9) Procedure 00055.

5.2.3. The Procedure 55 (PRC-00055)

A great challenge for the asset manager of the railways infrastructure lies on the fact that projects are done while operations. There is a constant tension between the project and the train runs. Disturbances might affect a new railway project to be available on time for the many users awaiting for it. Accordingly, the PRC-00055 aims to appoint all interactions involving collaboration in order to allocate responsibilities, ensure availability and avoid delays. (Infrasite 2015a)

There are two group of activities performed in a railway project: Operations and Infrastructure Project. Thereby, two sets of stakeholders can be associated to each group:

- Operation: Operator and Asset Manager
- Infra. Project: Rail Systems Engineer (RSE), Engineering firms and Contractors

The PRC-00055 aims to assure the maintenance interests in infrastructure projects through the collaboration of the Manager and the Project Organization (Infrasite 2015a).
It consists of ten phase rings or protocols labelled from A to J. Agreements are formalized by signing this protocols after each phase. Ultimately, is the project manager who is handed out the last protocol for implementation. The PRC-00055 applies if the management department of ProRail is the future manager and ensures that the project results are acceptable for ProRail. PRC-00055 is relatively flexible as not all the Phase Rings are mandatory for the committed parties. Though, ProRail has the last word (Bekendam, 2015). The Table below shows an overview of the ten phase rings.

Phase Ring	Signed between	Mandatory
A. Cooperation	Plan Coordinator Project Manager	Yes
B. Determination of Requirements		Yes
C. Determining preliminary draft protocol (SRS or VO)		No
D. Determining final design		No
E. Preparing transmission infrastructure project		Yes
F. Establish protocol cutlery		No
G. Providing construction site on infra projects	Route Manager Construction	Yes
H. Register Performance		Yes
I. Provisional transfer protocol		Yes
J. End transfer	Plan Coordinator Project Manager	Yes

Table 3: Table of phase rings in the PRC00055. (Own creation based on the PRC00055)

5.2.4. Business Information Document (BID)

Elaborated by ProRail, the BID00001 (Business Information Document) describes the planning model of infrastructural objects. It constitutes the basis for the exchange of object data and documentation. The model clarifies the way the objects within the rail infrastructure are stored and their interdependencies.

> **'An infra-object is a physical element or assembly that is determinative for the design of the rail infrastructure or the operation thereof'. (BID, 2013)**

The object structure is therefore an important part of the data architecture for the parties involved in the experts responsible for the data and the process contractors. The object structure is applied to all the clusters of rail infrastructure: support system support system, conduction system, power supply system, train security system, transfer, train control system, communication system and intersection. The BID00001 includes a summary of the important main objects of the object's structure (basic objects list). A basic object is the highest level of physical object, so it is an object with characteristics. These objects are exchanged inside ProRail and between ProRail and the contractors.
An object can be a separately in physical structure or a consistent part of it. In the object structure a bolt is an object as well as the power supply system. (BID, 2013)
In addition, based on their function, objects can be classified in the following way(ProRail 2015): wear(1), cut(2), guide(3), feed(4), manage(5), protect(6), transfer(7), and communicate(8). This is illustrated in the figure below:

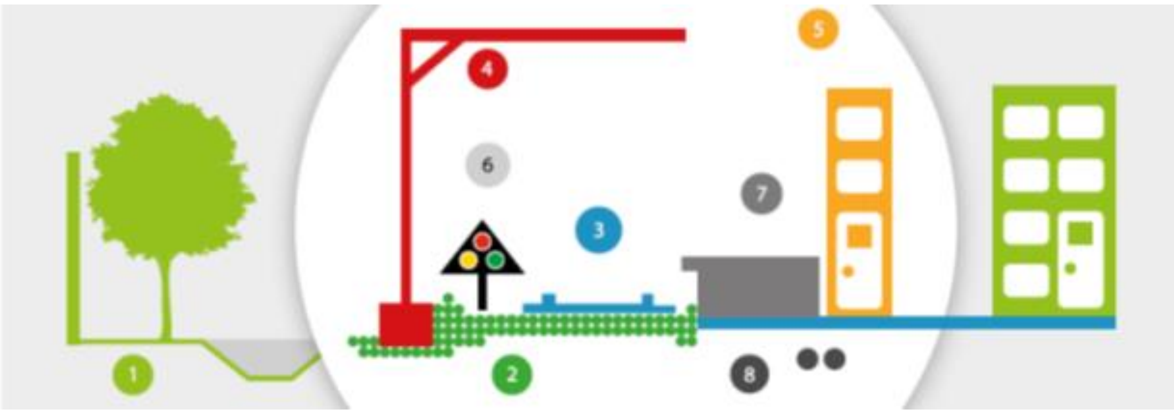

Figure 19: Oversight of the function-carriers from the Rail system. (ProRail 2015)

6. ProRail' current asset management systems and the information problem

In the Dutch railway sector there are many of ICT applications in use. Only within ProRail's Infrastructure Management department there are over one hundred applications (Infrasite 2015b). ProRail's ICT systems are divided in the following business units: Traffic, Capacity Management, Infrastructure Management and Rail Development. The following is an overview of the main ICT systems used by ProRail that are directly related to available and reliable infrastructure and the supply of train paths (Infrasite 2015b):
ProRail's ICT systems can be classified in(Infrasite 2015b): process-supporting systems (per discipline); generic systems that support more disciplines, such as SAP (db), BBK (dataset, small-scale topographic layout of the track); specific aspects collection systems (meet train).; general unlocking mechanisms.
The last group, the Unlocking Mechanisms are key retrieval mechanisms (Infrasite 2015b):

- **Apropos.** ProRail internal variant of www.prorail.nl.
- **The Office**: first contact for external parties: www.prorail.nl/prorail/loket
- **Rail infra Catalogue:** web application for formal definitions, allowable methods & systems.
- **ArtiWin:** for searching and ordering Technical Documentation data. These are all kinds of technical, geographic and schematic drawings of the Dutch rail infrastructure, and is divided into several so-called collections, covering several disciplines.
- **GeoWeb**: like the Base Management Card, KS drawings, and other geographic drawings.
- **GLOBE:** VPT data management (VPT = Transport By train, including: OBE drawings)
- **Infra Atlas:** information of railways infrastructure functions. External users can export and use input for various other applications, such as Donna, Traffic and train travelers.
- **GOBI portal:** Intranet platform for all data access based on geographic, object-oriented information. Unlock nationwide especially rail infrastructure and geocodes.
- **SAP:** The most of the database objects of ProRail / IM.
- **Sharepoint:** Internal application to multiple users on a single project.
- **EDMS:** Electronic Document Management System.

The mentioned mechanisms are often visible after authorized. EDMS is only accessible to Prorail's employees. The rest are sorted from general (left) to specific (right). That is also the correct sequence when looking to an unlocking mechanism which is needed

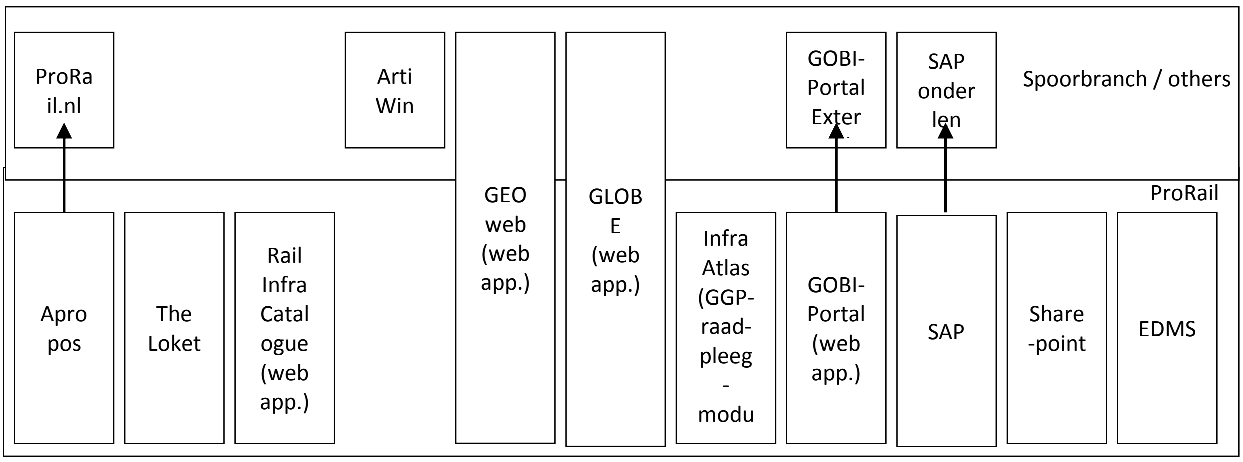

Figure 20: Unlocking Mechanisms (Adapted from Infrasite 2015b)

6.1. The current problem with Asset's Information

Railways Information is classified into two main categories: configuration data and steering data (Schouten J.& Soeters R. ,2014). The first refers to the object data and includes: location data, functional data and physical data (*Where is it?; What does it do?*; *What is it?*) The steering data includes: maintenance data; condition data; and performance data *(What are the planned and realized maintenance*?; *What is the condition?; What is the performance?)*

The main issue behind the current Model is that the different datasets are stored in separate databases which use a different formats (R.Soeters, 2015). There is lack of interoperability and exchange between them. Therefore, information from current databases is insufficient to meet the needs of the value chain and thus it leads to considerable error costs and risks in the business. Some examples are(Schouten J.& Soeters R. ,2014):

- the function Plans have no "functional photo" of the development of the infrastructure for years n + 2 and further
- the Builders offers mediocre quality of data about the location of the underground infrastructure, leading to costs for cleaning up, ducts damages etc…
- maintenance contractors have an insufficient reliable picture of objects in their area , the condition of these objects and of the performed maintenance on these items.

The mismatches between the main datasets and their consequences can be illustrated as in the Figure below.

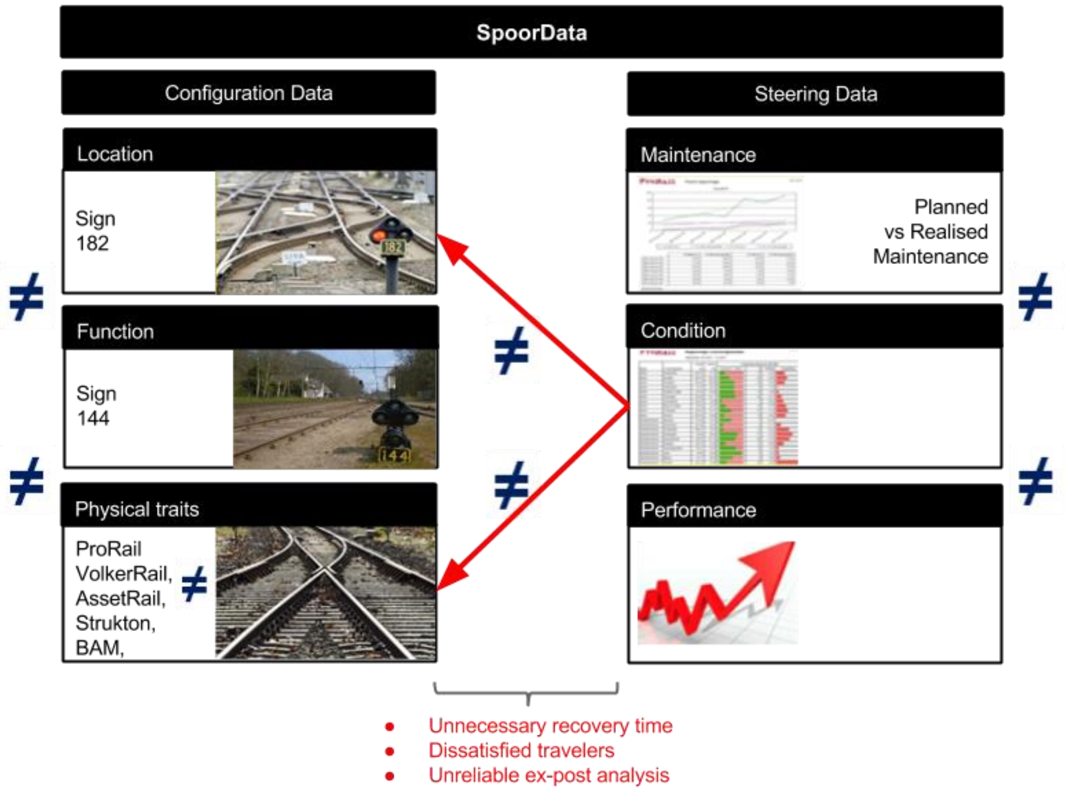

Figure 21: Scheme of the Current Data Management problem. (Translated and adapted from Spoordata, 2014)

7. Recent IT Initiatives: Semmtech, Dataroom, Spoordata, OTL Spoor

There are different asset-related systems used by parties operating in various life cycle phases. Next, a brief description is made for the most relevant systems currently used. For more details refer to the Appendix.

7.1.5 Semmtech(SEm)

ARCADIS main Systems Engineering goals are: to carry out projects under contract, within budget and time. Semmtech supplies software focused on semantics. Inside ARCADIS' System's Engineering "SEm"[9] is used to improve processes related to ARCADIS' main SE goals. SEm brings together customer requirements specifications (C.R.S), design trade-offs and well balanced choices. Besides, it sets the client's requirements and specifications on the design and implement them in a structured way de most appropriate solution. Moreover, it deals with fragmented information in large projects organising and capturing consistent, unambiguous and coherent data. Thereby, it lays the foundation for a substantial reduction of errors and improved communication in the handover between lifecycle phases and an overall asset management. (ARCADIS,2010)

SEm has a potential for improving C.R.S.' verification & validation and keep track if they are used in the right way. Therefore, it improves the S.E. capabilities of linking risks and information to the System's requirements specifications(S.R.S). (Stuiver,2015).

SEm aims to provide added value in three ways(ARCADIS,2010):

- working with an intelligent model that includes lifecycle data accessible any time;
- providing a basis for project's information management making choices explicit, unambiguous and documented in one traceable place;
- allowing information exchange and quick requirements updates based on an open-standards model; and
- matching information between the project team' process and the client.

7.2. Dataroom

It is a model-based management system that enables multiple users to work in a common model to retrieve information. Its main goal is to be a focal point of digestion wherein the user-specific project data can be introduced or retrieved. Moreover it considers the possibility of different project team members using the same data simultaneously(BIM Newsbrief, 2015). In the 2014 the application of BIM was included in the Meteren Boxtel project and the engineering organisation found an interesting opportunity to test the Dataroom. The common system enhanced the cooperation between experts, archaeologists, ecologists, landscape and designers. Besides, access was also enabled for advisors working in different locations. (BIM Newsbrief, 2015)

[9] As engineers in ARCADIS use to refer to the Semmtech's Systems Engineering platform.

ProRail's RIGID-LOXIA[10] is the first and base source of information of the Dataroom. Moreover, the Dataroom brings the advantage that all project team members can properly search, collect and share data. (BIM Newsbrief, 2015).

7.3. SpoorData.nl

The SpoorData program is a dedicated website for the parties to easily track, share and update data. For attaining this goal, data must be unambiguously defined and accessed by any interested stakeholder without any time or location constraints no matter when and where. Communication throughout the phases of a life cycle and therefore prevent clashes. (ProRail 2013).

This program pursues four main goals (Schouten & Soeters,2014): one truth(equal data inside and outside ProRail); easy access; supply chain integration; external requirements from ProRail transmitted in adequate way. Complementary, the goals above will be reflected in terms of expected results from a clear information architecture to be able to measure the reduction of error costs and durable rail network. (Schouten & Soeters ,2014)

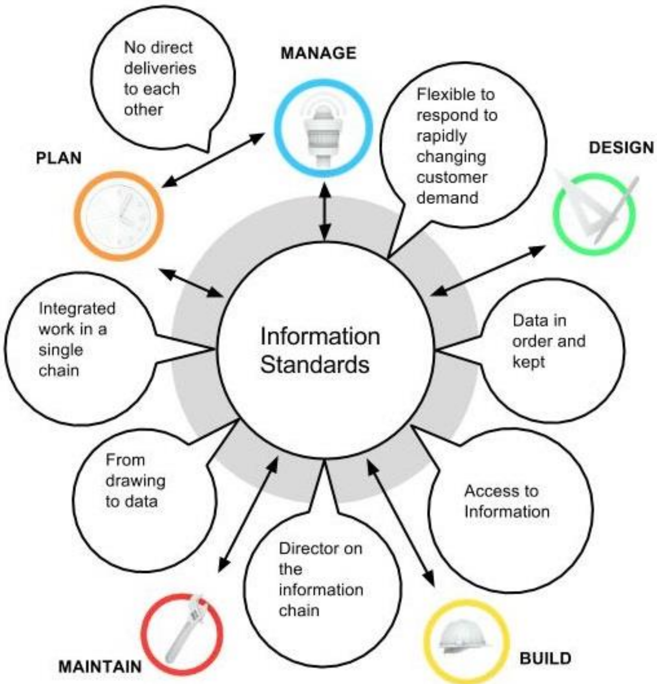

Figure 22: The concept of collaboration of SpoorData.nl. (Translated and adapted from Schouten & Soeters,2014)

Additionally, the program is based on five cornerstones(Schouten & Soeters,2014):

- Standardization of information: This pillar is the foundation of the four others.
- Organized data: It demands process integration in order to keep the data structured.
- BIM Rail branch: Common building information model can be shared with all parties.
- Requirements from external parties: (European Union and the Netherlands)
- Accessibility to information: everyone access to "plug-and-play" infra data 24/7.

The five cornerstones are related to ProRail' information projects in a table in the Appendix..

Complementarily, ProRail believes the Spoordata will bring the following expected benefits per business activity(Schouten J.& Soeters R. ,2014):

In the planning phase, the logistics planning process takes place earlier with reliable ' to build ' configuration data. Nowadays, in the first phases ProRail works with technical documents instead of real to build data. The process of creating data from technical documents is time consuming limiting the amount of projects to deliver (Soeters,2015).

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10 Alliance between ProRail and LOXIA for managing railway's projects information.

When designing, a designer is able to reuse his earlier work. Bad data is the result of the own work, being an incentive to restore faulty data. Moreover, transfer of data instead of drawings takes less time. The building contractor will be limited to supplement the previously captured physical data with some technical specifications. When building, there is one "playing field level" for all suppliers lowering the offer risk of over costs. During operations, timeliness 'to build' results in a higher quality plan timetable. The quality of the decisions of an operator is increased, because his instruments are synchronized "Outside=Inside". Finally, while maintaining, the manager and maintainer can be significantly earlier with reliable 'to build' configuration data. A summary of the expected benefits is shown in the table below.

	Lean	In control	More for less		Safety
			Cost	Quality	
Plan	information to build 5 years for IDS	Simulate possible	less peaks in planning	Europe reliable standard usage values	better predictability
Design	concurrent design	collaborate in digital space project	reduce budget risk and failure costs	good design at once	information is the same outside
Build	shorter construction phase	direct use in design	reduce failure costs and extra-work	optimal project portfolio	less changes of plan
Manage (Maintain)	lower function recovery time, less disruption	Information is extracted earlier	reduce budget risk and failure costs	reliable assets register	work in the track is safer
Operate	information infrastructure available earlier	timely information on train systems	reduce adjustments costs	5% less adjustments	better risk management

Table 4: Expected earnings with SpoorData.nl. (Translated and adapted from Schouten & Soeters,2014)

Adapted Organization within ProRail, 2015-2016

As stated in the Spoordata Executive program, integration of the different datasets will demand organizational adjustments within ProRail. Therefore it will be necessary to merge the many existing divisions into less and more efficient departments. The Location and Function divisions will be likely to be the first to merge. Additionally, all the different data standards currently existing between ProRail and the Management Contractors will be merged into one single standard managed by the Physical Data Department. Ultimately, the 3 different datasets within Steering Data (Maintenance, Condition, Performance) will be merged into 1-single Department in charge of the Steering Data production. (Schouten & Soeters,2014). This integration is illustrated in the Appendix.

Hierarchical standards

The Spoordata can be set under a hierarchy framework linked to the National and International levels of standards. Within the level of the Spoordata the Object Type Library(OTL) poses a solution for linking four main components: the requirements, the break down structure(PBS), the function tree and taxonomy. (Nagtegaal, 2014)

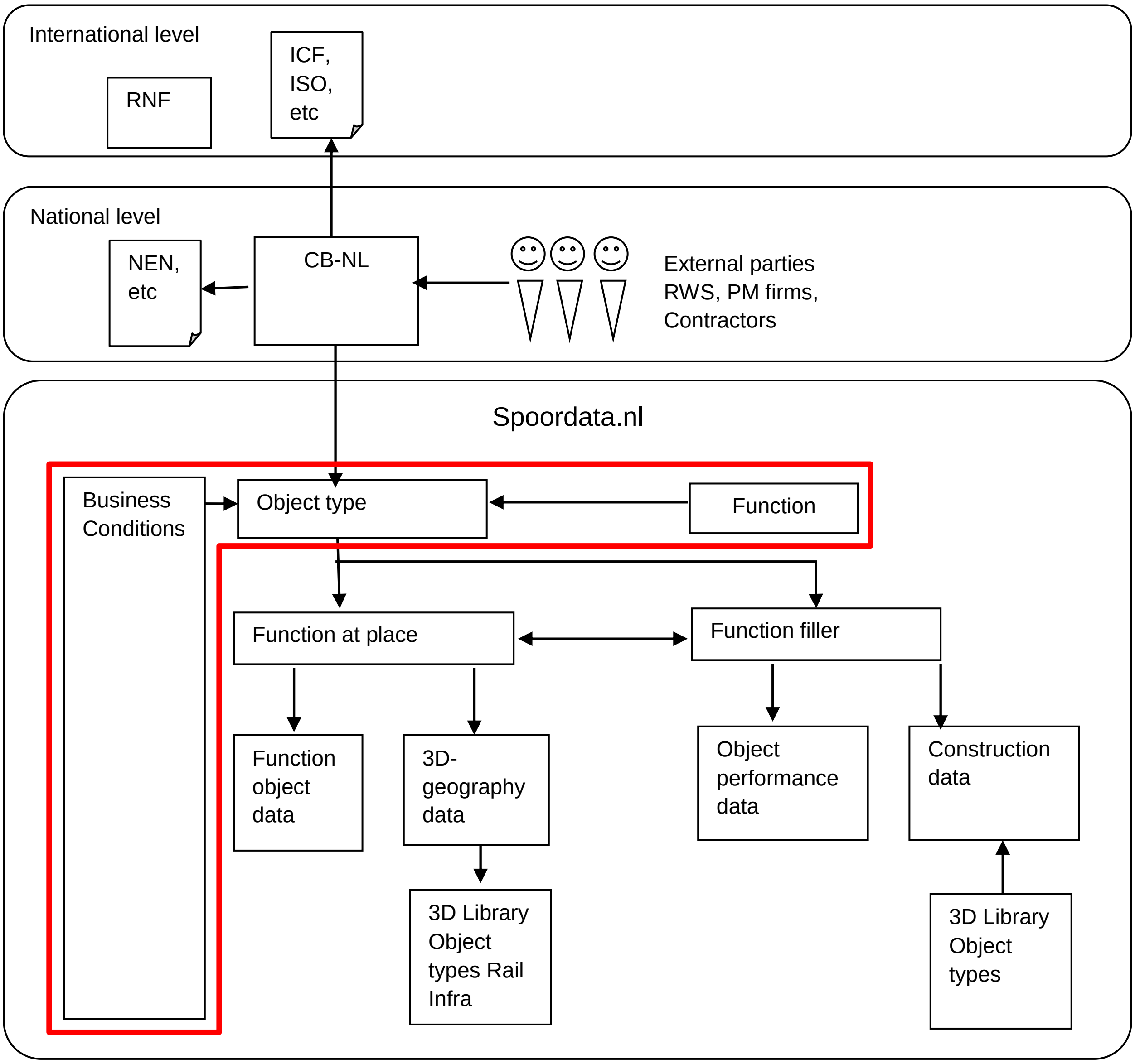


Figure 23: Spoordata hierarchy relationships and the OTL scope in red (adapted from Nagtegaal, 2014)

Information Model Spoor (IMS)

The IMS is based on four main types of data exchanged with ProRail(Nagtegaal,2014): object-type data; project-related data (two types: exchanged with the PM&E bureaus and with the contractors) and; operations data. These types are explained below(Nagtegaal,2014):The object-type data in the OTL is exchanged in the specifications/commission's phase. It includes certified infrastructure objects and their standing regulations. This forms the basis for infrastructure project's tenders and contracts. The first type of project related data is exchanged with the PM&E bureaus within the functional design phase. A functional design is made on the basis of the OTL which allows the infrastructure project achieve the desired result. This functional information is supplied about which train service is realized (planning and management).

Other type of project-related data is exchanged with contractors within the realisation phase. In this phase physical interpretation is given to the functional design. Physical infrastructure object information is delivered to the operating environment facilitating processes to be performed (inspection, maintenance and incident handling).

Operations data is exchanged in the operations & maintenance's phase. On the basis of the functional and physical object information to operational processes are performed. In addition, performance, maintenance and condition data are recorded. From the information mentioned above reports and analysis are made, what may lead to modifications and / or expansions in the OTL.

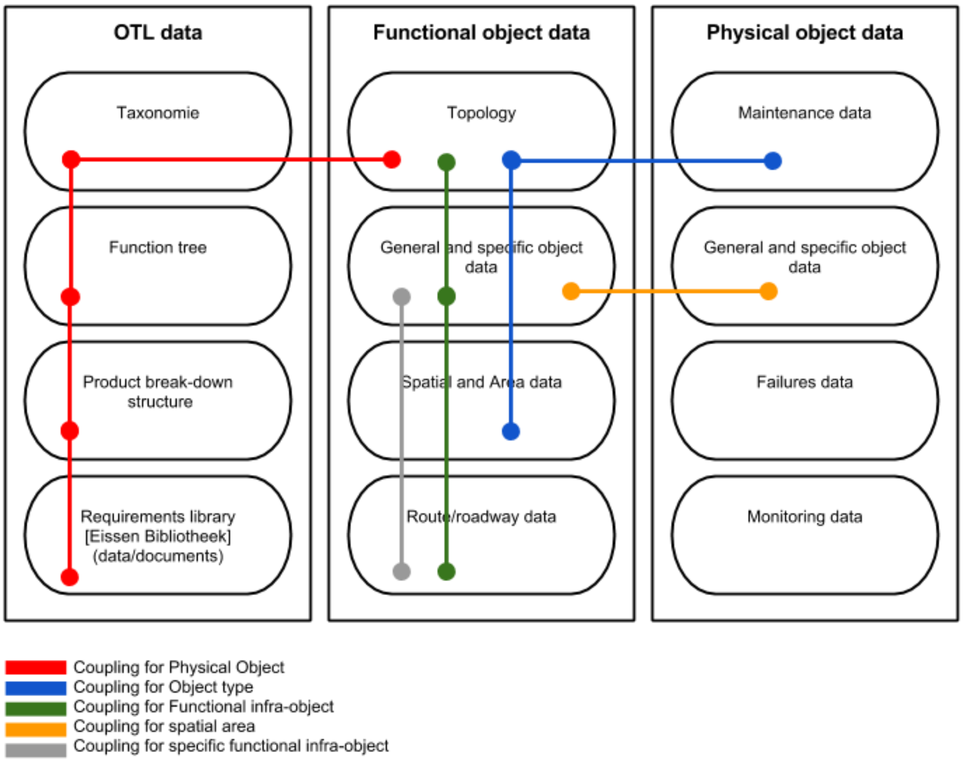


Figure 24: Data couplings between the OTL, functional and physical datasets, Concept. (based on Nagtegaal,2014)

7.4. OTL Spoor(pilot)

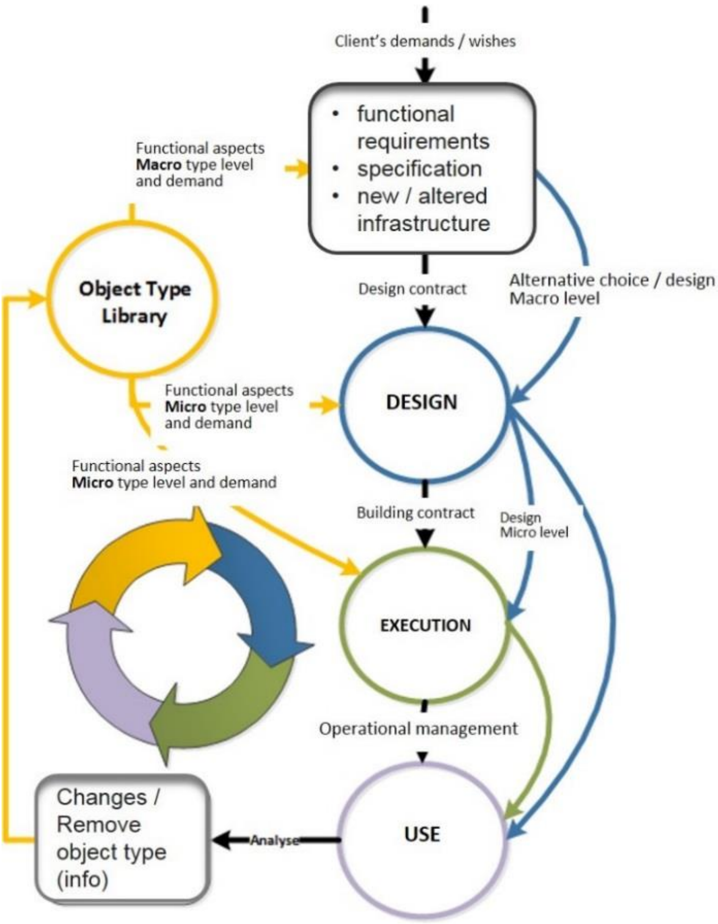
Together ARCADIS and Movares developed a pilot of the Railway's OTL, called "OTL Spoor", a prototype of a central source of information for concepts including objects. The following goal was stated(ARCADIS & Movares ,2014):

> **The OTL Spoor should be able, where possible, to connect to the OTL RWS and relevant developments within the market / industry like CB-NL or COINS.**

In a prototype plan the OTL Spoor was able to feed different phases of the Lifecycle with functional aspects at different levels. It started providing a macro type level for the specifications phase (S.R.S.) and then it provided a micro type level of functional aspects in the design and execution phases. This is illustrated in the next figure.
An object type includes features, definitions, functions and 3D images. The types of objects are related to a library and the requirements are related to a function library. The goal of the demo was to demonstrate that the OTL can become a central source for object oriented information about all disciplines throughout the lifecycle of railways. Thus, information has the follow traits: non-redundant; easy to find; and should include supply chains and asset management aspects(ARCADIS & Movares ,2014).

The main aspects of the OTL pilot were (ARCADIS & Movares ,2014):

- Publicly available[11].
- The Modeling principle is called 'triples' as it builds upon two elements and a relationship between them: subject, predicate(link) and object.
- It presents a search window in which concepts can be searched. The explanation is more focused on a requirement instead of a definition of an object.
- It links each concept with the html location of an image (jpg) or a unity.3D model.
- It has a tree-navigation for displaying either parent and/or underlying relationships.
- The search can go further up or down in the tree.
- Any object either from a higher or lower level can be set as a central object.



