
STRATEGIC MAINTENANCE ON THE RIGHT TRACK



PROJECT DETAILS

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Design requirements for solving technical and organizational lacks of knowledge in strategic maintenance planning for high-speed railway infrastructure in The Netherlands and France

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ABSTRACT

Strategic maintenance planning in the field of high-speed railway infrastructure maintenance is currently performed inefficiently. It is an important topic, since high-speed railway many kilometers of infrastructure will be constructed in the next twenty years. Interviewed experts state that the actual problem statements consists of five groups of lacks in knowledge: model and data lacking, financial aspects, organizational structures, emphasis on efficiency and interface problems. In order to solve these lacks of knowledge, seven design requirements for a railway infrastructure maintenance organization and seven design requirements for a type of computer simulation tool have been identified. A computer simulation tool is desired, since an optimum point in the costs of maintenance exists and, as stated, maintenance is currently performed inefficiently. Within company Oxand SA, computer simulation tool StrateGo is most suitable for efficient long-term maintenance planning. A case study and a confrontation with the design requirements showed that the functionality of StrateGo is promising, but it could not be used for operational maintenance planning yet. Main concern is the reliability of the simulation and data. Improvements are proposed to overcome the weaknesses of this simulation tool.

Thanks to the (moral) support of my family and friends

*En vérité, la clé primordiale de la sagesse
c'est de se poser des questions
assidûment et fréquemment.*

P. Abélard (1079 – 1142)

PREFACE

This report represents the final document of the Thesis Project, course code TIL5060, of the study Master Transport, Infrastructure and Logistics at Delft University of Technology.

This Master's Thesis provides a research of an overview of the technical and organizational lacks in knowledge in strategic maintenance planning for high-speed railway infrastructure in France and The Netherlands. An exploration of computer simulation tools, which could solve these lacks will be given too. This report is the final part of the Master Transport, Infrastructure and Logistics by Delft University of Technology.

This research has been performed in cooperation with Oxand France, an engineering/consulting firm, specialized in risk analyses. This company is based in France, where I did this research partly. The process of this research took more time than expected. In the process reflection (paragraph 11.2), I will elaborate on this issue.

I want to thank my daily supervisors Sophie CROUIGNEAU (Oxand) and Jan Anne ANNEMA (TU Delft) for their valuable input and suggestions for directions for further research. Professor Bart VAN AREM completed my graduation committee; I want to thank him as well for his input and efforts.

Bonne lecture.

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SUMMARY

In this report, the (latent) problems behind strategic maintenance for high-speed railway infrastructure are researched.

The recommendations of the Dutch parliamentary survey about railway maintenance serve as a starting point. Overall, the parliamentary committee has come to the conclusion that the focus on long-term investment strategy for maintenance of Dutch railway infrastructure lacks. The part in the report about efficiency of maintenance is weak. It states that the real evidence for proving that improvements could be made, have not been researched. Which improvements could be made in order to improve the efficiency of railway maintenance remain still unclear after having read the final report of the survey. All in all, the conclusions and recommendations give rise to more research.

The research questions in this report are:

- 1) *What are lacks of knowledge in strategic maintenance planning for high-speed railway infrastructure in The Netherlands and France?*
- 2) *In order to solve the mostly mentioned lacks of knowledge, what design requirements should a computer simulation tool for strategic maintenance planning for high-speed railway infrastructure have?*
- 3) *To what extent are existing computer simulation tools able to meet the design requirements, as stated in the second research question?*

In Europe, more and more high-speed railway infrastructure is constructed, mainly due the increased total activity area between 150 and 800 kilometres. In this research, high-speed railway is chosen instead of conventional railways since:

- ◇ The future lies in high-speed rail; a planned increase in the high-speed railway network of from 7.378 (2012) to 30.750 kilometers (2030)
- ◇ A limited number of high-speed railway projects have been or will be constructed;
- ◇ Nearly all high-speed railway infrastructure projects are organized in public-private partnerships .

At current, in The Netherlands, one HSR project has been constructed; in France multiple more, but three projects have been taken into account.

All organizational agreements of these HSR projects show that many actors are involved and that maintenance is part of comprehensive agreements. Nearly all high-speed railway infrastructure projects are organized in public-private partnerships. In France and The Netherlands, only partnerships and concessions exist as contractual agreements. Maintenance of the infrastructure is part of these contractual agreements. However, in literature is unclear to what extent maintenance is regarded in the first phase of the projects. On the other hand, many actors are involved in constructing and financing high-speed railway infrastructure.

In order to gain more knowledge about the lacks of knowledge in the field of maintenance of high-speed railways, seven semi-structured expert interviews have been performed. The interviewees are originated from The Netherlands and France, and work for public and private parties. All interviews listed yield to five groups of lacks of knowledge:

- ◇ Model and data lacking of railway infrastructure assets
- ◇ Financial aspects of railway projects
- ◇ Organizational structures of railway projects
- ◇ Emphasis on efficiency with new railway projects
- ◇ Technical and organizational interface problems

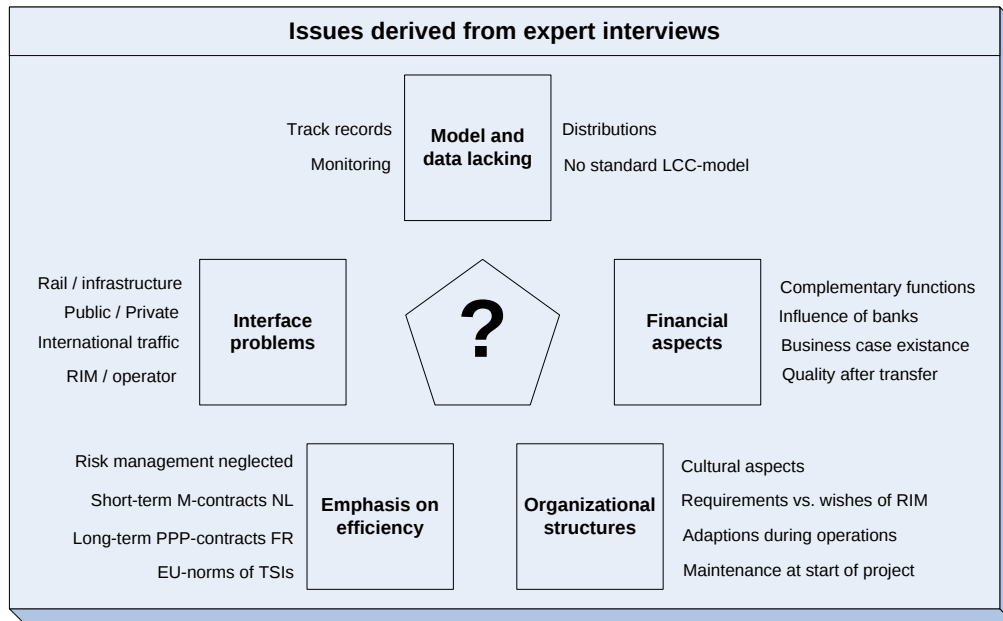


Figure 1: Overview of actual problem statement, mentioned by interviewed experts

Since it has been concluded by literature and by the interviewed experts that strategic maintenance planning is currently performed inefficiently, design requirements can be listed, in order to come to a more efficient strategic maintenance planning. The technical design requirements are about creating a type of computer simulation tool. The combination of technical and organizational requirements in the field of railway maintenance is called strategic maintenance. It takes not only into account the maintenance itself, but also its organizational issues. Maintenance management is a vital core business activity crucial for business survival and success and needs to be based on quantitative business models.

A railway infrastructure maintenance organization:

- ◇ should take into consideration the strategic maintenance planning during the phase of design and build;
- ◇ should regarding the quality of the assets, focus on the period around transfer of the infrastructure and balance the discrepancies in expectations of different actors;
- ◇ should mix project teams with employees from public as well as private companies and parties;
- ◇ should invest in risk management from an operational and maintenance point of view;
- ◇ should use an holistic approach during the whole concession period, with feedback loops when needed;
- ◇ should be able to work in different countries and with different cultures;
- ◇ should do as much as possible in-source; minimize outsourcing

A computer simulation tool:

- ◇ should exist of a well-performing ex-ante life-cycle-cost simulation tool for railway infrastructure maintenance;
- ◇ should own an overview of historical data for all components, which are taken into account, derived from previous high-speed railway maintenance projects;
- ◇ should have the possibility to change the model distribution of the life-time of an asset to its degradation;
- ◇ should have the possibility to alter data and parameters in the simulation model during operations;

- ◇ should be able to simulate long-term and short-term contract periods and come up with reliable results;
- ◇ should simulate an efficient maintenance planning, with use of (budget) constraints;
- ◇ should contain technical information about interface issues, like wheel-rail for new types of trains.

In order to come to a more efficient planning for estimating periodic and preventive maintenance, computer simulation tools can be used. In the end, these tools allow one to focus on the lifecycle costs of all assets involved and to find a (optimal) balance between costs of maintenance and the costs of breakdowns. As interviewees stated, no standardized life-cycle cost simulation model exists yet.

By means of an assessment of all computer simulation tools in company Oxand, computer simulation tool StrateGo is – on first sight – mostly suitable for strategic railway maintenance planning. This is the computer simulation which is macroscopic as well as strategic. This simulation tool will be tested to what extent it meets the technical design requirements.

StrateGo is an Excel-based tool and described as a strategic planning tool that enables the long-term technical and economic assessment of investment and maintenance policies. Simulating by means of StrateGo yield to three types of output:

- ◇ An overview of the costs of CAPEX/OPEX over time
- ◇ A semi-operational overview of the proposed maintenance actions
- ◇ The residual lifetime of every single component at the end of the simulation period

A real-life case shows the functionality of StrateGo in practice. It yields to observations which were positive and which should be improved. These observations yield to strengths and weaknesses of StrateGo.

Table 1: Strengths of computer simulation tool StrateGo

COMPUTER TOOL STRATEGO	
Strengths	
StrateGo enables to assess long-term strategies for maintenance in infrastructure	
StrateGo takes into account the costs and performance	
StrateGo is applicable to many infrastructural areas	
Outcomes of StrateGo are comparable to those of other computer tools	
StrateGo makes use of a structured process approach to enter projects and databases	
Not a very microscopic level for the data is required to come to calculations	
StrateGo consists of commercial (costs) and technical (residual lifetime) output	
Oxand possess different databases of infrastructures with details of different components	

Table 2: Weaknesses and proposed improvements of computer simulation tool StrateGo

COMPUTER TOOL STRATEGO	
Weaknesses	Proposed improvement
No standardized maintenance strategies possible to choose for simulation	Introduce strategies as only CAPEX, budget cuts and minimal residual lifetime
No reliable experience with risk and cost module	Introduce reliable risk and cost modules and link the three modules
Short-term, hands-on maintenance policies are not possible and not reliable	Only focus on strategic maintenance planning; skip hands-on schemes
No explanation of results in terms of bottlenecks or sensitivity analysis	Split the outcomes in terms of components; find the critical one

No other distribution possible than deterministic and knowledge about other distribution lacks	Introduce as least a Weibul distribution for residual lifetime (see interviews)
Slow if number of components exceeds 200, due to Excel-based program	Build a stand-alone computer program, with improved performance and interface
StrateGo has only been used for cases in France (electricity) and Switzerland (rail)	Gain more experience in other areas, sector wise and geographically
Only experience with conceptual strategic planning, not yet implemented	Exchange return of experiences with a client on a regular basis and gather details of spare parts from RAMS databases
No personal assessment of risk-treatment possible	Introduce a risk module, where risks can be mitigated to preferences of client

It is a real lack that no standardized maintenance strategies can be chosen in StrateGo. It is recommended to introduce maintenance strategies, like budget constraints, minimum level of service (standardized buffer in residual lifetime), budget cuts and only using CAPEX.

Although StrateGo is regarded as a maintenance planning tool on a strategic level, it is recommended not to generalize its outcomes. By finding the most critical component, the outcomes could have a real impact, rather than showing the state of the assets on a generalized level. Introducing probabilistic distribution functions for the residual lifetime is regarded as necessary, also by the experts, who were interviewed.

Confrontation with design requirements showed that StrateGo is well-performing on a meta-level, but recommended is to improve mainly the reliability of data and simulation.

Table 3: Confrontation of technical design requirements and StrateGo
Design requirements vs. StrateGo

Technical requirements	Suitability StrateGo
Existence of a well-performing ex-ante life-cycle-cost simulation tool	+
Overview of historical data of previous high-speed railway maintenance projects	+/-
Possibility to change model distribution of the life-time of an asset to the reality	--
Possibility to alter data and parameters in the simulation model during operations	+
Be able to simulate long-term and short-term contract periods	+/-
Simulate an efficient maintenance planning, with use of budget constraints	+
Technical information about wheel/rail interface for new types of trains	--

All in all, StrateGo could not be used for operational maintenance planning in practise yet. This is due to the lack of reliability in data and simulation. Experience with maintenance planning for real cases is non-existent, which causes risks. Moreover, a limited number of databases with details of components is possessed. Therefore, reliability of the data is at stake.

Confrontation with design requirements showed that StrateGo is well-performing on a meta-level, but recommended is to improve mainly the reliability of data and simulation. Moreover, there is still room for other improvements, like adding graphical representations, more detailed outcomes, implementation of the project management triangle and introduction of risk mitigation strategies.

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1. INTRODUCTION AND METHODOLOGY

Over the last years, the balance between input (money) and output (quality) of railway infrastructure maintenance has become an important topic in politics, as well as in public debates. In politics, a parliamentary survey of a committee of The Dutch House of Representatives (*Tweede Kamer der Staten-Generaal*) concluded that performance of the Dutch railways is at stake, due to the lack of long-term visions for maintenance of railway infrastructure. The committee stated that between 2005 and 2010 more than 1.4 billion Euros initially meant for maintenance for Dutch railway infrastructure was spent on construction of new railway projects and highways. Due to these findings, one fears more disruptions in operations and much higher maintenance costs on the long-term (*Tweede Kamer der Staten-Generaal*, 2012). In public debates, concerns about railway infrastructure are mainly about safety issues. Due to several deathly accidents caused by underperformed maintenance (*Le Figaro*, 2013) (*The Guardian*, 2006), some constructors even sent an urgent letter to the ministry, indicating that the current process of maintenance in The Netherlands will definitely cause disruptions and potentially severe accidents (*Volkskrant*, 2012).

In this report, the recommendations of the Dutch parliamentary survey of the committee “Spoor” will serve as a starting point. The committee has stated 29 recommendations about organizational structures of the Dutch railway system, its budgeting, level of innovation, effectiveness and efficiency and innovation and renewal in maintenance. The main conclusions and recommendations about maintenance are:

- ◇ The committee has not been able to assess the efficiency of railway maintenance, but has indications that improvements can be made (conclusion A-5);
- ◇ The minister should stimulate ProRail to arrange its maintenance and renewal process as such that the quality of the railways are assured on the long-term (recommendation 9);
- ◇ Maintenance is barely part of decisions about long-term investments. In practice, more second-hand material is used, probably triggered by the shortened contract period of five years (conclusion D-2);
- ◇ The database of current state of railways is not transparent, not actual and not reliable (conclusion D-3);
- ◇ Incorporate management and maintenance of railway infrastructure in long-term strategy of investments in replacement of renewal (recommendation 25).

Overall, the parliamentary committee has come to the conclusion that a focus on long-term investment strategy for maintenance of Dutch railway infrastructure lacks. A strong conclusion in the report is conclusion D-3 – the absence of an actual, reliable database. This gives a major cause for concern: reliable data is a prerequisite for decisions on the long-term. The part in the report about efficiency is weaker. For example conclusion A-5 is a gut feeling of the committee; the real evidence for proving that improvements could be made have not been researched. The rationales of which improvements can be made in order to improve the efficiency of railway maintenance remain still unclear after having read the final report of the survey. All in all, the conclusions and recommendations give rise to more research.