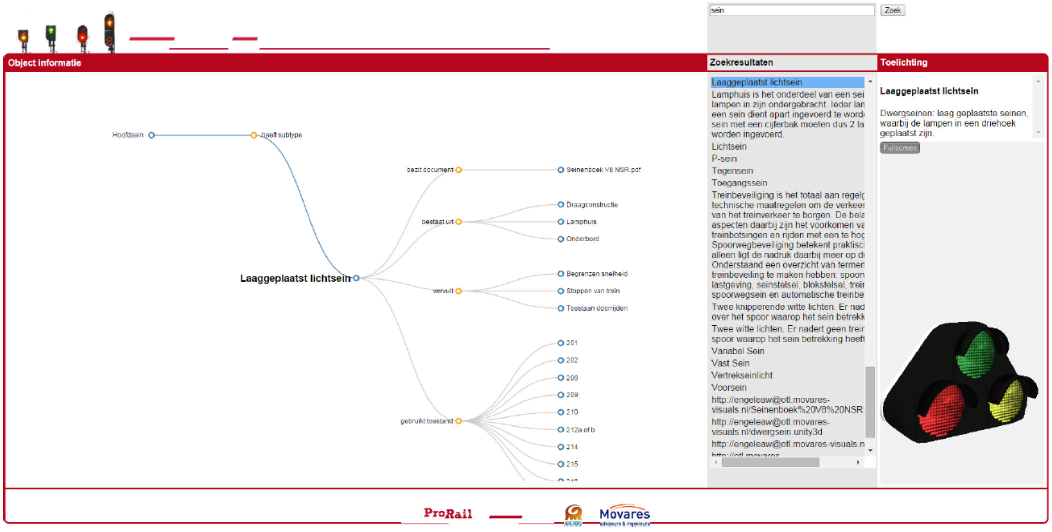


Figure 25: OTL Modellling, 3D viewer (ARCADIS & Movares, 2014)

In sum, the OTL Spoor pilot aimed to be linked to the OTL RWS and at the same time to the relevant developments within the market industry such as the CB-NL and COINS.
By using UML and keeping a generic top-structure the pilot OTL Spoor allowed to work with different systems. This was achieved partly due to the fact that the top model largely

11 At otl.movares-visuals.nl/OTL-spoor.htl

matches the OTL RWS. The visualization and tree-navigation provided a clear picture for the end user through the use of scope lines instead of using text solely. (ARCADIS & Movares, 2014)

Impact on the BID

The OTL Spoor pilot allowed to unlock inconsistencies in the Business Information Documents (BID) putting them in a single environment; e.g. a track rod is part of the rail system but not of the return system. However the rail is a crucial part of both the return and earth circuits and is also part of both the detection and the support systems. That makes one concept part of several systems in the OTL.
Additionally, definitions of objects given by the BID helped to disambiguation like for example a load bearing structure (draagconstructie) can refer either to a light signal or to a catenary electricity system (bovenleiding). The OTL Spoor unlocked different BID documents and helped to easily visualize the content. Thus, inconsistencies, omissions or other inaccuracies were quickly visible. (ARCADIS & Movares, 2014)

The OTL in Rail Systems Engineering(SE)

The semantic ontological Modeling in the OTL and the Modeling capabilities of OWL provide added value when using a concept library in relation to the development stage of the SE process (van Thiel,2014).

> **The SE process has three problems; linguistic disruption, organizational disruption and methodological disruption. The main objective of a concept library is to remedy the linguistic disruption. (van Ruijven, 2014)**

Nowadays, to input ProRail's requirements in the FBS and SBS are time-consuming processes. The full expressiveness of OWL is a step further than nowadays technologies as XML and RDF(S). However, it is not the last step. Ontologies can be made more and more expressive. A concept library within the construction industry is not able to provide only a taxonomy, but also another hierarchical structure and even checking on consistency. The OWL opens the possibilities to think in a OTL for automatic verification. (van Thiel,2014)

8. Asset's Data Management Outside the Dutch Railway Industry

8.1. The Netherlands: RWS, ZAD, NZ lijn, Schiphol and V-Con

8.1.1. RWS' OTL

Mick Baggen states the costs of a political decision were high. Based on this experience he suggests the following steps for developing an OTL and avoid the same mistakes:
First, to involve domain experts to validate information. They will help to answer the question: Is the OTL structure semantically viable?. Second, to develop a pilot and assign proper time to test it (no less than a year).

In the year 2012, only six months after the BIM program started in Rijkswaterstaat, the first OTL was rolled out without even being tested. No parties knew how to use it and therefore it brought negative consequences until present days (M.Baggen,2015)

RWS elaborated different use-cases in order to think in the possibilities of the OTL:

- **OTL used for Data Exchange:** In this case, RWS delivers information to Contractors about the current state to make a future state infrastructure. The Contractor retrieves this data as it is responsible for maintain the current assets and to build the new project.
- **OTL used for Mapping all sort of datasets:** In this use-case the OTL works as a Conceptual Integration Model transforming data from one model to another. This is an expanded use of the OTL that aims to define actual things in terms of relationships(mappings) to other datasets. A great amount of effort is needed for every mapping. However, that the value of the OTL lies in having all the definitions of concepts and their mappings at once(Baggen,2015). The Figure below exemplifies the mappings.
- **OTL for linking standards and design decisions or constraints:** This use-case is based on the OTL Definition Model that involves all definitions during the whole Lifecycle getting together different Lifecycle Models. It has two main components: Definitions along the whole Lifecycle and Specifications of each phase

Figure 1 in the Appendix shows the last use-case for RWS' OTL.

8.1.2. Zuidasdok (ZAD)

ZAD is a joint project from Rijkswaterstaat, ProRail and the Municipality of Amsterdam that aims to improve the accessibility of the Amsterdam South Axis and the northern part of the Randstad. It includes the use of a joint Object Type Library for which a Proof of Concept (PoC) OTL was elaborated. The principles and findings are classified in four groups: use, technique, Modeling guidelines and future content. (ProRail & RWS, 2015)

The project has one contractor and the contract includes information delivery specification (ILS). The supplies of asset information relate to the baseline 'to-build '(ProRail) and the baseline' As-built "(ProRail / RWS). The technical infrastructure of RWS is used for the creation of the OTL. The ZAD OTL is used as follows:

- RWS and ProRail develop both separated and joint parts of the OTL.
- The Management of the OTL ZAD is by RWS BIM and cooperation of ProRail.

- The Project enables the OTL ZAD available to the contractor who can validate asset information against the OTL ZAD.

The findings reveal that ProRail and RWS have a complete picture of the position, the application and the users of the OTL in the project Zuidasdok. For the OTL Zuidasdok, the RWS infrastructure structure will be used. This infrastructure among others has a Management Environment(based of Relatics) and Publication environment. The contribution of ProRail is the software package Case Talk. Case Talk is based on the method Fully Communication Oriented Information Modeling (FCO-IM) and builds a model from the facts that are exchanged within the knowledge domain. From Case Talk the model can be exported to the Management Environment RWS (Relatics) and/or to COINS. The findings reveal that RWS and ProRail have a shared view on how to display the joint OTL for Zuidasdok and the technologies involved.

To achieve unique naming in overlapping concepts selected a joint supermodel. This is preferred because it is a way on which ProRail and RWS can to sort out a joint 'top model' in accordance with CB-NL. The focus is on Physical object types (and less on the Functional object types). Within this framework Modeling guidelines RWS proved to be decisive.
The findings reveal that RWS Modeling guidelines proved to be sufficient for physical objects. Though, is it expected a small extension to the RWS side needed for the functional aspects; this is a limited effort.

The findings reveal that the OTL of Zuidasdok will be a joint (ProRail / RWS) top-down model which can be seen as a stepping stone to the CB-NL. The necessary distinction between functional and physical object has consequences for the effort in filling the OTL(ProRail & RWS, 2015).

The information needs of ProRail and RWS is in some respects strikingly different. While for RWS 'As-Built' information(SAP) is sufficient, ProRail wishes during the design phase 'To-Built' information. ProRail also makes a distinction between functional identification of an object (with associated features) and the physical identification of an object. For RWS physical identification is enough. This differences are shown in table 1 in the Appendix.

	To Build		As Built	
	Functional	Physical	Functional	Physical
RWS				x
ProRail	x	x	x	x

Table 1: Differences in the information needs of RWS and ProRail

8.1.3. Noord/Zuid lijn (NZL)

Nelleke Beerman is the Transfer Manager for the North/South line(NZ lijn) project managed by the Municipality of Amsterdam. As transfer manager she must aim to keep all objects in order within the system. Her main interest behind BIM is to get the financing needed for maintenance earlier. If the realized project is understood earlier, therefore the maintenance costs can be refined sooner. This can help to gain some time as the time for getting the approval tends to be long in public projects. (N.Beerman,2015)

In the NZ lijn project there are new objects specially in two fields: ICT and Safety. In both cases there is a need to update not only the systems but also their components and subcomponents.

The Municipality of Amsterdam uses a procedure based in the PRC-00055 from ProRail. When doing the breakdown structure they realized the high level of complexity of linking all assets to the steps in the procedure. Moreover, they faced several difficulties when trying to use the procedure in other projects. The main constraint is the time and transferring the knowledge between projects.

8.1.4. Schiphol Airport

In his research project funded by Grontmij, de Vries(2013) elaborated a 2-phased plan to analyse the main challenges for adopting BIM within the Amsterdam Airport Schiphol and develop a set of recommendations towards the creation of an implementation plan.
Based on a set of interviews the author classified the different benefits into three categories: design benefits, construction benefits, planning and facility management benefits. The design benefits turned to be the priority for Schiphol. An Increased collaboration within design team and within different disciplines and Clash detection are in first place. Then extracting automatic cost estimates, analysing and planning are in second place. A secondary focus was on the construction benefits where a quick reaction to design changes is the major concern followed by discovering errors and omissions before construction. Planning and facility management benefits were considered of less concern.
The main results of the interviews were in the form of scores per each decision making level.

Within the verification process the object library was rated with 4 out of 5, thus considered of big importance in the framework of the BIM implementation (de Vries, 2013)

De Vries(2013) pointed to other aspects influencing data exchange as shown in the Figure below. Interactions can be either inter(between firms) or intra-organisational(within a firm). They take place at different levels: executive/management level, operational level, technological level and object level. The object level refers to the exchange of object's properties data between organisations. This data is of three types: syntactic, structure or semantics. Finally, de Vries elaborated on the potential advantages of these BIM implementation within a lifecycle process: cost savings, efficiency, early decision making and early matching of 3D designs. More recently, Schiphol showed what they have been up to with BIM / GIS and dynamic data (Henk, 2015). The 'status' of the various assets e.g. moving walkways, lifts, passenger bridges, etc. Engineer's input is visible in the GIS using

‘track and trace’. The time to solve flaws is specially valued in an airport and BIM/GIS is a powerful aid. In the 'control room' any fault found on an asset is immediately seen and communicated to the closet mechanic. (Henk, 2015).
The Framework for data exchange interaction in the Schiphol experience is shown in the Appendix.

8.1.5. Virtual Construction for roads (V-Con)

The European V-Con project follows open standards and it aims to integrate the information from various sources within the European Highways industry. (Nederveen,2015). Thus, BIM, GIS, Systems Engineering and Asset Management are planned to be linked to each other. The responsible parties of the project are the Dutch Rijkswaterstaat and the Swedish Trafikerket in collaboration with TNO(NL) and CSTB(FR). The project’s development timespan is 4 years starting in the 2012. Two key phases in the road construction industry are the planning phase and the maintenance. In the first requirements management and systems engineering play a key role whilst in the maintenance this is role is played by asset management (Nederveen et al.,2013). The first V-Con’s project reports highlight the importance of working within the framework of a concept library managed at different levels(from project specific to national and international).

> **They found however, that to work with concept libraries, changes must be done to the traditional information Modeling and exchange. Accordingly they call this new approach “distributed Modeling”. (Nederveen et al.,2013)**

The V-Con references a concept called ‘Distributed Modeling’. This is based on a decentralized BIM model rather than a centralized BIM surrounded by stakeholders. Due to the different disciplinary views and domains, a straightforward integration was discarded. Instead, a distributed Modeling approach was developed. In this approach not all the domains information is covered in a single centralized model but a local storage is acknowledged(preventing loss). Based on this, the aim in the V-Con is to develop a sound structure based on semantic web technologies (mainly based on OWL, RDF and others).

Concept Libraries
The concept libraries expand the scope of the object libraries. They incorporate not only the explicit object but also its properties. A good example is the CB-NL in the Netherlands (Adriaanse et al.2012). Its main trait is a high level of flexibility to include local or national requirements.

Linearity vs No-Linearity in ICT
When elaborating the scope of the V-Con project van de Nederveen differentiated between two ways for ICT developments(Nederveen et. al. 2013): a traditional and linear way and a ‘world’ non-linear way. The linear approach includes the traditional steps of: problem identification, solution definition, software functionalities and support data structures. This result in a unique structure with fix standards. Contrastingly, a ‘world’ view is focused on semantics rather than on the languages that describe them. Semantics include object information like objects, classes, properties, relationships. An example can be found in the Appendix.

8.2. New Zealand: Municipality of Wellington

The New Zealand's capital City Council developed an Asset Management program based on sharing metadata. Over the space of two years the institution achieved 90% of reliability in their asset's information including roads, rails, power, water and buildings. This allowed them to unlock the true potential of BIM (Miskimmin, 2015). Using maintenance and cost predictions over the next 50 years the implemented system proves its value. This experience motivated other BIM diffusers in the world such as Ian Miskimmin from IADD4UK who reset part of his initiative based on the gained insights (Miskimmin, 2015).

Currently, the Wellington City Council is working in integrating a Multidisciplinary Model that builds on a vast variety of Models i.e. societal, cultural, environmental, economic, financial, demand, capacity, resilience, condition. More important, the base of all the previous models: statistical models. The metadata model main traits are(WCC, 2015):

- It has two categories of building blocks: standards and interdisciplinary models.
- The Model is asset agnostic , meaning that it involves the assets from different industries like water, transport, building and green assets.
- It constitutes the Council's asset platform as each set of standards and models will be used for building up the inventory of assets of the asset management authorities
- Is Intra-sectorial meaning that is intended to be used by different municipalities
- Is Inter-sectorial meaning that is intended to be used by different levels of governments, departments and ministries.

The intra-sectorial meta-data model of this information project can be found in the Appendix.

8.3. U.K.: The Ministry of Defence, the IADD4UK and the Crossrail

8.3.1. British Ministry of Defence (MOD)

In a work commissioned by the British Ministry of Defence, Bailey(2009) attempted to compare the disciplines of Taxonomy and Ontology. In this work, the concept of 4D Ontologies was used. A 4D Ontology incorporates the time dimension and it refers to the breaking-down of a part into temporal parts, each of which have a name. Bailey states that due to a lack of a formal method for developing ontologies, several methods are possible.

For this research The BORO[12] Method was picked. The method was designed to be used for re-engineering existing data into an ontology. Then, the BORO method was tested in developing ontologies for linking data of the country codes in Europe. According to Bailey the Enterprise Architecture of the Master Data has the following characteristics:

- Multidisciplinary, it involves different business processes, org structures, systems Modeling.
- Benefited from maximizing the re-use of existing architecture.
- It builds upon a Taxonomy to produce a user oriented ontology.

A caption of the MOD-country codes project is shown in the Appendix.

12 BORO: Business Object Re-engineering Ontology, designed by C.Partridge, ex-legacy data leader at KPMG.

8.3.2. IADD4UK

The "Infrastructure assets' data dictionary for the United Kingdom" (IADD4UK) main aim is "to provide a common asset data dictionary suitable for all UK infrastructure assets" (Miskimmin & Dentten, 2014). It involves the definitions for infrastructure components of several industries: roads, rail, power and water. The IADD4UK is supported by a common set of Asset Data Dictionary Definition Documents (AD4s) to be defined and rationalised by the industry. The AD4s are focused on providing the details of assets and this sense complements the information defined under the other standards. The AD4s defines three main aspects: (1) The functions and the Classes that relate to them; (2) Classes and the Attributes relevant to them; (3) Meaning of attributes like length, depth, etc. There are two types of AD4s: a system generic and an asset-specific.

A single generic AD4 covers generic common attributes: system definition, list of applicable assets Classes, generic functional naming conventions, generic labelling and worked examples. In the second AD4, more specific information is recorded such as: asset definition, visual examples, specific naming conventions, performance data requirements, attribute requirements. As an example the an air conditioning system can be decomposed into two AD4s: a HVAC Functional AD4 (heating, ventilation, air conditioning) and a Chiller Class AD4. This is illustrated in the Appendix.

The minimum level of detail required for the AD4 is defined by the needs of the stakeholders within the life cycle of a project. Thus, the information must be at least the required by (Miskimmin & Dentten, 2014):

- The decision making, in relation to requirements, surveys and constraints
- The Client must be assured with the right data for the outline solution
- The contractor and supply chain in order to deliver and build the asset
- The party responsible to operate and maintain the asset

Accordingly, the minimum level of information will be the one required by four stages of the procurement of an asset: Planning, Client approval, Design and Build, Operate and Maintain. The A4Ds will also dictate what that information is. However, the following is out of the scope of the A4Ds: how an asset is called and how information is transmitted. Ultimately, the A4Ds aim to define a wide method of measure the attributes for an asset and helps the supply chain to better understand the information they need to provide.

8.3.3. London Crossrail

Currently Europe's largest construction project, it includes the design and building of 118 km(including 21km of tunnel boring) of track that will connect east and west London (Stasis,2012). The project's complexity is raised by the amount of contracts(25 design, 20 advanced works and 60 construction and logistics) and interfaces. As complexity has an embedded risk, it was considered to use BIM in order to lower it (Taylor, 2013). Nonetheless, the integration between information systems of BIM and the life-cycle management systems pose a complexity in itself. There are not many software suppliers strong in all areas at the same time. Therefore, the management authorities of the Crossrail decided to work with Bentley Systems as the organizer of their information management. Bentley products supports web based collaboration and also provides asset management and configuration management features. The Crossrail has integrated GIS information, 3D BIM information and assets & documentation information (Stasis,2012). As a result, BIM boosted the information management of the project as it is used in the operation phase and for asset management and configuration management processes. Nederveen(2015) stresses the fact that in the Crossrail is the asset management who strongly influenced the structure of the building model. As stated by Stasis the building information model was developed as an ‘asset model’.

An important advantage is that the asset’s database helped the project to save IT costs normally incurred on conventional approaches in tasks such as: document control software, contract administration software and RFI software. (CIOB, 2014)

Documentation and asset information, which are treated as sets of configuration items, are considered in lifecycle terms rather than immediate delivery concerns. This is particularly important in preparing for the handover phase, as Crossrail aims to release information in a vendor-independent structure, allowing operators to handle the information for their own purposes with ease and flexibility (Stasis,2012).
According to Stasis the configuration items depend on four enablers: continuous training; defined management plans and business processes; internal and external specifications; a data dictionary and the perceived ‘best practice’. They are managed in the Electronic Document Management System (EDMS). The EDMS has been especially re-configured to facilitate asset-specific data resulting in a sub-management system Asset Information Management System (AIMS).The system helps users to transfer asset requirements to contractors, as well as capture the configuration items that those contractors return. The champions of AIMS see it as a vehicle for information reliability and availability throughout the programme’s lifecycle. (Stasis,2012)

8.4. Advanced information retrieval technologies

Ruitenbeek et. al.(2014) proposes an approach to gather information from different sources and using advanced algorithms to combine and integrate this information. This approach greatly differs from others like the Crossrail or V-Con in which information is managed and structured in a predefined way (like decomposed in trees and breakdown structures). The author suggests to use relevant asset information systems although they may be inconsistent and unstructured. In this sense, this approach is close to the big data use by the search engines that use any content available without dictating a specific format. Instead of been stored, the information is indexed to be analysed and recombined in new ways. It can also be retrieved by users in different ways. For example, users could search project documents, photos, inspections, design documents and all based on a map(x,y,z coordinates). The search engine will provide previews with hyperlinks. Another example is to predict user’s information needs by understanding his context(location, historical retrieval). Volker roughly implemented the examples above in a DBFM project with multi-source-engineering assets data. KPIs on data retrieval were measured showing positive outcomes in respect to traditional approaches.

9. Part B Conclusion

As introduced in this part, the Institute of Asset Management stresses the importance of information management as a key component of asset management. Besides, it was seen how regarding infrastructure's data, government parties in Europe bet on BIM. In the Netherlands the BIM initiative is led by Rijkswaterstaat and in the specific case of the railway sector is led by ProRail. Within these efforts, ARCADIS developed a BIM Maturity Model and the BIM Menu in order to bring an structure to BIM processes when adopted by different chain' parties. The BIM Menu lists possible benefits organised in goals and sub-goals brought by BIM. Moreover, based on several studies it can be expected that BIM would support Asset Management e.g. BIM can help to foresee consequences of design decisions over lifecycle performance.

Regarding system's integration three approaches were introduced : the vendor suite approach, the open standards approach, the use of advanced information retrieval technologies. The first only works in not-competitive environments when the monopoly of information management is granted to a single supplier. However, in an open-market they are license constraints. Therefore, the second is the one chosen by the Dutch authorities due to its flexibility. Additionally, semantic web ontologies offer possibilities for improving the organisation of information and enhance disambiguation of terms. Concept libraries are ontologies and can be potential tools for linking data. In the case of ProRail's OTL the ontological language used is OWL. However, as a new technology there are still limitations as for example the lack of temporal reasoning or the fact that the input models are usually tree-based what can lead to ambiguous information. There is no literature that elaborates on object-type libraries' development. Therefore, following experts' advice, a look was taken into IT software platform development theories and organisational science literature. Based on this, a five-dimensions-framework was proposed in section 4.4 which is built by: requirements engineering, architecture challenges, platform process improvements, organisation changes and operational and support process. The latter concluded that the roadmaps help in balancing long stakeholder's wish lists at the same time of providing an overview of the development' streamline. Complementary, literature on road-mapping provided advice on the framework, structure and relationships when designing roadmaps.

In addition, it was seen how the Dutch railway network is highly complex due mainly to its network' design, heavy utilization, number of tracks per line and stakeholders' organisation. Moreover, parties work under different collaboration schemes. These schemes define a collaboration framework whose main components are: System's engineering(SE), the Kernprocess(KP), the Procedure 55(PRC-00055) and the Business Information Document(BID). The latter consists in an comprehensive infrastructure' objects list where an object can be a physical structure or a consistent part of it. The BID constitutes the fundamental structure on which ProRail's OTL is based.

In relation to the asset management systems, only within ProRail Infra management department there are more than a hundred systems in use. The most important group are the unlocking mechanisms in which SAP, ArtiWin and Infra Atlas are among the most used systems. Complementary, in the railway market recent IT initiatives have been initiated like Semmtech, Dataroom, Spoordat.nl and OTL Spoor. The latter is a prototype developed in collaboration between ARCADIS and Movares in order to show ProRail(the client) the possibilities to link datasets to object types. The prototype allowed to unlock inconsistencies in the BID as the latter is based on fallible tree structures.

Ultimately, some initiatives to tackle asset management were found in national and international organisations outside the Dutch Railway industry. In the Dutch infrastructure sector, Rijkswaterstaat' OTL is the parent in hierarchy of ProRail's OTL. RWS made three OTL use-cases: data exchange, mapping datasets and linking standards. In the latter different levels define the data' management scope for the authorities, asset managers and contractors. A more recent experience, the Zuidasdok(ZAD) project brought insights regarding the information needs of the collaboration parties. RWS was found to need only physical as-built asset's data whilst ProRail needed both functional and physical aspects from as-built and to-build datasets. Other Dutch projects like the Noord/Zuid lijn(NZL), Schiphol and the V-Con support the importance of object type libraries for improving asset management.
Complementary, examples offshore were found in Wellington(New Zealand) and the Infrastructure' assets data dictionary for UK(IADD4UK), The Ministry of Defence(MOD) and London Crossrail(U.K.). The IADD4UK is document-based on AD4s which are separated in two types: asset and system. Being taxonomy-based, this approach however, can be considered less advanced and sophisticated than the Dutch OTL as it lacks of an ontology structure. In the case of Wellington City council an intra-sectorial meta-data model allowed them to achieve 90% of reliability in their asset's information after two years. The MOD project aimed to link data of the country codes in Europe for which efforts were put in developing an ontology model that re-uses existing data and seizes the already worked taxonomy structures. Similarly, major efforts have been made in the London Crossrail in which an asset model has integrated GIS information, 3D BIM information and assets & documentation information leading to IT costs savings. All the previous can be considered pilot experiences that point to conclude the following:

- Defining information requirements is a first necessary step for an integrated asset model. It needs collaboration between government authorities and industry parties.
- Asset's libraries are key components of asset management.
- Improvements in asset's information are likely to lead to cost savings.
- Ontology semantic technologies show potential to organize asset's data in a more efficient way.

PART C: DIAGNOSIS OF THE PROBLEM' CAUSES

"Courage is what it takes to stand up and speak; courage is also what it takes to sit down and listen"
— **(Winston Churchill)**

10. Part C Introduction

Based on literature, in Part B it was concluded that BIM can support Asset Management. In the Netherlands an open-standards approach has been chosen for integrating the information systems which are as complex as the rail infra network itself. Moreover, within the BIM efforts in the Dutch infrastructure sector, the Spoordata program leads the information projects in the Railway industry. The OTL is core of the Spoordata program and is based on OWL which organizes data based on ontologies and the BID constitutes the main source for filling object type information into the OTL. An study on information projects outside the Dutch railway industry leads to consider object libraries as a potential solution for organising and standardizing asset's information. However, benefits cannot be taken for granted. Literature on software platforms provides useful advice about considering people's culture and expectations towards the implementation of new technologies.

All that stated Part C centers on gathering the expert's views and perceptions through interviews and surveys(section 11). Based on them, the key findings are extracted and organised using the 5-dimensions framework(section 4.4). The surveys help to measure the parties preferences which are presented in the sub section results.
The interviews and surveys are the base for the stakeholder's mapping(section 12), value system design(section 13) and performance indicators(section 14). In order to understand the applicability of the latter use-cases are elaborated. Thus, section 15 elaborates on six use-cases.(4 ProRail, 2 ARCADIS). Section 18 provides a summary of the challenges and section 19 presents a risk assessment based on the insights provided by the experts.

11. Interviews & Surveys

While most of the interviewees are stakeholders in the Dutch Railway Industry, others are experts involved in international railway projects and other industries. The interviewees in the Dutch Railways can be classified in the following groups:

- Government(RIjkswaterstaat),
- Infrastructure manager(ProRail)
- Operators and Contractors(engineering firms: ARCADIS, construction companies, maintenance contractors: Volker Infra, Asset Rail).

The interviewees outside the Dutch Railways are subdivided in:

- The British Railways(IADD4UK, Network Rail)
- European Highways(V-Con)
- Water systems(Witeveen & Bos, Jakarta)

Table 2: Interviewed stakeholders (own creation, 2015)

The interviews represent the qualitative assessment. As stakeholders belong to different expertise and backgrounds there is no one a reusable template used for everyone. Thus, every interview is custom-made with the help of experts within ARCADIS. There are however some frequent questions regarding: background of the expert, link between his/her expertise and OTL & BIM, expected use of an OTL, challenges and pitfalls.

The surveys represent a more quantitative assessment. These forms are based on two sources:

- The Spoordata Executive Management Report(Schouten & Soeters 2014).
- The ARCADIS BIM Menu(ARCADIS, 2015).

The first survey form called "The OTL as the Core of Spoordata" includes questions regarding:

1) The Purpose: What would be your main purpose to use an Object Type Library?

2) The Content: What type of data would you like to have included in an OTL?
3) The Expected Results
4) Priorities: If the OTL were about to be released in the railway market. What would be your actual demands to be able to use it now and how would you use it?
5) Limitations & Challenges: What are your limitations for a total integration of your asset's data to an OTL?
6) Risks & Pitfalls: What pitfalls and risks would you associate to making the use of an OTL a standard in the railway market?; What other tools or technologies you know that can replace an OTL?
7) Extra Results

The first four points of the survey are proposed in response in line to the statements made by Opgenoort (2015): *The main challenge is to limit the Scope and be able to answer the following questions: Who is going to use it?, Why are they going to use it?, What is the intended use?.* The last two points are added based on Veeneman(2015). The latter stresses the tendency to be over-optimist when starting to plan the implementation of a new technology. This can lead to overstate benefits, overlook pitfalls and to dismiss better alternative technologies. The second survey form called: OTL expected benefits and is based on the ARCADIS BIM Menu. All the benefits in the BIM Menu are assumptions from experts in ARCADIS based on their experience. The purpose of the form is to know it the OTL is likely to meet certain BIM goals in the view of the stakeholders of the Railway market. In this way the value of the survey lies on gaining insights about ways to achieve certain BIM goals developed in ARCADIS.

11.1. Survey results

The OTL as core of Spoordata.nl

Most of the surveyed experts were young engineers between 25-34 years old(50%). There is a predominance of males(86%) what might reflect the traditional culture of the railway infrastructure sector. Regarding the organisations they belong to, the majority of the experts work in a PM&E bureau , followed by professionals working for ProRail; developers and others(Figure below). Depicting the lifecycle phase in which they operate, it is important to consider that some experts work in more than one phase. Though, most of them work in the design phase(11) followed by planning(10), maintenance(9), construction(8) and handover(5). Less parties are involved in handover(5),operations(5) and demolition(4).

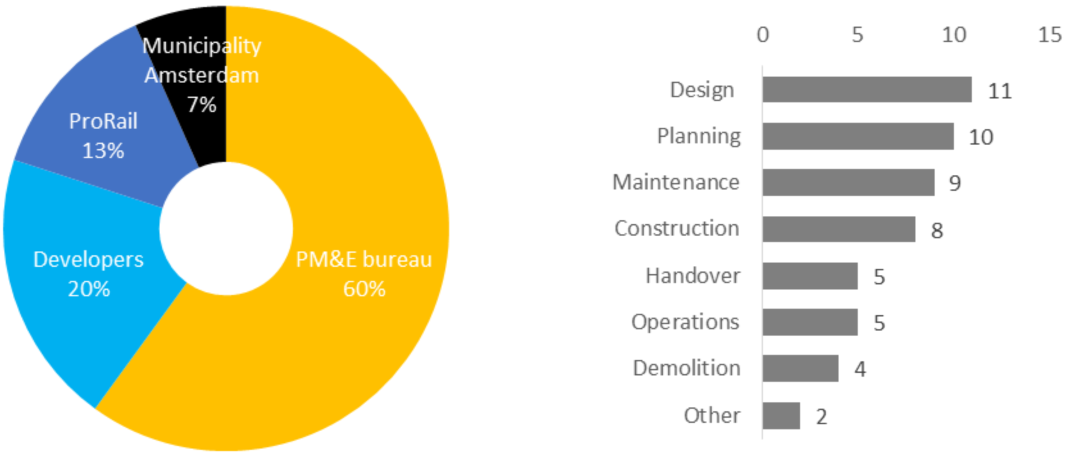


Figure 26: Surveyed parties' organizations and lifecycle phases (own creation,2015).

Purpose, content and results

Firstly, the experts were asked to choose four goals regarding their main purpose to use an Object Type Library. The first choice is 'to have a unified, semantically unambiguous exchange of data'.

For the second choice 'to have a future-proof and expandable database of assets' was chosen.

Thirdly, three goals had the same preference: 'to improve access to data towards multiple parties, in spite of the time and place'; 'to access to asset data organized by types' and 'to have a consistent source of specifications linked to assets and avoid dissimilarities'.

Finally, two were chosen as the fourth most preferable choice: 'to have a more complete view of my systems beyond traditional object trees' and 'to comply with other standards for further integration'.

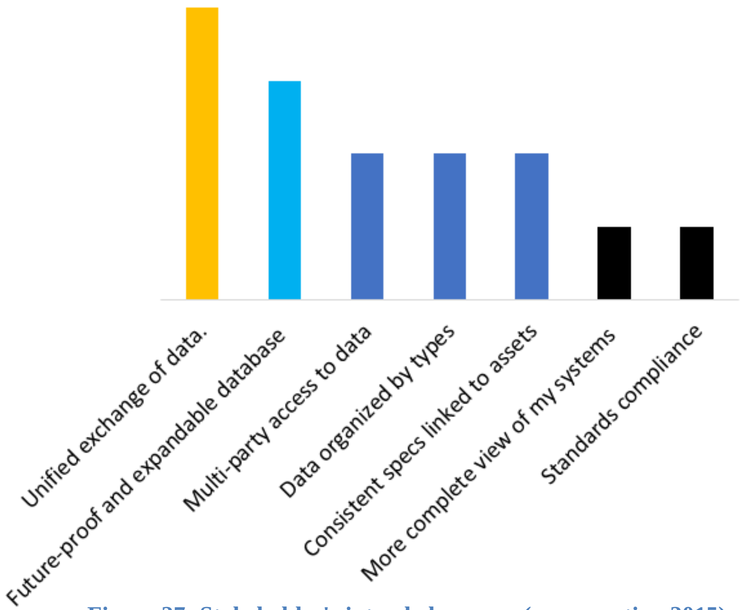


Figure 27: Stakeholder's intended purpose(own creation,2015).

Three main goals were decomposed in sub-aspects in order to know the preferences of experts within the possibilities of certain performance indicators. These aspects are: 'accuracy of data', 'accessibility' and 'alignment with state of art-technologies'.

Regarding the most important aspect for accuracy of data, most of the experts consider that both 'as built' and 'to build' data are of the same importance. In the case of the types of accessibility, the majority considered 'multi-party' access as the most important type; half of the first believe access should be 'place-independent' whilst only a few experts prefer a 'time-independent' access. In addition, when asked about the importance of different technological traits related to the OTL and its possibilities, most experts prefer 're-usability of data' closely followed by 'multiple systems likeability'. A smaller preference is shown towards 'traceability of faulty inputs' and 'testability'.

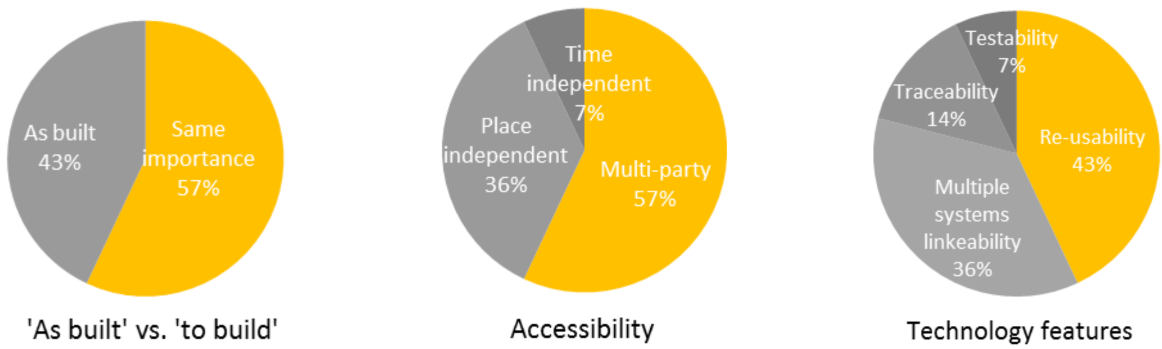


Figure 28: Three aspects break-down and parties' preferences(own creation,2015).

Following the purpose, the experts were asked to pick four choices that represent their most preferred content for the OTL. Thus, to the question 'what type of data would you like to have linked to an OTL?, the following turned to be the most desired datasets to link.

The first choice is 'as built' data followed by 'to build' data(as they were given as separate choices). In third place 'as maintained', 'functional data' and 'SAP data' are equally desired. The fourth most preferred content is 'locational data'.

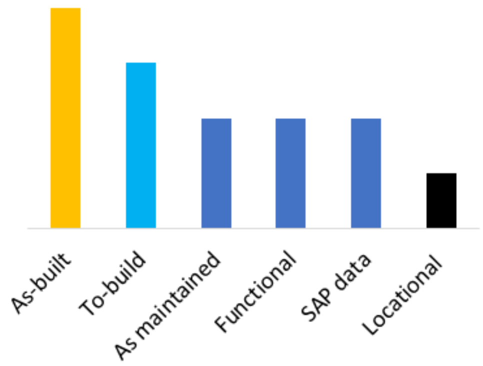


Figure 29: Stakeholder's preferred content (own creation,2015).

Regarding the expected results, the experts were asked about their view on the OTL regarding the goals aimed by the Spoordata program(Schouten J.& Soeters R., 2014) per lifecycle phase. For each phase experts had to pick one result in which they perceive the OTL can benefit their business activities. This was done for the planning, design, construction and maintenance phases where the following were chosen respectively: 'possibility to simulate the future', 'reduce budget risk and failure costs', 'reduce failure costs and extra-work' and 'reliable assets register'.

In the handover and operations phases however, preferences were split in more than one desired result. In the handover experts consider all the alternatives with equal potential for the OTL; whilst in operations 'better risk management and 'infrastructure data available earlier' were chosen.

Planning	Possibility to simulate future				
Design	Reduce budget risk and failure costs				
Construction	Reduce failure costs and extra-work				
Handover	Direct Link to PRC00055	Control over specific demands of PRC00055	Reduce man hours of checking PRC00055	Possibility to reuse a safety requirements template	Infrastructure information available earlier
Operations	Better risk management	Infra data earlier			
Maintenance	Reliable assets register				

Table 3: Expected Spoordata results(own creation,2015).

OTL expected benefits in the ARCADIS BIM Menu

The objective of this survey was to bring a better idea of how the OTL could fit within the goals and sub-goals of the ARCADIS BIM Menu. As described in the correspondent chapter the BIM Menu is structured in goals divided in sets of sub-goals. Thereby, at first glance one may think that the scope of a sub-goal is always limited to the goal family it belongs. However, based on the advice of Bram Mommers(European BIM Business Development Manager at ARCADIS) significant differences can be found between the BIM goals and underlying sub-goals(Mommers,2015b). Therefore, the survey avoided to constraint opting for sub-goals within their goal's families.

Regarding the demographics, similarly to the previous survey, most of the experts belong to the PM&E bureau followed by ProRail and developers. Besides, the design and planning phases are the stages in which most of the surveyed operate. This is not merely coincidence but it is due to the fact that the initial goal was to have both surveys filled by the same group of experts who were interviewed in first place. However, it was not possible to get the same amount of respondents for the second interview partly due to time constraints and also due to lack of knowledge about BIM by some experts.

Planning

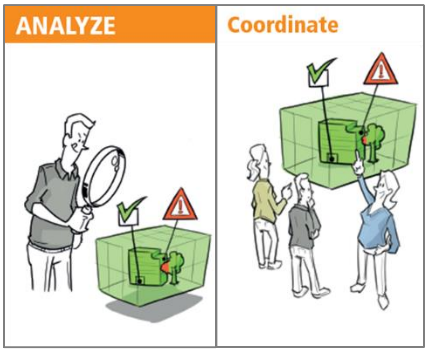


Figure 30: Analyze & Coordinate (ARCADIS,2015)

Accordingly, in the planning phase most of the experts find that the OTL would bring more benefits in 'gathering' information. Though, when asked to choose, then 'analyse' and 'communicate' were prioritized among the others. The BIM Menu defines the benefits of 'analyse' like 'the act to make objects understandable for all stakeholders and predict the behaviour of infra elements'. Thus, this goal matches the chosen use in the Spoordata' survey(Purpose) of ' to have a unified, semantically unambiguous exchange of data'. Within planning, Systems Engineering' concerns are on specifications' and SAP' data(Bekendam 2015, Stuiver,2015). Besides, 'predict the behaviour of infra elements' relates to 'Possibility to simulate the future' in the planning phase of the Spoordata' survey(Results).

In the same way, experts were asked to choose one sub-goal in which the OTL could benefit the most. In this case 'coordinate' was chosen. 'Coordinate' aims 'to ensure the efficiency and harmony of the relationship of facility elements'.

Design

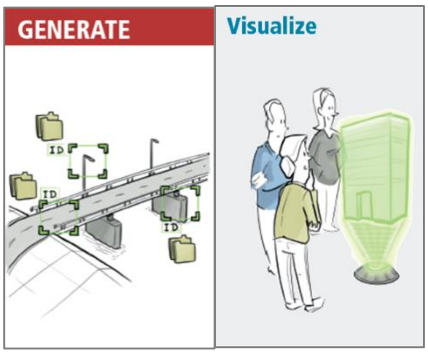


Figure 31: Generate & Visualize (ARCADIS,2015)

In the design phase experts consider 'generate' as the BIM goal best supported by the OTL. Based on the BIM Menu 'generate' benefits are 'generating information available in one place for multiple use; and combine current and new data'. Hereby, this matches the preference for 'multi-party accessibility' in the Spoordata' survey(Purpose). Additionally, 'combine current and new data' can be related to linking 'as built' datasets to the OTL what is also the most preferred type of data to be linked to the OTL (Content).

Though, differently to the results in the planning phase, when asked about the sub-goals the preferences did not match the previously chosen goal as warned by Mommers(2015b). Thus, 'visualize' and 'draw' (both belonging to the 'Communicate' family) were chosen. The most preferred sub-goal 'visualize' has the following benefits in the BIM Menu: Visualisations produced from BIM allow non-technical stakeholders to participate fully and interactively in projects. Realistic visualisations and 'walk throughs' avoid misinterpretations and speedup the decision making process'. This preference can be understood by the predominance of stakeholders working in the planning and design phases where 3d software is mostly used.

Construction

In the construction phase, the goal 'realize' was largely preferred. In the BIM Menu 'realize' is defined as ''to make a physical element using facility data'.

In order to attain this goal first efforts have to be put in integrating the Asset Management and Construction supply-chain (Baggen,2015 and Tissing,2015). Thus, the main Spoordata' aim 'to have a unified, semantically unambiguous exchange of data' can be related.

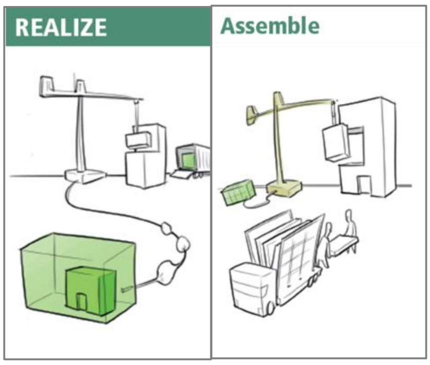


Figure 32: Realize & Assemble (ARCADIS,2015)

Besides 'realize' benefits are : 'improve productivity and price-value ratio of facilities; and support integrated asset management.' Also, 'facility data' can refer to 'as-built', 'as-maintained' for not-new projects or 'to-build' data for new projects. Moreover, the aim of improving productivity can be related to 'reduce failure costs and extra-work' chosen in the Spoordata survey(Results) as the most desired result by using the OTL in the construction phase. Additionally, the second part of the statement 'support integrated asset management' is supported by Tissing(2015) and exemplified in the three use-cases in system's maintenance.

In this case the preferred sub-goals were 'assemble' and 'coordinate'. The first belongs to the goal' family of 'realize'. 'Assemble' benefits in the BIM Menu are: 'less improvised works, fewer installation issues, less construction time and failure-costs, less waste and safer working conditions and practices'. Therefore, in this case both the preferred goal and sub-goal' benefits make reference to the aim of 'reduce failure costs and extra-work' chosen in the previous survey.

Handover

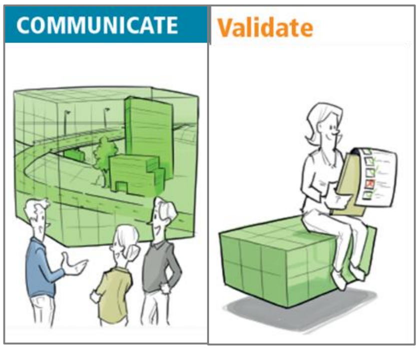


Figure 33: Communicate & Validate (ARCADIS,2015)

In the handover, the OTL' benefits are expected when 'communicating' data. It's benefits in the BIM Menu are 'to communicate more efficiently through a single data source; and less failure/costs downstream'. This relates to the current problem with contractors whom now benefit of the lack of information given by clients. Thus, through an improved communication the OTL would save a lot of iterations in the whole process. (Bekendam, 2015). Additionally, 'as-built' and 'locational data' can be linked to asset's performance early in order to avoid loss of performance data when asset's information is handed-over to the Asset Managers in charge of maintenance. (Tissing,2015)

Similarly to the previous phase, the preferred sub-goal did not match the 'communication' family. The sub-goal 'Validate' has the following benefits "to validate a design process against the initial requirements and/or legal regulations. This is related to the purpose of 'to have a consistent source of specifications linked to assets and avoid dissimilarities' ranked second in the Spoordata survey(Purpose). Besides, it is directly related to 'possibility to reuse a safety requirements template' chosen for the handover in the Spoordata survey(Results).

Operation & Maintenance

Similarly to the previous phase, in the O&M phase the most desired goal is 'communicate'. Besides, also in this phase the preferred sub-goal did not match the chosen goal family. Thus, the chosen sub-goal 'forecast' has as benefits: 'simulation on the virtual facility substantiates decisions and supports policy; reduces total ownership costs and optimises the construction processes and the performance of a planned facility'.

Figure 34: Forecast (ARCADIS,2015)

This can be related to the possibilities of using real object' data to start functional plans earlier(Schouten J.& Soeters R., 2014) aimed by the Spoordata program. Information about the asset's functions and how they were maintained is key for assuring proper maintenance tasks. Thereby, relevant content is the 'functional' and 'as-maintained' datasets. Besides, ProRail's asset management is likely to shift to a hierarchical Asset's data Management from a Contracting Management in order to manage an integrated dataset more efficiently(Tissing,2015). For attaining this goal, the OTL needs to be continuously adjusted and progressively expanded with data from the supply-chain lines. This is in line with 'to have a future-proof and expandable database of assets' from Spoordata (Purpose).
Moreover, 'forecast' is also related to 'better risk management' and 'infra data earlier'(Results). In the first case an OTL-aided forecast not only reduces risks but also sharpens the risk assessment with more and better quality data.

Demolition

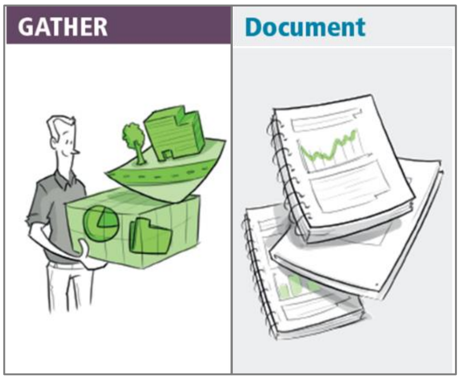


Figure 35:Gather & Document (ARCADIS,2015)

Last but not least, in the demolition and disposal phase 'gathering' was chosen. Its benefits are to bring 'updated and reliable data available for BIM processes and for all project partners'(ARCADIS,2015). This is aligned with the statements of Bekendam(2015) pointing out the role of the OTL in supporting reliability of data.
Differently than other phases, demolition closes the lifecycle of assets and therefore reliable 'as-built' data can be more helpful than other types for demolition' planning purposes. Additionally, the chosen sub-goal 'document' does not belong to the 'gathering' family but to the 'communicate' goal family. 'Document' is defined as 'to create a record of facility information including data to precisely specify the facility elements'. This can be related to 're-usability' of data which is the preferred technological trait based on the Spoordata survey. The reason is that the OTL aims to facilitate the re-use of data and to avoid loss of knowledge and repetition of efforts as today occurs in both the whole infra industry(Baggen,2015) and specifically in the railway industry(Tissing,2015).

11.2. Key findings

The key findings from other experiences and projects and the interviews are grouped according to the five dimensions that influence challenges faced by the OTL development. In the case of the last dimension, the insights are covered by the roadmaps in PART D.

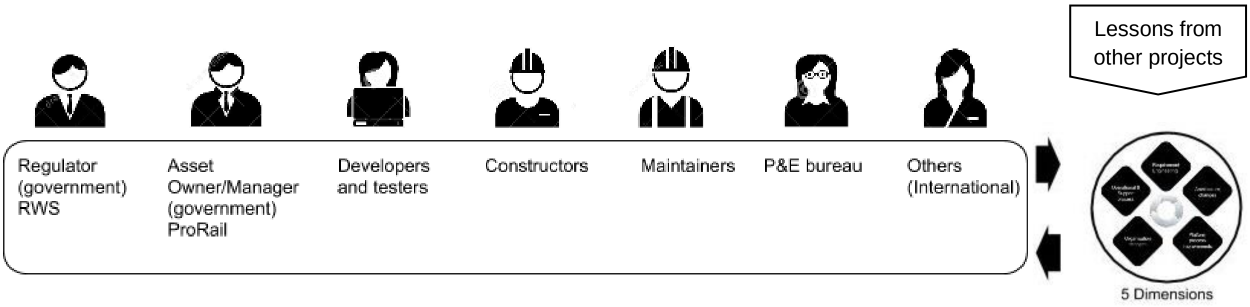


Figure 36: Five Dimensions as structure for the key Insights from the Interviews & Surveys (own creation, 2105)

11.2.1. Requirements engineering

The first challenge is posed by the requirements management process. This relates to the allocation of requirements to OTL, by separating functional and structural requirements. ProRail's Enterprise Model builds upon two main categories or views: Logistics view and Asset Management. The first is based on the system's structure and the second on functional specifications. The main requirements are the ones needed to get the following 3 main aspects: Product-breakdown structure (P.B.S.), Relation to function and Taxonomy.

Structural requirements

The requirements for the P.B.S and Taxonomy can be considered of less complexity. There are several legacy systems already in use by ProRail(BID, Rail Infra Catalog) that make it easier to start an OTL structure. Thus, as stated by Bailey(2009) in the project made for the British Ministry of Defence, a 4D Ontology can be benefited from maximising the re-use of existing architecture.

Functional requirements

The functional requirements are of high complexity as they involve a high level of cooperation and agreements about the entire scope of the OTL functionalities. So far, there is no common understanding of what an "OTL" actually is, nor what goal it serves (M.Baggen,2015). Moreover, although several versions are tested, ProRail's visibility on the functional features extends beyond the released versions. Therefore, a Roadmap can be used to highlight what functions are preferred by the stakeholders.

The surveyed expected results out of ProRail's business activities are a reference for insights of the alignments between the stakeholder's expected functions and the Spoordata business requirements. To cite an example, in the interviews several stakeholders point to the expected benefits of linking the PRC-00055 to the OTL. A consequential benefit will be in Portfolio Management. The OTL might help to standardize the Procedure in different projects by having a better view of all Portfolio's projects at a system level as stated by Beerman(2015), transfer manager of the Noord/Zuidlijn.

Another example is the use of an OTL for linking as-built assets documentation to the OTL systems. The OTL can aid the handover phase by providing an efficient environment to put all the project's information relevant to the maintenance(Beerman,2015).
The importance of linking as-built requirements is also stressed by Baggen(2015) from Rijkswaterstaat when pointing to the current disconnected work between the Asset Managers and the Constructors. When maintenance is required there is a re-engineering needed due to a lack of a register of as-built and as-maintained assets work. (Baggen,2015)

In sum, the expected functions vary per stakeholder and lifecycle phase. Therefore, a practical way to focus on specific uses is through the development of use-cases. Chapter 15 elaborates on five specific use-cases and the possible functions of the OTL to fulfil the main user's needs.

System requirements specifications
The system functional requirements are in the case of the OTL, the "model shall" statements. These were listed in the survey under "Purpose" and "Contents". The given list was largely based on the Spoordata Executive Management Report (Soeters,2014) and insights gathered from the interviewed experts. Accordingly, based on the stakeholders preferences the OTL above other requirements shall:

- Allow a unified, semantically unambiguous exchange of data.
- Include a consistent source of specifications linked to assets.
- Provide a future-proof and expandable database of assets.
- Improve accessibility to data towards multiple parties in spite of time and place.
- Provide a complete view of systems beyond traditional object's trees. (e.g. BID-1)
- Comply with standards for further integration
- Grant access to data organised by types.

11.2.2. Architecture challenges

Although, the OTL structure might have a good base in previous taxonomic legacy systems , long-term concerns might point to the integration difficulties due to structural differences between different OTL hierarchical levels. As stated by Ron Nagtegaal(2015) -OTL Architect in Rijkswaterstaat- RWS' OTL is structurally different than ProRail's. In the case of RWS the scope was not well defined what lead to a high level of complexity and messiness (Baggen,2015). These aspects can be partly understood by: Implicit dependencies and Incorporation of immature functionality (Bosch 2002 & 2007) explained in Chapter 2.4. Contrastingly, ProRail's OTL has a Service Oriented Architecture(S.O.A) which builds upon four main components: the model, the application(instances of physical and functional data),the project and the OTL-catalogue. The only link between both OTLs will be the Catalogue. It will be a sort of Integration Environment working in a bidirectional way (Nagtegaal, 2015): from the user to the catalogue/subsystems and from the subsystems to the users.

The differences are accentuated by the dissimilar standards used by the two parties. ProRail's OTL is based on an OWL(ontology) whilst RWS OTL is based on XML and XSD. aspects: *Dependencies on external software* (Meyer et.al.1998) explained in Chapter 6.5.To overcome structural difficulties. Baggen(2015) suggests to involve early as many domain experts as necessary. They should be able to answer the question: Is the OTL structure semantically viable?

11.2.3. Platform process improvements

The first step in an OTL is to bring a format/structure which is flexible in order to be able to add and change things on the way, and still stay consistent(Opgenoort, 2015).
Rik Opgenoort is the OTL Architect for the ARCADIS OTL. He points to the use of RDF or 'triples' standard as a way to make a future-proof OTL. 'Triples' are also used in ProRail's OTL and therefore they bring flexibility and future-proof to certain extent.

External market and business demands however could also bring uncertainty and disturbances (Jiang et. al. 2000). The requirements formulation is of major importance as even if they are known, mismatching interpretations could lead to a wrong prioritization. Therefore a formal requirements specifications for the OTL by ProRail is needed. Particularly, the risk of 'Redundant inheritances' is one of the main challenges of the OTL(van der Veen,2015). Properties are defined at high levels and therefore problems are likely at lower levels when attributes are inherited e.g. if same concepts with different meanings appear as attributes.

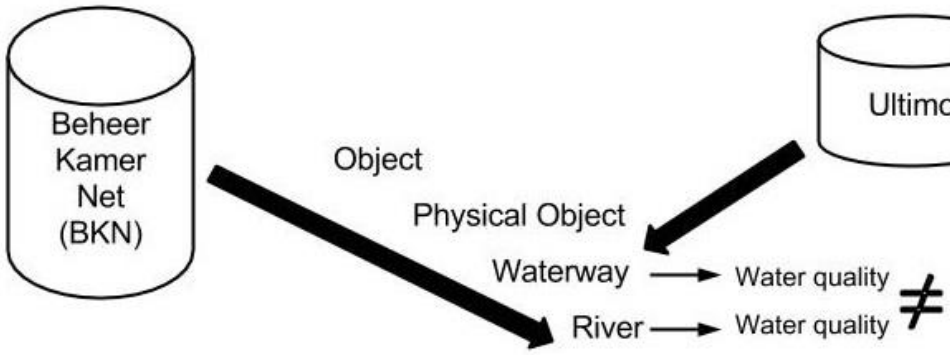


Figure 37: 'Redundant inheritances' (adapted from van der Veen,2015)

Too many disconnected PoCs may also lead to an misaligned process and to lose the North. Nowadays, different parties work on their own OTL processes. Therefore, their PoCs cannot progress in parallel. However, at the end all the parties will work in a the same OTL environment. Thus, efforts should be made in making a framework planning of the different initiatives not only within ProRail but also in coordination with the stakeholders. In this way, duplication of efforts can be prevented. In addition, lessons can be learned from the mistakes made in the early stages of RWS OTL. Therefore, a reasonable testing time should now be considered for ProRail's OTL. Applying strict deadlines and a reverse engineering could only lead to shrink the testing time. Chandrashekar et. al. (2006) and (Jiang et. al. 2000). The table below shows the timeline of the OTL development' process.

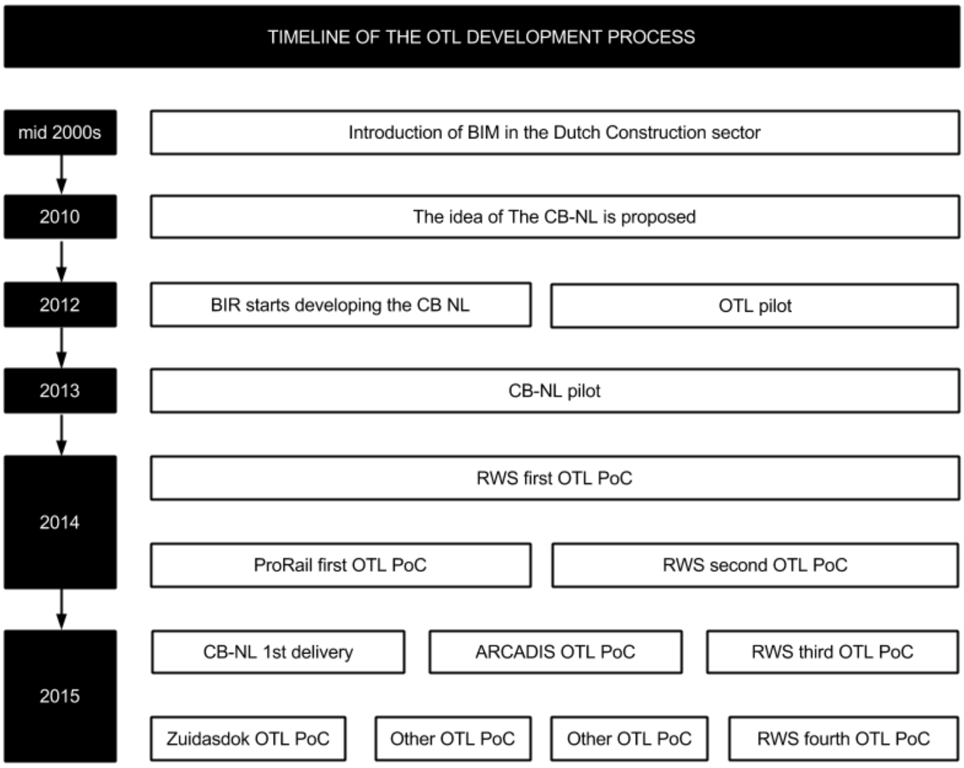


Figure 38: Timeline of the OTL. (Own creation based on Baggen, 2015 and Opgenoort,2015)

11.2.4. Organization changes

Based on the four mechanisms of Adriaanse(2007) the organizational challenges of the OTL can be elaborated. The personal perceptions of OTL from the experts are split. Some stakeholders see more benefits when others points more to the disadvantages.

Benefits:

The Government is more prone to see the benefits as they are the OTL Managers in search of a solution for the information problem. Mick Baggen -initiator of the RWS OTL- stresses the inefficiencies of the current way of working. Re-engineering is regularly done in RWS as the as-built or as-maintained information is totally disconnected between the Asset Management and the Construction systems (Baggen, 2015). Additionally, Baggen's perception of benefits is extended throughout the whole Lifecycle. This total-lifecycle-vision is shared by Adriaanse(2015).

> **Object information relevant to every Life Cycle stage from the planning to the Operations & Maintenance(O&M) can be useful. Moreover, the OTL has a high potential to link information from Lifecycle phases that were traditionally disconnected e.g. O&M data can be used for designing modifications or updating of projects. (Adriaanse,2015)**

As expected ProRail see also more benefits in his condition of initiator of the OTL. They need a solution for integrating the datasets within the asset's configuration group. Therefore, they want to have the OTL running. Ron Nagtegaal –ProRail's OTL architect- states that OTL will bring a more effective collaboration between people providing a tool for speaking the same language and reusing the information (Nagtegaal, 2015)

Besides the government' parties, benefits are seen at early stages by supply-chain parties e.g. in systems engineering as stated by Joey Bekendam and Melanie Stuiver both Rail Systems Engineers in ARCADIS.

> **In systems engineering, an OTL might provide added value starting from the design phase as it is likely to deliver a consistent, clear and reliable source of requirements. Otherwise, overlooking the requirements might represent cost overruns in the long term. (Bekendam, 2015)**

Although Bekendam stresses the importance of clear requirement specifications early in a project, he also supports the usability of the OTL extended to the whole lifecycle. Mart Folkerts(Asset Rail) finds in an OTL a potential complement to the current asset systems as the ArtiWin and SAP. Moreover the OTL can learn from the recent merge SAP-ArtiWin(planned to be released as SAP PLM) what is likely to result in an overkill of information. (M.Folkerts,2015). Using an internal OTL as an interface may prevent the overkill of working directly with ProRail's OTL (Pentenga, 2015).

Long-term benefits are seen by Roland Dijkhuizen –Data Analyst in ARCADIS-. He points to a potential use of the OTL in combination with Big Data. This type of use is also on research by Volker Infra called "Advanced Information retrieval technologies" introduced in chapter 8.

> **In the OTL, any asset could be decomposed into subparts and thereby if aided by Big Data, predictions might become more accurate. e.g. a switch might be decomposed and linked to other components. The different correlations between the subparts might help to predict when the switch is more likely to fail. (Dijkhuizen, 2015)**

Ya Chen Lin –engineering assistant at Witteveen+Bos- considers that the OTL could integrate conflicting views in the handover of engineering specifications between different team's nationalities working in the same project(Lin,2015). Also in the field of international projects, Dijkhuizen find potential benefits in tender projects which is in his perspective is still done in a limited way not in accordance with the latest IT developments. Within the scope of the rail industry, a common legislation for all the EU member states is not a very far horizon. Since many years ago there have been visible efforts from the EU to integrate the different members rail networks.

> **I think an OTL could be useful in the specific case of EU member states for referencing since early stages as tendering. If our EU clients abroad would manage the same standard for storing the information about their assets a lot of paperwork could be saved. An OTL would help for automating the reviewing of tendering requirements and therefore it would possibly reduce costs in terms of man-hours used within the engineering firm. (Dijkhuizen, 2015)**

Disadvantages
On the other hand an expert working for Volker Infra -a traditional maintenance contractor- do not find many benefits of linking certain datasets as some key assets need to be updated regularly. Therefore the main constraint will be the updating costs. Additionally, the integration aimed by the OTL makes visible the existing data mismatching between different departments within organizations like Rijkswaterstaat. Therefore, there is resistance from different levels starting from the management. (M.Baggen,2015).

From the side of the contractors, they can benefit from extra-works in non-performance based contracts, it can be expected some reluctance on their side to adopt solutions as the OTL. This concern is bore by Joey Bekendam –systems engineer.

> **An OTL would save a lot of iterations in the whole process. Contractors now benefit of the lack of information given by clients. This means it will be hard to convince contractors of the benefits of OTL. (Bekendam, 2015)**

Moreover, for contractors using a new system involves investments they prefer to avoid. They see more the complexities and costs in short-term than the benefits in Long-Term as the horizon is not clear (M.Baggen,2015). This is related to the primary impediments described by London(2006) at the Initial state of IT developments. Moreover, a high resistance to heterophilic communication (i.e. communication between individuals who have different beliefs, education and socioeconomic status) is noticed as the OTL demands collaboration. To get an acceptable level of heterophilic communication is specially necessary between currently disentangled departments and along the supply-chain. Another disadvantage, relates to the category External motivation (Adriaanse, 2007) and the availability of contractual arrangements about the Open Standards.

> **Open Standards agreements affect RWS and also ProRail in a less extent e.g. standards used are COINS(Dutch), IFC and OWL. However, COINS was designed only for the building world and not for the Infra world. OWL does not tell about content as it was designed for artificial intelligence but not for Infra engineering. For this reason we decided to not use it in Rijkswaterstaat. (M.Baggen, 2015)**

Another kind of arrangement is related to the potential loss of competitiveness of e.g. PM&E bureaus if showing “more data than necessary” from an project’s OTL in a tender. There is the risk that the tender authority will share it with other market parties damaging the competitive stance of the private firm as former OTL’s data owner. (Folkerts, 2015). Regarding the knowledge and skills category (Adriaanse, 2007) this is more evident in case of the required knowledge by the field inspectors or mechanics from Maintenance Contractors. In the case that new standards to upload the inspection data are demanded by an OTL, the inspection staff would deal with knowledge issues(Folkerts, 2015). As Maintenance inspections are mostly focused on the reliability of the data, a big challenge when using an OTL for inspection will be to find a way to validate the data from the mechanics. This is related to the category of acting opportunities, subcategory of Alignment between ICT and working practices(Adriaanse, 2007).