In this report, the current state of organizational structures in railway infrastructure in The Netherlands and France is researched. By means of expert interviews the actual problems of maintenance in the field of railway infrastructure are researched. The first part of this report will provide a comprehensive overview of the important problems and issues, mentioned by actors. The second half of this research provides directions to solve (a part of) these problems.

1.1. RESEARCH GOAL AND QUESTIONS

In this report, three main research questions will be answered. The first question unveils the existing, but latent problems behind maintenance for high-speed railway infrastructure: the lacks of knowledge will be made clear. These lacks lead to design requirements for a type of computer simulation tool, which is able to meet the lacks of knowledge, which are the most existent. Therefore, the second research question determines the design requirements. The third research question elaborates on existing computer simulation tools, which are assessed to what extent they can meet the design requirements.

The research questions are:

- 1) What are lacks of knowledge in strategic maintenance planning for high-speed railway infrastructure in The Netherlands and France?
- 2) In order to solve the mostly mentioned lacks of knowledge, what design requirements should a computer simulation tool for strategic maintenance planning for high-speed railway infrastructure have?
- 3) To what extent are existing computer simulation tools able to meet the design requirements, as stated in the second research question?

1.2. SCOPE OF RESEARCH

The scope of this report is high-speed rail, due to its future developments in rapid network expansion. According to decision 1692/96/EC *Community guidelines for the development of trans-European network* (European Parliament, 1996), a Trans-European Network for Transportation will be designed, indicating a high-speed railway network of 30.750 kilometers in 2030 (European Commission, 2011); a massive investment compared to the current network dimensions of 7.378 kilometers (UIC High Speed Department, 2013). At least 550 billion Euros will be required for completion (European Investment Bank, 2009). Maintenance of this railway infrastructure is researched, mainly since research of maintenance is far behind research about the phases of design and construction (Zoeteman, 2011) (Shokri, S., Safa, M. et al., 2012). As stated, the Dutch parliamentary survey is a starting point for this research. Geographically, high-speed railway projects are researched in The Netherlands and in France.

1.3. RESEARCH METHODOLOGIES

In this research, four different research methodologies will be used. In order to provide an answer on the first research question, literature research and semi-structured interviews are performed. For the second research question, a fit for purpose test and case study is done for a certain type of computer simulation tool.

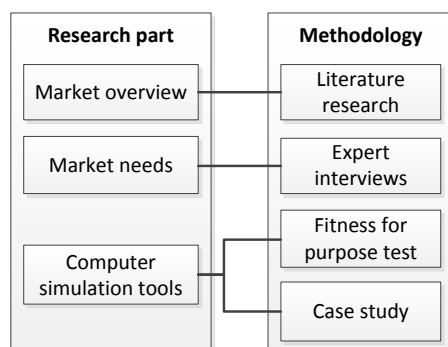


Figure 2: Overview of methodologies to be used

1.3.1. LITERATURE RESEARCH

To get an in-depth knowledge of the existing high-speed railway infrastructure projects, research for the Dutch and French situation will be done. The characteristics of these railway lines are elaborated, like their physical dimensions, their organizational forms and their involved actors. Literature research will also be used for the state of computer simulation tools in infrastructure.

1.3.2. SEMI-STRUCTURED INTERVIEWS

The interviews to be held with different experts can be categorized as semi-structured interviews. The semi-structured interviewing technique is chosen for a couple of reasons:

- ◊ The topic and research question has a fairly clear focus;
- ◊ It is not all about *what* the interviewees say, but also the *way* they say it; it is among others about their different perspectives;
- ◊ Actors from very different backgrounds (public versus private and The Netherlands versus France) are interviewed, who should be approached in a different way.

Bryman describes the process of these kinds of interviews as *flexible*, by which he means that *the emphasis must be on how the interviewee frames and understands issues and events – that is, what the interviewee views as important in explaining and understanding events, patterns, and forms of behavior* (Bryman, 2001). In his book, the author also adds that the order of the prepared questions is loose. Therefore, the interview is prepared with predominantly open questions, and also a couple of closed questions. The order of the posed questions depends on the answers given. In practice, when the interviews were held, it turned out that a natural difference between the first and last interviewees was raised. The order of the interview was changed into a more convenient order and the latter interviewees have been confronted with statements of early interviewees.

1.3.3. FITNESS FOR PURPOSE TEST

In order to match the type of computer simulation tool with the design requirements, a fitness for purpose test is performed. Fitness for purpose has been a widely used approach by quality agencies. As one of the five definitions of quality, Harvey and Green, (1993) state: *Fitness for purpose sees quality as fulfilling a customer's requirements, needs or desires. Theoretically, the customer specifies requirements* (Harvey, L. and Green D., 1993). The fitness for purpose in this field of research is to what extent the computer simulation tools match the requirements, which have been derived from the interviews with the experts.

1.3.4. CASE STUDY

A case study is used in order to gain more knowledge of a type of computer simulation tool working in practice. The case study will also assess the design requirements and will unveil the lacks in these requirements. Yin defines a case study which investigates a contemporary phenomenon within its real-life context, especially when the boundaries between phenomenon and context are not clearly evident. The performance of this computer simulation tool is tested by a case, which comprises real data of an existing railway line. By Yin, a single-case study is appropriate if it concerns a critical, extreme, unique or revelatory case.n (Yin, R.K. , 2013) The latter applies to the database to be used. By analysing the computation process and its outcomes, conclusions about its performance will be drawn. Based on these conclusions recommendations will be given, in order to provide an answer on the question to what extent existing computer simulations tool are able to meet the design requirements, as stated as an answer on the first research question.

1.4. DEFINITIONS

In order to have a common understanding of the topics used in this thesis, four terms will be explained by their definition. The connection between these terms is that every high-

speed railway infrastructure project is a large engineering project. Maintenance is an important part of the such large engineering project and public-private partnership is an organizational form which is often seen in high-speed railway infrastructure¹.

1.4.1. HIGH-SPEED RAILWAY INFRASTRUCTURE

According to the European Commission, the definition for a high-speed rail is the possibility of a train to run at least 200 km/h on a conventional, upgraded track and at least 250 km/h on new lines (European Commission, 2010). According to directive 2008/57/EC, different categories in high-speed railways are distinguished, dependant on the maximum possible speed and the nature of the railway line (European Commission, 2008).

- ◊ Category I: Specially built railway lines, equipped for maximum speeds, which equals or exceeds 250 km/h.
- ◊ Category II: Upgraded railway lines, equipped for maximum speeds of 200 km/h.
- ◊ Category III: Specially upgraded lines, suitable for high-speed trains, however with a maximum speed, equal to conventional speed. Due to environmental circumstances, as intersections of towns, connections from a high-speed line to a conventional line and crossings of stations.

In statistics, Eurostat considers all three categories of high-speed railway lines as being part of a high-speed network (Eurostat, 2010).

1.4.2. LARGE ENGINEERING PROJECTS

For Large Engineering Projects, the definition of Millar & Lessard is used in this research. Large engineering projects (LEPs) are high-stakes games characterized by substantial irreversible commitments, skewed reward structures when they are successful, and high probabilities of failure. Their dynamics also change over time. While the “front end” of a project – project definition, concept selection, and planning – typically involves less than one third of the total elapsed time and expense, it has a disproportionate impact on outcomes, as most shaping actions occur during this phase. Once built, most projects have little flexibility in use beyond the original intended purpose. Managing risks is thus a real issue. Within LEPs interface problems always occur. Interfaces are considered as links between different construction elements, stakeholders and project scopes. Poor management of interfaces may result in deficiencies in the project cost, time, and quality during the project life cycle execution, or may result in failures after the project has been delivered (Miller, R. & Lessard, D.R., 2000) (Shokri, S., Safa, M. et al., 2012). Project in high-speed railway infrastructure can be characterized as large engineering projects.

1.4.3. (STRATEGIC) MAINTENANCE

By means of maintenance, an asset will have a higher quality in the end, compared to its state before the maintenance. On a basic level, two types of maintenance can be differentiated: planned and unplanned maintenance. The difference is whether a failure has occurred, or not. Unplanned maintenance is also called corrective or breakdown maintenance. Planned maintenance is divided into periodic maintenance and preventive maintenance. This variance is based on executing maintenance based on time or state of the asset.

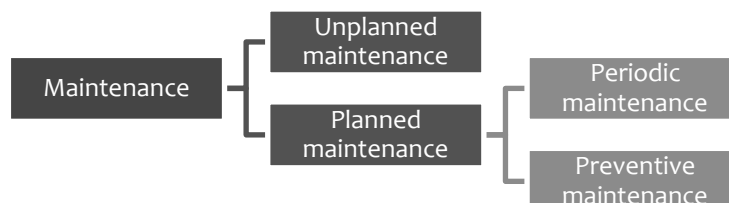


Figure 3: Breakdown of different maintenance categories

¹ See examples in Chapter 2.

In his paper, Wilson says that *Maintenance management is the art to do the right maintenance at the right time* (Wilson, A., 1999). Maintenance for railways is executed for different purposes. The generalized goal of maintenance is to have an improved level of quality after maintenance works. In his paper, Dekker describes the reasons why maintenance is executed, in general (Dekker, 2000). He identifies six reasons:

- ◊ Reducing failure rate
- ◊ Identifying hidden failures
- ◊ Extending lifetime
- ◊ Improving use-efficiency
- ◊ Reducing user-fees
- ◊ Complying with legislation

Strategic maintenance

This research takes not only into account the maintenance itself, but also its organizational issues. This is so-called strategic maintenance. Murthy et al. (2002) describes in Strategic Maintenance Management the two key elements of the strategic maintenance management approach:

- ◊ Maintenance management is a vital core business activity crucial for business survival and success, and as it must be managed strategically;
- ◊ Effective maintenance management needs to be based on quantitative business models that integrate maintenance with other decisions such as production etc.

These two key elements make clear that strategic maintenance for railway infrastructure is of vital importance. This research also elaborates on the actual state of quantitative business models. Murthy states that strategic maintenance is viewed as a multi-disciplinary activity. It involves:

- ◊ Scientific understanding of degradation mechanisms and linking it with data collection and analysis to assess the state of equipment;
- ◊ Building quantitative models to predict the impact of different actions (maintenance and operations) on equipment degradation; and
- ◊ Managing maintenance for a strategic perspective.

1.4.4. PUBLIC-PRIVATE PARTNERSHIP

It will turn out in latter chapters² almost all high-speed railway infrastructure projects are organizational structured in public-private partnerships. In literature, many definitions about public-private partnership exist. Annex 5 gives an overview of several definitions. The definition for public-private partnership, which will be used in the rest of this research, is:

Public-private partnership is an integrated process life-cycle arrangement between a public entity on one side and one or more private sector entities (often joined in a special purpose vehicle) on the other. It is performed for the provision of public assets and/ or related services for public benefit, through investments being made by and/or management undertaken by the private sector entities for a specified time period. A substantial risk sharing with the private sector exists and the private party receives output-performance linked payments that conform to specified, pre-determined and measurable performance standards (van Ham, H. & Koppenjan, J. , 2011) (Government of India, 2010) (PPS Netwerk Nederland, Wat is PPS?, 2013).

1.5. READING GUIDE

On a macroscopic level, this report will consist of two parts, see bow-tie in Figure 4. The first part researches the current state of strategic maintenance in (high-speed) railway

² See Chapter 2 for high-speed railway infrastructure in The Netherlands and France

infrastructure; its goal is clarify the actual problem statement. All input from the research part will lead to design requirements for a type of simulation tool, which could (partly) solve the researched problems. The second part of this report elaborates on a design for a type of simulation tool. In this part, an existing simulation tool will be tested on its fitness for purpose.

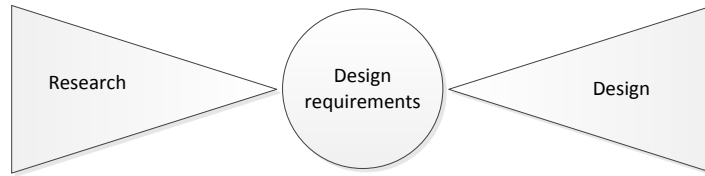


Figure 4: Bow-tie of research and design part in report

In Chapter 1 an introduction into the problem of strategic railway maintenance has been given, as well as definitions and descriptions of the research methodologies to be used. Chapter 2 provides a description of the current and future high-speed railway market in The Netherlands and France. It concludes with notable similarities between the high-speed railway projects. In Chapter 3, the actual problem statement will be researched. Experts interviews are used to clarify the actual problem; in Chapter 3 the research design, findings, discussion and conclusions of the interviews are elaborated. Chapter 4 enumerates the organizational design requirements for a more efficient performance of strategic maintenance planning; and the technical design requirements for a type of computer simulation tool.

In Chapter 5, the design requirements are applied to computer simulation tools for railway maintenance, leading to the choice of one tool. Chapter 6 elaborates on this chosen computer simulation tool and provides its theoretical background information. In Chapter 7, a case study is used with the chosen computer simulation tool, in order to test its functionalities in practice. Chapter 8 describes the evaluation of the type of computer simulation tool, with strengths and weaknesses, confrontation with the design requirements and proposals for improvements.

This report ends with conclusions (Chapter 9), recommendations (Chapter 10) and reflections (Chapter 11). Attached are different annexes, which provide background information and are referred to in the main text.

2. DESCRIPTION OF HIGH-SPEED RAILWAY MAINTENANCE MARKET

In this chapter, the current state of the high-speed railways in The Netherlands and France is researched. In this research, high-speed railway is chosen instead of conventional railways since:

- ◇ The future lies in high-speed rail; the Trans-European Network for Transportation indicates an increase in the high-speed railway network of 316%: from 7.378 (2012) to 30.750 kilometers (2030) (European Commission, 2011) (UIC High Speed Department, 2013);
- ◇ A limited number of high-speed railway projects have been or will be constructed, which makes it suitable to compare;
- ◇ Nearly all high-speed railway infrastructure projects are organized in public-private partnerships (see paragraph 2.4).

High-speed Rail (HSR) is a very complex system, consisting of many elements, like: infrastructure, rolling stock, operation rules, signaling systems, marketing, maintenance systems, management, financing etc. (UIC High Speed Department, 2013). In this report only a set of elements will be researched: infrastructure, maintenance systems and to a smaller extent financing and management. The UIC also states that high-speed projects are unique and should be adapted to all the counties and circumstances. Therefore, it is interesting to do in-depth research for different countries; in this report two countries will be taken into account: The Netherlands and France.

This chapter will start with background information on why high-speed railway infrastructure is constructed at all. Secondly, high-speed railway infrastructure projects in The Netherlands and France will be listed, of which the financial and organizational details will be researched. The last part of this chapter focusses on the conclusions derived from the researched HSR-projects. These observations are input for the next steps in the research process.

2.1. RATIONALE OF HIGH-SPEED RAILWAY INFRASTRUCTURE

Constructing high-speed railway infrastructure has many advantages. The International Union of Railways lists several considerable advantages of high-speed trains (International Union of Railways (UIC), 2013), like:

- ◇ High capacity: up to 400.000 passengers per day per railway line and traffic congestion on highways is reduced
- ◇ Environmental respect: efficient use of land and energy efficient
- ◇ High safety: up today, no accident with injured passenger at more than 200 km/h³

Other performance indicators support high speed for customers even more. Indicators like: Commercial speed, Total time of travel, frequency, reliability, accessibility, price, safety and freedom during trip.

Due to its high speed, more destinations can be reached in the same travel time as before. In order words, the total activity area of people is enlarged by this new type of modality. According to Figure 5⁴, HSLs offer the quickest transportation way, for journeys between 150 and 800 km. Below 150 km, they offer a limited bonus compared with

³ Although stated by the UIC, this statement can be discussed. In July 2013, a high-speed train accident in Spain caused 79 victims, but the train ran 190 km/h (El País, 2013). In July 2011, an accident in China caused at least 40 victims, but also this train ran less than 200 km/h, namely 99 km/h (Railway Gazette, 2013).