> **In Maintenance there are strong needs to link data as e.g. frequency of maintenance or weight on tracks, however the OTL would demand a strong change management and training starting with the field inspectors. (M. Folkerts, 2015)**

Solitro(2015) from Network Rail(UK) also states a potential pitfall related to a knowledge problem as many accidents have taken place due to not appropriately reusing solutions from other systems. Thus, even if the information in the OTL can become very comprehensive, the human component should not be underestimated. At the end are the users of the OTL who decide how to use the advantages of re-useable data within unique projects.
Frans Többen-senior advisor in systems engineering in ARCADIS- also warns about totally relying on the OTL even if it achieves a high level of accuracy.

> **Even in the case that the OTL becomes very complete and accurate it might be risky to assume that all data inside is a replica of reality. The datasets cannot always be a hundred percent correct and therefore human validation will always be necessary (Többen, 2015)**

12. Stakeholders Mapping

As soon as the OTL is planned to be implemented, the process involves many actors. Finding an optimal way to implement the OTL involves to consider the interests of all the interested stakeholders. The context for the implementation is the Dutch Railway sector. The OTL is likely to have a stronger impact on the work of actors whose activities are more closely related to the handling of asset's data.

Rijkswaterstaat(RWS) is the most powerful party. It regulates the process and dictates the rules that can change the direction of the OTL. Although they have a high interest in the CB-NL, their interest in the rail's OTL is moderately high as they rely on ProRail.
ProRail is the second most powerful party after RWS. They can decide on particular aspects of the rail's OTL that are more in line to the needs of the Railway Industry. They are the most interested party in making the rail's OTL work.
The PM&E bureaus and Construction companies are not as powerful as RWS or ProRail. However, their knowledge and expertise gives them a privileged position in terms of power, especially when fulfilling the role of asset manager. Their interest in getting involved in the OTL is high as they are pushed by ProRail to improve their efficiency and update their systems. If not doing so, they might face the threat of loss of competitiveness.

Construction companies are not too interested in the OTL as they profit under non-performance contracts and therefore they might not show too supportive for improving data exchange processes early. (Bekendam, 2015).
The Maintenance Contractors are of two types(Folkerts,2015): the tradition-oriented and the IT-oriented. The first group includes the oldest and largest contractors whom might have a slightly more powerful position in terms the market due their credibility. They are however, more reluctant to new technologies partly due to high investments in legacy systems and also due to the age of their experts. Thereby, they might be not very interested in the OTL as it would mean a paradigm shift and big changes within their organisations. The second type, the more IT-oriented contractors are more open to new technologies and state-of-art practices. They support new initiatives like the OTL and are more open to R&D initiatives in order to become more competitive in the market toward bigger players.
The Operators, might find less direct benefits of an OTL. Therefore they are the less interested party. The link of the OTL with operations is done in an indirect way. As the OTL is intended to bring efficiency in maintenance tasks it might shorten maintenance times and

delivery sooner information to the operators and traffic controllers(Tissing,2015). The latter is exemplified in the Use-Case Traffic Control.

The Table below summarizes an Stakeholder analysis of the interests, influence and dependence regarding an OTL standardisation in the Railway Industry. It is followed by a 'power vs. interest grid'. Although the table and matrix' contents are based on insights provided alongside the interviews, it also includes subjectivity and personal interpretations. Therefore it is a referential base rather than a definitive assessment.

Actor	Goal	Substitutability	Dependence	Power	Interest
Government(RWS)	To standardize the exchange of asset data of all Dutch Infra systems.	Low	High	High	Medium
Infra Manager(ProRail)	To standardize the exchange of asset data of the Railway systems.	Low	High	High	High
PM&E bureaus	To speak the same language of the industry chain aiming for delivering quality services.	Medium	High	Medium	High
Construction Companies	To have the right data for tenders and during realisation.	Medium	High	Medium	Medium
Maintenance contractors(IT)	To use reliable and up-to date data based on state-of-art techniques.	Medium	High	Medium	High
Maintenance contractors(Traditional)	To use reliable and up-to date data based on credibility and experience.	Medium	High	Medium	Medium
Operators(NS)	To access faster to reliable maintenance data.	Low	High	Low	Low

Table 7: Substitutability, Dependence, Power and Interest of Stakeholders (own creation, 2015)

The 'Power vs. Interest Grid' ranks all stakeholders in a two-by-two matrix. The axis are the stakeholder's interest in the issue, and the stakeholder's power to influence the issue. This results in four different categories of stakeholders: 'players', who have both a high interest and a high power; 'subjects' who have a high interest but little power; 'context setters' who have a little interest but high power; and the 'crowd' who have little interest and little power. The primary function of this grid is to identify the players, whose interests and power bases must be taken into account in the project(Eden & Ackermann, 1998).

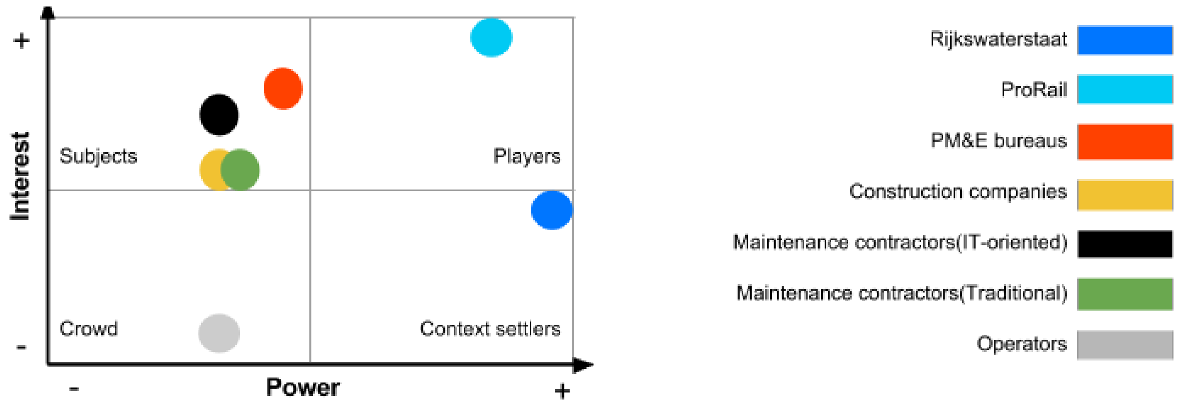


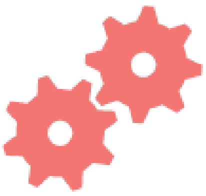
Figure 39: Stakeholder's Power VS. Interest Grid (own creation, 2015)

13. Value System Design

Based on the survey results the main purpose of the OTL model is to have a unified, semantically unambiguous exchange of data. This applies to any asset's data exchanged between ProRail, collaborators and contractors. In the current model the interoperability of the subsystems is very limited, which results in unnecessary repetition, duplicate data and additional overhead. To overcome this, the system design must aim for improving the efficiency and user friendliness of the system. Moreover, the development of the OTL needs strong collaboration to get early agreements and change management to overcome acceptability issues within ProRail and within each chain party.

To enhance efficiency of asset's data exchange
(Functionality, Consistency, Openness)

- Challenges: IT Systems compatibility; costs of upgrading data in existing systems; consistency of current regulations and requirements.
- Risks: miscommunication; chain's parties commitment is not possible; supply chain clashes with the new otl's hierarchical model; resistance to switch from contracting to maintenance department mindset; resistance to change contracting culture.
- Tensions:
  - ProRail: chain's parties collaboration.
  - Contractors: transition costs.
  - Developers: legacy systems, scope complexity(features, attributes).



To build a usable OTL model and dataset
(Completeness, Accessibility, Technical advanced, Adaptability)

- Challenges: Different engineering cultures; understanding object-oriented designing; integration in design-programs; BIM development versus short term adjustments of data structures; visibility on the functional features extends beyond the released versions; ownership of data; hierarchical integration of standards.
- Risks: poor and/or incomplete handover; software vendors not interested in open standards; overdeveloped OTL becoming too complex; being too broad and abstract; the tree structures is solely object-based; same concepts with different meanings appear as attributes; other interests are overlooked e.g. SEs.
- Tensions:
  - ProRail: chain's parties collaboration.
  - Contractors: training.
  - Developers: scope complexity(features, attributes).

To ensure reliability of data
(Accuracy, Updatability, Clarity of Architecture)

Challenges: Many initiatives for OTL's; costs of keeping the OTL up-to-date; data validation; real-time availably; training of inspector.

- Risks: transfer of flaws from ProRail's OTL to contractor's; inspectors cannot sent the right data; updating ongoing project's data.
- Tensions:
  - ProRail: chain's parties collaboration.
  - Contractors: transition costs, training.
  - Developers: legacy systems, scope complexity(features, attributes).

The user friendliness of the OTL interface determines how easy users can retrieve the desired asset's data. This comprises the complexity, clarity and amount of features attributes included in the OTL environment. Moreover, it relates also to efficiency of the implementation, the usability of the system and the reliability of data defined and structured within the OTL.
Additionally, the interoperability between systems affects how efficient is the OTL Model. Moreover, the efficiency consists of many aspects like operational, investment and maintenance costs. Though, based on the focus of the Spoordata program and the stated preferences of stakeholders in the surveys, the Functionality in terms of interoperability turns to be the main criteria to judge the OTL's efficiency. In order to achieve this first some challenges need to be overcome like the current systems incompatibility; costs of upgrading data in existing systems and improve the consistency of current regulations and requirements.

Furthermore, in a critical time-oriented industry like the Railways (especially during operations) it is of major importance that the asset's data can be relied on. Otherwise extra-time to validate and fix is costly and may affect performance and the passengers experience. Thus, formal validation protocols to assure reliability of data, turnarounds and redundant processes should be also considered in the case the OTL fails. These objectives and their structured relationships are depicted in the objective tree below. Complementary, a table of the criteria and definitions per objective can be found in the Appendix.

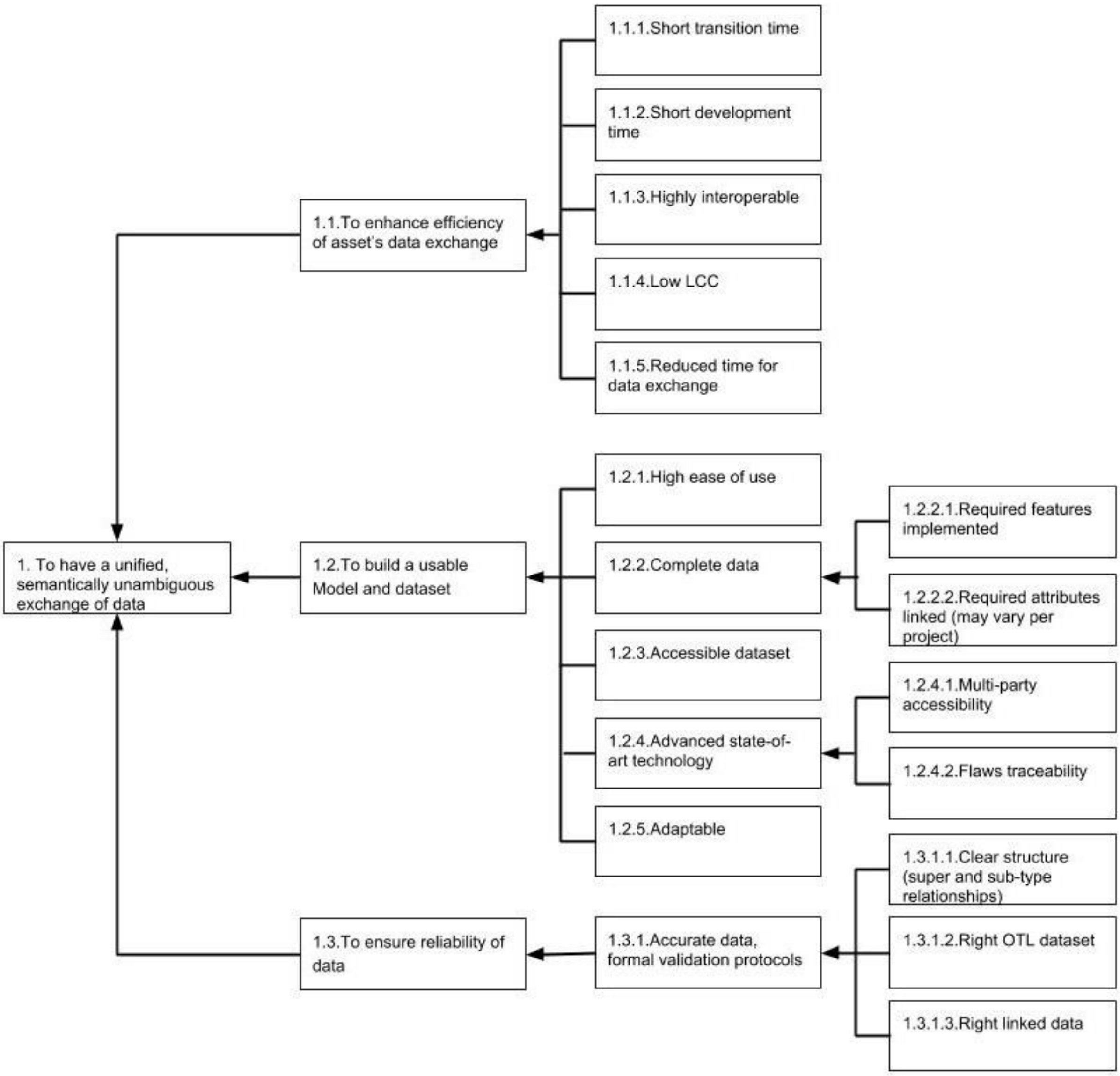


Figure 40: OTL' objectives tree(own creation,2015).

Constraints
The constraints or limitations are the restrictions or boundaries to the OTL' development problem. These restrictions set the boundaries of the conceptual system. Besides, the constraints can be separated in two main groups: formal constraints and stakeholder's perceptions of constraints. The first group includes formal requirements, regulations, laws and implicit limitations to the system. The second group relates to those constraints seen by stakeholders based on the interviews and surveys. Accordingly, the following constraints can be listed in the case of the OTL development: First, the formal constraints are:

- Requirements of ProRail Departments.
- Requirements of the Supply-chain.
- Information Standards.
- Dutch Law.
- Future data' ownership regulations.
- Internal ProRail's regulations.
- Specific project's agreements on data exchange.
- Budget.
- Amount of OTL users retrieving information at the same time.
- Subsystem integration.

Secondly, a group of stakeholder's perceived constraints are:

- Current engineering cultures and understanding of object-oriented design.
- Compatible software.
- Structure of current datasets.
- BIM development goals vs short-term adjustments of data structures.
- Time to integrate current systems.
- Reliability of source data.
- Reliability of supporting technologies.

Alterables
The Alterables, also known as variables or parameters, are the factors of the problem that have an important impact when changed. The variables can be controllable or uncontrollable, but the focus in this research in on the ones that ProRail is more capable to control. Thus, they can be adjusted in order to reach a specific outcome.

- Duration of transition to new system.
- Duration of development.
- Number of subsystems that are integrated and interface.
- Number of features.
- Integration to future scenarios.
- Clarity of system hierarchy and decomposition.
- Validity of information.
- Validity of linked information.
- Budget

System diagram
The system diagram is a helpful graphical aid which illustrates the different interdependencies within a large and complex system in a structural manner. Moreover, relevant assumptions and expectations are shown in a system diagram which makes it a good communication tool towards a client (Enserink, 2010). A limitation however depicts to the completeness of the diagram which increases proportionally to its complexity. Thus, only the most relevant aspects have to be chosen. A system diagram builds upon the following main elements:

- Means: the inputs regarding the activities per objective.
- System: includes all the different system factors, assumptions and alterables.
- Criteria: the agreed criteria to assess each objective.

- External factors: such as the constraints which may limit the room for maneuver for certain system factors.

In addition, the system diagram helps to show different actor's perspectives. The figure below shows an overview on how the most relevant components of the assessed system interact with each other. Accordingly, arrows show how the means and external factors affect the system' factors; how factors interact with each other and finally how these factors affect the criteria. The blue colored arrows represent a positive impact whilst the red colored arrows sign represent a negative impact (grey arrows represent a variable impact dependent on the predecessor).

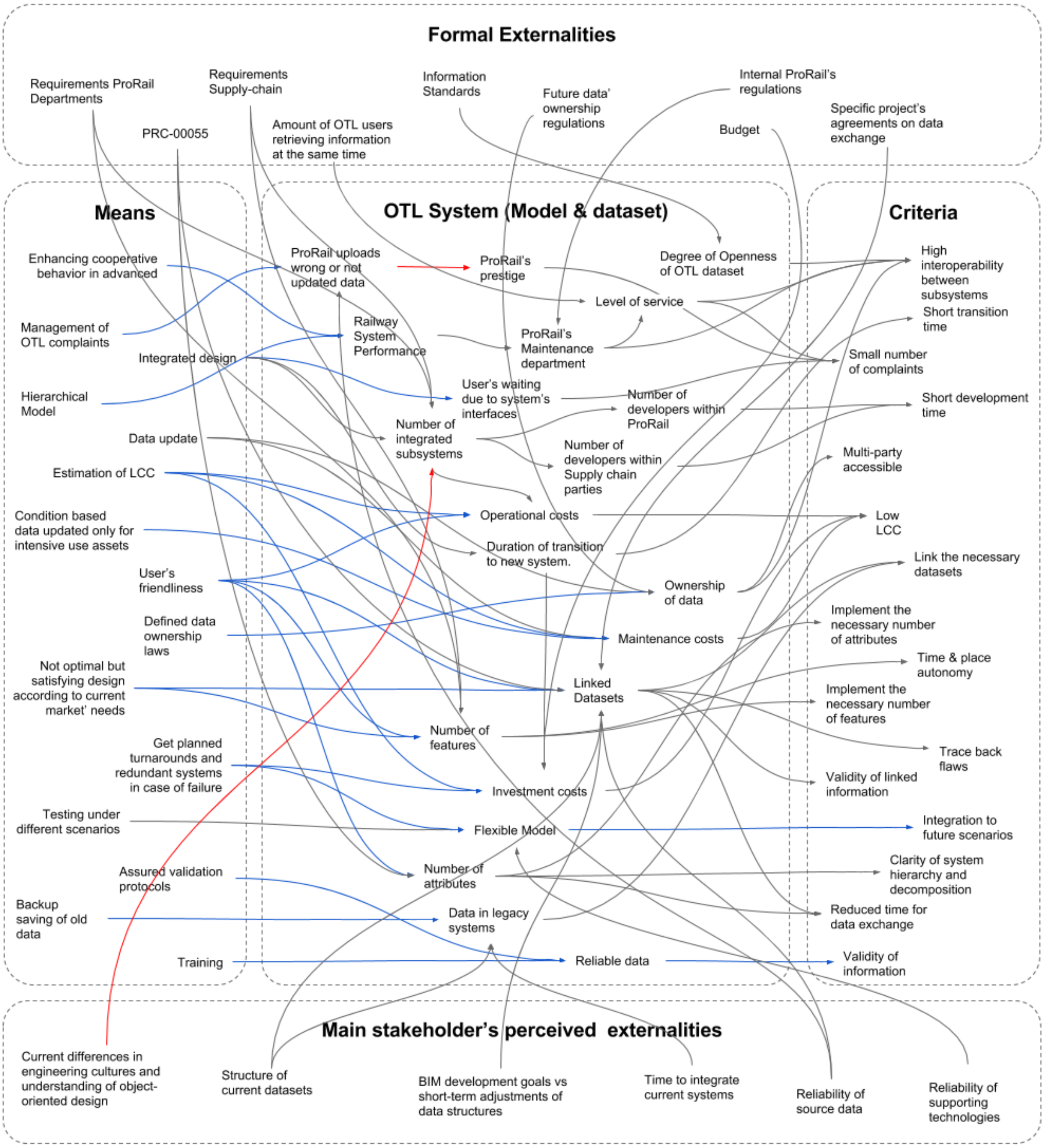


Figure 41: OTL' value system design(own creation,2015).

14. Performance Indicators

From KPIs to EPIs

At its highest model the OTL is a conceptual information model and does not contain data(sets). (Baggen,2015b). In Literature the Key Performance Indicators(KPIs) often found are used to assess the quality of actual datasets, systems or software(M0 level, Figure 35) but not for the Information model that classifies them. The same lack of measures can be noticed in the Infrastructure sector' models.

> **When you start comparing the quality aspect of the OTL itself to other existing Modeling approaches you will discover that e.g. there are no established quality guidelines within RWS that tell you how to develop a "good" ARC-GIS M1 model (for Geographic information systems), such as Kern-GIS, DTB, BKN or a (M1) SAP or other Relational Database model, (M1) Relatics environment, etc. (Baggen,2015b)**

At the level of content(M1 level, Figure 35) however, the OTL can be view as a dataset which is classified based on the OTL metamodel (M2 level, Figure 35) and thereby, KPIs can be used at this level. According to Baggen(2015b) the OTL' performance will be possible to be measured in long term after a number of datasets have been acquired.

At the time this research takes place the OTL is still at an early stage and thereby it is not possible to assess the quality performance of the OTL yet. Nowadays the tests done to the OTL are mainly automated and report the internal consistency whilst other aspects are subject to human assessment by experienced model developers(Baggen,2015b). Therefore, KPIs can be rephrased as EPIs (expected performance indicators) that aim to gather information about the expected quality performance of an OTL aligned with the expected possibilities based on the current level of development and pilot projects such as the Zuidasdok.

Definition of EPIs

The criteria derived from the Value System Design set the basis for defining performance indicators. They were compared with a comprehensive list of indicators extracted from Nederveen S. et. al.(2013), Schouten & Soeters(2014) and Opgenoort(2015) to be furtherly refined after linking the preferred choices from the two surveys. The links in the figure below represent the strongest relationships between the components of each survey. This is based on insights form the surveys, though it also includes personal interpretation and therefore subjectivity. However, it provides a systematic approach that can be referenced for further Performance indicators development.

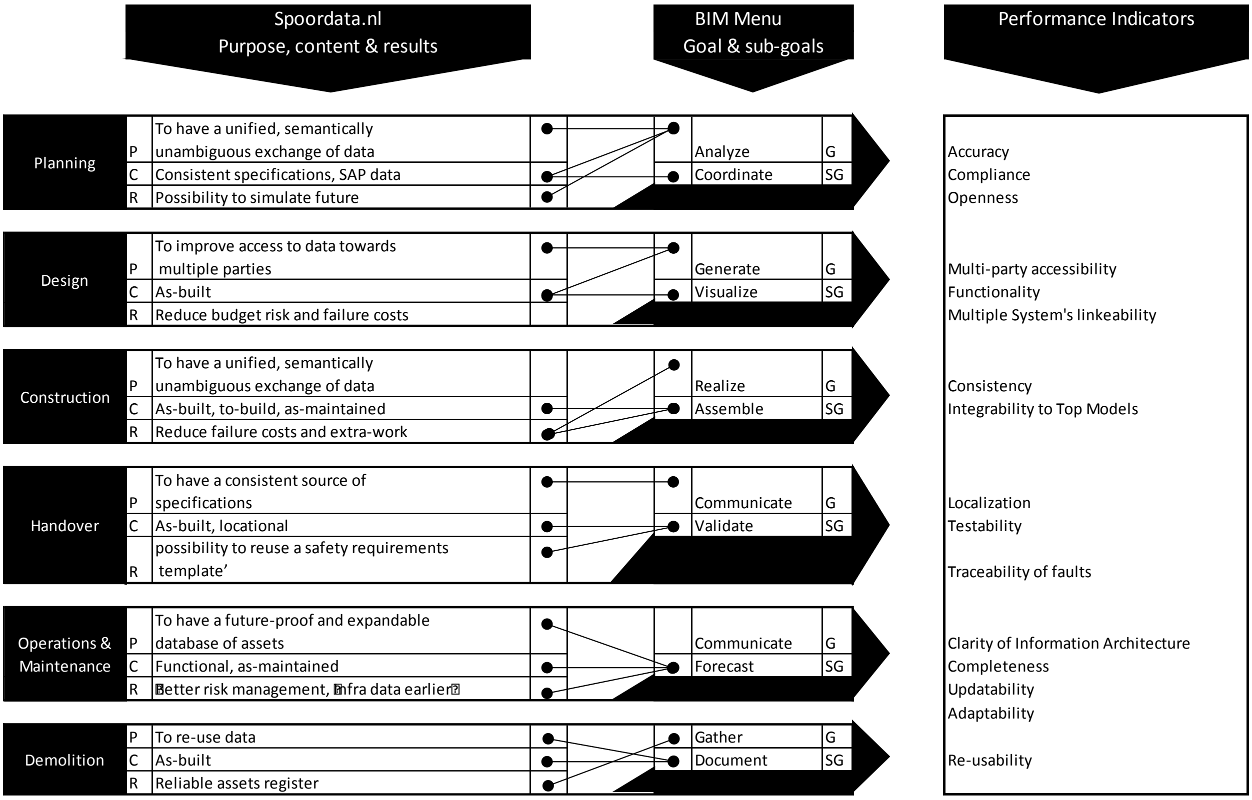


Figure 42: Performance Indicators derived from both surveys(own creation,2015).

For instance, to be able to start using an OTL, it needs to comply with the different standards agreed between ProRail and the supply-chain parties. For the same reason there is a strong need of openness without license constraints for exchanging asset's data. In addition, when analysing project's information the linked data need of high accuracy.
In the design phase, in order to agree on the generation of models multiple parties need to access to the same BIM environment. An OTL provides a previous step where definitions of objects are agreed alongside all the supply parties. Complementary, in order to be useful, ProRail will demand a good functionality in terms of inter-operability between different systems and the OTL. In addition, supply-chain parties need the OTL assures the right linkeability with requirements datasets.

In the Construction phase the OTL needs to provide a consistent environment in order to realize infrastructures without incompatibilities, clashes and time/costs overheads. Additionally, awareness about BIM started in the building industry and therefore it can be considered a cornerstone within the lifecycle in order to look for the integrability, The latter is pursued by Rijkswaterstaat with the CB-NL and it reaches international standardization goals with initiatives like Building Smart. In the Handover of data to Maintenance, an OTL will bring more value if it provides asset's identification based on location as described in the use-cases in the next chapter. Besides, as validation is pointed out as a BIM goal, the OTL system's architecture and content needs to be tested before information is transmitted. Complementary, when faults are found they need to be traceable in order to allocate responsibilities and find the most suitable party for updating changes.

Parties working in the O&M phase, can demand data to be traced in complex information structures. Thereby, the OTL' information architecture must be clear enough in order to forecast reliable data based on functional and as-maintained datasets. In addition the more complete the OTL, the better the forecast made for risk assessment purposes. Moreover, in order to get a future-proof and expandable OTL, it's performance should be assessed in terms of ease to update and adapt to iterative information needs.

Finally, in the demolition phase asset's data need to be re-usable to facilitate the gathering of reliable data to support BIM processes. Data that has been already validated and recorded/documented would be of high value when new interventions take place on an existing project. Though, typical asset's data which is possible to be used in more than one project will speed up processes throughout ProRail's projects portfolio.
Besides the indicators described above, other indicators have been added based on suggestions brought by personal interviews. Thus, based on Baggen(2015) accuracy of data is split up in reliability of 'as-built' and 'to-built' data. Moreover, several experts (Baggen,2015, Opgenoort,2015 and Tissing,2015) stressed the importance of the transition time needed to understand the object-oriented-design mind-set necessary to make the OTL work. Additionally, some performance indicators can be clustered according to common traits like in the case of testability, traceability and re-usability. All the previous represent OTL' technological features and thereby they were grouped under 'technical advancedness'. All that stated, the table below provides an overview of the EPIs and the performed clusters. Nevertheless, a more practical description of the EPIs listed above can be made in terms of the actual use of the OTL for the stakeholders. Thereby, some use-cases are proposed as elaborated in the next section.

Indicators	Sub-indicators	Definition	
		Model	Dataset
Accuracy	Reliability of 'as built' data	How accurate the model represents reality.	Deviation of OTL data in respect to actual as built data.
	Reliability of 'to build' data	How accurate the model represents reality	Deviation of OTL data in respect to actual to build data
Accessibility	Time-independent	Ease to access in spite of time	
	Place-independent	Ease to access in spite of place	
	Multi-party Accessibility	Number of parties able to access to same data	
Technical advancedness	Testability	Easy process to validate Model	Easy process to validate data
	Traceability of faulty inputs	Number of faults tracked	
	Re-usability	How many data can be re-used	
Clarity of Information Architecture		Clear structure and system' relationships.	Time it gets to find desired object since logged.
Functionality (Interoperability)		Capability to interface with a number of systems.	
Completeness		Sufficient structure and connections.	All needed data is in the dataset.
Consistency		Model is valid according to agreed rules	Object's definitions are valid based on agreements.
Updatability		Time it takes to update model	Time it takes to update data
Openness		Number of license barriers when interfacing	

Table 4: Expected Performance Indicators (own creation, 2105)

15. Use-Cases

The elaborated use-cases are collections of possible sequences of interactions between the OTL implementation and its external actors(the Rail's stakeholders), related to the expected EPIs. Based on Cockburn(1997) "actor-to-actor" communication model, systems can be understood as actors that interact with the external actors. The interactions are made between the actor's whom have responsibilities, goals and actions.
Besides, there are two main aspects of the Use-cases (Cockburn,1997):

- An action connects one actor's goal with another's responsibility.
- An interaction can be simple(just sending a message) or compound(sequence of interactions).

From the two aspects above it can be stated that:

- The OTL system constitutes the *interfacing actor* that connects the primary actor' actions (ProRail) with the secondary actor' responsibilities(stakeholders).
- The interaction between ProRail's goals and the stakeholder's responsibilities will be likely to be compound i.e. a set of sequences bundled in a single message item e.g. retrieval of information from ProRail's SAP PLM system.

All the previous stated, the format suggested by Cockburn et al. (2002) is used for structuring the Use-cases.

	<the name should be the goal as a short active verb phrase>
Context of use:	<a longer statement of the goal, if needed, its normal occurrence conditions>
Scope:	<design scope, what system is being considered black-box under design>
Level:	<one of: Summary, User-goal, Sub-function>
Primary Actor:	<a role name for the primary actor, or description>
Stakeholders & Interests:	<list of stakeholders and key interests in the use-case>
Precondition:	<what we expect is already the state of the world>
Minimal Guarantees:	<how the interests are protected under all exits>
Success Guarantees:	<the state of the world if goal succeeds>
Trigger:	<what starts the use-case, may be time event>
Main Success Scenario:	<put here the steps of the scenario from trigger to goal delivery, and any cleanup after> <step #> <action description>
Extensions	<put here there extensions, one at a time, each referring to the step of the main scenario> <step altered> <condition>: <action or sub-use-case> <step altered> <condition>: <action or sub-use-case>
Technology and Data Variations List	<put here the variations that will cause eventual bifurcation in the scenario> <step or variation # > <list of variations> <step or variation # > <list of variations>
Related Information	*<whatever your project needs for additional information>*

Table 5: Use-case Fully dressed Form (Cockburn et al. ,2002)

This model considers three levels of goals(Cockburn,1997)::

- The user goal is the goal of greatest interest. It is the goal the primary actor has in trying to get work done, or the user has in using the system at all.
- Summary level goals involve multiple user goals. They serve three purposes in the describing the system: to show the context in which the user goals operate, to show life-cycle sequencing of related goals; and to provide a table of contents for the lower-level use-cases.
- Sub function-level goals are those required to carry out user goals. They are needed on occasion for readability, or because many other goals use them.

All the above stated, six use-cases are elaborated below. The first four cases are: System's Architecture and Three use-cases in system's maintenance(corridor Schiphol, switches and traffic control). They are focused on personal interviews made to ProRail' experts.
The last two use-cases are SAP-PLM and DOOB for which insights were gathered from ARCADIS' experts.