⁴ Figure derived from Commission for Integrated Transport (Commission for Integrated Transport, 2004)

conventional rail travel. Above 800 km, air travel gains the upper hand, except for journeys on which rail offers specific advantages (European Commission, 2010).

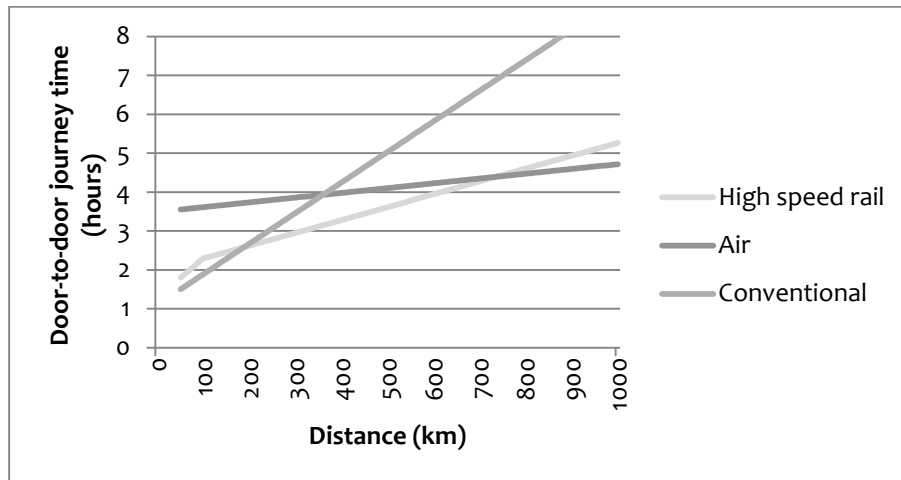


Figure 5: Journey times vs. distance for 3 modes (HSR, Air and Conventional rail)

2.2. HSR INFRASTRUCTURE PROJECT IN THE NETHERLANDS

Between Nieuw-Vennep and the Belgium border, the only high-speed line of The Netherlands has been constructed (see Figure 6⁵). It was completed in 2007 and has a length of 125 kilometres, of which 85 suitable for high-speed trains. The HSL-South Project is the largest Public Private Partnership (PPP) contract ever awarded by the Dutch government and one of the largest high speed railway projects in Europe to date. The total construction project was split into multiple subcontracts, of which one was a partnership for a DBFM-contract. The consortium Infrasppeed (Fluor, Siemens, BAM, Innisfree and HSBC) has won this contract. The contract was meant for 5 years of construction of the superstructure of the infrastructure. The total value of this DBFM-contract is 1.320 million Euros (Infrasppeed, 2012) (PPS Netwerk Nederland, HSL-Zuid, 2012).

For the operations of the railway line, a concession was granted to High Speed Alliance (HSA). HSA is a joint venture of Dutch Railways (Nederlandse Spoorwegen, 95% of shares) and Royal Dutch Airlines (KLM, 5% of shares). This consortium pays the Dutch State 160 million Euros yearly (price level of 2010). The concession will last for 15 years. Due to the relative high concession costs, in respect to the low amount of passengers and revenues, it is still the question if HSA will be able to pay the concession costs at all times (Infrasppeed, 2012) (Hoogzaad, B.F. and Van Ham, J.C., 2006) (PPS Netwerk Nederland, HSL-Zuid, 2012).

Maintenance works of this high-speed railway line are done by Infrasppeed Maintenance, which is part of consortium Infrasppeed. Infrasppeed Maintenance is responsible for maintenance on the line (substructure and superstructure) for 25 years, so



Figure 6: Route of HSL Zuid

⁵ Figure derived from Railway Page (ARP, 2013)

until 2031. Because of the form of contract that was chosen (DBFM in a single contract), it was in Infraspeed's interest to think ahead in the design and construction phase; and make the maintenance after completion efficient (BAM PPP, 2013) (Hartman, 2011).

2.3. HSR INFRASTRUCTURE PROJECTS IN FRANCE

During the last years some large projects regarding new railway infrastructure have been started. All projects are part of the “Grand Projets Ferroviaire à l’Horizon 2020” (“large railway projects until 2020”) (Réseau Ferré de France, GSM-Rail: 1er contrat ferroviaire en PPP, 2010). The extension of the network to the east of France (HSL Est Européenne) was the first project to be executed. The railway line was split into two parts, which both were covered by an amount of investment costs of over 5 billion Euros. Only the construction phases (Design and Build) were arranged by contract with private partners. The operation and maintenance of the line is operated traditionally by the (public) body SNCF and RFF. This line cannot be regarded as created by public-private partnership investments.



Figure 7: Lay-out of high-speed railways in France in 2020

In the French railway infrastructure three projects have been/are constructed with public-private partnership models. Figure 7⁶ shows these projects, which are:

- ◇ HSL Nîmes – Barcelona
- ◇ HSL Sud Europe Atlantique
- ◇ HSL Bretagne – Pays de la Loire

HSL Nîmes – Barcelona

The high-speed train connection between Nîmes and Barcelona in Southern France is constructed for a faster international connection between France and Spain. Due to the new high-speed line the total travel time Paris – Barcelona decreased from 8h40 in 2010 to 7h25 in 2011. Due to upgrade of the track Figueras – Barcelona in Spain, it will even decrease to 5h40 in 2012. It has been split into three sub divisions, namely: Nîmes – Montpellier, Montpellier – Perpignan and Perpignan – Figueras (Spain).

The first part is a bypass around Nîmes and Montpellier, and the railway track in between. It will be financed by a public-private partnership in a DBFM-organization. A total of 1.630 million Euros is involved in this PPP-deal. The second part will be an upgrade of the conventional train line Montpellier – Perpignan. This modernization will take place from 2016 onwards. In 2020 the line should be in operation. Financial agreements have not been made yet. The last part is the cross-border connection Perpignan – Figueras. This 44-kilometer track has a total PPP-value of 1.096 million Euros. This is financed by the public French and Spain entities and the European Union. As private parties, Eiffage (French) and ASC Dragados (Spanish) are joined in a special purpose vehicle called TP Ferro. The PPP-deal is a 53-year concession and its first operation was 19th December, 2011 (Réseau Ferré de

⁶ Figure derived from (Réseau Ferré de France, Lignes nouvelles en construction ou en projet, 2013)

France, Ligne nouvelle Montpellier - Perpignan, 2013) (Réseau Ferré de France, Contournement Nîmes - Montpellier, 2013).

HSL Sud Europe Atlantique

The high-speed connection to be constructed between Tours and Bordeaux (South-West France) is the largest PPP-deal in the world ever signed. It is a concession contract with a total value of 7.800 million Euros, with 6.200 million Euros for construction of the line. The contract lasts for 50 years and is financed by the special purpose vehicle LISEA, which is compiled of Vinci and two different banks. Construction and maintenance is done by different SPVs, but Vinci is always part of these SPVs. The exploitation of the line (operations) is done by Vinci as well. It directly charges users of the line. This could be done in passenger kilometres, type of train of length of train. The construction phase has started in 2012, the line will be operational at 2017 (Réseau Ferré de France, Ligne de Grande Vitesse Sud Europe Atlantique, 2013).

HSL Bretagne – Pays de la Loire

To connect Western France to the high-speed rail network, the high-speed line Bretagne – Pays de la Loire will be constructed. The line will run between Rennes and Connerré, a total of 214 kilometres. The PPP-outline is a total of 3,400 million Euros in a partnership for 25 years. In January 2011, the contract was awarded to Group Eiffage for constructing and maintaining the railway line. RFF will operate (exploit) the railway line. Eiffage will be paid yearly in fixed amounts by RFF. The railway line will be in operation in 2017, but the partnership contract has already started by 2011 (Réseau Ferré de France, La Ligne à Grande Vitesse Bretagne - Pays de la Loire, 2013).

2.4. OVERVIEW OF DUTCH AND FRENCH HSR-PROJECTS

Three high-speed railway infrastructure projects in France and one project in The Netherlands have been researched. In order to get a comprehensive overview, Table 4 has been constructed. The next paragraph discusses the conclusions which can be drawn from the information in this table.

Table 4: Overview of PPP-projects in railways⁷

Project name	Total costs	Financial arrangements	Type of contract	Time span
HSL Sud Europe Atlantique	M€ 7.800 M€ 6.200 construction	49% LISEA 38% public authorities 13% RFF	Concession DBFMO	50 years
HSL Nîmes – Barcelona	M€ 1.100	29% French State 29% Spanish State 27% TP Ferro 15% European Union	Concession DBFMO	53 years
	M€ 1.620	To be determined	Partnership DBFM	? years ⁸
HSL Bretagne - Pays de la Loire	M€ 3.400	Eiffage ← French State, Regions, RFF	Partnership DBFM	25 years
HSL Zuid	M€ 1.320 DBFM Superstructure	Infraspeed ← Dutch State Reimbursement: M€ 105/year Siemens, BAM, Banks	Partnership DBFM	5 + 25 years
	M€ 160 / year	High Speed Alliance (NS + KLM)	Concession O	15 years

⁷ Figures in table from (Réseau Ferré de France, Contournement Nîmes - Montpellier, 2013) (Réseau Ferré de France, La Ligne à Grande Vitesse Bretagne - Pays de la Loire, 2013) (Réseau Ferré de France, Ligne de Grande Vitesse Sud Europe Atlantique, 2013) (Réseau Ferré de France, Ligne de Grande Vitesse Sud Europe Atlantique, 2013) (Réseau Ferré de France, Ligne nouvelle Montpellier - Perpignan, 2013) (PPS Network Nederland, HSL-Zuid, 2012) (European PPP Expertise Centre, 2011) (Réseau Ferré de France, Lignes nouvelles en construction ou en projet, 2013) (Hoogzaad, B.F. and Van Ham, J.C., 2006)

⁸ Organizational model has been agreed upon, but the actual partnership has not been signed yet.

Derived from the table above, among others three main conclusions can be drawn:

- ◇ In all contracts, maintenance is part of all Dutch and French comprehensive high-speed railway infrastructure contractual agreements;
- ◇ Only two types of contracts are applied: partnerships and concessions.
- ◇ Many actors are involved in constructing and financing high-speed railway infrastructure;

The rationales behind these conclusions will be researched in-depth in the next chapter, but first background theoretical information will be given.

Maintenance phase is part of contractual agreements

The first conclusion states that in high-speed railway infrastructure projects always one consortium is responsible for the comprehensive process life-cycle of design – build – finance – maintain (and sometimes operations as well). The so-called process life-cycle is part of the total product life-cycle (PLC); it does not take into account the actual state of the object, but the progress in time.



Figure 8: Different stages of process life-cycle

The PLC is divided into five stages. In Figure 8, the 6th phase (transfer) is added, since this phase is very important, due to choices in life-span and in maintenance (Koppenjan, 2008).

Only two agreements applied: partnership and concession

The second conclusion states that only two different organizational forms are applied in (to be build) high-speed railway infrastructure in The Netherlands and France, see graphically in Figure 9 and Figure 10⁹. The main difference is the inclusion (concession) or exclusion (partnership) of the operation phase. Concessions are also called licenses or in case of fully integrated contracts: DBFOM. It is mainly based on required output performances. A partnership is defined as integrated process life-cycle approach contract, where the DBFM-phases are included. The operation of the infrastructure is no responsibility of the private party. With partnerships mainly a consortium of private parties comes into play, since multiple phases of the process life-cycle should be served: the construction, financing and maintenance.

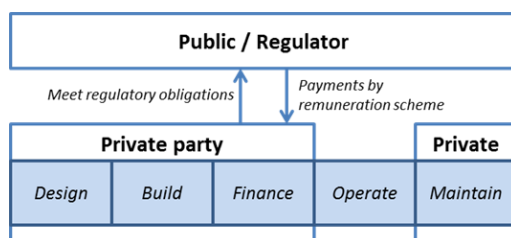


Figure 9: Organizational structure of concession

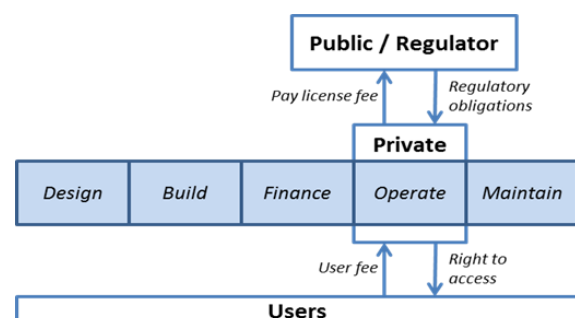


Figure 10: Organizational structure of partnership

In both organizational structures the ownership of the infrastructure during the operational phase is with the private party. At the end of the concession period, the ownership is transferred to the public party. The role of the public party during the

⁹ Figures partly derived from Koppenjan (Koppenjan, 2005)

concession changes into a regulator, who takes care of the quality control of the object and may give penalties, which have been determined before the project had started (Koppenjan, Public-private partnerships and infrastructural projects. Marriage made in heaven or Problem, Problem, Problem?, 2008) (Koppenjan, The formation of public-private partnerships: lessons from nine transport infrastructure projects in The Netherlands, 2005) (Bennet, E. & Grohmann, P., 2000) (van Ham, H. & Koppenjan, J., 2011).

The existence of both different organizational agreements justifies the question why one organizational form is preferred above another. Also the influence of a different organizational form on strategic maintenance will be researched.

Many actors are involved in high-speed railway infrastructure

In The Netherlands, a clear distinction between the infrastructure owner and the operator exists. The Ministerie van Infrastructuur en Milieu is – among others – responsible for general railway policy. ProRail is the infrastructure manager of the Dutch railway network and is owned for 100 percent by the Dutch government (Velde, D.M. van de & Rontger, E.F., 2009).

In France, the former all-integrated SNCF has been split into two different sub organizations, which SNCF calls Pôles. The Pôle Transport Publique deals with the operational part: the transport itself and its employees. The Pôle Infrastructure owns all rail-related real estate that is used for operations. RFF (Réseau Ferré de France) is the owner of the French railway infrastructure. SNCF is the operator of passenger train services. The Ministry is in charge of policy concerning the long-distance passenger rail services. The French Regions sign contracts for their regional train services with the respective regional division of SNCF (Velde, D.M. van de & Rontger, E.F., 2009) (Réseau Ferré de France, 2013).

The maintenance field for non-high-speed railway infrastructure in France differs a lot from The Netherlands, where in France it is mainly done by (semi-)public organisations; in The Netherlands it is totally executed by private companies, to which a concession of multiple years is granted by the infrastructure manager (ProRail) (France, 2011) (Zoeteman, 2011) (van Rossum, A., 2011). In high-speed railway infrastructure in The Netherlands and France, maintenance is executed by private consortia, which are indicated in the table above. In particular in France, no previous experience exists in the change of responsibility from public parties to private parties (France, 2011).

2.5. CONCLUSION OF DUTCH AND FRENCH HSR-PROJECTS

In Europe, more and more high-speed railway infrastructure is constructed, mainly due the increased total activity area between 150 and 800 kilometres. And the future will bring more high-speed railways. At current, a limited number of high-speed railway projects have been or will be constructed: in The Netherlands, one HSR project has been constructed; in France multiple more, but three projects have been taken into account.

All organizational agreements of these HSR projects show that many actors are involved and that maintenance is part of comprehensive agreements. Nearly all high-speed railway infrastructure projects are organized in public-private partnerships. In France and The Netherlands, only partnerships and concessions exist as contractual agreements. Maintenance of the infrastructure is part of these contractual agreements. However, in literature is unclear to what extent maintenance is regarded in the first phase of the projects. On the other hand, many actors are involved in constructing and financing high-speed railway infrastructure.

In the next chapter, the actual problems within the field of railway infrastructure maintenance will be researched.