15.1. System's Architecture

According a System's Architect in ProRail an OTL can help to improve the information of objects/systems in a System's Architecture management process. When an goal(Organizational Targets Level) is set e.g. improve the maintenance time, the OTL can enable to take a deeper and detailed look into the "as built" or "as maintained" information of systems at an object (Design Solutions" level). Moreover if an OTL makes possible to trace back maintenance information linked to assets at "decomposition levels" , the possibilities for improving the overall maintenance of the system will be higher. (Kalshoven, 2015)
The figure below illustrates the System's Architecture process of ProRail.

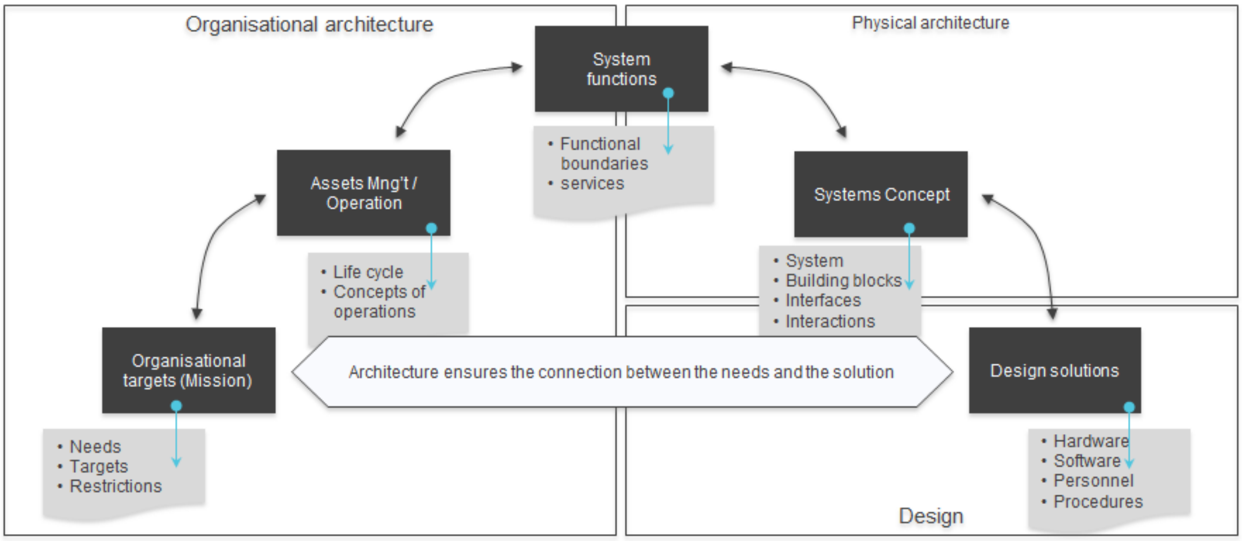


Figure 43: System's Architecture process Model (Kalshoven,2015)

One subsystem which poses big challenges is the train detection' subsystem that contains isolated weldings, relais, and a rail section including ballast which is an important (but almost unknown) part of this subsystem. In 2013 there were 40 failures with this subsystem on the track Hertogenbosch-Eindhoven. Each incident took about 68 minutes to solve. Therefore, for ProRail's interests this subsystem is not reliable enough so far. Moreover is a concern for the future when the trains' frequencies will increase. (Kalshoven, 2015). As suggested below, the OTL might save a great amount of work and time, necessary to update solutions due to the linking of safety requirements to train detection assets from document based sources.

If the recipe 'train detection' were part of the OTL ProRail and therefore part of an architecture Railway it wouldn't take a lot of time to change the object = recipe train detection (including specifications, maintenance records, etc.) when the solution is found. Nowadays it takes a lot of work to change all design specification (ontwerpvoorschriften) which are linked with the subsystem. (Kalshoven, 2015)

To exemplify the use of the OTL in System's Architecture the case of the rail joints with insulated (or isolated) welds is assessed.

Rail Joints and Isolated welds

The rail joints assure the continuity of the rails until certain speeds and thereby ensure safety of rail traffic(van der Wald, 2015). Complementary, sections of rails are insulated joints which are mutually electrically insulated track sections used for train detection. An important part these sections are the isolated welds (ES-las). These electrically separated sections are required to prevent trains collide with each other. In total, the Dutch railway network contains approximately 50,000 of these separation welds. Although their reliability and availability is important they have a limited life due to train vibrations. Moreover, the current ES-las have two main flaws: *they cause noise and signal failures of train's location.* (movares.com)

The breakdown components of the joints are: broken rails, glued fish-plates and steel bolts as seen in the two Figures below.

Figure 45: Components of Insulated Rail Joints (Sheikh et. al, 2014)

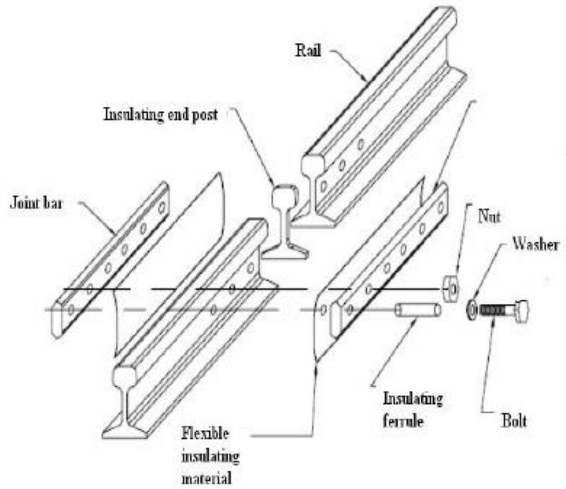


Figure 44: Standard joint (PixOnTrax, wikipedia.com)

A maintenance engineer involved in ES-las points to the fact that many datasets are currently worked in a document-based manner adding to the inefficiencies of gathering joints data. (van de Wald,2015)

> **The problem is that from an Asset Management perspective we have realized that there are processes related to joint's maintenance' information that can be optimized. The current document-based processes cause time delays and affect the maintainability of the assets. (van de Wald, 2015)**

The OTL offers a solution for updating the data of train detection subsystems like in the case of the ES-las. This can be achieved by improving the current way of working (document-based) and linking requirements to assets within a OTL 's train detection recipe(as suggested by Kalshoven). This benefit is elaborated in the Table below.

"I want to use the OTL create a 'Train Detection Recipe' in order to link safety requirements to the ES-las"	
Context of use:	The System's Architect uses the OTL to create a 'Train Detection Recipe'(system's liked to safety requirements) which links requirements and specifications to the ES-las.
Scope:	• Train Detection Recipe', focused on Insulated welds (ES-las). • Use: System's Architecture. • Asset system: Train Detection subsystems. • Lifecycle phase(s): Maintenance. • Linked data: Safety requirements.
Level:	Sub-function
Primary Actor:	ProRail' Systems' Architect.
Stakeholders & Interests:	• Asset Owner (ProRail): Standardization of data exchange within ProRail and with the Asset Managers and Contractors working with ES-las. • Asset Manager: Condition data is available earlier. Improve information process.
Precondition:	ES-las' safety requirements already in a system makes validation easier(e.g. SAP)
Minimal Guarantees:	(To define by collaboration between interested parties and OTL developers). Recommendations: • Linked requirements can be validated / updated.
Success Guarantees:	When a solution to ES-las is found, the safety specifications are quickly updated based on a quick overview of the Train Detection Recipe in the OTL.
Trigger:	The user logs in the OTL and browses the object type "rail joints"
Main Success Scenario:	1) The user logs in and browses 'ES-las'. 2) The subsystem' tree shows object types from which "Train Detection" is selected. 3) Options are displayed to identify a desired joint e.g. based on location. 4) A sub-tree shows the 'Recipe' --i.e. a new set of attributes relevant to Train Detection-- from which the user selects "Safety requirements". 5) Links to requirements are displayed from which the user is directed to an external dataset containing relevant information to the specific desired asset.
Extensions	5a) The information in the dataset needs to be validated. 5a1) After validated. The validation records can be linked in the OTL under a new attribute/set of attributes.
Technology and Data Variations List	2a) A link to an external dataset "Train Detection" is displayed. This external system -e.g. SAP- includes information relevant to the specific asset including safety requirements.
Related Information	Most relevant EPIs: • Clarity of Information Architecture • Accuracy(reliability of as built & to build data) • Technical advancedness • Updatability • Consistency

Table 6: Use-case Systems' Architecture (own creation, 2105)

15.2. Three Use-cases in infra system's maintenance

The Supply chain's Data-Management Problem

Ruurd Tissing-Specialist in Rail's Construction and Maintenance- from ProRail points to the Supply-Chain Data-Management Problem as one of the biggest challenges in railways' Maintenance. The amount and variety of levels/lines of contractors raises the complexity of the problem. Consequently, two main issues are derived (Tissing, 2015):

- **First issue: The Distributive Model**
  The current ProRail's information management model is distributive. This can be linked to a contracting-oriented culture. In this case as the Information system is only focused on the needs of a System Architect/Designer, he/she relies on external parties' knowledge. Therefore, there is not the "necessary level of partnership" needed for an integrated functional breakdown.

- **Second issue: Ownership of data**
  Who owns the datasets of the System at the highest top level?
  There is not a clear ownership of a Central Information Management System that integrates all their views e.g. Volker Rail is a 1st line maintainer and another contractor let's say a 3rd line party is in charge of modifications. Often, they don't know what they're doing in relation to the whole system performance (contrary to ProRail's view in which maintenance should support design systems and performance).

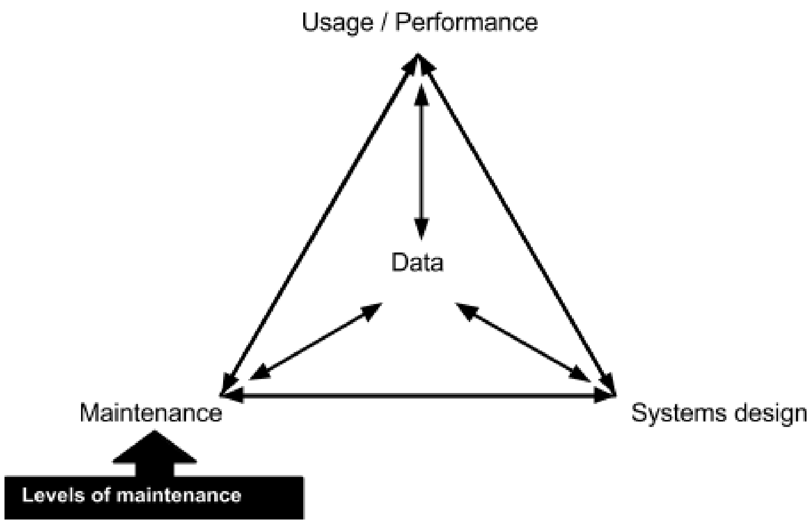


Figure 46: Maintenance' data inputs in a whole System' Overview (Tissing, 2015)

According to Tissing (2015) the solution should involve an integrated information system that provides a complete chain overview of maintenance tasks which goes into the system design and is linked to the performance. This however won't work without clear directives for data ownership and integration. Lessons can be learned from the automobile industry. e.g. BMW management of the production chain of "Mini cooper" with a complex network of production suppliers. BMW was able to manage the operations not only within their organization but alongside the supply chain.

To achieve a comparable level of data integration in the Dutch railway industry, a strong level of cooperation and structural changes are needed within both the supply market and the Management organization.

Regarding the structural changes within ProRail, now there is an absence of a real Maintenance Department; instead there is a Contracting Department. This makes it complicated to manage the whole maintenance chain. Regarding the structural external changes with external parties, now the contracts are rule based instead of performance based. This is reflected in a rule-based system design. (Tissing, 2015)

Although the scope is much broader than a single solution, the OTL Model can add to the efforts for integrate the systems alongside the supply chain. This can be better understood in the cases of three asset's systems: Corridor Utrecht, Switches and Traffic Control.

15.2.1. Corridor Schiphol-Utrecht, handover to Maintenance

In this corridor a project ("Schiphol Utrecht-Arnhem/Nijmegen stretch") is in progress as one of the first major steps is an adaptation of the flow station Utrecht (DSSU). Trains in the station area run in high speed to increase both the capacity and reliability of this important node. (rijksoverheid.nl)
This project adds to the complexity of maintaining the corridor. Regarding information management a major problem is related to the issue of Ownership of data (Tissing, 2015).

A design bureau like ARCADIS can work with a Building Contractor. But their relationship will only last a limited time. Then the handover to maintenance is done and the Route Managers can control only the part of the data/knowledge that affects the first line/level of maintenance. (Tissing, 2015)

As intended by RWS the OTL aims to fill the information gap between the Contractor parties and the Asset Management parties (Baggen, 2015). Accordingly, ProRail has a similar purpose with and within the Railway's supply chain (Schouten & Soeters, 2014).
This can be done if contracting parties work in close collaboration in advance in order to transfer their data/knowledge to the ProRail's Information Management Systems including the OTL.
Thus, the OTL use is elaborated for the case of information handover for the Corridor Schiphol-Utrecht as seen in the Table below.

“I’d like to use the OTL to improve the Handover of data to Maintenance in Rail Corridors”.	
Context of use:	ProRail’s Information Supply-chain Management uses the OTL to avoid loss of performance oriented-data in the Handover from Realisation to maintenance and throughout the different lines.”
Scope:	• Keep performance-relevant information to be handed over to and by the Route Managers. • Use: Maintenance’ Supply Chain Information Management • Asset system: Corridor Utrecht • Lifecycle phase(s): Realisation, Handover, Maintenance • Linked data: Performance oriented
Level:	Summary goal
Primary Actor:	ProRail’s Information Supply-chain Management
Stakeholders & Interests:	Asset Owner (ProRail): Keep performance oriented-data even if is not used at earlier LC stages. Asset Manager: Efficient communication with the different lines. Improve the total system’s overview. Contractors / Builders: Avoid extra-costs from innovation and extra effort
Precondition:	• Shift from Contracting view to an Integrated Maintenance view. • More use of performance based contracting instead of rule based. • Data that is relevant for performance is kept in a standard format and then handed-over to the Asset Manager
Minimal Guarantees:	Defined by Supply-chain Management based on performance goal’s needs..
Success Guarantees:	• The OTL provides an overview of the parties contributions to the total system’ performance. • The OTL helps to integrate performance data alongside the supply chain within all the lines.
Trigger:	The Information Supply-chain Manager logs in the project’s OTL.
Main Success Scenario:	1) The user logs in and browses a desired system/asset. 2) The OTL’ system tree is opened displaying options to identify a desired asset e.g. based on location. 3) Branches display different attributes from which the user selects “Performance” 4) A sub-tree shows a new set of attributes from which the user selects e.g. “Performance Indicators” 5) Links to performance indicators are displayed from which the user is directed to an external dataset containing relevant performance information to the specific desired asset.
Extensions	5a) The information in the dataset needs to be validated. 5a1) After validated. The validation records can be linked in the OTL under a new attribute/set of attributes.
Technology and Data Variations List	3a) A link to an external dataset “Performance” is displayed. This external system includes information relevant to the specific asset’s performance including performance indicators.
Related Information	Most relevant EPIs: • Functionality (Interoperability) • Consistency

Table 7: Use-Case Corridor Schiphol-Utrecht (own creation, 2105)

15.2.2. Switches' decomposition

Figure 47: Passing on the switch(es) (Harry Klinkenberg)

Thanks to switches, trains, can change tracks. In the Dutch rail network there are approximately 7000 switches. They are susceptible to interference and duration (including security they cost around 500,000 euros each). ProRail therefore gives additional priority to effective preventive maintenance. (prorail.nl)

There are currently about 30 kinds of switches in use. ProRail strives to increase standardization and innovation, to manage the switches faster, easier and cheaper. That's why in 2012 a project started where switch manufacturing and use is controlled from start to finish. It includes all the life cycle of the asset: design, location, construction and maintenance. (prorail.nl)

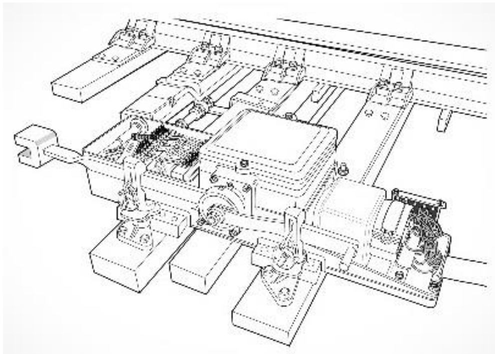


Figure 48: Dual Control Power Switch Motor (psdcovers.com)

Tissing(2015) provides some insights about the challenges of integrating switch maintenance' data within the supply-chain lines. If the data of a component needs to be integrated e.g. the electric contacts of the motors the following challenges can be expected (Tissing,2015):

- Design contractors would prefer to buy a complete switch;
- First-line maintenance contractors would not be interested in data at this level of details;
- Financial Managers would show the same lack of interest.

Thereby, the problem is that each party is interested only in working with a fragment of information about the system. This problem needs efforts in collaboration in order to make the parties realize about common goals. To totally overcome this challenges, long-term plans are necessary as it involves a change in the parties "culture and core values".
However, the OTL Model can represent the environment that helps to integrate datasets and that shows the parties the bigger picture of the systems they form part.

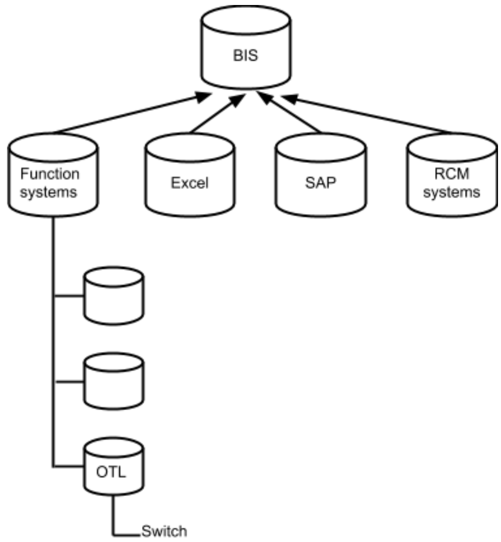


Figure 49: The OTL as a Function system within the ProRail's BIS (Tissing, 2105)

Complementary, Tissing(2015) supports the idea of an OTL used to enrich the assessment of system's performance. The case of switches can illustrate this aim. Switches' data is assessed in Information Business System(BIS) fed by excel, SAP, Asset's functions systems and others. Based on information extracted from these systems, a visual platform is used to verify the correct functioning of the infrastructure at an specific section of railway. The same process is made for different sections to be furtherly put together to assess the performance of a complete corridor/railway system.

The main problem comes when focusing on the Function Systems. Nowadays the information goes to an asset's level missing many details about the subcomponents. (Tissing,2015)
The OTL allows to go deeper into details in an efficient and quick way. Thereby, the details i.e. data about subcomponents e.g. The Electric Contact will enrich the assessment of the system's performance. This benefit is elaborated in the Table below.

"I'd like to use the OTL to improve the assessment of performance by increasing the level of detail of switches' data in the Function Systems".	
Context of use:	ProRail's Information Supply-chain Management uses the OTL to get a deeper view in the decomposition of switches in the Function Systems of their BIS. This enables a better assessment of performance in the visualization environment.
Scope:	• Switches are decomposed until a desired level e.g. Electric contacts. • Use: Maintenance' Supply Chain Information Management • Asset system: Switch • Lifecycle phase(s): Operations & Maintenance • Linked data: Performance-oriented
Level:	User goal
Primary Actor:	ProRail's Information Supply-chain Management
Stakeholders & Interests:	Asset Owner (ProRail): To improve the assessment of performance. Asset Manager: To improve maintenance' performance. Contractors / Builders: Avoid extra-costs from innovation and extra effort
Precondition:	• Shift from Contracting view to an Integrated Maintenance view. • More use of performance based contracts instead of rule based. • The Parties collaborate to complete the details of the switch and to provide the performance-oriented data required by ProRail.
Minimal Guarantees:	Defined by Supply-chain Management based on performance goal's needs..
Success Guarantees:	The OTL brings a consistent and complete view of the switch decomposition linked to performance data.
Trigger:	The Information Supply-chain Manager logs in the project's OTL.
Main Success Scenario:	1) The user logs in and browses "Switch". 2) The OTL' system tree is opened displaying different attributes from which "Switch Construction" is selected. 3) Branches display different attributes from which Box is picked. The same process is done and "box">"motor">"electric contact" is selected. 4) A sub-tree shows a new set of attributes from which the sequence "Performance"> "Performance Indicators" is selected. 5) Links to performance indicators are displayed from which the user is directed to an external dataset containing relevant performance information to the Electric contact. 6) The system's data is exported to the visualization platform.
Extensions	5a) The information in the dataset needs to be validated. 5a1) After validated. The validation records can be linked in the OTL under a new attribute/set of attributes.
Technology and Data Variations List	4a) A link to an external dataset "Performance" is displayed. This external system includes information relevant to the specific asset's performance including performance indicators.
Related Information	Most relevant EPIs: • Functionality (Interoperability) • Consistency • Completeness (sufficient breath, scope for a task) • Updatability

Table 8: Use-case switches' performance(own creation,2015)

15.2.3. Traffic Control

The design and construction of rail infrastructure and rolling stock are affected by the operation rules; thus the performance of the railway system is also impacted by the operation rules(Wang, 2014). In railway systems, the operation of trains is in general controlled through a hierarchical control framework with five levels, i.e., scheduling, real-time (re)scheduling, remote traffic control, interlocking and signalling, and train and infrastructure control(Luthi, 2009).

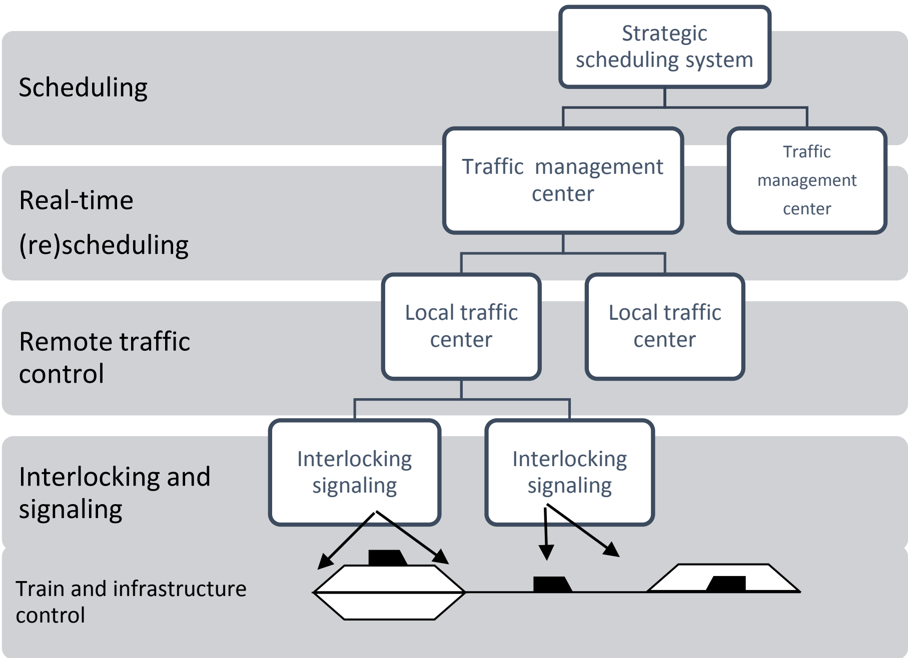


Figure 50: Hierarchical structure of the railway operations (adopted from Luthi, 2009)

Regarding information management, currently the main problem is the lack of a Client's role in the system due to incomplete data affecting the overall performance. (Tissing, 2015) Performance needs metrics and has to deal with changes during planning. Both aspects- metrics and changes- complicate the system design, resulting in incomplete information handed over to maintenance parties and finally used by traffic controllers.

The Spoordata program states the following goals for the Operations phase: Infrastructure information available earlier, timely information on train systems, reduce adjustments costs, 5% less adjustments, better risk management. (Schouten & Soeters, 2014)
From the surveys the first goal "Infrastructure information available earlier" is the choice in which most stakeholders find the OTL might benefit them. "Better risk management" occupies the second place. Accordingly, the OTL can be used to provide the environment to integrate performance metrics at early stages and therefore improve the maintenance' data transferred to traffic control. This use-case is elaborated in the Table below.

“I’d like to use the OTL to link performance metrics and improve the maintenance’ data used Traffic Control”	
Context of use:	ProRail’s Information Supply-chain Management uses the OTL to link performance metrics to assets in order to improve the data delivered by Maintenance to Traffic Control.
Scope:	• Switches are decomposed until a desired level e.g. Electric contacts. • Use: Maintenance’ Supply Chain Information Management • Asset system: Generic • Lifecycle phase(s): Design, Maintenance • Linked data: Performance-oriented
Level:	User goal
Primary Actor:	ProRail’s Information Supply-chain Management
Stakeholders & Interests:	Asset Owner (ProRail): To improve the maintenance’ data used by Traffic Control. Asset Manager: To improve performance metrics management.
Precondition:	• Shift from Contracting view to an Integrated Maintenance view. • More use of performance based contracts instead of rule based. • The Parties collaborate to provide the performance-oriented data required by ProRail.
Minimal Guarantees:	Defined by Supply-chain Management based on performance goal’s needs..
Success Guarantees:	The OTL integrates performance metrics at early stages and helps to improve the maintenance’ data transferred to traffic control.
Trigger:	The Information Supply-chain Manager logs in the project’s OTL.
Main Success Scenario:	1) The user logs in and browses a desired system/asset. 2) The OTL’ system tree is opened displaying options to identify a desired asset e.g. based on location. 3) Branches display different attributes from which the user selects “Performance” 4) A sub-tree shows a new set of attributes from which the user selects e.g. “Performance Indicators” 5) Links to performance indicators are displayed from which the user is directed to an external dataset containing performance metrics of the specific desired asset 6) The system’s data is exported to the traffic control platform.
Extensions	5a) The information in the dataset needs to be validated. 5a1) After validated. The validation records can be linked in the OTL under a new attribute/set of attributes.
Technology and Data Variations List	4a) A link to an external dataset “Performance” is displayed. This external system includes information relevant to the specific asset’s performance including performance indicators.
Related Information	Most relevant EPIs: • Functionality (Interoperability) • Consistency • Completeness (sufficient breath, scope for a task) • Updatability

Table 9: Use-case performance metrics to traffic control(own creation,2015)

In this case a challenge will be to prioritize which datasets are in the OTL as stated by Folkerts(2015). Thus, the frequency of inspections can be the criteria to estimate efforts for updating the linked data to the OTL. Some assets are inspected much more frequent than others. e.g. interlocking systems are inspected every week while contrary some safety systems (some used since WWII times) are only inspected every 6 years. (Folkerts, 2015)

15.3. SAP-PLM

Railways' asset managers use different systems e.g. SAP(ProRail), Maximo(Volker), SAP(Strukton). This variety adds to the challenge of using the right data for asset management. Until recently, the main asset management interface systems were SAP and ArtiWin. The first worked as some sort of object library which provides the interface between ProRail and the asset managers/engineering bureaus and it is used for communicating changes. The second, ArtiWin used to provide the visualisation environment for different disciplines. (Folkerts,2015)
Lately, both systems have been merged into SAP-PLM(Product Lifecycle Management) a web based portal to exchange documents and object information between ProRail and his partners, such as contractors (Mars,2015). Folkerts(2015) however, still cast doubts on the usability of this new merge.

The main problem with the new SAP-PLM is that it has turned into a data overkill. It is a "broad vs. deep" problem. It includes large datasets but is harder to get specific essential information. (Folkerts,2015)

Additionally, SAP-PLM is not 'user friendly'. To find specific object information you need to have specific knowledge/experience. To find documents it's easier. (and easier than Artiwin) (Mars,2015)

Asset Rail --an IT oriented maintenance contractor-- uses Datastream[13]. The latter has a mobile interface for tablet devices used by the inspectors. It allows a quick communication between the inspectors and the office. There is however a step that is done manually, and is related to the object management from a ProRail's subsystem in SAP. Thus, the engineers in Asset Rail manually take the data output from SAP into Datastream. (Folkerts,2015)
Complementary, problems regarding the information to use in SAP-PLM are(Mars,2015): a definitions problem and a problem with ProRail's BID manager and linked objects.
The first relates to the uncertainty about the definition and function of objects in the BID-1.
The second problem takes place when working in the BID manager linked object's data. There are two types of links: documents (including drawings) and objects (including attributes). In the latter the link is made to the complete drawings but not the objects within them (it is expected in the near future that there will be a link with the Infra-Atlas' drawings).

All the previous stated, the OTL could complement SAP-PLM harnessing the opportunities brought by the recent merge SAP-ArtiWin. In this case the OTL would supply object's information, connecting objects from Infra-Atlas and partly replacing the BID-1. (Pentenga,2015 and Mars,2015).
The present Use-Case elaborates on the case in which the OTL is used together with SAP-PLM. The figure below illustrates this concept. Furthermore, the table below focuses on the specific example of the OBE[14] drawings(schematic layout for the rail network) within Infra-Atlas. The exemplification is made with the object train crossing (overweg).