3. ACTUAL PROBLEM STATEMENT

According to Chapters 1 and 2, many questions about maintenance in the field of high-speed railway infrastructure arise. In Chapter 1, it was concluded that the conclusions and recommendations of the Dutch parliamentary survey give rise to more research; the actual problems and lacks of knowledge in the field of railway infrastructure maintenance have not been researched. Chapter 2 rose the questions to what extent maintenance is planned during the design and build phase, and why only partnerships and concessions are used as contractual agreements.

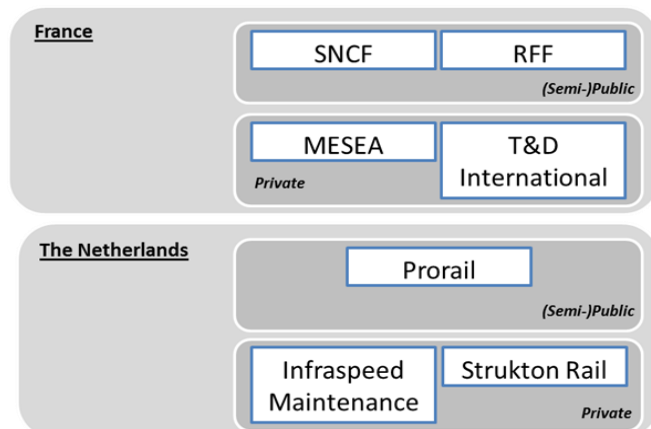
In order to gain more knowledge about the issues in the field of maintenance of high-speed railways, expert interviews are to be performed. In this chapter, the process of getting to the main leads of the interviewees and the conclusions derived from the interviews will be described. The chapter starts with an overview of the research design, followed by an comprehensive overview of the main lacks of knowledge, mentioned by the interviewees.

3.1. RESEARCH DESIGN FOR EXPERT INTERVIEWS

In this paragraph, the process of selecting experts, who are to be interviewed is explained. The goal of these interviews was to research the main leads and needs in the European railway field. The outcomes and overall conclusions of these interviews will be discussed in the next chapter.

3.1.1. PROCESS OF SELECTING INTERVIEWEES

In order to get a good overview of the lacks and needs in the market, actors of very different parties are interviewed. As could be seen in the previous chapter(s), the railway world in The Netherlands and France consist of a few key-players. Those key-players are divided over private and public parties in both countries. The persons interviewed within are those who have decision power within



companies. The research is focused to them, since they could give information and answers to the questions on a strategic level, based on experiences.

In total, seven expert interviews with top-notch interviewees have been conducted¹⁰. As can be seen in Figure 11, geographically and sector-wise, a mix in variety between the actors exists: the interviewees are equally divided over France and The Netherlands and over public and private parties. Four actors are from France, three from The Netherlands. Moreover, the same mix holds for the variety in sector: four actors play a role in the public railway sector; three actors in the private railway sector.

A description of the actors SNCF, RFF and ProRail have already been elaborated in the previous chapter. The other interviewed actors are:

- ◇ MESEA: Maintenance organization responsible for high-speed railway project Sud Europe Atlantique

¹⁰ Although more than 40 persons had been contacted, only seven actors agreed on being interviewed. This was mainly due to reasons of time-constraints and confidentiality of information.

- ◇ T&D International: A French strategic advisory firm in the field of railways
- ◇ Infrasppeed Maintenance: Maintenance organization of Dutch high-speed line HSL Zuid
- ◇ Strukton Rail: A major Dutch railway maintenance company, involved in traditional contracting of conventional (non-high-speed) railway infrastructure

Besides these seven external actors, multiple employees of company Oxand¹¹ have been asked about their experiences with public private partnership and maintenance in the railway field. For these employees no formats have been filled in, but their responses are used in the synthesis of the interviews.

3.1.2. DETAILS OF INTERVIEWEES

In the table below, the details of the interviewees are shown.

Table 5: Details of interviewed experts

Actor	Name	Function	Location
Réseau Ferré de France (RFF)	[anonymous] ¹²	Head of financial department	Paris, France
Infrasppeed Maintenance	Roel Hartman	Chief Operating Officer (COO)	Dordrecht, The Netherlands
ProRail	Arjen Zoeteman	Strategic manager of technology	Utrecht, The Netherlands
Strukton Rail	Arnoud van Rossum	Tender Manager	Utrecht, The Netherlands
T&D International Consultancy	Jean-Xavier Rochu	President / Railway consultant	Paris, France
Bureau de maintenance de ligne à grande vitesse Sud-Europe Atlantique (MESEA)	Laurent Cavois	President of MESEA	Poitiers, France
Société nationale des chemins de fer français (SNCF)	Pascal Dumont	Operational director of Inexia, project SEA ¹³	By phone, France

3.1.3. QUESTIONS TO BE ASKED

The interview is divided into four (plus a conclusion) main parts, which are discussed with each actor. The different parts with their main topics belonging are:

- ◇ High speed railway infrastructure
 - The most successful high-speed rail projects, their main differences throughout the world and the most risky phases of the process life-cycle, and how they are controlled.
- ◇ PPP investments
 - Different methodologies to predict costs and risk and the most suitable PPP-scheme, from a public and private perspective.
- ◇ Remuneration schemes and cooperation
 - The interaction between the public and private actor(s) in terms of remuneration schemes, cooperation and performance-based output schemes.

¹¹ Oxand SA is a French company active in the field of asset, ageing and risk management (see Annex 2)

¹² Name known by author.

¹³ Interviewee is delegate of SNCF, working for Inexia (engineering firm of SNCF) and incorporated in high-speed line project Sud Europe Atlantique.

- ◇ Maintenance
 - *The process, tools, ability and difficulties of predicting maintenance schemes and costs, including their innovation rate.*
- ◇ Conclusion
 - *An overall conclusion whether or not public-private partnership and construction in high-speed rail fit perfectly and what kind of tools or methodologies are missed.*

In order to process the interviews in a more convenient way, these interviews have been recorded. The content of the interviews is public, unless the interviewee demanded not to publish a certain part or name. The interviews lasted for approximately two hours and the outcomes were placed in a general format, which was sent back to the interviewee to check its accuracy and public status. Since the main goal of the interview is to research the main leads and needs in the European railway field, the most questions were qualitative.

3.1.4. PROCESS FROM SEPARATE INTERVIEWS TOWARDS GENERAL OUTCOMES

In all seven interviews a lot of topics have been elaborated. Although the same format for every interview was used, some actors went very much in-depth into one topic, where the others did not know anything about. In order to compare and synchronize the different interviews a structural analysis for all interviews has been conducted. The following steps have been followed:

1. Sending blank format with questions to the interviewee
2. Performing the interview
3. Filling out the template, according to spoken word
4. Sending the filled template back to the interviewee
5. Listing all answers and sub-conclusions of all interviews
6. Listing of keywords, which could comprehend most answers
7. Assign all answers to one (or a couple of) keyword(s)
8. Elaborate on the main issues

3.2. FINDINGS DERIVED FROM THE INTERVIEWS

All answers and conclusions of the interviews¹⁴ have been listed, see Annex 18. If all answers are determined into keywords, five groups of answers appear: the five directions of issues. Every direction consists of four elements. The most interesting elements will be described in detail later on in this chapter; it ends with the main lacks of knowledge which are to be solved. The five directions are:

- ◇ Model and data lacking of railway infrastructure assets
- ◇ Financial aspects of railway projects
- ◇ Organizational structures of railway projects
- ◇ Emphasis on efficiency with new railway projects
- ◇ Technical and organizational interface problems

3.2.1. MODEL SIMULATION AND DATA LACKING

By all actors, conflicting issues with data and simulation models regarding maintenance are mentioned. Both infrastructure managers (RFF and ProRail) elaborate on the fact that no good computer simulation tool about life-cycle costs exists. This is a clear lack according to them. In practice, this has become clear at the interview with MESEA, the maintenance department of COSEA: the construction company of the to be extended high-speed railway line *Sud Atlantique* between Poitiers and Bordeaux. All calculations and planning for planned maintenance on the railway line were done *by hand* in a simplified Excel-sheet. All in all a

¹⁴ (Cavrois, 2011) (Dumont, 2011) (Hartman, 2011) (France, 2011) (Rochu, J-X., 2011) (van Rossum, A., 2011) (Zoeteman, 2011)

standardized ex-ante LCC-tool for railway maintenance is needed. But also ex-post monitoring tool is hoped-for by the interviewees. The infrastructure managers complain about the lack of data of previous maintenance costs for high-speed rail. It is in the nature of commercial parties to be very reserved in providing value information. This is sometimes also even the case for intergovernmental relations.

Another remarkable, more specific outcome of the interviews is the use of distributions in self-created LCC-models. Different actors mention the single use of the normal distribution for either availability of the infrastructure and the lifetime of the asset. A construction firm suggested that these distributions should be changed into values, corresponding to reality; for example more use of the Weibull distribution. The Weibull distribution is mentioned in literature as a distribution that can model data that are right-skewed, left-skewed, or symmetric (Minitab, 2013). It also fits normal distributed data (Weibull Statistics, 2103). For this reason, the distribution is used to evaluate reliability across diverse applications. The Weibull distribution can also model a hazard function that is decreasing, increasing or constant, allowing it to describe any phase of an item's lifetime.

Formulas (1)¹⁵ represents the cumulated probability of failure at time x. The cumulative distribution function can be used to calculate the probability of the occurrence of a failure up to that particular time-unit (Engineering Statistics Handbook, 2013).

$$F(x; \lambda, k) = \begin{cases} 1 - e^{-\left(\frac{x}{\lambda}\right)^k} & x \geq 0 \\ 0 & x < 0 \end{cases} \quad (1)$$

x = time-scale $(-\infty, +\infty)$

λ = scale or life-parameter $[0, \infty)$

k = shape or slope parameter $[0, \infty)$

If plotted, one may see the difference between the Normal distribution and the Weibull distribution. In the figure below the cumulative distribution of those two have been plotted. It is clearly visible that the Weibull distribution better fits with assets, which lifetime shows a deviation in the time of deteriorating, compared to the Normal distribution.

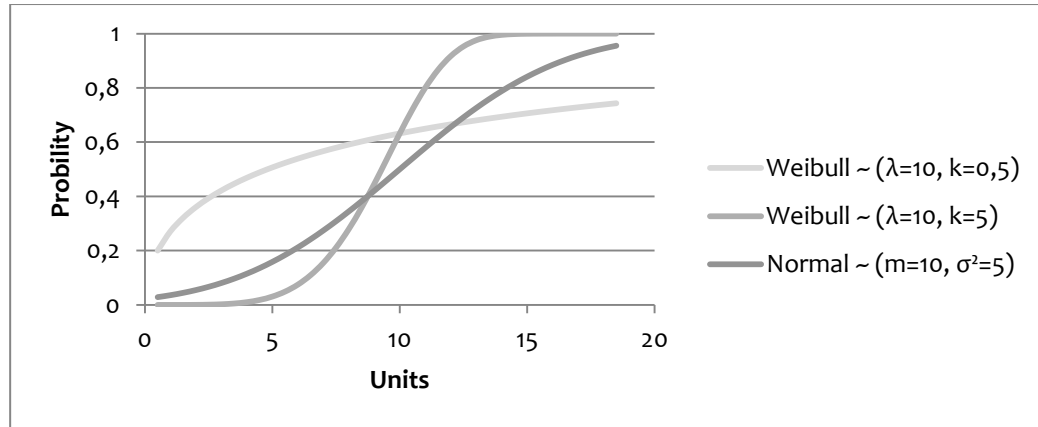


Figure 12: Graphic representation of Weibull and Normal distribution

The actors request for more reliable data of the infrastructure usage in a more coherent way. The ability to get historical data is not very wide-spread. Moreover, some actors request simulation models, which could alter the preliminary assumptions, in particular during the phase of operations or maintenance.

3.2.2.

FINANCIAL ASPECTS

Almost all issues about finances, mentioned by the interviewees, refer to the lack of communication between the financial departments and the departments of planning and

¹⁵ Formula derived from (Engineering Statistics Handbook, 2013)

operations. The influence of banks is mentioned as huge, since those banks provide the initial loans for the construction of the infrastructure. This influence leads towards a tension between quality and costs, and mainly at the end of a concession period. The quality after transfer of the infrastructure is therefore always a point of discussion: should the quality be just enough to fulfill the needs in the pre-signed contracts, or should all needed maintenance actions be executed in order to have an infrastructure of the best quality possible at the end of the period? The actors fear for an already noticed movement towards *doing the least effort for the least costs*, mainly driven by the harsh influence of the banks. On the other hand, efficiency of maintenance actions during the project or concession period could be made more efficient, mentioned by some actors. Not necessarily, this will interfere with the struggling balance between costs and quality at the end of the transfer period.

Some actors also lack the resistance towards *out of the box* solutions. One actor gives the example that financial institutions and departments only look to the balance CAPEX/OPEX¹⁶. However – for example – an increase of the utilization rate for trains means less investment in to be built trains.

3.2.3. ORGANIZATIONAL STRUCTURES

All actors interviewed admit that maintenance planning is often introduced too late in railway projects. They suggest that maintenance teams should already be involved during the construction phase in order to find the optimal balance between quality, initial costs, maintenance costs and lifetime of the asset. Some construction companies tell that the indicators about the remuneration of the maintenance actions should also be clarified at the start. It is for that reason that most actors complain about the gap between the (soft) vision and the (harsh) requirements of the infrastructure manager.

One actor regards large, rigid organizations less suitable for public-private partnerships, since the private maintenance company should bear a lot of risks. Moreover, it is recommended to outsource as little as possible, because PPP requires a comprehensive overview of all risks and responsibilities. Other organizational issues concern the interoperability of public and private parties, or in fact the lack of it. Many actors tell that public and private parties are separated worlds; generally no persons from private parties work or have worked at a public and the other way around. The overall suggestion is to mix the people and let them integrate. This will also be a requirement for the future projects: all actors expect that different public-private partnership models will become existent in the future. Therefore, more emphasis on partnership and shared responsibilities will be needed.

The last issue about organizational structures is about the quality of the infrastructure at the moment of transfer of concession. All private parties lack an in-depth analysis of the state of the infrastructure. The physical quality of the infrastructure influences largely the amount of money a party is willing to pay.

3.2.4. EMPHASIS ON EFFICIENCY

The goal to strive for more efficiency is seen by most actors as possible and sometimes necessary, but not always positively. Efficiency is mostly seen two-ways: either doing the same amount of work for less money, or providing less quality for the same amount of money. In conventional railways, a huge difference between railway maintenance actors in The Netherlands and France exists. France makes use of long-term concession periods, which may last up to 50 years (see previous chapter). The responsibilities and risks are fully taken by the private party, which has to do the maintenance, as well as remunerate it by user fees. In The Netherlands, short-term contracts (mainly 5-6 years) are more common. The actors state that the goal towards more efficiency in terms of costs, quality, time and hindrance has more emphasis in The Netherlands than in France, all due to the much shorter total time of the concession period. The strive towards performing just cost-efficient sometimes triggers the use of newly non-proven technology. As all actors say, technology

¹⁶ Capital or non-recurring expenditures and Operating or recurring expenditures (Maguire, 2008)

can only be used when it has been fully proven; despite the fact of being cheaper for the private party.

The Dutch actors discussed the harsh competition between railway maintenance actors during the tendering period. All tendering parties write proposals which are very (cost) efficient, due to the fact a tendering party wants to win. The interviewed Dutch actors discussed the paradox: during the concession period hardly any feedback loops exist; the project plan – which has been confirmed by tendering – is hardly altered. In particular at the end of the concession period, by the time of transfer of the infrastructure, is too little taken into account. The same actors state that risk management from an operation and maintenance point of view is often a neglected aspect. They are more in favour of a holistic approach, with feedback loops during the concession period.

All actors do like the existence of the European norms for Technical Specifications for Interoperability (so-called TSIs). Due to these TSIs more emphasis on standardization is existent and moreover interface problems are mostly solved, or at least treated in a more efficient way.

3.2.5.

INTERFACE PROBLEMS

The actors interviewed consider different interfaces within maintenance of railways as critical. At the technical side, the interface railway track and wheel of the train causes problems. If new material or new technology is used for the railway track, the consequences to the interaction of the train and the infrastructure are unknown and can't be translated into simulation models. The impact of the wheels on the wear of the track is a main driver for planning of maintenance.

At a more organizational side, the interfaces between public and private parties, the interfaces between different countries and the interfaces between the Rail Infrastructure Manager and the operator are regarded as critical, by the interviewees.

The actors warn for the unequally divided information between public and private parties. Mainly at the end of the concession period, critical information about the state of the infrastructure is sometimes (partially) kept secret by the private party. This information is essential for the public parties, as well as for the private party in the next concession period. The different paradigms within public and private organizations about culture and technology are also considered as a possible ground for misunderstandings.

Interface problems between countries come into play when international traffic is taken into consideration. Actors support the project TEN-T (Trans European Network – Transport), but regret the very patriotic way European projects are executed. One actor mentioned the Dutch *HSL Zuid*, which – in essence – is part of the railway line Amsterdam – Brussels – Paris. Although this railway line crosses three European countries and is part of TEN-T, the line is considered as three parts: each country separately. In practice, at the border-crossing of The Netherlands and Belgium trains should switch to another voltage, which causes sometimes large delays. Another problem is the safety system ERTMS, which is not commonly used by the European member states. In some countries an obsolete safety system is used, which causes obligatory adaptations to the train, which run. All interviewees would like that TEN-T projects are taken into consideration as one European project, with all European standardizations attached.

The last interface problem, considered by the interviewed actors, is the relation between the Rail Infrastructure Managers (ProRail (The Netherlands) and RFF (France)). The main concern derived from the interviewed actors is the lack of or insufficient communication and clarity of expectations. One actor mentions the lack of communication between the RIM and the operator about the type of trains which run on the track. One example, which is mentioned: due to trains, which are loaded too heavily, switches are damaged; causing an increase in maintenance.

3.3. DISCUSSION OF FINDINGS OF INTERVIEWS

Interviews with seven actors have led to five main groups of findings. Although all seven actors are top-level experts in the field of railway infrastructure, some remarks can be drawn at this interviewing process.

Content-wise, the responses of the interviewees could be compared to literature. The conclusions of the Dutch Parliamentary Commission *Spoor* are in line with the answers of the interviewed actors. The Commission draws conclusions on a more meta-level, where the actors provide more in-sight details of the actual problems in the field of railway infrastructure. For example, the Parliamentary Commission has concluded, among others:

- ◇ The committee has indications that the efficiency of railway maintenance can be improved;
- ◇ Maintenance is barely part of decisions about long-term investments;
- ◇ The database of current state of railways is not transparent, not actual and not reliable.

Since these conclusions are also drawn by the interviewees, the content of their responses can be regarded as reliable and in line with literature.

The number of interviews (seven) is limited. The actors are spread between public and private parties and geographically between France and The Netherlands. Due to this distribution, one actor could provide more information about the railway infrastructure maintenance itself, where the other actor was more involved in financing the infrastructure. As stated, the responses of all actors are – on a meta-level – the same: efficiency of railway maintenance can be improved and maintenance should become part of long-term investments. However, more specific information – for example short-term contracts or the influence of banks – are derived from only one or two actors, which makes this information less reliable.

Besides the reliability of the content of information, also five other drawbacks can be drawn. These drawbacks are more about the interviewing process itself, like:

- ◇ *Confidentiality of information*: Every interviewee was very careful during the interviews, since the actor was aware that the information gap between the public and private parties often leads to a competitive advantage.
- ◇ *Biased responses*: After having performed the interview, the template was filled in and sent back to the interviewee. Their response took a while, which sometimes lead to altering the answers as well.
- ◇ *Suspicious*: Since the interviewees were asked for an interview by a regular student from Delft University of Technology, mostly the French actors were suspicious. This could have influenced the quality of the answers given.
- ◇ *Anonymously*: One interviewee only wanted to cooperate anonymously. However, for this research it turned out not to be a problem, since he/she agreed in mentioning the name of his/her company.
- ◇ *Not being recorded*: Although the samples were only used for filling in the templates, one actor refused in being recorded. Since the template was sent back to the interviewee, the checking process could continue.

3.4. CONCLUSIONS DERIVED FROM INTERVIEWS

As was concluded by literature and by the interviewed actors: strategic maintenance planning of railway infrastructure is currently performed inefficiently.

In this chapter seven actors have been interviewed. As mentioned in paragraph 3.1.4, all answers and sub-conclusions of the interviewees have been listed. In order to be able to group their conclusions the answers have been rewritten into keyword, which could comprehend most answers. Finally, five main keywords turned out to be the main topics for the actual problems in railway infrastructure maintenance. The next step was to assign all answers to one (or a couple of) keyword(s). The long-list of this assignment can be seen in

Annexes 18 and 19; a part of this long-list is shown in Table 6. As already written in paragraph 3.2, the five keywords have been elaborated on.

Table 6: Part of long-list of assigning interviewees' answers to keywords

	Organizational	Efficiency	Interfaces	Data	Financial
No focus on period around transfer		X			X
Cultural aspects mostly neglected	X				
Involvement of operation and maintenance in design	X				
Focus on efficiency at short concessions		X			
Monitoring of state of infrastructure				X	
Need for computer models				X	
Misunderstanding between public and private parties	X		X		
Integration of employees is not standardized	X				
Not just one PPP-model be dominant	X	X			X
Ambiguity between specifications and wishes of RIMs	X		X		
Maintenance is mainly done at day-time	X	X			X
Specifications for transfer lack					X

The five groups of comprehensive keywords about actual problems in railway infrastructure maintenance are shown graphically in Figure 13. Each group consist of four most-mentioned topics. This figure can be regarded as the conclusion of this chapter.

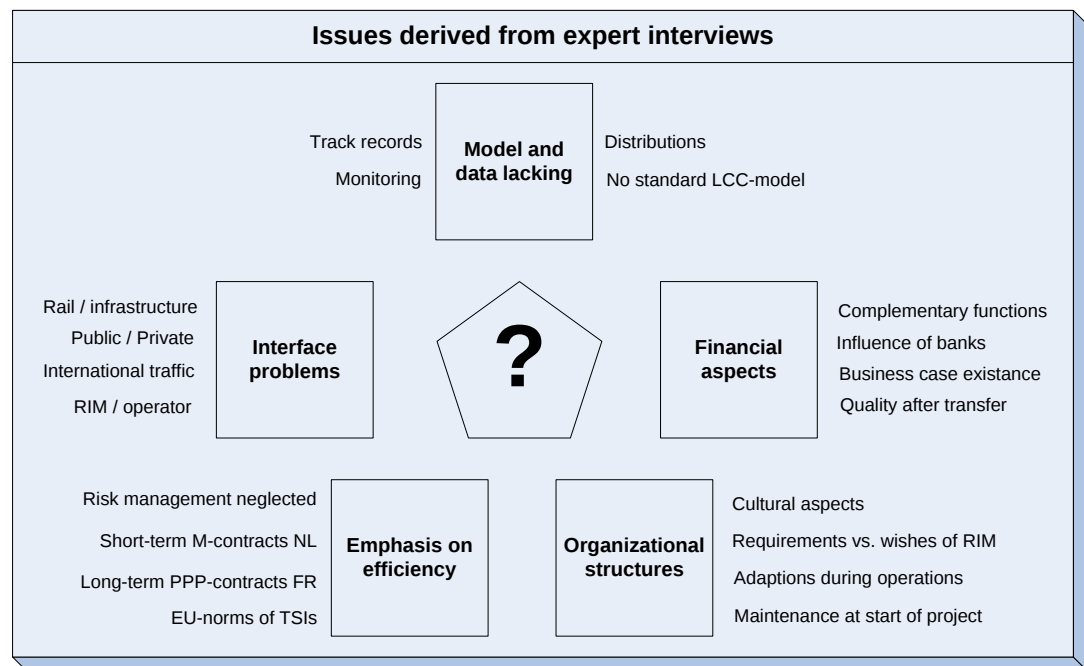


Figure 13: Schematic overview of outcomes derived from expert interviews

The first research question *What are lacks of knowledge in strategic maintenance planning for high-speed railway infrastructure in The Netherlands and France?* has been answered by these five main groups of lacks of knowledge. In order to answer the second research question *In order to solve the mostly mentioned lacks of knowledge, what design requirements should a computer simulation tool for strategic maintenance planning for high-speed railway infrastructure have?* the lacks of knowledge are rewritten into design requirements for a computer simulation tool and an organizational structure.

4. DESIGN REQUIREMENTS TO SOLVE THE ACTUAL LACKS IN KNOWLEDGE IN RAILWAY MAINTENANCE

The actual problem statement in the field of railway infrastructure maintenance is made clear by the expert interviews, on which have been elaborated on in the previous chapter. These problems were grouped into five main groups:

- ◇ Model and data lacking of railway infrastructure assets
- ◇ Financial aspects of railway projects
- ◇ Organizational structures of railway projects
- ◇ Emphasis on efficiency with new railway projects
- ◇ Technical and organizational interface problems

This research stated two more research questions. The second question was:

In order to solve the mostly mentioned lacks of knowledge, what design requirements should a computer simulation tool for strategic maintenance planning for high-speed railway infrastructure have?

This chapter will elaborate on this second research question. It is a goal not only to mention the actual problems, but also to solve them at least partly. In this chapter so-called *Design Requirements* will be listed. These requirements were derived from the interviews, as well as literature.

4.1. DESIGN REQUIREMENTS FOR MORE EFFICIENT MAINTENANCE PLANNING

In order to come to come closer to possible solutions for the issues mentioned, all conclusions of the actors have been listed (see Annex 19). Figure 14 shows the frequency of all conclusions, divided into the five groups. This figure has been made with the input of the classification, shown in Table 6.

One can see that organizational structures and data and model lacking have been mentioned the most.

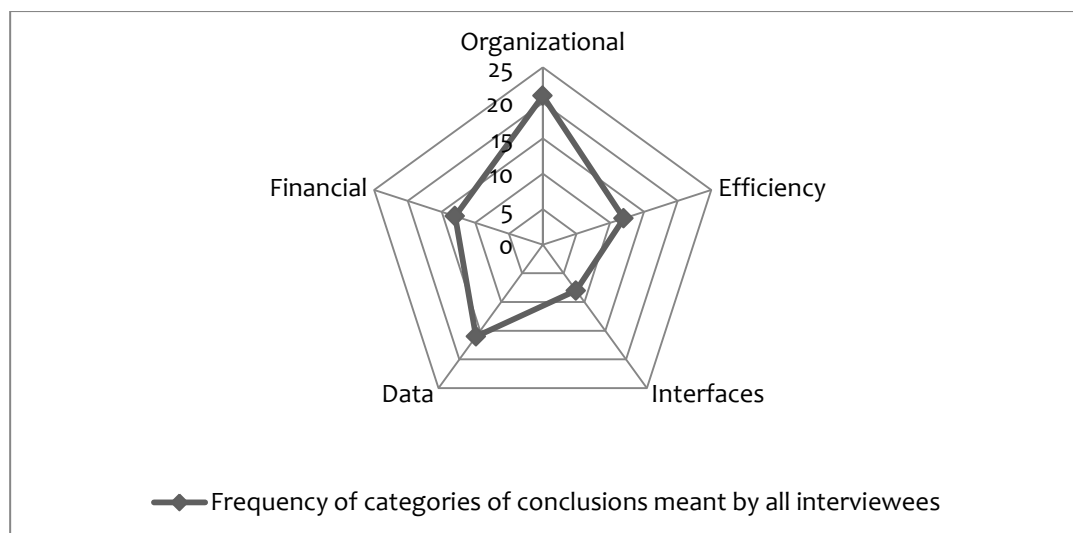


Figure 14: Frequency of conclusions meant by all interviewees.

In the other groups many statements of the interviewees belong to either organizational issues or technical issues. So, from this point forward two comprehensive groups are taken into account:

- ◇ Organizational issues
- ◇ Technical issues

Since it has been concluded that strategic maintenance planning is currently performed inefficiently, design requirements can be listed, in order to come to a more efficient strategic maintenance planning. The technical design requirements are about creating a type of computer simulation tool; in the next chapters these requirements will be brought into practice.

4.1.1. ORGANIZATIONAL DESIGN REQUIREMENTS

The organizational design requirements have also been mentioned by the interviewed experts. These design requirements are as important as the technical design requirements, in order to come to a more efficient performance of strategic maintenance planning for railway infrastructure.

A railway infrastructure maintenance organization:

- ◇ should take into consideration the strategic maintenance planning during the phase of design and build;
- ◇ should regarding the quality of the assets, focus on the period around transfer of the infrastructure and balance the discrepancies in expectations of different actors;
- ◇ should mix project teams with employees from public as well as private companies and parties;
- ◇ should invest in risk management from an operational and maintenance point of view;
- ◇ should use an holistic approach during the whole concession period, with feedback loops when needed;
- ◇ should be able to work in different countries and with different cultures;
- ◇ should do as much as possible in-source; minimize outsourcing

4.1.2. TECHNICAL DESIGN REQUIREMENTS

The technical design requirements are meant for a type of computer simulation tool, which is desired by the interviewed actors. These requirements elaborate on the technical, inside details of a simulation tool.

A computer simulation tool:

- ◇ should exist of a well-performing ex-ante life-cycle-cost simulation tool for railway infrastructure maintenance;
- ◇ should own an overview of historical data for all components, which are taken into account, derived from previous high-speed railway maintenance projects;
- ◇ should have the possibility to change the model distribution of the life-time of an asset to its degradation;
- ◇ should have the possibility to alter data and parameters in the simulation model during operations;
- ◇ should be able to simulate long-term and short-term contract periods and come up with reliable results;
- ◇ should simulate an efficient maintenance planning, with use of (budget) constraints;
- ◇ should contain technical information about interface issues, like wheel-rail for new types of trains.

4.2. CONCLUSION ABOUT DESIGN REQUIREMENTS

In order to get design requirements for more efficient maintenance planning, two types are unveiled: Organizational and Technical requirements. Each group of requirements consists of seven detailed requirements.

Due to scoping reasons, the technical requirements will be elaborated more in the next chapter, compared to the organizational requirements. In the next chapter, it will be tested to what extent these technical requirements meet current computer simulation tools.

5. APPLICATION OF TECHNICAL DESIGN REQUIREMENTS

In Chapter 3 the main lacks in knowledge, meant by experts, were stated. In order to solve (a part of) these lacks, in Chapter 4 design requirements were elaborated. Due to scoping reasons, only technical design requirements are taken into account in this chapter. In the first part of this chapter the rationale of a type of computer simulation tool is described, including what kind of maintenance computer simulation tools could predict. The second part of this chapter elaborates on the current computer simulation tools, which could meet the design requirements. Computer tools in the field of railways will be analyzed, as well as in other areas. This chapter concludes with a recommendation for further research in one of these specific computer simulation tools.

5.1. ELABORATION OF TECHNICAL DESIGN REQUIREMENTS

Derived from the literature research and the interviews with experts, it can be concluded that the current strategic maintenance planning for railways is – by definition – inefficient, on other words: room for improvements still exists. In this paragraph answers will be provided to the questions how maintenance can be predicted and why computer simulation tools could help to identify efficient maintenance planning.

5.1.1. HOW RAILWAY MAINTENANCE CAN BE PREDICTED

By means of maintenance, an asset will have a higher quality in the end, compared to its state before the maintenance. However, not just one type of maintenance exists. On a basic level, two types of maintenance can be differentiated: planned and unplanned maintenance.

Unplanned, or corrective maintenance is a retro-active maintenance strategy, which refers to action only taken when a system or component failure has occurred. The task of the maintenance team in this scenario is usually to effect repairs as soon as possible. Costs associated with corrective maintenance include repair costs (replacement components, labour, consumables), lost production and lost sales (NACE International Resource center, 2013) (Dekker, 2000).