13 In 2006 Infor acquired Datastream. Datastream 7i, is now Infor EAM, an Enterprise Asset Management system that gives control and visibility of operating and maintenance costs as well as energy consumed by assets. (go.infor.com)

14 Overzicht Baan en Emplacement (OBE) drawings can be filtered by elements that appear in the drawing. Searches can be so for example, a change number or a crossing street name. (rigd-loxia.nl)

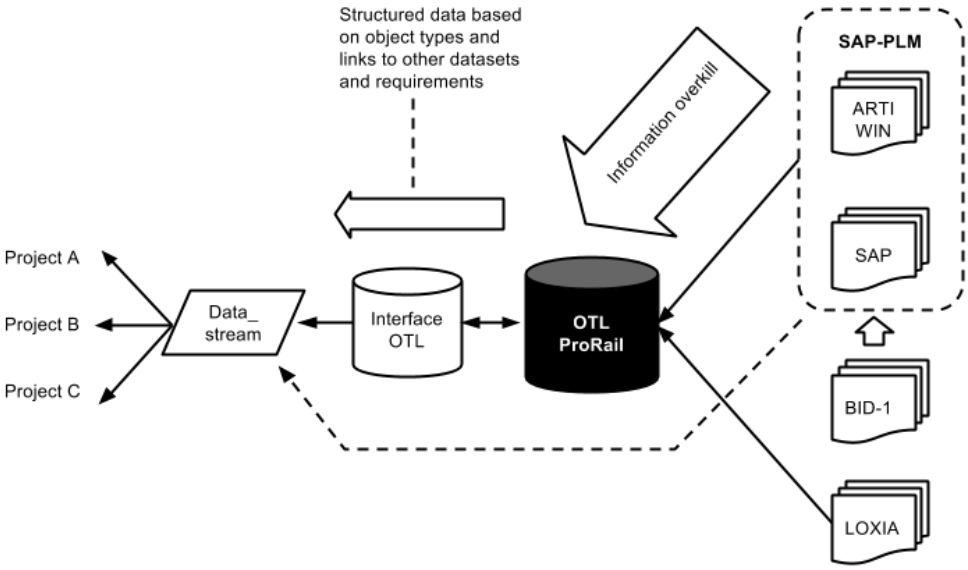


Figure 51: Concept SAP-PLM to OTL(own creation,2015)

Level crossing

A level crossing is level intersection between a road or path and a railway line. There are secured and unsecured crossings. The first means that a warning system is put in motion when a train arrives. There are also public and private crossings. Private crossings have no security and are "on private paths". Based on the type of security and warnings crossing may consider different types. Depending on the degree of protection different components can be included like(Infrasite,2015b):

Security Installation(active), railway signalling, on-driving-side announcement. promulgation out-driving-side-control boxes- authors. Crossing trees. Bells. Lamps, St. Andrew's crosses(varies according to the number of rails), etc…

Warning (passive), fences. diagonally striped red and white boards. wait boards ("wait until the red light goes out "), passage arrangement, narrow crossings, crossing with crossing trees, crossing without crossing trees, crosses painted on the road, warning portals, middle conductor- separation fences, zigzag fences, etc…

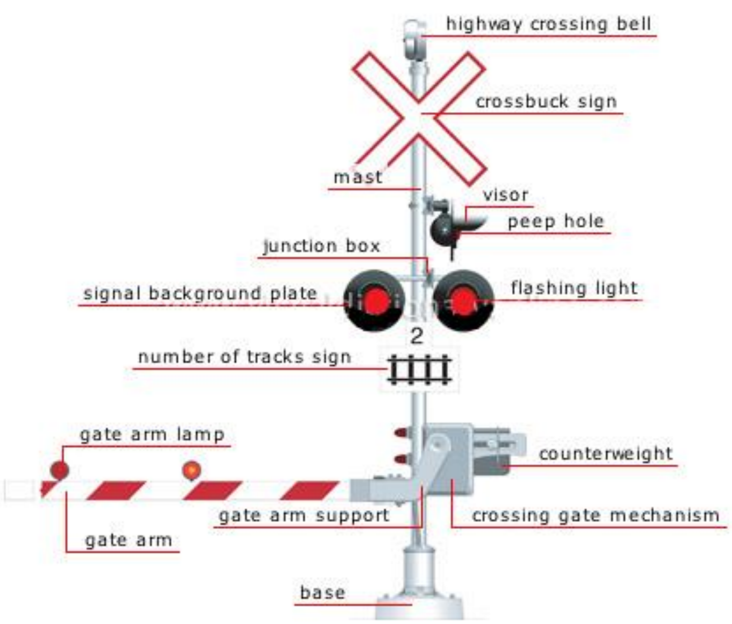


Figure 52: Level crossing' components(ikonet.com,2015)

“I’d like to use the OTL to link OBE crossings’ data more efficiently to Datastream”	
Context of use:	The Asset Manager uses the OTL as complement of SAP-PLM and retrieves object’s data from the Infra-Atlas OBE to be input of Datastream. This can partly replace looking into the BID-1 and therefore lowers uncertainty associated with it.
Scope:	• OBE drawings. • Use: Asset Management. • Asset system: Generic. • Lifecycle phase(s): Maintenance. • Linked data: a desired asset’s data within the OBE.
Level:	User goal.
Primary Actor:	Asset Rail’s engineers.
Stakeholders & Interests:	• Asset Owner (ProRail): To improve the maintenance data’ exchange. • Asset Manager: To avoid data’ overkill. To save time and costs in data retrieval processes.
Precondition:	To have the right data within the Infra-Atlas .
Minimal Guarantees:	Defined by Asset Management firm based on data retrieval goal’s needs.
Success Guarantees:	The OTL provides structured links to OBE’ crossing objects within the Infra-Atlas that are used as inputs to Datastream.
Trigger:	The Asset Management user logs in the project’s OTL.
Main Success Scenario:	1) The user logs in and browses “level crossing”. 2) The OTL’ system tree is opened displaying options to identify a desired crossing e.g. based on location. 3) Branches display what crossings are already in Infra-Atlas and the user picks a desired one. 4) A sub-tree shows links OBE drawings and again a desire crossing’ system/part is selected (e.g. St. Andews crossbuck sign). 5) The user is redirected to the Infra-Atlas’ OBE environment. 6) The system’s data is exported to Datastream.
Extensions	5a) The information in the dataset needs to be validated. 5a1) After validated. The validation records can be linked in the OTL under a new attribute/set of attributes.
Technology and Data Variations List	3a) Branches display what objects are already in Infra-Atlas and after picking one the user is redirected to the Infra-Atlas’ environment.
Related Information	Most relevant EPIs: • Clarity of Information Architecture • Accuracy • Functionality (Interoperability) • Consistency • Completeness (sufficient breath, scope for a task)

Table 10: Use-case level crossing(own creation,2015)

15.4. DOOB and WVs

The project “Data Brought in Order” (*Data Op Orde Brengen*) is part of the program SpoorData.nl. At least 21 track’ systems whose attributes are spread in ProRail’s systems SAP / BBK / Infra-Atlas will be put in order. In other words the managed data in these systems will be aligned with the reality. For each object the characteristics that fall within the scope of this project are recorded in 'Information Delivery Specifications (ILS) which Doob aims to substantiate. ILS comprises not only Configuration data but also other data. The minimum scope of DOOB covers the Configuration data. The goal is, however, to obtain as much as possible of the ILS-data. The contracting will take place on the basis of the first cluster of about 35 object’ types in 9 track’ systems. The total 21-track systems include more than 150 object types. This project started to be procured in the late quarter of the year 2015 and it will be implemented by the method of Best Value. Afterwards, DOOB will be followed by another project within the program “Data Hold in Order” to create and integrate appropriate agreements with all parties involved in the chain to the information obtained by Doob. (Tenderned, 2015)

Accordingly, being a tender contestant ARCADIS’ main goal is to provide a solution for DOOB which brings the highest possible value to ProRail. The main challenge posed by DOOB is to find the most efficient way to validate the population and attributes of certain instances within an object type(Pentenga,2015c). This validation comprises a cross-checking of attributes from datasets contained in three ProRail’ primary systems: SAP, BBK and Infra-Atlas; and secondary sources such as process contractors’ data in the PCA(*procescontractaannemer*). In the view of Pentenga(2015c), the OTL can provide an interface management platform to browse through additional sources and overview links between systems. Accordingly, Pentenga expects that the OTL could enhance the projection of asset’s population within the DOOB based on primary and secondary sources and business rules that result from linking datasets. After the elaborated performance indicators were explained to him, Pentenga considers the OTL will be likely to support DOOB in three aspects: completeness, accuracy, consistency. For exemplifying purposes the use-case elaborates on the application of the OTL for validating data from the switch heating systems. The latter is introduced below.

Current data validation process

Overall, the previous ARCADIS’ process to validate asset’s data is complex and time consuming. It involved many system’s interfaces and uncertainties. Figure 54 shows the current general validation process. For exemplifying purposes Pentenga(2015c) describes the specific process for validating the switch heating system(wisselverwarmingsysteem) in ten steps as shown in Figure 52.

In step 1, the population of objects is first compared between systems extracted from different primary sources like SAP and GIS drawings. After been compared the percentage of mismatching objects can be known. As introduced in the previous section SAP-PLM combines both SAP and ArtiWin -document and object data-. In steps 2 and 3 drawings are downloaded into SAP-PLM and exported in the form of metadata to then be combined in step 4. The same metadata is visualized in Step 5 where present and non-present drawings can be compared. In step 6 a dataset is created based on the primary sources BBK(systems/object) and SAP(attributes). The correctness of data of checked and in step 7 the additional data is browsed in secondary sources like: monitoring data or the PCA.

A second visualization is made in step 8 where four drawing/switch combinations are displayed: (a)present drawing and switch; (b)present drawing without switch; (c)non-existing drawing but present switch and (c)non-existing drawing nor switch. The analysis from the visualization may lead to two kind of questions: are there missing drawings? (in cases like e.g. there continuity of (a) is interrupted by (c)); or Are there any systems/object at all? (in cases where e.g. isolated datasets have been found and there is not alignment with business rules). The visualized WVs' data is then exported to excel in order to get insights on the deviations in terms of number of geocodes relative to data/drawings found in source systems e.g. SAP and ArtiWin drawings. Finally, step 10 consists in concluding what systems bring the most valid/reliable data about the population based on the deviation insights. Although, data from different systems were used for a cross-checking there were uncertainties that remained during the process until the last steps. They were associated to the question: *what is the right data from the chosen system(s)?*

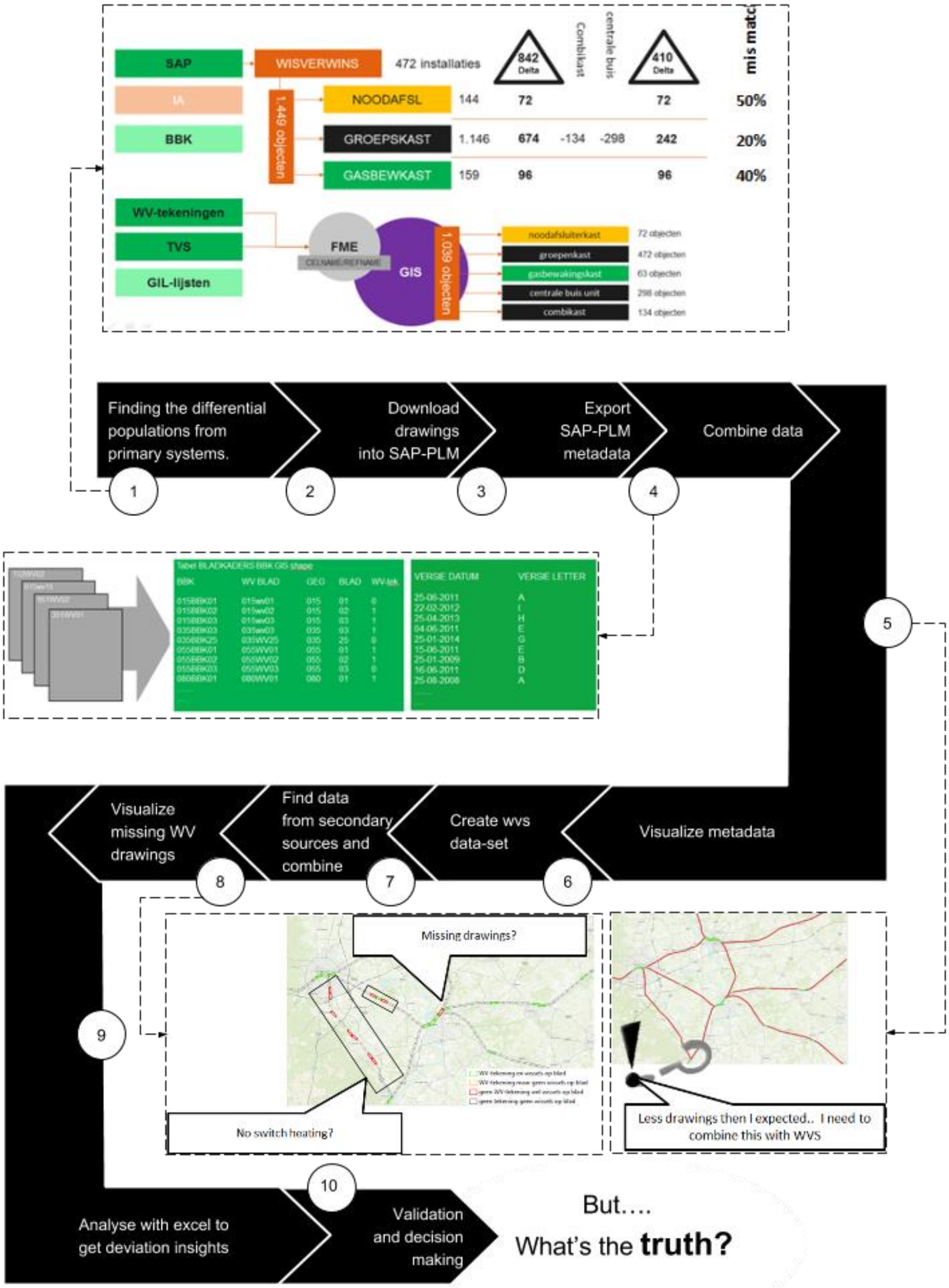


Figure 53: Previous data validation process(own creation based on Pentenga, 2015)

Transition to an integrated OTL Model

In order to tackle current inefficiencies, data processes must be structured. Based on the concluded in section 8 -international experiences-, a key lesson was: 'to re-use existing architecture data'. In addition, insights from the interviews and surveys revealed that the most desired systems requirements are: to allow a unified, semantically unambiguous exchange of data; and to include a consistent source of specifications linked to assets. Accordingly, current systems in ARCADIS can be reused and combined with the OTL Model aided by insights gained in the first OTL pilot. This will allow a more integrated exchange of data that enables a better transfer of asset's specifications. Current ARCADIS' systems and activities with potential to be reused for an OTL are(Zanen,2015):

- SEm
- Rail asset's information model and functional plot
- Business rules based on a periodic analysis of activities.
- Performance indicators' model

The DOOB project is an opportunity for seizing the already existing information developments stated above which could aid an OTL Model framework. Complementary, ARCADIS' data validation process has being progressively switching into a more integrated fluid model aiming for improving exchange and lowering information loss. The Figure below illustrates the similarities between two processes: the current general data validation(based on ARCADIS 2015b) and the expected OTL validation(based on Pentenga,2015c) in which data is re-used and there is less information loss. The 'P' and 'S' stand for primary and secondary source systems respectively; and 'fn' stands for functional name which is the key for integration in this model e.g. 021_wv_gk_2_66355 (Geocode_system_object_number_km).

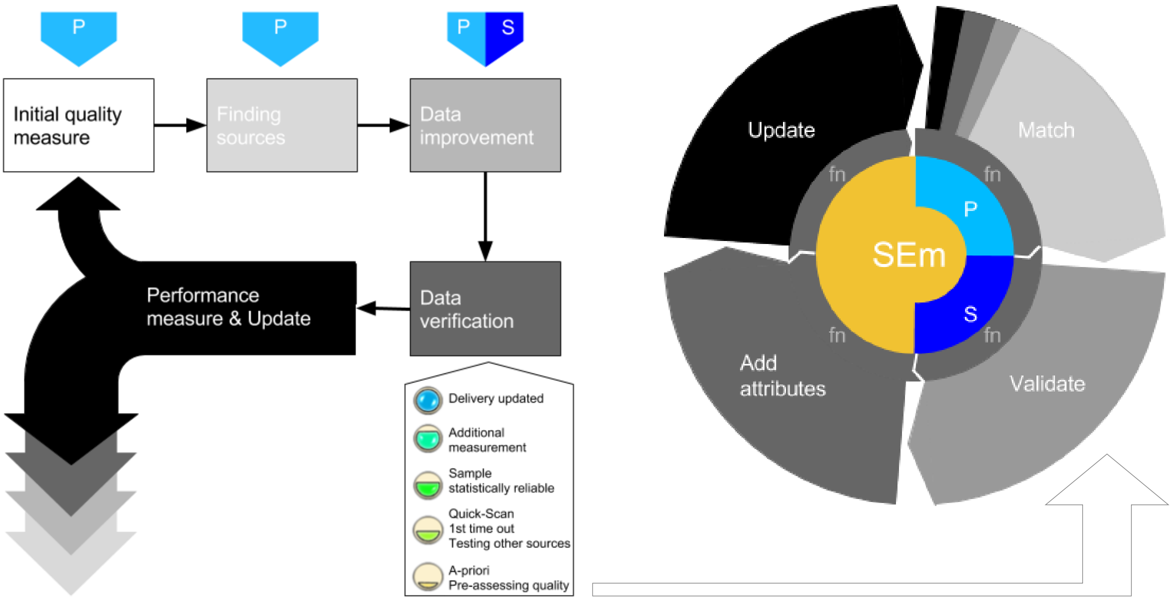


Figure 54: Comparison between current ARCADIS approach and an integrated OTL approach(own creation based on ARCADIS 2015b and Pentenga 2015c)

The left-side figure illustrates the process' approach by ARCADIS towards the DOOB project. Therefore, it can be understand that the focus is more on matching and verifying data. A single-project focus however might overlook possibilities for re-using data and prevent information loss. From an OTL perspective, data can be kept in order to be re-used on further projects. This is illustrated on the right-hand figure. For the same reason, once validated, data can be re-used in a next project. In this line of reasoning, initiatives like Pentenga's model(2015c) can be considered for further exploration of the possibilities to aim for a more integrated system's interface which re-uses the actual information architecture.

Pentenga's model can be found in the appendix. Based on it, the following insights can be derived for ARCADIS' OTL:

- It potentially aligns and validate data from different sources(primary, secondary and projected by business rules).
- It stimulates innovations and a new concept of structuring information like e.g.:
    - An interface system to export data(visualisation graphs, performance dashboards, pivot tables). Possible through an API SQL query.
    - To securely import data and integrate SAP_PLM deliverables like e.g. drawings.

In order to exemplify the use of the proposed model the scope can be narrowed down to the CBG instances within the switch heating systems(WVs).

Switch heating heating systems(WWs)
WWs(*wisselverwarmingsysteems*) are used to keep tracks free of snow and ice. Although a moderate amount of snow is acceptable on rails, its accumulation between switch' rail tongues[15] may result in switch malfunction. In the Netherlands close to 80% of the total number of switches are equipped with a heating system.
In the Netherlands four main types of wws are used(wikipedia.org): gas, central pipe gas(CBG), electric and geothermal.
The gas systems work with gas burners and controlled combustion which generates heat transfer via radiation to the rail and surrounding area. In this case heating takes longer. In the CBG(*centrale buis gas*) the heat is gotten by burning gas in a boiler similar to those of household' use. The electric type works with resistance elements attached to the rail which generate heat transferred by conduction. Geothermal systems are CBG variants using a heat pump instead of a boiler which uses geothermal and electric energy(in a +/-3 to 1 proportion). The most used type in The Netherlands is the CBG. However, these kind of switches can also become blocked by hail and/or heavy snow causing serious train failures. Therefore, reliability of a heating system depends on the quality, good built and a regular inspection and maintenance. (wikipedia.org)

ProRail is responsible of the maintenance of the wws and this asset forms part of the scope of the DOOB project. Therefore, improving the accuracy of the wws' data will bring benefits in its maintenance. The use-case below focuses on how the OTL can be used to improve the validation of a number of instances within the object type CBG wws(central pipe gas switch heating system).

Figure 56: CBG' heat exchanger (wikipedia.org)

Figure 55: Snow clearance around the switch point (wikipedia.org)

The table below elaborates on how information related to the CBG instances within the WVs type can be extracted from the OTL. In this example the current complex process is simplified with the OTL model into four simple steps proposed in the main success scenario.

[15] Narrower end section in a switch' that makes contact with the fixed/stop rails when the switch operates.

“I’d like to use the OTL to validate the population of CBG WVs in DOOB”	
Context of use:	The data analyst uses the OTL to project the population of CBG’ switch heating systems based on business rules from linked datasets.
Scope:	• Population of CBG(central gas pipe) instances within the WVs(heated switch) type. • Use: DOOB Data Analysis. • Asset system: Switch heating heating systems • Lifecycle phase(s): Exploration (DOOB Tender) • Linked data: BBK, Infra catalogue, SAP(container/source systems)
Level:	User goal.
Primary Actor:	Rail’ data analyst.
Stakeholders & Interests:	• Asset Owner (ProRail): know the right number of CBG wvs. • Data analyst: find the most efficient way to perform a cross-check in the three systems.
Precondition:	To have an access to datasets in primary and secondary sources based on agreements and the ILS(given in DOOB).
Minimal Guarantees:	Defined by ProRail in the ILS.
Success Guarantees:	The OTL enhances a reliable count on the population of CBG switch heating systems.
Trigger:	The user logs in the project’s OTL.
Main Success Scenario:	1) The user logs in and browses “CBG heated switches”. A background process creates a functional name that is used to match the information with primary source systems linked to SEm(1st time). 2) Links to the secondary source systems are displayed. Attributes show the covering population per source system. Validation is made between secondary sources. Then, business rules are validated by primary systems and the additional sources. 3) Missing/Incorrect attributes information is added or adjusted, and a report is generated. Mismatches are checked by humans(e.g. locations by photographs, surveys) to keep data in control. 4) Updated data is exported being possible to measure by performance indicators. New data is updated in SAP-PLM.
Extensions	2a1) The functional name is used by Contractor to identify the asset. 2a2) The links are made to interface management systems.
Technology and Data Variations List	--
Related Information	Most relevant EPIs: • Accuracy • Consistency • Completeness

Table 11: Use-case level crossing(own creation,2015)

15.4.1. Example of application of EPIs

For exemplification purposes the Use-case DOOB-WVs was chosen. The graph below is based on the open source platform Dashboard(Shopify,2015) and it exemplifies how a dashboard of the DOOB' EPIs might look.

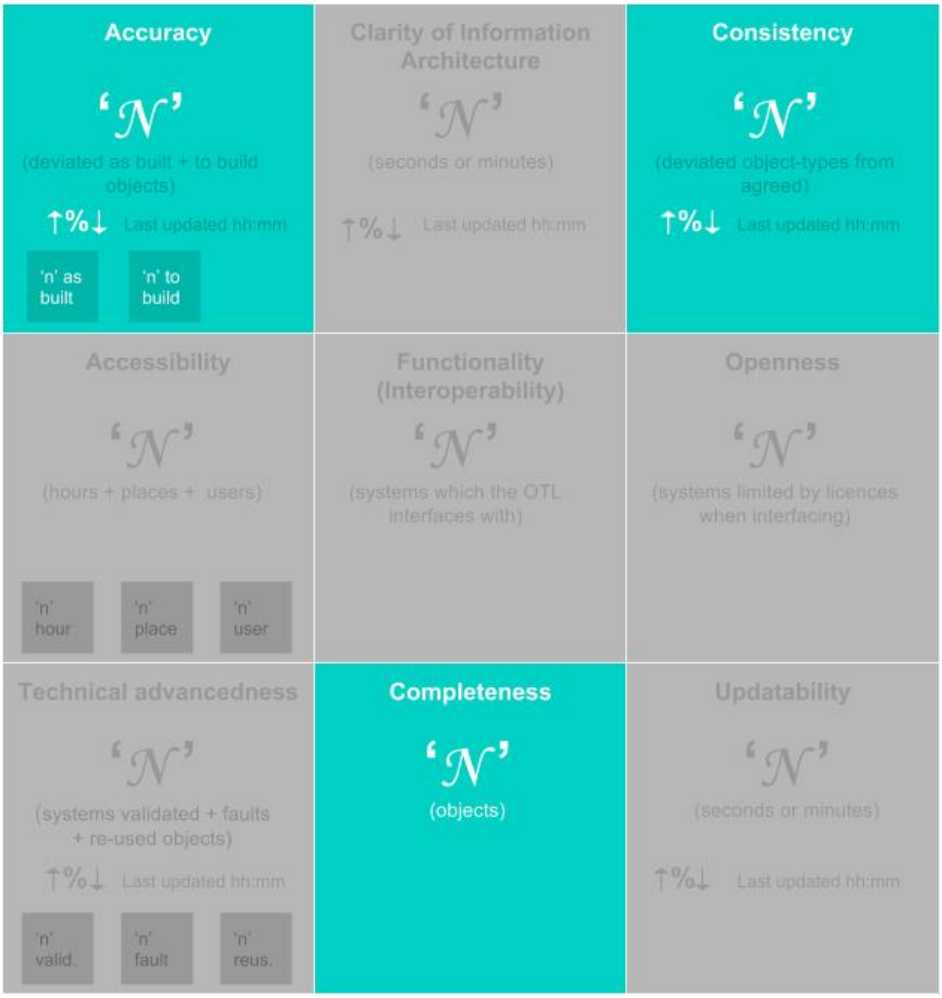
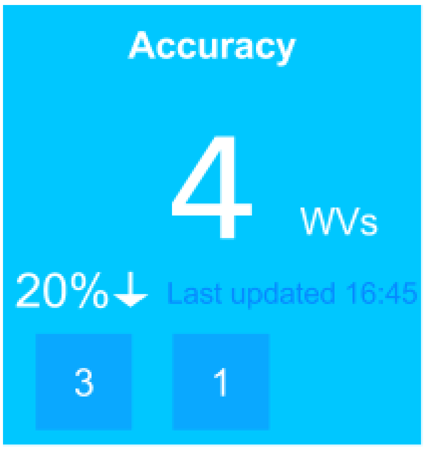


Figure 57: Example of dashboard with the relevant EPIs for the Use-case System's Architecture(own creation,2015)



The highlighted quadrants above are the ones relevant to the use-case. Each quadrant presents performance information based on the definitions given per indicator in Table 5. For instance the big "N" gives the main measurement which in some quadrants is the result of the indicator's sub-components e.g. for accuracy the big 'N' is the sum of both the number of deviated 'as-built' objects and the number of deviated 'to-build' objects (small 'n's). Thus, the number of deviated WVs objects and/or attributes from the reality could be tracked. Moreover, a percentage shows either the raise or decrease of 'N' in respect to the previous time performance data was updated e.g. A 20% decrease means an improvement as the number of deviated objects was higher(5 WVs) in the previous count.

15.4.2. OTL added value for ARCADIS

Pentenga's model states the possibility to export asset's data useful as input for a Performance Dashboard. Within the framework of the 4-steps proposed in the use-case DOOB, the Dashboard can be set in the updating phase. The graph below schematizes the processes taken place in every step. Linking objects to a functional and a technical name help to standardize objects. The functional name helps an easy checking of whole population(and matching), whilst a technical name(calculated by algorithm from the primary source systems) provides a number to assure the same object is extracted throughout datasets. The latter also helps to avoid mistakes when overwriting and updating records.

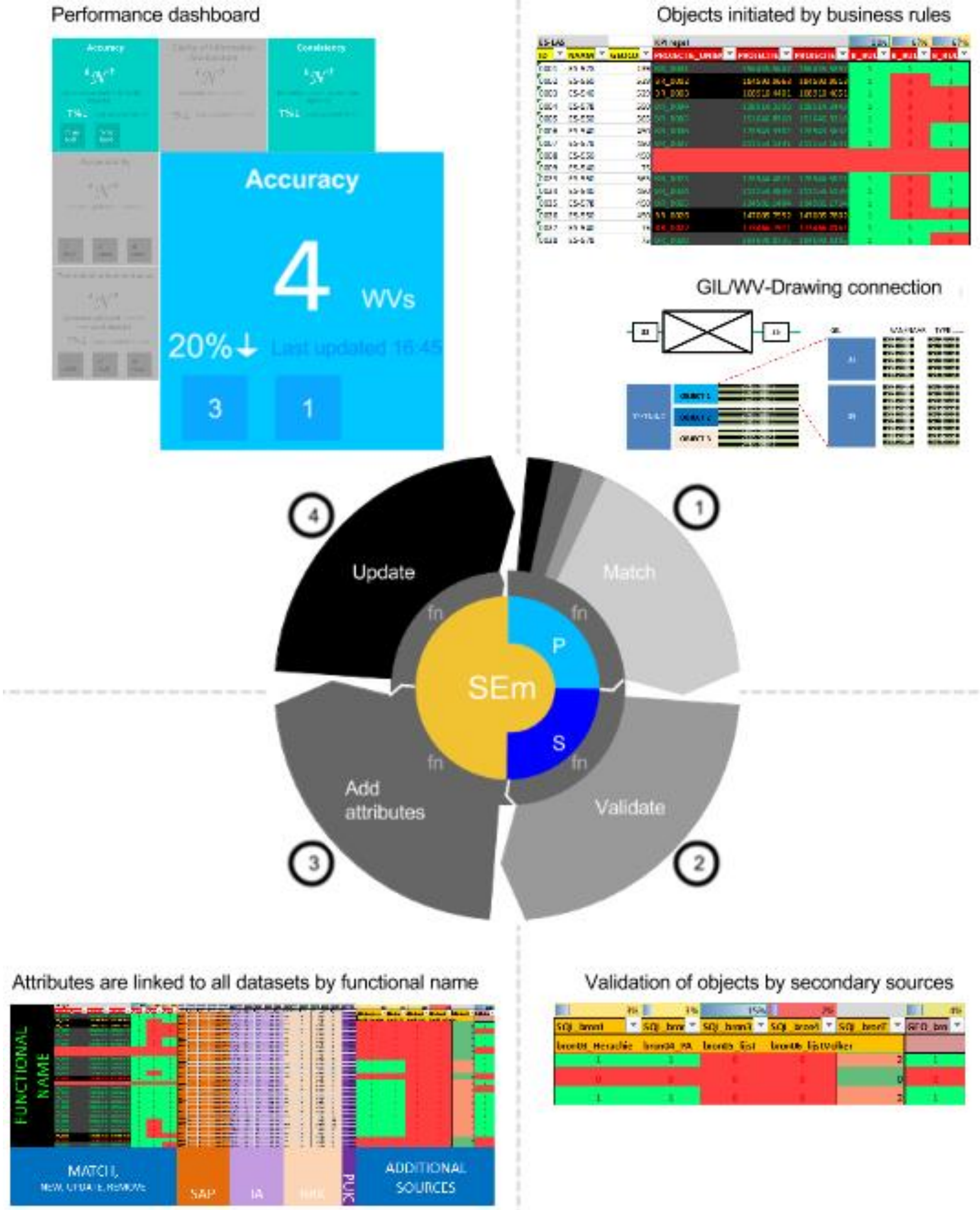


Figure 58: 4-Steps validation model(own creation based on Pentenga, 2015c)

The previous stated, it can be expected that there will be advantages of switching from a time consuming and complex process to an easy four-step process where all the hard work was done at once. Though, advantages can be better understood by comparing the resources needed to in both processes in terms of man-hours. The resources used in the first conventional process, are known from a test with the switch heating systems for DOOB. In other systems than the WVs, the validation time might change proportionally to the complexity of the system.
In the second case –using the OTL- the man-hours are estimated with the help of expert' advice. Relevant aspects that influence the validation time are: user knowledge and the type of extra-validation e.g. surveying tasks can increase considerably the coordination and time(Pentenga, 2015c). The table below shows an scenario where all the data is already in SEm and no other external sources are necessary for validation.

Current validation process			OTL expected validation process(4-step)		
Expert involved	Task	Man/hours	Expert involved	Task	Man/hours
Data analyst	Link datasets and drawings Assessing deviations System modeling Oversight	25-30 hours	Data analyst	Match Validate Add attributes Update	0.1-0.5 hours
Systems specialist	Drawing rules(SAP) Relations objects-drawings(SAP) Business rules	6-8 hours			
GIS expert	Modules based on Geo-Information to be linked to datasets	4-6 hours			

Table 12: Comparison of resources used in the conventional validation vs. the OTL(own creation,2015)

16. Advice for functional requirements based on the Use-cases

The use-cases infer the use of a collection of functional requirements put into context of users' actions. This helps to lower ambiguity from an otherwise out-of-context list of system' shalls. Accordingly, in the use-cases the functional requirements are the OTL's shalls necessary to fulfil every step listed in the main success scenario. Based on the use-cases the OTL shall:

- Allow the log-in of authorized users.
- Bring a clear identification of subtypes within specific projects (e.g. location-based)
- Complete asset's 'Recipes'(set of attributes) e.g. for the recipe 'train detection' the attribute "Safety requirements" should be included.
- Verified links to external datasets.
- Agreed systems' decomposition e.g. "switch">"box">"motor">"electric contact".
- Verified exporting outcome in visualization platforms.
- Verified link and interface OTL-Infra-Atlas (suggested to start testing with OBE drawings).

17. Summary of Challenges

In previous chapters different challenges were discussed. Some of them result after applying the five dimensions framework(section 4.4) to assess the insights from the interviews. Other challenges come from open questions explicitly stated in the surveys. Ultimately, specific challenges are brought by the situations elaborated in the use-cases.

In the first stages of the OTL development challenges relate to the allocation of both functional and structural requirements aligned with ProRail's Enterprise Model. This challenge involves cooperation of the Logistics(functions) and Asset Management(system's structures) to improve their exchange capabilities. Moreover, based on the view of Spoordata, they will move towards an integration of datasets and therefore data management. According to Baggen(2015) special attention must be put on functions as their definitions for the same assets may considerably vary throughout the lifecycle.

Architecture challenges can be found in relation to the interoperability of OTLs due to structural differences. This problem starts from the top level OTLs(Rijkswaterstaat and ProRail). As stated by Nagtegaal(2015) the first has become too large whilst the second relies on the S.O.A model to organize its requirements and architecture. Important focus must be on the Catalogue what according to experts is the only common point between both OTLs. Moreover, as RWS uses XML/XSD and ProRail OWL, different scenarios can be assessed based on the possible clashes due to format's differences. Baggen(2015) suggests to involve early as many domain experts as necessary in order to validate the semantic viability of the OTL releases. Additionally, agreements must be made in order to get consistent asset 'recipes' as in the use-case 'systems architecture'(Kalshoven,2015).