The goal of planned maintenance is to prevent assets for failure, before it causes too much damage to the system or users. Planned maintenance could be divided into periodic and preventive maintenance.

Periodic maintenance is defined as maintenance of equipment on a fixed regular basis that is sufficient to prevent unplanned failure. Daily maintenance is designed to retain the healthy condition of equipment and prevent failure through the prevention of deterioration, periodic inspection or equipment condition diagnosis, to measure deterioration. The higher the failure consequences, the greater the level of preventive maintenance that is justified. This ultimately implies a trade-off between the cost of performing preventive maintenance and the cost to run the equipment to failure (EDP, 2013) (Plant Maintenance Resource Center, 2013) (Dekker, 2000).

Preventive maintenance – or condition-based maintenance – is a condition-based maintenance strategy. It takes the current state of an asset into account; the required maintenance actions are determined by this state. By measuring and analyzing data about deterioration, it manages trend values (Plant Maintenance Resource Center, 2013). Dekker states that whether the impact of a failure is large to a system or to users, it could be more effective to execute preventive maintenance (Dekker, 2000).

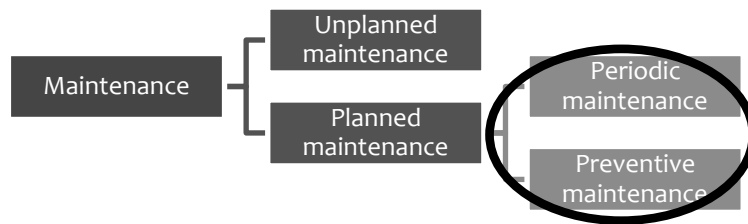


Figure 15: Breakdown of maintenance categories, choice for planned maintenance

Planned maintenance is chosen as point of interest, since the interviewed actors demand for an efficient maintenance planning, which can already been made in front of a project. From this point on, the research question can be focused to periodic and preventive maintenance.

5.1.2. AN OPTIMUM POINT IN COSTS OF MAINTENANCE EXISTS

Much of planned maintenance costs a lot due to its high frequency and the amount equipment, which is repaired based on avoidable reasons. Since assets are replaced by new assets before they become obsolete (the actual end of the useful lifetime), some life-time is wasted and cost-negative. However, the consequences of a failure of some crucial assets contribute in such a negative way to the system or users that the lost life-time in money is compensated by the potential loss costs due to the failure. All in all it is about finding the optimal balance between maintenance costs and the costs of breakdowns.

Table 7: Details of maintenance costs and breakdown costs

Maintenance costs	Breakdown costs
Salaries maintenance staff	Cost of idle production or service during lost time when equipment is down for repairs
Cost of inventories kept for the maintenance procedures	Production or service losses during breakdown
Cost of outsourced maintenance activities	Cost of penalties or damages claimed by the customer

The optimal balance between expenditures for maintenance and costs due to breakdowns leads to the most advantageous (financial) result, as one can see in Figure 16 (Zoeteman, A., 2004) (Management & Development Center, 2013) (Mishalani, R.G. and Olayé, R.A., 1999).

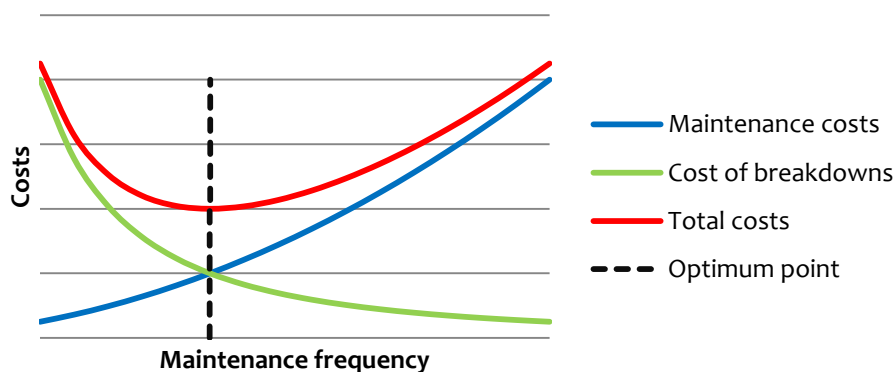


Figure 16: Optimum point in costs of maintenance¹⁷

The curve illustrates that there is an optimum level when preventive maintenance programs should be carried out when Cost of Maintenance and Cost of Breakdowns are equal. It is a theoretical optimum, since the axis are not defined and the curves are assumed to be gradual. Studies have indicated that if good preventive maintenance management practices are applied, and integrated with other operations activities, cost reductions of 35% or more

¹⁷ Figure derived from: (Management & Development Center, 2013) and (Zoeteman, A., 2004)

are possible (Waller, D., 2012) (Thomson, 2013). In detail for railway-maintenance, the American Public Transportation Association (APTA) has identified that the non-vehicle maintenance expenditures (almost half of which is just track maintenance) form nearly 9% of total operating costs and 78% of that is just labour cost (Tyagi, W., 2002).

5.1.3. MORE IN-DEPTH RESEARCH OF COMPUTER SIMULATION TOOLS DESIRED

During the interviews, experts stated that no standardized lifecycle cost model for high-speed railway maintenance exists. All actors discuss the problem about the lack of data itself and the estimations behind the computation models. Two actors mention the existence of maintenance optimization models in other areas.

At the maintenance project team MESEA, which is responsible for the maintenance works on the future train line Sud-Europe Atlantique (France), could be experienced how maintenance regimes are planned. According to the interviewed actor for most components a maintenance plan exists, but no optimization is made for an optimal regime, taken into account all assets. For some components no maintenance plan can be constructed, since the life-cycle is unknown; for example the effect of the trains on the ballast, which is used for the first time here. Large renewal actions are simply done as latest as possible. One actor mentions that new maintenance schemes are made, right from the start at a new contract period; however, it is usually not adapted to reality during the period.

In the previous chapters it has concluded that:

- ◇ Maintenance planning is currently performed inefficiently (paragraph 3.4);
- ◇ An optimum point in costs of maintenance exists (paragraph 5.1.2)
- ◇ the usage and the performed maintenance of the infrastructure influence its useful life-time (paragraph 5.1.1);
- ◇ experts state that no standardized lifecycle cost model for high-speed railway maintenance exists (paragraph 3.2.1);
- ◇ not enough focus on the period after transfer of infrastructure is present (paragraph 3.2.4).

Based on these statements, it is worthwhile to research the design of a standardized lifecycle cost model for railway maintenance, with a focus on the period after transfer of infrastructure and with which an optimum point in costs of maintenance can be computed. Nash & Huerlimann describe in their paper the added value of such simulations. They state “computer simulation is especially valuable for railroad planning, since once developed and calibrated, models can be used to compare the benefits, impacts, and costs of various different improvement packages. Effective railroad simulation models enable planners to identify and evaluate more alternatives ultimately leading to more creative and comprehensive problem solutions.” (Nash, A. & Huerlimann, D., 2008). Elaboration of – and application for – these improvements will be discussed from this point onwards. It is clear that optimal maintenance schemes yield to more efficient maintenance projects.

5.2. MATCHING OXAND’S COMPUTER SIMULATION TOOLS WITH TECHNICAL REQUIREMENTS

In this paragraph the different computer simulation tools available within company Oxand will be researched. By means of a classification, the different computer tools are ranked. The company Oxand SA¹⁸ is a French company active in the field of asset, ageing and risk management and is taken into account, since it has large in-depth knowledge about computer simulation tools, but limited knowledge in the field of railway infrastructure.

¹⁸ See more information about company Oxand SA in Annex 2.

Oxand has asked for exploring the applicability of their existing computer simulation tools in railway infrastructure projects.

During the last years, Oxand has executed many projects in different areas. For each project separately, Oxand performed it by the use of different computer tools or methodologies. It resulted in several computer tools: all applicable to one specific and all different in terms of input and output parameters. Besides these specific tools, Oxand has developed some more generic tools as well.

5.2.1. OVERVIEW OF COMPUTER SIMULATION TOOLS OF OXAND

In order to gain insight into these different tools the overview Table 8 has been created. The information in this table has been derived from internal interviews with employees who have worked with these tools (Crouigneau, S., 2011) (Proust, J., 2011) (Thillard, G., 2011) (Goy, R., 2011) (Le Drogo, J., 2011) (Paderno, C., 2011) (Putallaz, Y., 2011).

The information in Table 8 distinguishes main areas of application, the level of detail, the level of decision making and the kind of risk which could be mitigated by means of the computer simulation tool. The main areas of application are examples of real projects where this type of simulation tool have been used. The – self-chosen axis – level of detail refers to what kind of input data is needed. The range starts at a microscopic level of detail, which refers to the need of more detailed information about the components of the asset. A macroscopic level of detail refers to the need of more structural and less detailed information. The type of input determines the type of output: macroscopic input lead to directions of outcomes, rather than specified numbers on the short-term. A mesoscopic level of detail refers to the hybrid form of micro- and macroscopic level.

The second axis is the level of decision making, which has three values: operational, tactical and strategic. On a strategic level of decision making more future-based, higher level decisions are made, which cannot be implemented immediately; it is more about getting an in-sight in different maintenance strategies on a long-term. On the other hand, an operational level of decision making determines detailed output figures and schemes, which are ready to be implemented.

Table 8: Overview of computer simulation tools of Oxand (abstract)

		Main areas of application	Level of detail	Level of decision making	Kind of risk to be mitigated
SIMEO Consulting		Aging assessment of civil works (mostly reinforced concrete)	Microscopic	Operational	Technical risks during life-cycle
SIMEO Maintenance	SIMEO IPA	Actual state of nuclear power plants	Microscopic	Operational	Technical risks during life-cycle
	SIMEO Ports	Large seaports	Mesoscopic	Tactical	Operational risks (e.g. budgets, human resources)
	SIMEO Voie navigable	Inland waterway transportation	Mesoscopic	Tactical	Operational technical risks
	SIMEO Ferroviaire	Railway transportation networks	Mesoscopic	Tactical	Operational risks (e.g. budgets, human resources)
	SIMEO ITE	Branch railway lines to and inside nuclear power plants	Mesoscopic	Operational	Technical lifecycle and operational budget risks
	SIMEO StrateGo	Maintenance policies for railway assets	Macroscopic	Strategic	Financial risks driven by technical risks
SIMEO Risk		Graphic representations of industrial risk assessments	Microscopic	Operational	Criticality analyses
SIMEO MC ²		Probabilistic approaches of risks and dependency of variables	Micro to Macroscopic	Operaional and strategic	Financial, safety and maintenance risks
SIMEO ERM		Collaborative tool to manage the process of risk management implementations	Macroscopic	Operational and strategic	Cooperate risks: image, financial and resources, operational follow up
SIMEO STOR		Critical aging analysis of pipe-lines	Microscopic	Operational	Leakage of geological storage of CO ₂

At first sight, SIMEO Ferroviaire seems to be fully suitable for railways, since *ferroviaire* is the French word for railways. By means of different scenarios, this tool uses the state of

maintenance of a railway track to define state-related risks, associate necessary maintenance actions and costs, priorities at a fleet's scale the needed maintenance actions. The tool is only suitable for medium-term maintenance planning, so from 3 until 5 years and was specifically made for a client in the railway infrastructure, which makes it hard to implement it in other areas.

The tools SIMEO Stor, Consulting, IPA and Risk are very detailed and only for operational purposes. Therefore, these tools are hardly applicable to other areas.

ERM is a different tool, compared to MC² and StrageGO. It is a collaborative tool to manage risk registers, edit risk mapping and list risk mitigation plans with associated risk owners. It leads to a wide range of outcomes, from mitigation actions (operational) to the state of the human resources (more strategic).

MC² is a more scientific tool, which makes use of Monte Carlo-simulations and Markoff-chains. It is able to calculate different output parameters by means of intermediate variables, where different distributions can be assigned to. In simple terms, it quantifies a causal diagram.

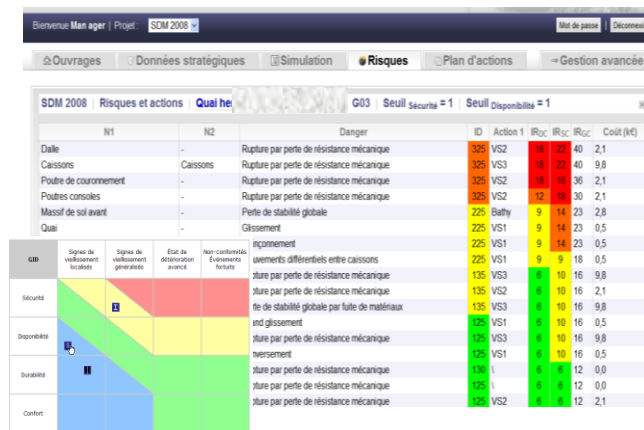


Figure 17: Outcomes of Simeo Ferroviaire

5.2.2. ASSESSMENT OF OXAND'S COMPUTER SIMULATION TOOLS

The different computer simulation tools, described in Table 8, are to be confronted with the technical design requirements, as mentioned in paragraph 4.1.2. By means of this confrontation that computer simulation tool can be assessed, which matches the design requirements the most. Table 9 has been constructed with the help of the employees of Oxand, who were also mentioned in paragraph 5.2.1 (Crouigneau, S., 2011) (Proust, J., 2011) (Thillard, G., 2011) (Goy, R., 2011) (Le Drogo, J., 2011) (Paderno, C., 2011) (Putallaz, Y., 2011)..

Table 9: Assessment of different simulation tools of Oxand to design requirements

Design requirement	1 st choice	2 nd choice	3 rd choice
1. Ex-ante simulation tool for railway infrastructure maintenance	StrateGo	Ferroviaire	ERM
2. Showing an overview of historical data for all components	Ferroviaire	StrateGo	MC ²
3. Possibility to change model distribution	Ferroviaire	MC ²	-
4. Possibility to alter data and parameters during operation	StrateGo	-	-
5. Ability to simulate long-term and short-term contract periods	StrateGo	ERM	MC ²
6. Simulating an efficient maintenance planning, with (budget) constraints	StrateGo	Ferroviaire	-
7. Containing technical information about interface issues	ITE	StrateGo	Consulting

5.2.3.

CONCLUSION ABOUT MATCH COMPUTER SIMULATION TOOLS WITH REQUIREMENTS

Table 9 makes clearly visible that StrateGo and SIMEO Ferroviaire are the two computer simulation tools, which match the technical design requirements to the most extent. As mentioned in Table 4: *Overview of PPP-projects in railways*, most new (high-speed) railway infrastructure project contracts last for over 30 years, and even 50 years. Maintenance is often part of the contract, which requires a computer tool to make simulation on the long-term: a strategic level of decision making. Moreover, since an ex-ante maintenance simulation tool is desired before the project is even operational, the level of detail cannot be too microscopic, since most assets and scenarios are yet unsure.

Figure 18¹⁹ represents a graphical overview of Table 8. The only computer simulation which is macroscopic as well as strategic, is StrateGo. Figure 18 and Table 9 combined shows that SIMEO StrateGo is the computer simulation tool of Oxand, which matches most design requirements and has macroscopic level of detail and strategic level of decision making. In the next chapter this computer simulation tool will be researched in-depth, and will be tested to what extent it really meets the technical design requirements.

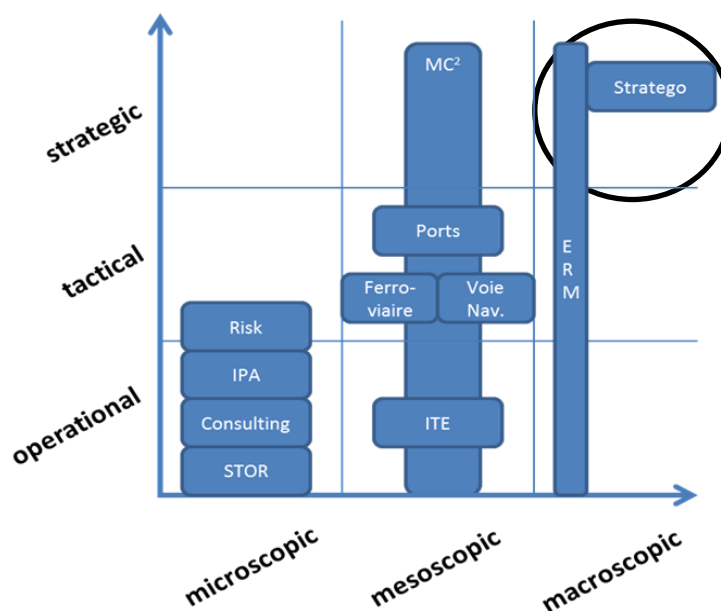


Figure 18: Graphical overview of tools of Oxand

5.2.4.

GENERAL DISADVANTAGES OF COMPUTER SIMULATION TOOLS

While computer simulation is an excellent tool for analysis and planning of railroad, railroad network simulation programs have limitations. StrateGo is to be assessed to these general limitations, in order to unveil the consequences in simulating. According to Gibson et al. these limitations arise²⁰:

- ◇ Programs must be validated to actual conditions
- ◇ Resource constraints such as crew scheduling are largely ignored
- ◇ Simulations only include the modelled study area
- ◇ Simplifying assumptions generally create an inherent optimism about overall congestion, schedule adherence, and recoverability.

The first limitation – validation to actual conditions – has already been mentioned by the interviewed experts and has turned into the fourth design requirement. StrateGo scores

¹⁹ Annexes 9 and 10 provides more background information to this figure.

²⁰ Limitations derived from Gibson (Gibson, J., 2002)

well on this requirement. The second limitation holds for StrateGo, but since this maintenance simulation tool is used for strategic, long-term maintenance planning, microscopic output parameters, like crew scheduling, is not regarded as one of the goals. The limitation that simulation only include the modelled study area comes less in play with railway infrastructure. As one will read in Chapter 7, the number of railway infrastructure components is finite. On the other hand, this limitation also implies that the outcomes cannot be generalized to the entire system. The results only count for the (geographical) scope, which is taken into account.

The last limitation is more crucial for simulations made by means of StrateGo. It is crucial that all simulation results are carefully reviewed and discussed with those familiar with the operations. It is therefore recommended to introduce different scenarios, where progressive and conservative projections for the future can be simulated. So, in order to come to more reliable results, no component should be simplified. However, since for new projects not every component is known yet, simplifications should be made.

5.3. CONCLUSION ABOUT APPLICATION OF TECHNICAL DESIGN REQUIREMENTS

During literature research and interviews it was concluded that strategic maintenance planning is currently performed inefficiently. In order to come to a more efficient planning for estimating periodic and preventive maintenance, computer simulation tools can be used. In the end, these tools allow one to focus on the lifecycle costs of all assets involved and to find a (optimal) balance between costs of maintenance and the costs of breakdowns. As interviewees stated, no standardized life-cycle cost simulation model exists yet.

Within the company Oxand, computer simulation tool StrateGo is mostly suitable for strategic railway maintenance planning. However, it is crucial that all simulation results are carefully reviewed and discussed with those familiar with the operations.

In the next chapter theoretical background information of simulation tool StrateGo will be given. In Chapter 7 the simulation tool will be tested by means of a case study.

6. THEORETICAL BACKGROUND OF SIMULATION TOOL STRATEGO

In the Chapter 3, it was concluded that no standardized life-cycle cost simulation model for strategic railway maintenance exists yet. Chapter 4 ended with design requirements, which were identified after literature research and expert interviews. A computer simulation tool was regarded as desirable, since these tools allow one to focus on the lifecycle costs of all assets involved and to find a optimal balance between costs of maintenance and the costs of breakdowns. In Chapter 5.2, research into existing computer simulation tools which could be used for this strategic planning yielded to simulation tool StrateGo of company Oxand, which seemed mostly suitable. In this chapter this computer simulation tool will be researched in-depth.

This chapter starts with an overview of StrateGo. The functionalities of this computer simulation tool are stated. Paragraphs 6.1.2, 6.1.3 and 6.1.4 describe the three types of output, generated by StrateGo. This chapter can be regarded as theoretical background information of StrateGo. In the next chapter, StrateGo's functionality is tested by means of a case study.

6.1. DESCRIPTION OF STRATEGO

In this paragraph a description of computer simulation tool StrateGo will be given. StrateGo is described as a *Strategic planning tool that enables the long-term technical and economic assessment of investment and maintenance policies*. The tool projects, based on simulations with or without budget constraints, the evolution of the selected assets' state as well as potential technical and financial evolutions.

6.1.1. FUNCTIONALITIES OF STRATEGO²¹

StrateGo takes into account maintenance and replacement for the life cycle of components of assets. It is a general computer simulation tool, which is able to simulate very different (maintenance) systems, like railways, highways and buildings. It enables to introduce financial constraints for investments (CAPEX) and operational expenditures (OPEX). In the end it the simulation program evaluates the consequences for the components, which are taken into account, on:

- ◇ mean life time
- ◇ the total value of all assets
- ◇ management of costs
- ◇ the volume of the predicted maintenance works
- ◇ the risks in the system

StrateGo is an Excel-based computer simulation tool (see Figure 19). Currently, it consists of two main modules: costs and performance. In the first module, performance, all components which are taken into account are to be specified. It enables to simulate the impact of the different maintenance strategies on a short-, medium- and long-term, with use of degradation laws, mean life-time and frequency of replacement.

The second module, costs, takes into account all costs associated with the component: CAPEX, OPEX and degradation laws in terms of costs. For the upcoming future, a third module is about to be introduced: risks. It enables to evaluate to impact of different maintenance policies on the development of failures due to a lack of investment for the renewal or lack of operating expenses of the components of the infrastructure.

²¹ In order to write this paragraph, input from different employees of Oxand have been used (Crouigneau, S., 2011) (Goy, R., 2011) (Le Drogo, J., 2011) (Putallaz, Y., 2011)

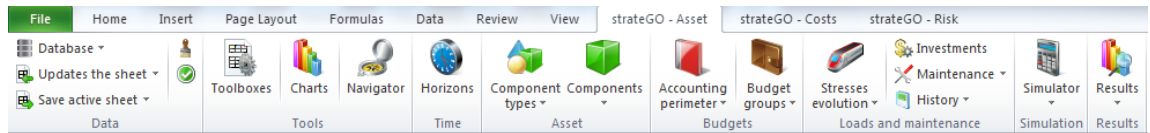


Figure 19: Outline of taskbar of StrateGo in MS Excel

As one can see, in the following figures, input data is shown. Firstly, StrateGo needs a description of all components, which are taken into account. The components are classified into different civil systems and for each component the quantity and date of commissioning (start date) are specified.

COMPONENTS							
Component	Component type	Civil system	Quantity	Date of commissioning	Calculated age	Load	Active
TR 2132	Lignes 220 kV 2 ternes	R	220 kV	8,235	1967	43 ANS / YEARS	TRUE
TR 2150	Lignes 220 kV 2 ternes	S	n 220 kV	20	1955	55 ANS / YEARS	TRUE
RR 5198	Lignes 125 kV 2 ternes	G	10 kV	20	1960	50 ANS / YEARS	TRUE
RR 5198	Lignes 125 kV 2 ternes	G	10 kV	14	1960	50 ANS / YEARS	TRUE
TR 2030	Lignes 380 kV 2 ternes	R	380 kV	8	1991	19 ANS / YEARS	TRUE
TR 2031	Lignes 380 kV 2 ternes	V	380 kV	10,017	1992	18 ANS / YEARS	TRUE
BANO	Champ GIS 220 kV_2 JB	B	-Ouest 220 kV	1	1991	19 ANS / YEARS	TRUE
BT BANO	Contr-cde et Prot	B	-Ouest 220 kV	1	1991	19 ANS / YEARS	TRUE

Figure 20: Overview of several components, defined in the database

Secondly, the maintenance actions are to be specified. As it is explained in the next paragraph, two different maintenance actions exist: capital expenditures (replacement) and operational expenditures (periodic maintenance). The first type of maintenance concerns replacement of components; when the residual lifetime of the component is zero (more on residual lifetimes in the next paragraph). For each replacement action the improvement in lifetime and the costs must be specified (see Figure 21).

LIFE TIME FOR ACCOUNTING							
Index	Component type	Technical domain	Active	Investment duration (years)	Accounting perimeter	Technical life (years)	Unit replacement cost
adv_1	AdV_UIC 2-4	Voie	TRUE	1	CAPEX	25	100000
adv_2	AdV_UIC 7-9	Voie	TRUE	1	CAPEX	30	80000
bal_1	ballast_UIC 2-4	Voie	TRUE	1	CAPEX	30	250
cat_1	Ligne type A	Catenaire	TRUE	1	CAPEX	60	400
rail_2	Rail50_UIC 2-4	Voie	TRUE	1	CAPEX	30	150
rail_1	Rail60_UIC 2-4	Voie	TRUE	1	CAPEX	30	170
trav_1	TraversesBois_UIC 2-4	Voie	TRUE	1	CAPEX	40	280

Figure 21: Overview of the different defined CAPEX maintenance actions

Figure 22 shows the maintenance actions which are periodically executed, either for safety reasons or in order to prolong the lifetime of the component. For each maintenance action a distribution of the progress of the residual lifetime can be specified. However, currently only the deterministic distribution can be chosen: always at point x in time, maintenance action a will be executed, regardless of the residual lifetime of the component. Several databases from existing railway infrastructure of the French railway companies RFF/SNCF and the Swiss railway company CFF are known. These databases enable StrateGo to compare the results and complement missing parameters like mean life-cycle time, costs and degradation laws.

MAINTENANCE LAWS								
Maintenance activity	Occurrence	Ideal technical life span	Scale	"Date"	Scale	Impact on "max. life time"	Unit cost	Distribution
Ctrl Cmd Prot Surveillance	0	15	ANS / YEARS	0	ANS / YEARS	5	0	DETERMINISTE
Ctrl Cmd Prot Surveillance	1	15	ANS / YEARS	5	ANS / YEARS	10	6	DETERMINISTE
Ctrl Cmd Prot Surveillance	2	15	ANS / YEARS	10	ANS / YEARS	15	6	DETERMINISTE
GIS 380 2J Gros Entretien	0	35	ANS / YEARS	0	ANS / YEARS	25	0	DETERMINISTE
GIS 380 2J Gros Entretien	1	35	ANS / YEARS	20	ANS / YEARS	35	70	DETERMINISTE
Lignes 380kV 2t changement cordes	0	100	ANS / YEARS	0	ANS / YEARS	60	0	DETERMINISTE
Lignes 380kV 2t changement cordes	1	100	ANS / YEARS	50	ANS / YEARS	100	151	DETERMINISTE
Lignes 380kV 2t Peinture pylones	0	100	ANS / YEARS	0	ANS / YEARS	32	0	DETERMINISTE
Lignes 380kV 2t Peinture pylones	1	100	ANS / YEARS	25	ANS / YEARS	55	99	DETERMINISTE
Lignes 380kV 2t Peinture pylones	2	100	ANS / YEARS	50	ANS / YEARS	78	99	DETERMINISTE
Lignes 380kV 2t Peinture pylones	3	100	ANS / YEARS	75	ANS / YEARS	100	99	DETERMINISTE
Lignes 380kV 2t refecton fondation	0	100	ANS / YEARS	0	ANS / YEARS	32	0	DETERMINISTE
Lignes 380kV 2t refecton fondation	1	100	ANS / YEARS	25	ANS / YEARS	55	30	DETERMINISTE
Lignes 380kV 2t refecton fondation	2	100	ANS / YEARS	50	ANS / YEARS	78	30	DETERMINISTE
Lignes 380kV 2t refecton fondation	3	100	ANS / YEARS	75	ANS / YEARS	100	30	DETERMINISTE

Figure 22: Overview of defined OPEX maintenance laws

Simulating by means of StrateGo yields to three types of output:

- ◇ An overview of the costs of CAPEX/OPEX over time
- ◇ A semi-operational overview of the proposed maintenance actions
- ◇ The residual lifetime of every single component at the end of the simulation period

The theoretical background of these outputs will be discussed in the next paragraphs.

6.1.2. OUTPUT IN CAPITAL EXPENDITURES AND OPERATIONAL EXPENDITURES

As specified in the Project Management Body of Knowledge, two types of maintenance actions are distinguished: Capital Expenditures (CAPEX) and Operational Expenditures (OPEX) (Project Management Institute, 2008).

Capital expenditures is the cost category associated with research and development, planning and design, and construction of the components. Sometimes CAPEX is also called Investment Costs or Purchase Costs. CAPEX yield benefits over multiple periods (Damodaran, A., 2010).

Operational expenditures may be defined as operation and maintenance costs which include the costs of using the infrastructure, based on operating times, the quantity, personnel costs and maintenance costs. (Hokstad, P., 1998).

In railway infrastructure maintenance CAPEX is the replacement of a component at a given moment in time, while OPEX is defined as regular, periodic maintenance.

6.1.3. OUTPUT AS AN OVERVIEW OF MAINTENANCE ACTIONS

The output of StrateGo in terms of a semi-operational overview of the proposed maintenance actions provides an overview of which component should when be repaired. It is regarded semi-operational, since the overview does not provide a very detailed order of the proposed maintenance actions. It is able to show an overview of all components separately, when these should be repaired or renewed. The associated costs are shown too.

6.1.4. OUTPUT IN TERMS OF MEAN RESIDUAL LIFETIME

Already back in 1982, Bhattacharjee observes the mean residual life functions occur naturally in areas such as optimal disposal of an asset and renewal theory (Bhattacharjee, M.C., 1982). By definition, the residual lifetime is unit-specific. Therefore, in systems with multiple same components, the *mean residual lifetime* is a more valuable variable (Whitt, P., 2012). Given that a unit is of age t , the remaining life after time t is random. The expected value of this random residual life is called the *mean residual life (MRL)* at time t . Since the MRL is defined for each time t , we also speak of the MRL function (Guess, F. & Proschan, F., 1985).