Platform process' problems can be avoided with formal requirements is necessary. This can help to avoid requirements misinterpretations and to prioritize requirements. Additionally, 'redundant inheritances' poses a major challenge for developers. To lower the risks of the challenge early collaboration and decision-making is necessary at high levels.(van der Veen,2015). Besides, communication between the parties involved in the different PoCs is as important as providing reasonable testing times for every OTL application in projects. Complementary, the use-cases in systems' maintenance introduced the problem of ownership of data in which a major concern is on the top level' systems.

Organisational challenges are the main focus of this research and represent a vital component for attaining success in the OTL development. Governmental parties optimism about the OTL has positive and negative sides. In one hand, human resources allocation and knowledge can set the base for shaping a powerful tool for semantic standardisation. In other hand however, over-optimism may also lead to overlook pitfalls and/or providing a too complex and not useful OTL. Therefore, supply-chain parties can provide valuable insights as the case of stakeholders who cast doubts about the OTL usability. This was found to be the case of some traditional maintenance contractors show themselves more resilient to use the OTL pointing to costs overheads and updating effort. Complementary, the risks of having a solely 'asset management' view have to be assessed. This is exemplified with the case of systems engineers who although find many potentialities in the OTL, they also believe a 'function-based' approach may be more useful for their daily practice.
As extracted from the open questions in surveys, stakeholders concerns point to current difficulties in the industry's contracting schemes. Additional works and adjustments come from communication flaws early. The latter is likely to be overcome if the OTL is

standardised in the supply chain and thereby Contractors may not be interested if they do not perceive other benefits to balance the losses represented by the OTL. Accordingly, incentives can be offered by governmental parties in order to achieve the overall industry's benefits. They can be focused on tendering advantages and strategic PPP partnerships. In addition the use-cases in systems' maintenance introduced the closedness of supply-chain parties in receiving and keeping data beyond their business' interests. This includes performance' data(Tissing,2015). Similarly, tendering' contractors would not be keen to share data if they perceive a risk of losing competitiveness(Folkerts,2015). Therefore, regulatory agreements are necessary on rules and guarantees towards supply chain parties.

18. Risk Assessment

A study by FERMA, the Federation of European Risk Management Associations, among 289 leading European companies, showed that 37% considered data systems among the greatest risks, surpassed only by commercial, operational/production, legislation and major crisis risks. This perception even grows to 48% when companies were asked about tomorrow. However, it is important to consider that risks can defy conventional thinking e.g. What is the most likely cause of death for a New York police officer?. It is not being killed by a drug pusher's bullet, but by his own poor driving ability. In one year alone, 1230 officers of the NYPD (known as Not Yet Proficient Drivers!) were hurt in car crashes, compared with 20 who were wounded in shootings(Sadgrove,2015).

Therefore, a systematic approach is important. A risk register is a useful tool for identifying risks at an early stage of a project. Miller&Lessard(2001) developed a theoretical basis for assessing risks of large engineering projects. Accordingly, risks first need to be dissected into categories such as (1) market-related: demand, financial and supply; (2) completion: technical, construction and operational; (3) institutional: regulatory, social acceptability and sovereign. Different projects, industries and activities pose different risks. The OTL development can be considered close to the category of Research & Development projects which although present scientific challenges, they face fewer social acceptability and market risks. This is due to the possibility of be broken into smaller testable investments (Miller&Lessard,2001). In this line of reasoning the following risks were identified in the OTL development:

1) Market risks:

As stated before the market risks are not the major concern of the OTL development as it can be progressively tested in small projects. However, supply risks can be found. The OTL should deliver quality data. In this regard, there is a risk of (1)poor and/or incomplete handover due to a mismatch of requirements linked to asset' specifications(Mommers,2015). Another market risk can be associated with the (2)difficulties to get software vendors interested in work with open standards.(Bakker,2015)

2) Technical risks:

Projects face technical risks that reflect their engineering difficulties and degrees of innovation: some of these risks are inherent in the designs and technology employed.(Miller&Lessard,2001)
Being at an early stage of development yet, the OTL is going through a 'trying and error' phase which poses many technical risks. Based on the interviews and surveys, the parties perceive the following as the major technical risks: (3)Risk of becoming too complex and

thus difficult to understand and use(Mommers,2015 and Stuiver,2015); and (4)Risk of being too broad and abstract, lacking of depth.(Soeters,2015)

Additionally, other perceived risks are: (5)Object-based trees cannot be optimal for some parties whom would benefit more from function-based trees(Stuiver,2015 and Mars,2015); (6) 'Redundant inheritance' risk.(van Der Veen,2015); (7)Risk in 'customized filtering and displaying'.(van Der Veen,2015); (8)Errors in validation in ProRail's OTL can transfer flaw to Contractor's OTL.(van der Veen,2015 and Többen,2015); (9)Risk of quality validation by field mechanics/inspectors(Folkerts,2015).

3) **Institutional risks:**

Even though, these risks are often due to political instability(Miller&Lessard,2001) there are Institutional risks that can be associated to the regulatory and decision-making position of RWS and ProRail towards the OTL' development.
In this category a current risk is (10)ownership of data between ProRail and Contractors. Especially when is needed to update a running project's data. (Tissing,2015)
Besides, the OTL development also poses risks related to the (11)parties' acceptability of using a new system which demands more communication between different engineering cultures. This is both within ProRail and within the chain-parties(Baggen,2015 and Nagtegaal,2015). Moreover, using an OTL demands (12) a new way of thinking in asset's information management from a Distributive to a hierarchical reasoning.(Tissing,2015)
One risk that can be considered both technical and institutional is the one regarding the (13)Hierarchical integration of standards at both national(CB-NL-OTL) and international level(BUILDING SMART). The bottom-up design responding to particular needs of the different projects adds risk to these differences(Nederveen,2015; Bakker,2015 and Baggen,2015)

4) **Organisational risks:**

Regarding the developing requirements, there is a risk that (14)the OTL is too focused on the needs of the initiator overlooking the supply-chain parties. RWS' OTL is already being developed focused on Asset Management. The risk of ProRail doing the same is that it can overlook benefits in other fields like e.g. Systems Engineering. (van Der Veen,2015)
Risks affecting the organisation are(Tissing,2015): (15)Structural changes risk (Between ProRail and the supply-chain) and (16)Structural changes risk (Within ProRail)

Risk register

All the previous risks stated, a table can be elaborated that shows the risks descriptions, pre-response assessment, response and post-response assessment for the main identified risks. Although these aspects are derived from the interviews and surveys, the estimated probability(from Very Low to Very High) is based on expert's and personal assumptions. Therefore, they should be considered as referential and could vary based on different views and level of knowledge about the OTL.

#	Risk Category	Risk Description			Pre-response Assessment		Risk Response (ATOM and description)	Post-Response Assessment	
		Cause	Risk Event	Consequence	Probability	Impact		Probability	Impact
1	Market-related	Assets not linked to asset's specifications	Poor and/or incomplete handover	Extra time and costs in gathering specs. late	Medium	Very High	Link all feasible specifications to the OTL early in LC	Low	Low
2		Open standars are seen as a threat to vendor's profitability	Software vendors not interested in open standards	Not possible to integrate to OTL	Medium	High	To develop more open software(but time and cost consuming)	Low	Medium
3	Technical	Too many features	Overdeloped OTL becoming too complex	Difficult to use.	High	High	Priorize features and start simple to get familiarized	Medium	Low
4		Too many super-types without enough depth into the subtypes	Being too broad and abstract.	Not useful	High	High	Start small, prioritizing datasets. Less types= less relations.	Medium	Medium
5		Object-based vs function-based trees	The tree structures is solely object-based	The OTL is not of much use for SEs or other experts at early stages	High	High	Asses possibilities of the semantic technology and visualisation environments to provide an "optimal for all"solution.	Medium	Medium
6		'Redundant inheritance'	Same concepts with different meanings appear as attributes	Misinterpretation, use of wrong data	High	Very High	Decisions at higher levels and/or automatic combinations.	Medium	Low
7		The OTL tree model contain several models in which an attribute can still be a container	The OTL has too many attributes and complexity.	Lots of useless background info.	High	High	'Customized filtering and displaying'. Testing in collaboration with contractors to filter background information.	Medium	Medium
8		Flaws in ProRail OTL	Transfer of flaws from ProRail's OTL to Contractor's	Contractor uses wrong information	Medium	Very High	Systematic validation protocols.	Low	Medium
9		Need of quality validation by untrained inspectors	Inspectors cannot sent the right data	The Asset Managers are not provided with accuracy all the needed information.	High	High	To capacitate inspectors in order to work with a system that uses XML Spoor to make its use generalised (from drawings to data).	Medium	Medium
10	Institutional	Ownership of data	Updating ongoing project's data	Update is not possible	Medium	Very High	Clear regulatory framework.	Low	Low
11		Different engineering cultures	Miscommunication	Not getting agreements on definitions and functions	Very High	High	Develop a change-management program.	Low	Medium
12		Switch to hierarchical reasoning	Chain's parties commitment is not possible	Distributive mindset remains	High	High	Develop a change-management program.	Medium	Medium
13		Current distributive model of contracting	Supply Chain clashes with the new OTL's Hierarchical Model	Exchange not possible	High	High	Agreements on Standards for all the different initiatives	Medium	Medium
14	Organisational	OTL solely focused on Asset Management	Other interests are overlooked e.g. SEs	OTL does not exploit all its potential	High	Medium	Include other views at early stages of development	Medium	Low
15		Structural changes within ProRail	Resistance to switch from Contracting to Maintenance Department mindset	A complete chain overview is not possible to facilitate the OTL	Medium	Medium	Develop a change-management program.	Low	Low
16		Shift to performance based contracts	Resistance to change	The link between chain activities e.g. maintenance and performance is missing	Medium	Medium	Develop a change-management program.	Low	Low

Table 13: OTL' risk register(own creation,2015).

19. Part C Conclusion

Five dimensions(section 4.4) provided an overview of key findings(section 11.2) after interviewing supply chain parties. The key findings together with insights from the use-cases were included in the main challenges(section 17) which are related to the five dimensions in the points below:

- Requirements' engineering insights shaped structural and functional requirements. In addition, system' requirements specifications were drafted based on surveyed preferences. Thus, 'to allow a unified, semantically unambiguous exchange of data' turned to be the most preferable aspect, followed by a 'consistent source of specifications linked to assets' and 'to provide a future-proof and expandable database of assets''.
- The main Architectural challenges point to structural differences and different standards between RWS and ProRail what might bring long-term unexpected exchange' difficulties . Besides, the use-case 'systems architecture' introduced the challenge of getting consistent asset 'recipes'.
- In the platform process improvements, it was found that 'triples' enhance the potential of the OTL providing flexibility. Contrastingly, the risk of 'redundant inheritances' can be lowered with early coordination at top levels when defining object types. Besides, a planned vision is necessary to align the different initiatives and avoid repetition of efforts. Moreover, the use-cases in system's maintenance introduced the problems of ownership system's data at high levels and the current ProRail's distributive model that needs to turn into a more central asset management.
- The organisational changes are the main focus of this research. They were split in perceived benefits and disadvantages of integrating to the OTL. Within the first group there are experts whom see benefits in the whole lifecycle, finding in the OTL a potential tool to connect traditional disconnected phases like design and O&M. In addition, benefits are also seen in aiding systems engineering, seizing big data possibilities and improving tender processes. In case of the disadvantages, the reluctance of the contractors in non-performance contracting schemes can be anticipated. Besides, the limitations coming from open standards are mainly related to the use of OWL by ProRail which remains unexplored in an intensive infrastructural use. Moreover, in order to integrate system's in the maintenance phase, parties suggest the strong need of change management.
- The operational and support processes are covered by the roadmaps in PART D.

In addition, the stakeholder's mapping helped to set the position of the stakeholders as players(ProRail), context settlers(RWS), subjects(contractors) and crowd(operators).
The value system design structured the system's main objectives(efficiency, usability and reliability) and their sub-goals based on the surveyed preferences. Additionally, the value system diagram provided an overview of all interconnected components(means, alterables, constraints, criteria and externalities). It allows to go back when prioritizing needs for the OTL development and see the possible relationships. The basis for Performance indicators is set by the value system design but they are finally refined after linking the two surveys. The list has been contrasted with indicators from relevant papers such as the V-Con and ARCADIS PoCs. Moreover, use-cases helped to illustrate the applicability of performance indicators. Six use-cases were elaborated following literature' advice. For instance, the use-case 'systems' architecture' elaborates on the creation of a 'train detection recipe' that links safety requirements to assets' data. Similarly ProRail's maintenance managers strive to keep performance related-data throughout the lifecycle and the supply-chain. Three use-cases in systems' maintenance provide an approach of the potential of the OTL to tackle this problem. The last use-case DOOB shows possibilities for ARCADIS to validate the population of switch heating systems in four steps. Moreover, the conceptual model of Pentenga shows the potential of re-using upgraded data which can be measured by performance indicators as proposed in the dashboard. Ultimately the risks help to draw different scenarios and to set preventive measures.

PART D: ROADMAPS, CONCLUSIONS & ADVICE

20. Part D Introduction

In Part C the interview' key insights were organised using a five-dimension framework from which relevant insights were gathered by experts regarding requirements engineering, architecture changes, platform process and the potential of using road-maps. In addition the stakeholders were mapped and performance indicators derived from a value system design and matching preferences from the surveys. Complementary, use-cases exemplified the use of performance indicators and provided a more realistic application of the OTL towards actual demands from ProRail's experts.

In Part D the information from parts A,B and C is condensed and the main aspects are filtered based on advice found in road-mapping literature. Accordingly, an Strategic roadmap(section 22.1) gather the views of ProRail' experts whilst the views of the supply-chain parties are shown in a Tactical Roadmap(section 22.2).

Last but not least, the main conclusions and contributions are elaborated in section 23 and recommendations and future research advice are given in sections 24 and 25 respectively

"Technological innovations alone are not the solution to human shortcomings. "

—*Love, Edwards et al. (2011)*

21. OTL Lifecycle Roadmaps

Framework

In the case of the this research, the framework is defined for two viewpoints: the government assets' owner i.e. ProRail (strategic view) and the supply-chain parties(tactical view). The main sources of insights for both views are the interviews, surveys and use-cases. The common framework is set by the Spoordata program goals, being the main goal 'inside equals outside'(*binnen=buiten*).

Overall, the message to be conveyed is: *'The OTL is expected to standardize the exchange of object-type information alongside the whole railway's supply chain and throughout the total Lifecycle'.* Based on the principles for defining the reference' frame of a simplified communication roadmap(Phaal & Yoshida,2014) both roadmaps aim to illustrate three main questions: *the why, the what and the how.*

In the strategic roadmap the reference' frame is*: 'The OTL will provide an efficient environment and tool(the why) for information exchange(the what) through the integration to a standard OTL model and dataset(the how)'.*

In the tactical roadmap the reference' frame is: *'The OTL is based on strong collaboration and agreements about its content and ownership(the how) for developing a useful and reliable asset's inventory(the what) that finally brings sector-level benefits(the why).*'

Had been the framework defined, below the elaboration of both roadmaps is organised in the following three main aspects of a design-driven approach(Phaal,2015) as seen in section 4.4.5: structure, relationships and direction.

21.1. Strategic View

Structure

For the OTL development' strategic view the representation is structured in three columns. The left-hand column states the current problem with information management and the framework initiatives along with the *Why*—the rationale for pursuing the OTL's implementation. The middle column outlines the What and the How aspects and introduces the timeline. The scope is defined by the context of the ProRail's use-cases (sections 15.1 and 15.2) following the advice of experts to start 'small" (Baggen 2015, Stuiver 2015, Opgenoort 2015). The *What* aligns the potential uses with windows of opportunity of integrating the OTL with the current systems used by the railway industry parties. The *How*, outlines the OTL development maturity based on advice and expectations from the experts interviewed. Besides, the *How* feeds up to inform and support the *What*.

Ultimately, the right-hand column presents the vision driving the OTL' roadmap, in terms of the Spoordata Program and future targets for the OTL' development.

Relationships

The relationships shape the structure into a more expressive visualisation. This follows the basis of the design driven approach, since "content without form is invisible and inaccessible" (Kazmierczak 2001).

In the strategic view the relationships between the three workstreams is made with Sankey[16] flow diagrams. The varying width of diagrams stresses when the most work is to be done for each workstream. At the start of the OTL strategic roadmap the focus is on the 'wants' from the Use-cases(lower channel). Then a transitory phase with the expected performance indicators(EPIs) and testing are applied(intermediate channel).
In the final phase, full-integration is achieved and therefore the success guarantees from use-cases(section 15) are met(upper channel).

In addition, ProRail' information projects have been plotted in parallel and related to the OTL implementation based on the planning shared by ProRail' information experts. Accordingly, projects to be finalised in the year 2016 affect in more proportion the 'potential specific uses' and 'test & measure' stages. Similarly, projects to be finalised in 2017 affect mote the 'system's integration' phase.

Direction

In the strategic view of the OTL development, the principal narrative direction is the horizontal flow. The supportive narrative is created by the relationship between workstreams represented by the Sankey channels in a diagonal pattern from bottom left to top right along time. Colours aim to help the narrative progressively changing from grey to blue.
Complementary, the system's imported data(right hand within all channels) meets the requirements of the different levels of integration
On the lower channel(left hand), the lifecycle phases show themselves misaligned at earlier stages where use-cases have been just introduced and explored. Besides, on early stages the configuration and steering datasets are split yet matching the current problem with asset's information(section 6.1).
Life-cycle phases are better aligned in the middle stage after trying, testing and measuring the performance of the OTL in the potential uses. In addition, configuration and steering datasets are more integrated.
Finally, had been met success guarantees, LC phases get an integrated information' exchange at the later stage(upper channel at right hand). Moreover, there is a total integration between configuration and steering datasets. Complementary, both imported and exported system's data meet the requirements for this level of integration.

All the previous stated, the figure below schematizes the OTL strategic view for implementation.

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16 Sankey diagrams depict flow to and from various nodes in a network, and have been most typically applied to analysis of energy or material flows. Arrows or directional lines are used to represent these flows, with the thickness of the arrow or line proportional to the magnitude of the flow; thus give emphasis to the size and direction of flows within a system. (Cuba,2015)

What to implement and how?

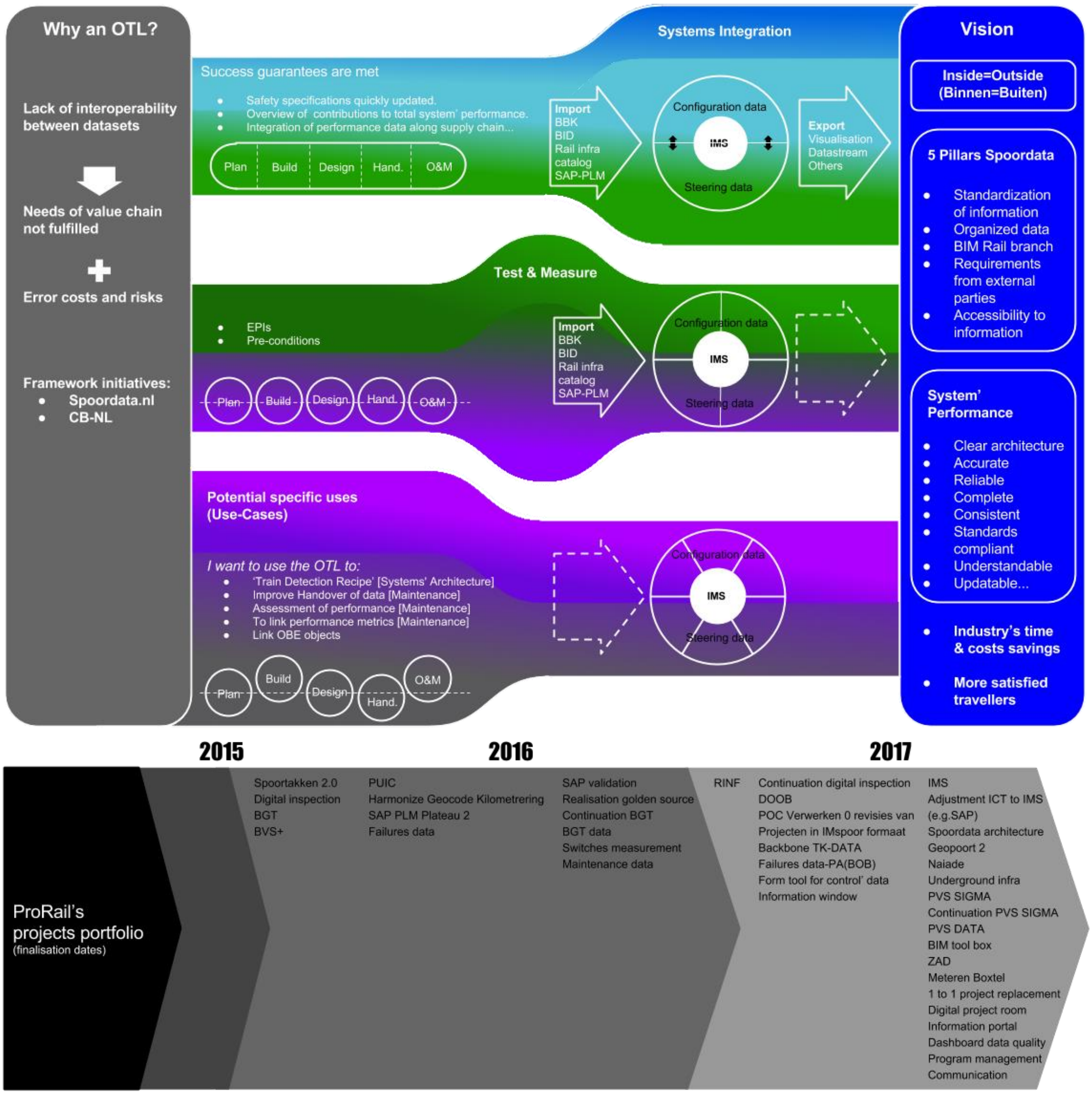

Figure 59: Strategic view Roadmap (own creation,2015)

21.2. Tactical View

Structure

The tactical view' structure directs attention to the data elements within each workstream and the interactions between workstreams, with the central section being used to portray the overall development route. It focuses primarily on the three workstreams, and its structure consists of three corresponding diagonal sections: enablers, capabilities and drivers. Merged with the diagonal sections, the tactical view includes a left section with the purpose behind using the OTL(needs) and below the possibilities of the state-of-art OTL. The needs are extracted from open questions in the surveys about the Short-Term expectations to use the OTL. Moreover, the needs are organised by Lifecycle phase. A central section presents the required system capabilities along with the drivers and enablers. The right section presents the surveyed expected benefits per lifecycle phase and the shared vision with the Spoordata program elaborated in the Strategic roadmap. The roadmap presents two external set of developments(top and bottom arrows' groups) that are compared to the OTL development. On the top the BIM LODs are plotted and then on the bottom GIS developments are shown. Both correspond to ARCADIS BIM planning for Europe(Mommers, 2015b).

Relationships

Important elements to connect are resources to uses and stakeholders; therefore the interconnections between these elements have to be mapped. The dynamic systems are drawn up by making connections in cause-effect way. Implied relationships between objects reinforce the strategic narrative read from left to right. In addition, the Lifecycle phases can be related to Uses according to ARCADIS prioritization of goals (Mommers, 2015b) and based on the Surveyed preferences of Uses per phase done in this research. Together the BIM Uses and the OTL planned development lead to an Integrated BIM.

Direction

In the tactical view the Needs and benefits are horizontally aligned. Besides, an implicit relationship links the enablers. drivers and capabilities. Although part of the roadmap's narrative is horizontal(needs & benefits), the storyline is diagonal that starts with 'OTL Now' and ends in the Vision. The capabilities present arrows symbolizing towards what direction in the lifecycle they expand. Therefore most of them are not restricted to a single phase. Short-term priorities extracted from open questions in the surveys provide insights about the stakeholder's needs. For road-mapping purposes it was found useful to organize them based on the lifecycle phase the stakeholders operate. Though further research must focus on filtering and organising theses needs based on the specific lifecycle phase they affect. The table below can be found in the Appendix and it sets the basis for linking the stakeholder's needs to the lifecycle phases.

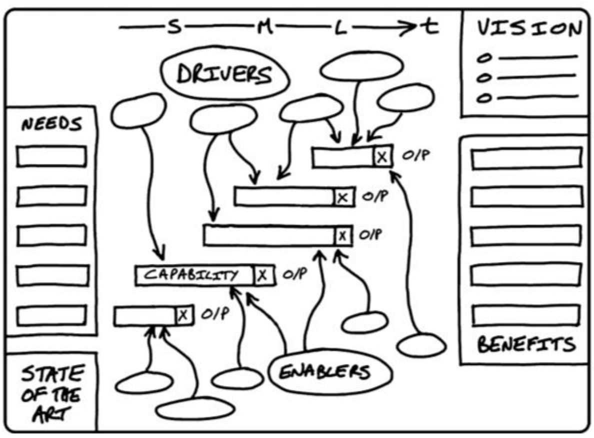

Figure 60: Tactical view layout (Phaal,2015)

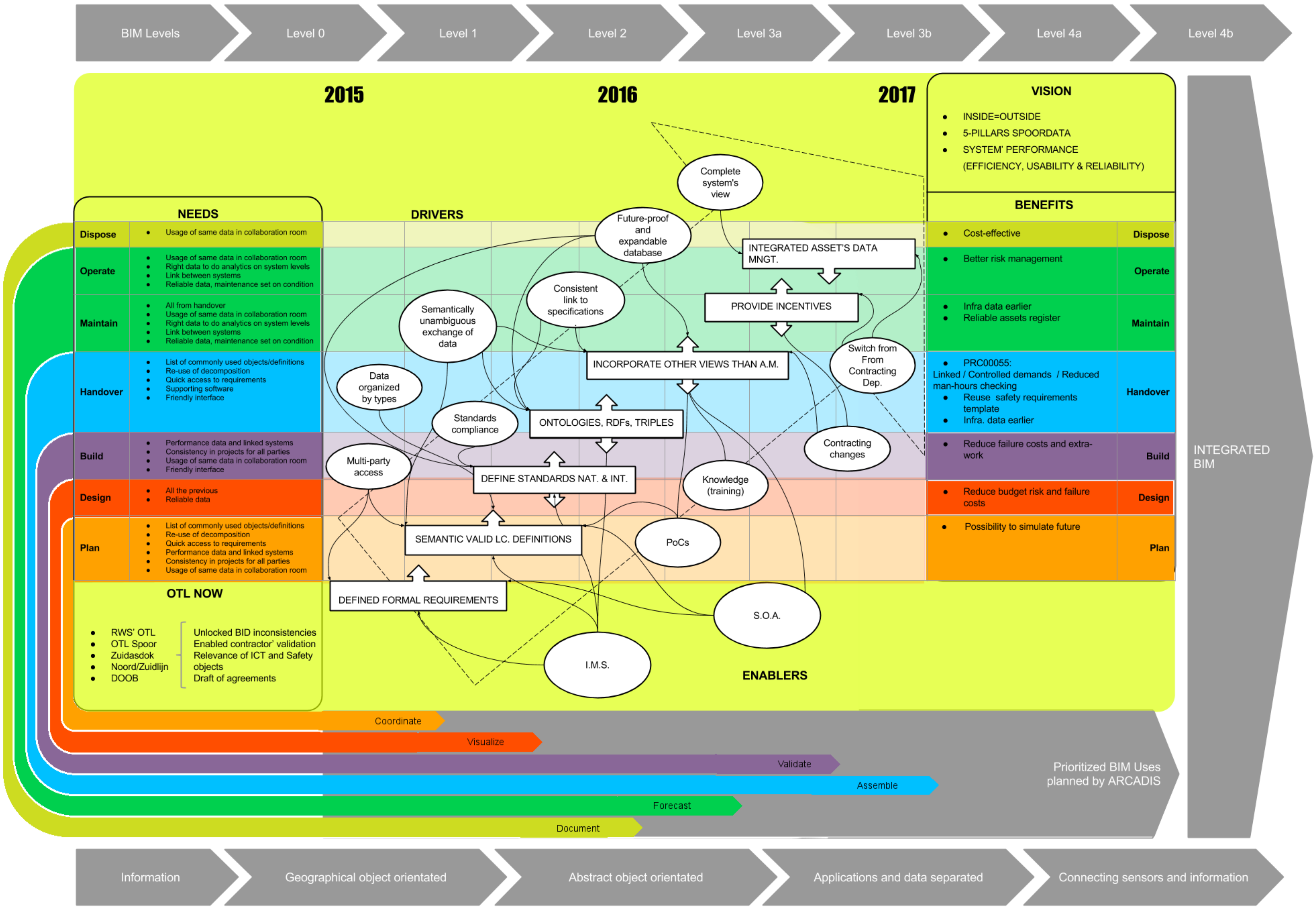

Figure 61: Tactical view Roadmap (own creation,2015)

22. Results

This research revealed that the Dutch railway' stakeholders are currently experiencing different problems with asset's data storage and exchange. The main problems point to the inefficiencies of working with document-based sources when linking asset's data.
Therefore, as seen in international experiences, an asset register(inventory of relevant data to an infrastructure' asset or system) turns out to be a potential solution to tackle these problems. In addition, the relationship between BIM and Asset Management has been strengthen within time. More literature has been progressively expanding BIM potential uses to other life-cycle phases rather than solely design.
The interviews and surveys made for this research support the use of object-type libraries for improving asset's data exchange and also to achieve part of the BIM' goals throughout the life-cycle. This was found to be in line with the Spoordata program goals.
In order to understand the conclusions, the research outcomes are first elaborated under the following aspects: the asset's information problem, the current state of RWS' and ProRail' OTLs and the views of the parties and the research questions. These aspects are further elaborated under the respective titles. Based on them, the following results can be listed:

- The OTL offers the possibility of terms' disambiguation which is the main concern of the surveyed parties. Disambiguation can improve data management and enhance life-cycle integration. The latter, however cannot be achieved without a planning for a scalable integration. The roadmaps set the basis for it.
- From an organisational perspective ProRail' OTL has two main aspects: it is based on open standards and it has a focus on data' criticality(filtering the most relevant information). The latter can reflect a lesson learned from Rijkswaterstaat experience whom built an OTL considered as too broad by many surveyed parties. Another distinctive trait is that ProRail' OTL has the potential to become more flexible than RWS' as it is based on the OWL semantic technology. This is supported by the research on international experiences(section 8) and it is likely to bring two main benefits: expandability and adaptability to future systems.
- The OTL has the potential to reduce significantly the data validation time as elaborated on the use-case DOOB(section 15.4). Moreover, it can seize the opportunities of re-using existing architecture. In this respect, some parties are likely to be more prepared to integrate to an OTL. This is partly explained by their position in the market and an IT-oriented culture rather than a traditional one. In order to extend the awareness to the rest of the supply-chain an organizational re-structuring is needed focused on: a shift to a centralized asset management department within ProRail(with a key focus on asset' intelligence) and provision of incentives to chain parties in order to keep and share data.
- As shown by the use-cases(section 15), the OTL can potentially link traditionally disconnected phases like design and maintenance. Experts expect benefits in performance that can be extended to traffic control. More use-cases can be further elaborated in order to assess value provided and make agreements on data priorization and criticality.
- An OTL implementation needs cooperation of all sector' parties and alliances for R&D between the industry and the academic world. A first attempt to bring structure to its implementation has been drafted in this research. Though, focus must be on the definition of requirements and agreements on cornerstones and objectives.

The infrastructure asset's information problem

Literature study and surveys support the potential of Building Information Modeling(BIM) in aiding asset management. Within the European infrastructure sector, initiatives such as IAAD4UK(United Kingdom) and the CB-NL and OTL(The Netherlands) aim to organise assets' information. Although, the IADD4UK has been tested in large projects like the London Crossrail, it has been conducted in a conservative way, assuring information ownership under a single-vendor scheme. Conversely, the Dutch OTL lead by RWS chose an open standards approach and it is more focused on semantics and disambiguation of terms. Thus, ProRail's Spoordata program aims to match inside(ProRail) with outside(supply-chain) data. Its main pillar 'standardization of information' is where OTLs play a fundamental role.

The surveys made for this research revealed that supply-chain parties consider *'a unified exchange of data'* as the main goal that should be pursued by an OTL, supporting in that sense the Spoordata' main pillar. In addition, the second most expected goal is *'to have a future proof and expandable database'* that supports the need of an integrated asset data management department within ProRail. The latter, is fundamental for a good implementation of the OTL. Therefore, it is stressed in the roadmaps made for this research in order to seize most of the value when implementing the OTL.

Current state of the OTL in RWS and ProRail

RWS' OTL has become too broad in the view of many interviewed railway' experts. Three years after the first pilot was rolled out, two main lessons are: to assign proper time for development and semantic validation; and to constraint the scope focused on practical applications. On the other hand, ProRail's OTL -based on the Information Model Spoor(IMS)- proposes a model where object' type data is exchanged in the specifications phase, when a project is commissioned. In this sense it forms the basis for infra project' tenders and can be later used for functional design. Complementary, OTL Spoor -ARCADIS and Movares' pilot- unlocked inconsistencies in the Business Information Documents(BID). Its whole applicability however is not completely known nor yet understood. In parallel, ProRail is still dealing with challenges that can be separated according to their nature with a five-dimensions framework as summarized under the next title.

Views and expectations of the supply-chain parties

Five-dimensions extracted from literature were used to assess expert's insights focused on: requirements, architecture, organisation, platform processes and operational support processes. Insights regarding requirements show that collaboration and planning are necessary for both functional and structural requirements aligned with ProRail's Enterprise Model. Depicting the OTL architecture, parties warn about future interoperability difficulties between RWS and ProRail's OTL. In addition, early agreements on 'asset recipes'(section 15.1) have to be made. In the platform processes, formal requirements will prioritize needs and prevent misinterpretations. Moreover, a regulatory framework will clarify ownership of data and provide guarantees to market parties. The organisational process' insights were the main focus of the research. Government optimism should not overlook different views and expectations. Proponent's views can enrich the capabilities of the OTL, whilst opponent's views point to implementation' costs and time, especially for non-IT contractors. Possible incentives are suggested(section 22.4.3). Ultimately, literature on operational support points to roadmaps to condense the main insights. The roadmaps propose a first draft of an OTL' planning in the industry and therefore they attempt to become a reference for structuring and prioritizing in the OTL implementation.

23. Answers to the research questions

1) In which uses could an OTL add value to the lifecycle management of railway assets?

The research introduced different potential uses based on: surveys' expectations, the organisational dimension, and use-cases. First of all, the surveys pointed to high-level expected results based on the Spoordata program. Thus, in the planning phase, parties expect the OTL will help in simulating the future whilst in the design and construction phases a reduction in budget risk, failure costs and extra-works are expected. In the handover, a preferred result is less clear. The reason might lie on the fact that most of the surveyed parties work in early life-cycle phases which are not very involved in handover procedures(see recommendations, section 23). In the operations phase, improvements in risk management and obtaining data earlier are expected. Finally, maintenance parties expect the OTL would provide them with a reliable assets register.

In the organisational dimension, experts found benefits using the OTL as a link between traditionally disconnected phases e.g. design and maintenance. Other group of experts focus on the OTL for aiding systems engineering, linking big data and improving tender processes. Further, use-cases supported the benefits of linking early phases to maintenance. The latter was elaborated in three use-cases on 'systems maintenance'. For instance, based on the use-cases, experts expect that an OTL will be used to:

- Keep performance data.
- Improve the depth of performance assessments made at decomposition levels.
- 'Create system recipes and link requirements',
- 'Link drawings data as inputs for other systems' and
- 'Validate the population of systems'.

In sum, further expanding the scope and reach of the surveys will be likely to reveal new and more potential uses.

2) What is this value?

The value can be better understood from achieving the success guarantees in the use-cases(section 15). The first four use-cases were based on ProRail' insights whilst the two last focused on ARCADIS' insights. Therefore, value can be split in two groups:
For ProRail:

a) Time savings due to having systems' recipes which re-use attributes and requirements.
b) Improvements in systems' performance from integrating and keeping performance data.
c) Less effort and system-knowledge is required to have a complete overview of systems.
d) Improvements in traffic control due to a better quality of maintenance' data transferred.

For ARCADIS:

a) Less time and effort resulting from linking the OTL with drawings data (Infra Atlas OBE) instead of referring to the traditional sources(BID).
b) Time and cost savings brought by a simplified validation process that re-uses data.

3) How could stakeholders' systems can be integrated to the OTL over time?

In this research two roadmaps were sketched based on road-mapping literature. The roadmaps relate to two viewpoints: The government(ProRail) strategic view and the supply-chain' tactical view. The first is based on the vision of the Spoordata program. Its scope was defined by the context of the use-cases following the advice of experts to 'start small'. The tactical view is based on short-term priorities extracted from the surveys which provided stakeholder's needs per life-cycle phase. In sum, based on the roadmaps, a prioritization for the implementation can be made in order to seize most of the value of the OTL. Accordingly, it is advised to prioritize the following steps:

i. Definition of formal requirements

ProRail should lead a formal definition of requirements for the Dutch Railways' OTL. These requirements should be aligned with RWS' vision for the Dutch OTL and the needs of the supply-chain parties. Experiences like the Zuidasdok help to estimate efforts in meeting the information needs from ProRail and RWS. In order to avoid misinterpretations, formal requirements can differentiate between the OTL as a model and as a dataset. In the case of the first, RWS represent a key partner due to their experience in the CB-NL and OTL development. This research provides a draft of requirements for the OTL model based on parties' preferences that can be used as a basis(section 11.2.1). In the case of the OTL dataset, advice from experienced supply-chain parties can help to prioritize datasets to be used as inputs. Moreover, key subjects in the railway market(section 12) represent an strategic partnership. Ultimately, based on recent experiences like DOOB, lessons can be learned and reflected in advice for requirements.

ii. Provision of incentives

Procurement authorities should provide incentives to smooth structural reforms in the railway sector. Incentives differ according to their focus inside ProRail or towards the supply-chain parties. In the first, incentives should be focused on communication and training of ProRail' experts in order to switch from a distributive contracting management department to an integrated asset' data management department. In the case of incentives towards supply-chain parties, the focus should be on enhancing collaboration in keeping and sharing data beyond own business interests.
Besides, change management strategies should focus on involving contractors and their concerns. Based on the interviews, main concerns are on ownership of data regulations and loss of competiveness in tenders facilitated by an open data exchange in tenders(see sections 23 for recommendations).

iii. Use of performance measures

ProRail and chain-parties should collaborate to define a set of indicators to measure the OTL' performance. As found in this research, currently there are not indicators to measure performance of semantic models and datasets. It is advised to develop fit-for-purpose indicators and their underlying criteria. This research provides a first attempt to list indicators that can be used a base(section 14). However, agreements have to be made on their definitions and their applicability for different uses. As exemplified in the use-cases the indicators might vary according to different OTL' uses. Similarly, within ARCADIS a framework of BIM' performance indicators would help to assess the contribution of the OTL to BIM' organisational goals per project and for their whole projects' portfolio. The tactical roadmap can be used a reference as it already sets together the OTL implementation and prioritized BIM' uses based on ARCADIS' experience.

24. Conclusions

After being stated the main results and answers to the research questions, the following conclusions can be rounded:

- Based on the interviews and surveys made for this research, railway experts support the need of standardisation and disambiguation of terms in the industry. Therefore, an OTL is the logic response to tackle infrastructure' data inefficiencies.
- Although Rijkswaterstaat and ProRail OTLs have overlapping aspects, they also have fundamental differences. Had been started earlier, Rijkswaterstaat left two lessons to learn from their experience: limit the scope and prioritize.
- In relation to Rijkswaterstaat' OTL, ProRail' OTL has two main advantages : it is based on open-standards and its focus on context-relevant data(criticality).
- Flexibility is a key trait provided by the OWL language which has the benefits of expandability and adaptability to future systems.
- The OTL can be used to enhance infra system's performance. Data has to be linked to decomposition levels in order to improve performance assessments.
- Time and costs will be reduced if stronger links are made between traditionally disconnected life-cycle phases re-using data. Therefore, R&D efforts have to be put on developing a linking tool such as the OTL.
- Use-cases are a practical way to assess the usability of the OTL for fulfilling stakeholders' information needs. Though, performance indicators are needed in order to measure the impacts of different OTL uses in relation to previous systems.
- A successful OTL implementation will rely on the following key actions:
  a) Planning of a scalable integration of systems.
  b) Awareness must be built about the sector' information problems and the benefits of standardization. An IT-oriented mind-set is more prone to seize the benefits brought by an OTL integration.
  c) Structural changes must take place in the internal organisation of ProRail and within the supply-chain parties in order to overcome two paradigm shifts:
     - A shift from a distributive contracting management to an integrated management.
     - A shift from a rule based to a performance based contracting culture.
  d) Prioritization of the most challenging aspects of implementation such as:
     - Definition of formal requirements.
     - Provision of incentives.
     - Use of performance measures.

25. Contributions

In sum, the main contributions of the research are:

- The research introduces a framework that can be used to assess different dimensions in the OTL development from requirements, to platform processes and organisational changes among others. The purpose of using the framework was to organise all the different insights and expectations on a new technology based on a scientific approach. Surveyed experts whom were involved in the CB-NL development, agreed on the usability of IT development theories for referencing the OTL development. The dimensions framework showed to be useful also for organising challenges(section 17) which help to understand difficulties and allocate efforts and resources.
- The research provides a system-approach to the OTL, deducting performance indicators based on a comprehensive set of interviews and surveys made to experts operating throughout the lifecycle of railway projects. The performance indicators set the basis for defining a measurement system to assess the OTL performance.
- A risk assessment provides insights(section 18) on what risks can be expected, how likely they are to happen and what mitigating measures can be used against each.
- The research stresses the importance of road-mapping in order to plan the OTL implementation and compare it with parallel scattered initiatives. The roadmaps summarize the advice of a relatively large set of interviews that partly reflect the current needs and expectations of stakeholders. Therefore, after validating them, they can support asset managers in prioritizing requirements and taking decisions for further steps in the OTL' development.

26. Limitations

The following limitations must be overcome to get more robustness in further researches:

- Current literature on BIM is mostly focused on the design phase and it barely elaborates on type libraries. Specific literature about object type libraries and performance indicators for data models was not found. This was tackled with referencing to IT platform development and organisational theories(see next section for recommendations).
- ProRail's OTL is the first attempt to use semantic technologies for asset management in the railway industry. In addition, relevant information about ProRail's Information Business Model was considered confidential. However, when asked about a similar model framework as the V-Con, it seems to be inexistent for the Railway Industry(see advice for future research, section 24).
- Due to time constraints more elaboration about the value provided in use-cases could not be done prior to the Roadmaps(see advice for future research, section 24).
- Although the strategic roadmap is based on developing and testing use-cases, they provide a general approach. For each specific case, adjustments might be necessary which may vary the symmetry of the Sankey flows and implementation times.
- The timeline for the roadmaps was set on a 2-year horizon based on ProRail's planning for information projects. However, some components in the Roadmaps are likely to last longer e.g. contracting changes based on incentives. Similarly, prioritized BIM' uses planned by ARCADIS and plotted in the tactical roadmap might vary(see recommendations).
- Personal interpretation and subjectivity plays an important role in key parts of this research like the value system design, performance indicators, use-cases' success scenarios, risk assessment and roadmaps. Some recommendations are given in next section to tackle this problem.

27. Recommendations

After being involved in this research for nine months the following recommendations can be given for industry parties and future researchers:

- In relation to the literature constraints stated in the previous section it is advised that a research program is started by all interested parties including the railway industry and the academic world. Due to the likely long-term horizon of a research, practical implementation lead by ProRail can run in parallel. The latter could become an iterative source of insights to add up to the research.
- It is advised to align ProRail's information model(IMS) with RWS' in order to get consistent requirements for the OTL architecture. Agreements will be necessary to get consensus about the right 'asset recipes' for specific user demands as introduced in the use-case 'systems architecture'(section 15.1).
- Regarding the threat to parties competiveness when sharing data, it might be worthy to asses different scenarios in collaboration with market parties more experienced in the OTL such as engineering bureaus, developers and semantic' software suppliers.
- The OTL user interface should aim for a 'visualisation of everything'(within the scope of every interested party). This, however should be done in a friendly and easy-to-understand way(avoiding the data overkill warned by some experts like in e.g. SAP-PLM). Ontology trees have potential to fulfil this aim as explored in the OTL Spoor pilot.
- The principles of open standards[17] should be part of training programs in order to create awareness on the benefits of collaboration. Experiences from other sectors such as software development(XML, Linux) show how collaborators become also benefited users.
- The surveys and interviews should be expanded as they constitute the basis on which advice and challenges are built. Although, the initial aim of the research was variety and homogeneity, at the end more people were surveyed for early LC phases. As shown in the survey' results(section 11.1) parties preferences were particularly spread for the handover phase. Therefore, future interviews should give special focus to the handover from construction to maintenance. Not extending the interviews and surveys could lead to a biased advice that is not applicable to the supply-chain as a whole.
- In the tactical roadmap more precision can be obtained through phase-specific questions when surveying the parties' needs. In this research due to time constraints, the needs of the parties were generalised and related to the life-cycle phases in which the parties operate. However, not necessarily all needs would be the same for every phase. Therefore, it is suggested for further surveys to differentiate the needs per phase.
- Awareness have to be built on the information needs of the sector as a whole. Not doing so, would be likely to result in resilience from contractors to shift to a more integrated supply-chain what is needed to pursue a centralized information management model .
- The release of ProRail's OTL roadmap is expected before the end of 2015. Therefore it is suggested to contrast it with the strategic roadmap designed in this research. Even though the priorities and content may vary, the overall structure and sequence of integration might be helpful as a reference. Similarly, in the case of the tactical roadmaps, the OTL content can be re-organised but the enablers and drivers can also be a useful aid for avoid losing track. Prioritization can be made based on interfacing information projects from ProRail' portfolio in order to adjust implementation times.

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[17] According to open-stand.org there are five principles: cooperation, adherence to principles, collective empowerment, availability and voluntary adoption.

28. Future Research

The present research is a first attempt to find common grounds on the views of an object-type library in the Dutch railway industry. Consequently, there is still much more to add in terms of exploration, analysis and innovation. The following points are suggestions for future research:

- Technological aspects of the OTL that were not part of the scope of the present research can be investigated. Thus, advantages and limitations of the OWL' semantic technology can be assessed within the context of the railway industry. A worthy comparison will be between artificial intelligence -where the OWL technology started- and railways in order to find overlapping aspects.
- As seen on the requirements dimension(section 4.4.1) special attention must be given to functions as their definitions for the same assets may considerably vary throughout the lifecycle. In the case of ARCADIS, current information architecture can be re-used to make an OTL. Pentenga's model(section 15.4.1) introduces the possibility of integration through a common functional name. However, other components of this model remain unexplored as the creation of the GIS modules and the API interface systems.
- The V-Con project can provide a thorough reference when defining the information model framework in the recent IMS(Information Model Spoor). It must be considered however, the differences coming from the core values of two different industries such as roads and railways.
- The presented use-cases should be extended and new-use cases should be elaborated. The interviews and surveys can be very helpful to find expectations and potential uses based on chain' parties experience and knowledge.
- Further research can focus on proving advice for getting the right regulations that rule the ownership of public infrastructure' assets data. The interests and competitive stance of market parties can be assessed. Complementary, the interests of traditional maintenance contractors who show themselves more resilient to use the OTL can be also assessed.
- Being Systems' Engineering an important framework of asset management in the Dutch railways, it is advised to thoroughly assess the practices of systems engineers in relation to the OTL. A grasp of this approach was introduced in the interviews key findings(section 11.2) however, some aspects worth of more exploration are: their view of a 'function-based' OTL and interface with systems like SEm which is relatively new.
- Gaming techniques can be introduced in order to dig deeper in the use-cases applicability. Decision situations between clients and contractors can be role-played in which the OTL solution is introduced and expectations and possible outcomes are assessed in different scenarios.

29. Reflections

Last but not least, some reflections related to the research content and my personal experience are:

- The OTL is set by the government and industry authorities within the BIM' framework. BIM however, is barely understood yet in the railway industry and it has been more focused on early life cycle phases in the building sector. This was reflected in the low rate of respondents to the second survey.
- Similarly, the OTL is not totally developed nor tested in large projects. So far, it can be stated that only a few developers really know how it works. Therefore, when introduced in the interviews most of the expected value brought by an OTL was based on experts' speculations and their experience.
- Even though the surveys show certain preferences, they are however too general for developing and implementation purposes(e.g. disambiguation, standardisation). After more testing time in real railway projects, the OTL will reflect the chain' requirements into its physical web-interface solution. Thereby, an OTL as conceived in the pilot OTL Spoor could not necessarily represent the only solution for standardizing asset's data.
- Although the OTL and BIM have common goals, in practice they have been worked separately. As shown by this research the OTL can help to achieve BIM objectives and therefore it is advised to consider a common framework based on the potential of the OTL to aid BIM. The basis for a shared framework BIM-OTL in the railway industry has been set. This was done with the alignment of Spoordata.nl goals to BIM goals(section 14).
- Not only the railway industry is broad and complex but dealing with semantics is highly complex itself. Therefore, the most important advice for the OTL might be "start small". Therefore, many benefits are more likely to be in Long-term(specially for traditionally disconnected life-cycle phases).
- A great challenge lies on the way to display information on the Roadmaps. When pursuing to do it, one can fall under the same document-based source flaws that the OTL aim to overcome i.e. visualisation of information constraints (as the roadmaps are fixed and cannot be extended to understand its details).
- Even though costs were considered out of the scope of the research, some stakeholders would have expected that the OTL value would be supported by costs estimates. This however, was not done but approximated in the estimation of man-hours for the specific case of DOOB.
- A generalist position was adopted in order to assess the OTL problem from an asset management perspective. However, since experts communicated using specific terms from their own specializations, this represented a slow learning curve and extra-digging at the beginning of the research process.

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Collaborators

Although many people collaborated with insights for this research, below are the ones who provided physical documents.

Martijn Pentenga(ARCADIS):	OTL model. Systems' engineering papers.
Sander van Nederveen(V-Con):	V-Con papers and project' insights.
Laurens Vet(ARCADIS):	Asset management papers.
Rik Opgenoort(ARCADIS):	ARCADIS' OTL Proof of Concept.
Bram Mommers(ARCADIS):	BIM Europe planning.
Raymond Soeters(ProRail):	Spoordata program, Information' projects portfolio.
Willem Kalshoven(ProRail):	ProRail' systems architecture.
Rene Wubbels(ProRail):	ProRail information architecture.
Marteen Zanen(ARCADIS):	ARCADIS' BIM papers, Zuidasdok, DOOB.
Mick Baggen(Rijkswaterstaat):	RWS' OTL Information model and use-cases.
Melanie Stuiver(ARCADIS):	SEm in ARCADIS paper.

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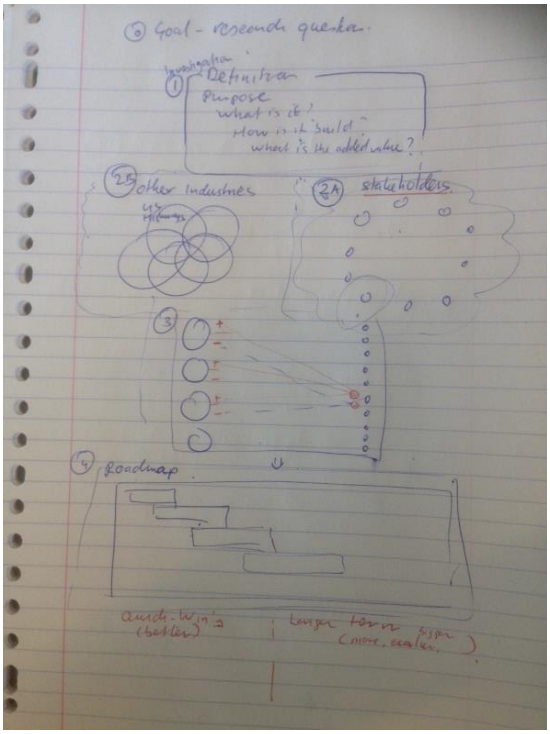
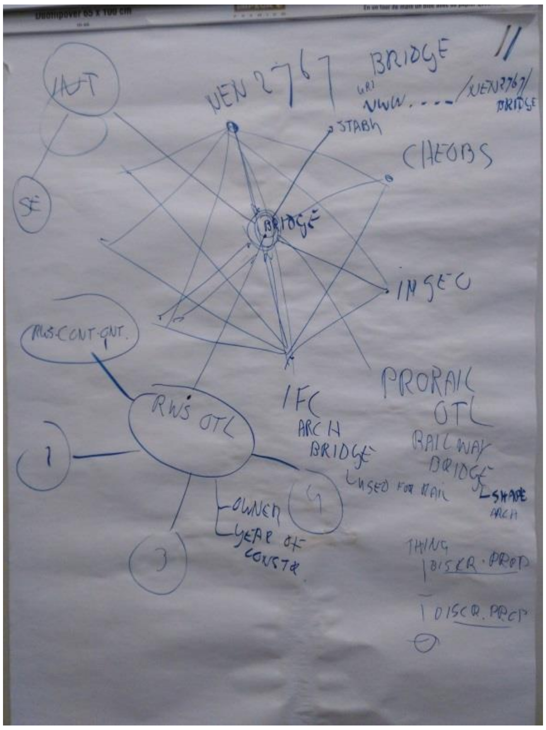
Sketches


Goal - research question
Definition
Purpose
other industries
stakeholders
Roadmap


BRIDGE
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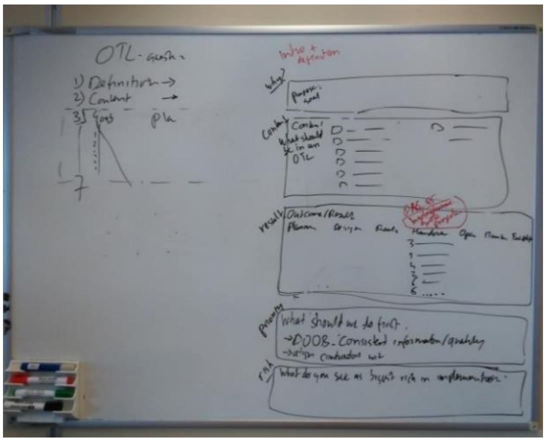
OTL
RWS OTL
IFC
ARCH
BRIDGE
RAILWAY
BRIDGE
OWNER
YEAR OF
CONSTR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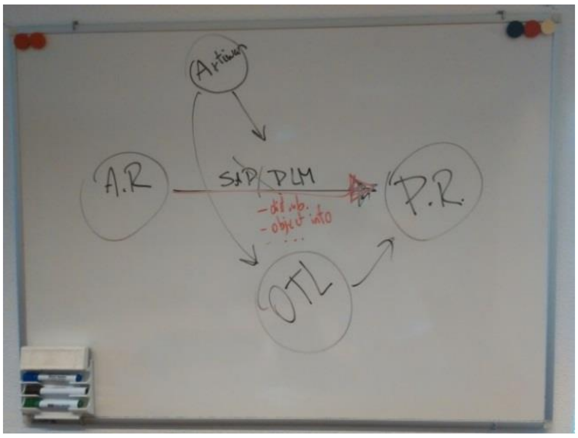
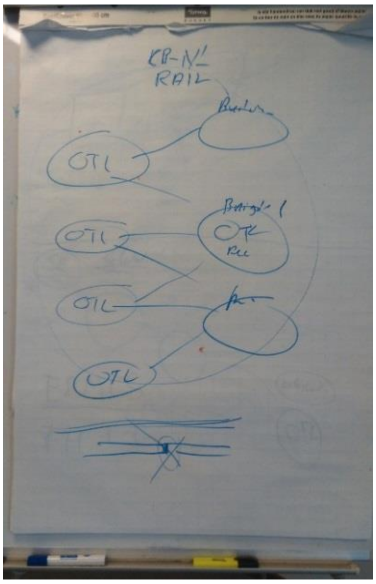
2) Content


A.R
SAP/PLM
P.R
OTL


A.R
SAP
P.R
SAP PLM
Lokia


1 year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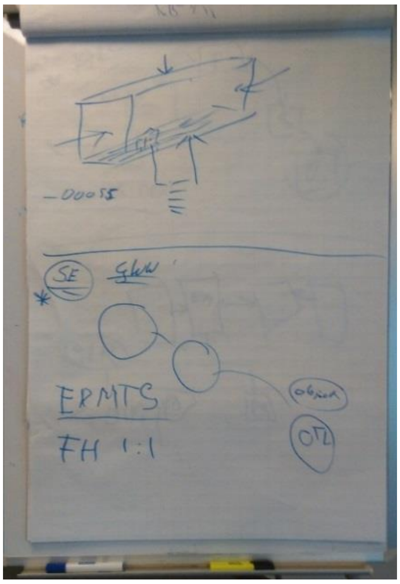
OTL
OTL
OTL
OTL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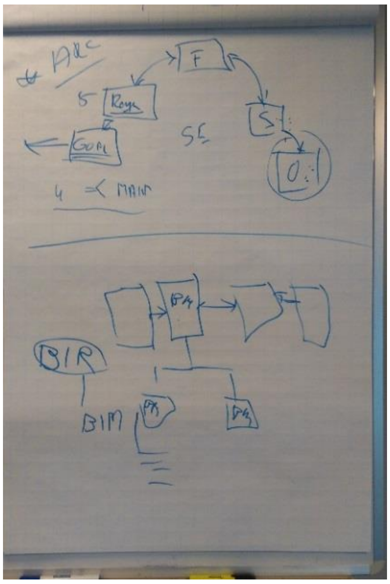
ERMTS
FH 1:1
OTL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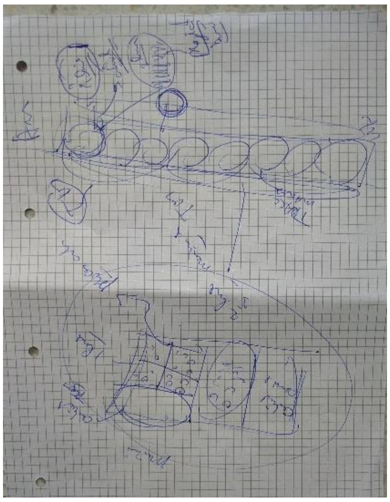
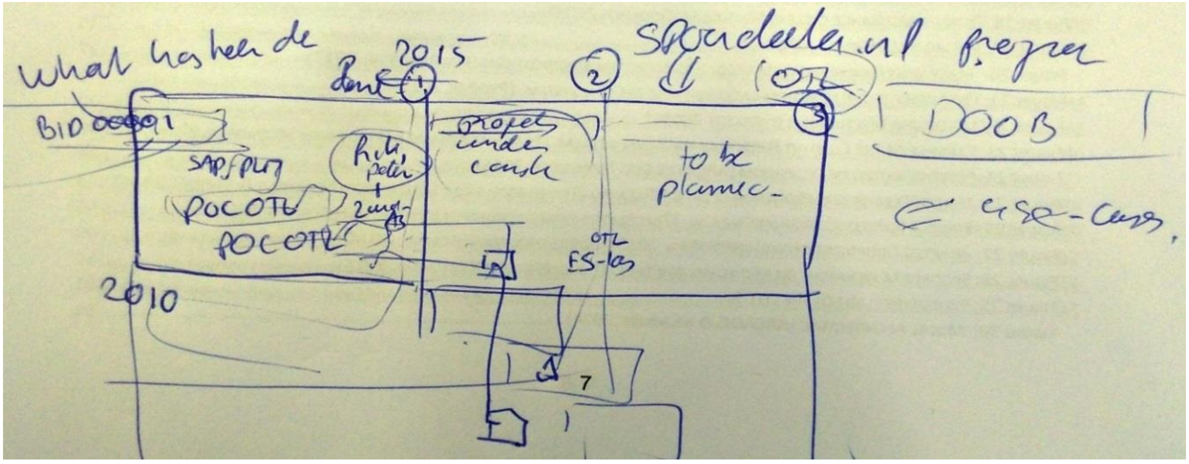
SAP

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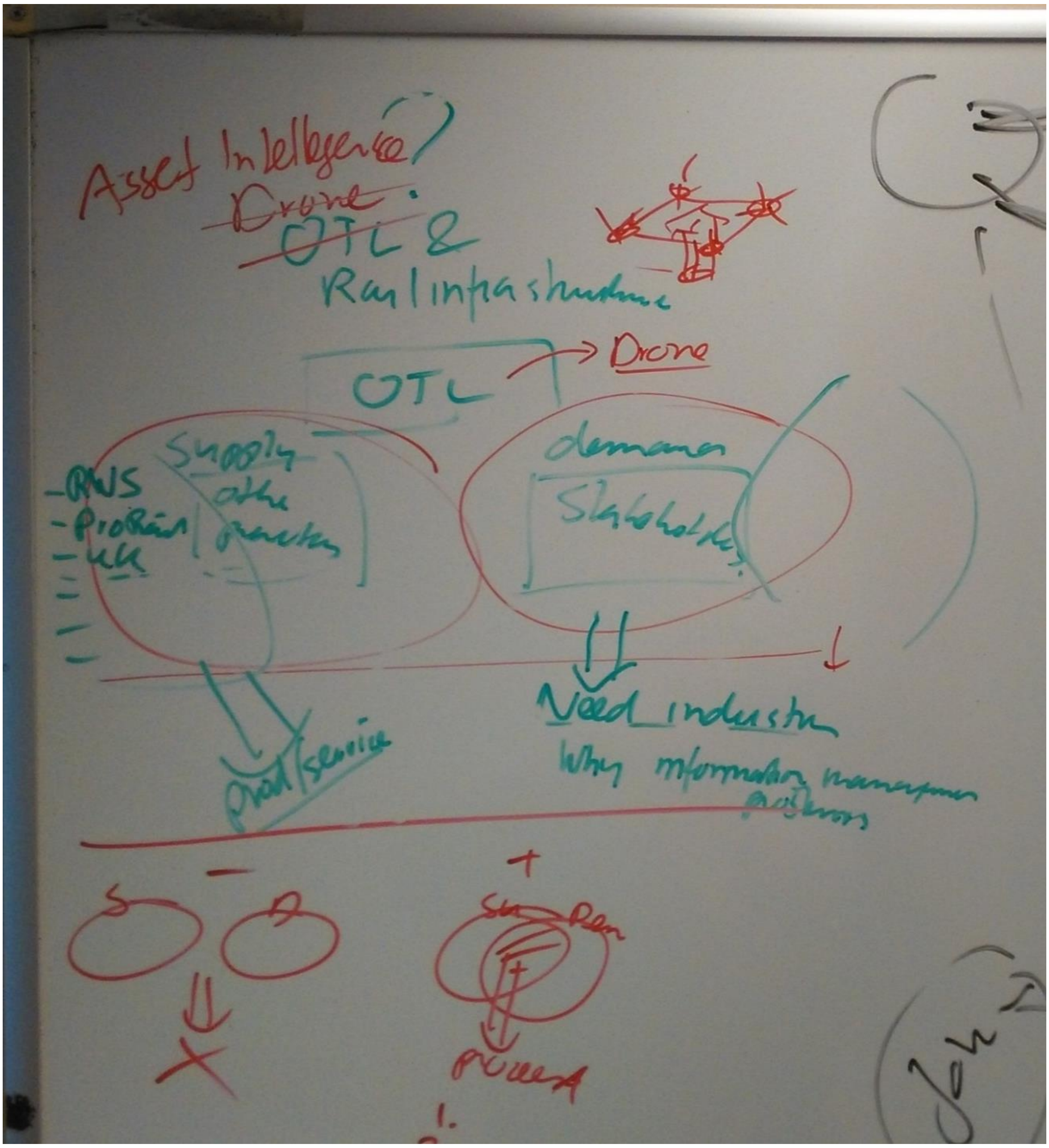
OTL
DOOB
2010
7


Asset Intelligence?
Drone
OTL &
Rail infrastructure
OTL
Drone
Supply
demand
Need industry