In Figure 23²², the residual lifetime for unit k is described graphically. In StrateGo the residual lifetime is relative to its total lifetime. The residual lifetime equals 1 (=100%) at point t_0 or at the time of CAPEX maintenance; an (relative) residual lifetime of 0.5 equals the half of the maximum lifetime. In Figure 23, point b represents the maintenance action at time t_1 . Due to this maintenance action, the residual lifetime is prolonged by:

$$\Delta MRL_t = a - b$$

a = Residual lifetime of an unit after maintenance action(s)

b = Residual lifetime of an unit before maintenance action(s)

MRL = Mean residual lifetime of an unit $\in [0,1]$

And due to the maintenance, the maximal lifetime is prolonged by:

$$\Delta L_{max} = y - x$$

L_{max} = Maximum lifetime of an unit $\in [0,\infty)$

x = maximum theoretical lifetime of an unit without maintenance action(s)

y = maximum theoretical lifetime of an unit with maintenance action(s)

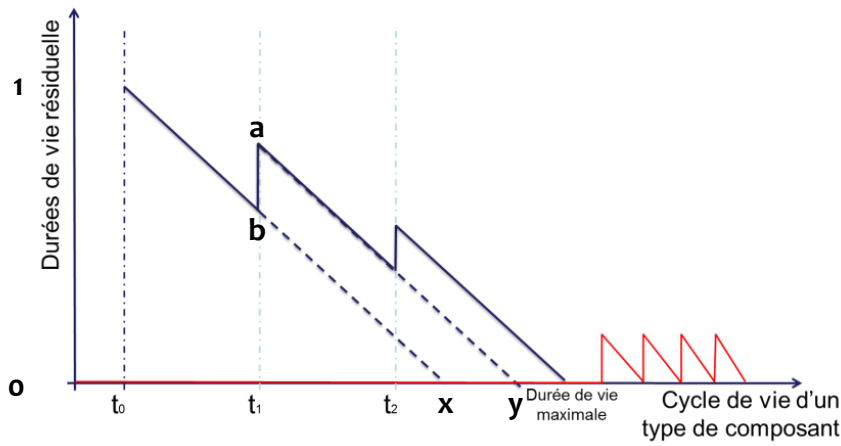


Figure 23: Development of residual lifetime of a component as a function of time

In Figure 23, the actual position of time x is dependent of the Mean Residual Lifetime function after time t_1 . In this figure, the projection of x is a linear or deterministic function: the maximum lifetime of unit k always equals the predefined maximum lifetime and no room for random variation exists. Since the deterministic distribution also holds for the maintenance actions, in this case the maximum lifetime is prolonged by the same predefined increase in lifetime, due to the planned maintenance.

$$\begin{aligned} \Delta MRL_t = a - b = \Delta L_{max} = y - x & \text{ only if } MRL_t \sim D(MRL_t) \\ \Delta MRL_t = a - b \neq \Delta L_{max} = y - x & \text{ if } MRL_t \not\sim D(MRL_t) \end{aligned}$$

Concerning the costs of the maintenance actions, with respect to the increase of the residual lifetime, the operational expenditures in Figure 23 can be calculated as:

$$OPEX = \frac{n(a - b)}{(y - x)} = [cost/year]$$

n = number of maintenance actions

A capital expenditures in terms of maintenance is performed when the residual lifetime of a component has gone to zero. By definition, a CAPEX maintenance action causes an increase in the residual lifetime from 0 to 1 (relatively, where 1 equals the maximum lifetime). The CAPEX costs are defined as:

²² Figure derived from interview with J. le Drogo (Le Drogo, J., 2011)

$$CAPEX = \frac{a - b}{x} = \frac{a - 0}{x}$$

As stated, a CAPEX maintenance action always yields to a maximization of residual lifetime of a component, where an OPEX maintenance action only increases the residual lifetime during the usage of the component. The increase of the MRL of an OPEX maintenance action is – by definition – less than an increase of the MRL of a CAPEX maintenance action, otherwise the component would have been renewed totally (CAPEX). The costs between these two actions are described as:

$$OPEX < CAPEX \rightarrow \left[\frac{n(a-b)}{(y-x)} \right]_0 < \left[\frac{a-0}{x} \right]_c \rightarrow \frac{n_0(a_0-b_0)}{(y_0-x)} < \frac{a_c}{x}$$

6.2. CONCLUSION OF BACKGROUND OF TOOL STRATEGO

StrateGo is theoretically described as a *Strategic planning tool that enables the long-term technical and economic assessment of investment and maintenance policies*. Simulating by means of StrateGo yields to three types of output:

- ◊ An overview of the costs of CAPEX/OPEX over time
- ◊ A semi-operational overview of the proposed maintenance actions
- ◊ The residual lifetime of every single component at the end of the simulation period

The theoretical background of these outputs have been elaborated in this chapter. In order to test the functionalities of StrateGo in practice, a case study will be performed in the next chapter. This case study will lead to a conclusion to what extent StrateGo matches the design requirements.

7. CASE STUDY USING COMPUTER SIMULATION STRATEGO

In the previous chapter a theoretical introduction of computer simulation tool StrateGo was given. In this chapter a case with existent data will be used, in order to test its functionalities. This case study will be used as input for Chapter 8: to what extent StrateGo matches the design requirements.

The case, regarded in this chapter, will be used to reveal the functionalities of StrateGo in practice. The case could be considered as a revelatory case, which is appropriate to be used as case study, by the definition of Yin. Yin defines a case study which investigates a contemporary phenomenon within its real-life context, especially when the boundaries between phenomenon and context are not clearly evident. Due to confidentiality of information, just one database is used in chapter. By Yin, a single-case study is appropriate if it concerns a critical, extreme, unique or revelatory case (Yin, R.K. , 2013).

Firstly in this chapter, the elements in the database will be discussed. In the second part of this paragraph the specifications of the database will be shown, where more background information will be provided. This paragraph concludes with an overview of the outcomes of the database, generated by simulation program StrateGo.

7.1. CASE DESCRIPTION

The case used in this chapter describes a conventional railway line in Switzerland. Regarding previous research in this report, a case study about a high-speed railway line would be preferred. However, it was not possible to acquire a database of a high-speed line, since:

- ◇ Parties in charge of maintenance of high-speed railway lines were hesitant to provide databases due to confidentiality reasons
- ◇ Only a few high-speed railway infrastructure projects have been constructed in the world, which makes pool of projects to be chosen from, smaller

Since the functionality of StrateGo is tested by means of the case study – and the accuracy of the outcomes are of less importance – it is not an insurmountable problem that only a database of a conventional railway line will be used.

7.1.1. ELEMENTS IN THE DATABASE OF THE CASE STUDY

The data in the database describe a small part of the Swiss railway network. Only the very basic elements of railways have been taken into account in this database. Therefore, the outcomes of this set of data only provides a direction and size. In earlier research, the database has been used to prove that the outcomes – calculated by StrateGo – would be similar to those outcomes calculated by other computer tools. A comparison of both results

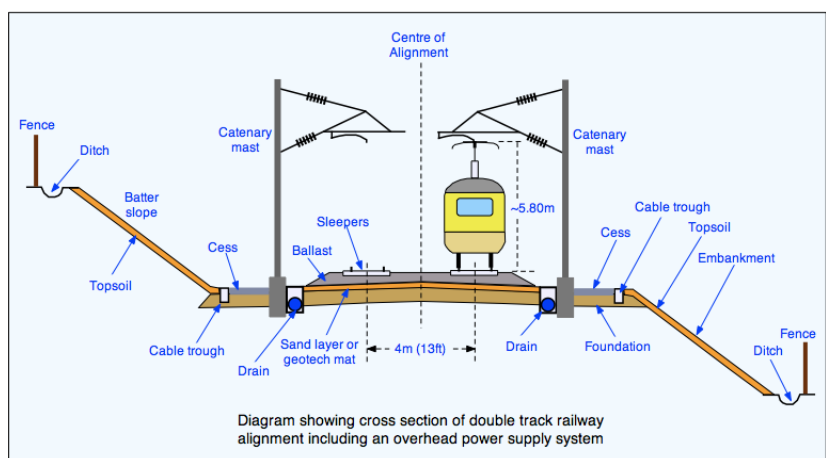


Figure 24: Graphical representation of different railway infrastructure components

lead to the conclusion that StrateGo could be used as a computer tool with confident outcomes for asset management forecast problems.

The database takes into account only the linear infrastructure of a railway track. Only five elements of a railway track included; those elements can be regarded as the basic elements:

- ◇ Railway track
- ◇ Switch
- ◇ Wooden sleeper
- ◇ Ballast
- ◇ Catenary system

Figure 24²³ shows these elements graphically.

7.1.2. SPECIFICATIONS OF DATABASE

The existing database describes the five elements in terms of number of units, their lifetime, their possible CAPEX and OPEX actions with their associated costs; see Table 10.

Table 10: Details of all elements in the database, used for the case study

Component	Component in StrateGo	# lo- cations	Number of units	Lifetime	CAPEX Action	Costs	OPEX Action	Costs	Maximum number of actions
Switch	AdV_UIC 2-4 ²⁴	26	99 x	25 years	Replace- ment	100000 € /unit	Stuffing	70 €	6 x
							Replacement of mechanism	90 €	1 x
Switch	AdV_UIC 7-9	5	8 x	30 years	Replace- ment	80000 € /unit	Stuffing	45 €	7 x
							Replacement of mechanism	90 €	1 x
Ballast	Ballast_UIC 2-4	6	14.755 m	30 years		250 €/m	Stuffing	40 €/m	6 x
Catenary	Ligne type A ²⁵	36	120.969	60 years		400 €/m	Painting	10 €/m	1 x
Railway track	Rail50_UIC 2-4	19	55.180 m	30 years		150 €/m	Grinding	15 €/m	2 x
Railway track	Rail60_UIC 2-4	9	63.314 m	30 years		170 €/m	Grinding	15 €/m	2 x
Wooden sleeper	TraversesBois_UIC 2-4 ²⁶	13	81.583 m	40 years		280 €/m			

As one may see, different types of the five elements are used. In the database, two types of switches and two types of railway tracks are used. Regarding the switches, an *Appareil de voie UIC 2-4* and an *Appareil de voie UIC 7-9* is used. The classification UIC 2-4 and UIC 7-9 refers to the notional traffic loads of the railway, where UIC1 is a most dense traffic load and UIC9 is the least dense traffic load (Ögüt, K.S., 2004). Referring to the database, it is clear that 99 switches at 26 locations endure very dense traffic loads, which causes a decrease in lifetime compared to the 8 switches at locations with less traffic loads. The maintenance costs at the more dense locations are higher, probably due to the direct costs for a switch of better quality (more traffic yields to more wear) and indirect costs for disrupting more trains when the switch is replaced.

Regarding railway tracks, in the database two different types are used: Rail50 and Rail60. A rail (spoorstaaf in Dutch) consists of a head, web and foot (see Figure 25²⁷). Figure 25 represents a flat-bottom rail, which is preferred over a bullhead rail (Palmsy, R., 2013). The difference between Rail50 and Rail60 is mainly due to its weight.

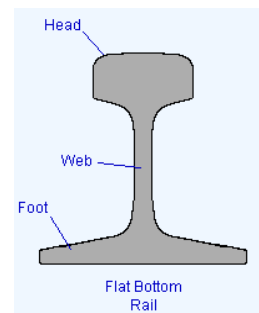


Figure 25: Elements of railway track

²³ Figure 24 derived from (Railway Technical Web Pages, Infrastructure, 2011)

²⁴ AdV = *Appareil de voie*, Switch in English

²⁵ Ligne = line, meant is catenary

²⁶ Traverse Bois, Railway sleeper in English

²⁷ Figure 25 derived from (Railway Technical Web Pages, X-section of types of Rails, 2011)

Rail50 weights approximately 50 kg/m, where Rail60 weights approximately 60 kg/m. Heavier railway tracks are used for either high-speed railways or heavy-duty railways. For HSR lines the track should be straight, flat and fatigue-resistant; heavy-duty railways require hardened rail for unrivalled wear resistance in extreme conditions as heavy axle loads (25-35 tonnes) (Tata Steel, 2013). In The Netherlands the Rail60 (*de facto* UIC60) is only used at the High Speed Line Zuid and Betuweroute; outside The Netherlands the UIC60 railway track is most common (Verheijen, E., 2013). The rationale why UIC60 is used at the Betuweroute is that this railway track is only accessible for heavy railway freight traffic (Keyrail, 2013).

Table 11: Details of two different railway tracks, see Figure 26²⁸

	Rail UIC50	Rail UIC60
Section weight	50,46 kg/m	60,21 kg/m
Rail height (H)	152 mm	172 mm
Head width (C)	70 mm	72 mm
Web thickness (A)	15 mm	16.5 mm
Foot width (P)	125 mm	150 mm

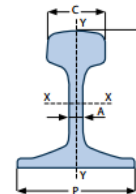


Figure 26:
Representation of H,
C, A and P in table 5

7.2. OUTPUT OF CASE STUDY

In the case study, the database of the previous paragraph is used. Within StrateGo different options can be chosen, like:

- ◇ Including vs. excluding planned maintenance
- ◇ Defining a budget constraint
- ◇ Period in years of simulation

For the simulation of this case study, the options *including maintenance, no budget constraint and a simulation period of 20 years (2010 – 2030)* have been chosen. In the simulation, the reference year is 2010.

As stated previously, simulating by means of StrateGo yields to three types of output:

- ◇ An overview of the costs of CAPEX/OPEX over time
- ◇ A semi-operational overview of the proposed maintenance actions
- ◇ The residual lifetime of every single component at the end of the simulation period

7.2.1. OVERVIEW OF THE COSTS OF CAPEX/OPEX OVER TIME

Figure 27 shows the expenses of capital and operational expenditures over twenty years. One can see that the right in 2010 and in 2016 huge capital expenditures are to be made. Its correctness could be check in the database itself. The most expensive components in terms of CAPEX costs are switches (see Table 10). In 2010, most of the 99 switches, which all have a lifetime of 25 years, are near their palliative period. Since the residual lifetime is determined with a deterministic distribution, the maximum lifetime always equals 25 years. It is to be expected that in 25 years from 2016 on (so, in 2031), the CAPEX costs will rise again.

RESULTS : EXPENSES			
Year	Sum	CAPEX	OPEX
2010	25750300	25750300	0
2011	1110225	200360	909865
2012	2539175	1584900	954275
2013	1346660	557590	789070
2014	438520	341840	96680
2015	5009370	4935600	73770
2016	52602355	50618550	1983805
2017	5331000	4780500	550500
2018	2506160	2248580	257580
2019	607835	472110	135725
2020	5637805	4886430	751375
2021	4089495	1671540	2417955
2022	1666425	868420	798005
2023	897615	180	897435
2024	120080	0	120080
2025	1297260	1214600	82660
2026	4247585	1640060	2607525
2027	4458810	3611590	847220
2028	2322955	1246080	1076875
2029	2173635	2083590	90045
2030	23657615	23270660	386955

Figure 27: Numerical representation of CAPEX, OPEX and total costs

²⁸ Numbers derived from (Voest Alpine, 2013) (Tata Steel, 2013)

7.2.2. SEMI-OPERATIONAL OVERVIEW OF PROPOSED MAINTENANCE ACTIONS

The semi-operational overview of the proposed maintenance is an overview on a mesoscopic level. For each component is specified in which year what kind of maintenance is required. It is an overview which provides insight in the number of maintenance action per components, but does not provide a very detailed order of performing maintenance actions. In this case study, one type of maintenance is to be considered: grinding of the rails. Rail grinding helps to prevent the dangerous build-up of rolling contact fatigue, and also reduces running noise for line side communities (European Railway Review, 2013). Figure 28²⁹ shows a grinding maintenance train and Figure 29³⁰ shows in detail the grinding process.



Figure 28: Maintenance grinding train



Figure 29: Detail of grinding process

Figure 30 shows the output which is given by StateGo. One can distinguish renewal actions and maintenance actions. In 2018 the component Rail60 should be renewed for 8.549 meters. In 2012, 2028 and 2029 the same 8.549 meter is to be maintained by grinding the rails. In the database grinding is called *meulage*, French for grinding. The total expense of 128.235 euros equals the 8.549 meters times €15 per meter (see Table 10). An overview like Figure 30 can be shown by StrateGo for each component separately.

RESULTS : MAINTENANCE LOGS							
Year	Maintenance activity	Component type	Technical domain	Maintenance quantities	Expense duration (years)	Expense	Maintenance status
2010	Meulage_Rail60_UIC 2-4	Rail60_UIC 2-4	Voie	0	0	0	Maintenance necessary
2011	Meulage_Rail60_UIC 2-4	Rail60_UIC 2-4	Voie	0	0	0	Maintenance not necessary
2012	Meulage_Rail60_UIC 2-4	Rail60_UIC 2-4	Voie	8549	1	0	Maintenance in progress
2013	Meulage_Rail60_UIC 2-4	Rail60_UIC 2-4	Voie	0	0	0	Maintenance not necessary
2028	Meulage_Rail60_UIC 2-4	Rail60_UIC 2-4	Voie	8549	1	128235	Maintenance in progress
2029	Meulage_Rail60_UIC 2-4	Rail60_UIC 2-4	Voie	8549	1	0	Maintenance in progress
2030	Meulage_Rail60_UIC 2-4	Rail60_UIC 2-4	Voie	0	0	0	Maintenance not necessary
RESULTS : RENEWALS LOGS							
Year	Component	Component type	Technical domain	Renewed quantities	Investment duration (years)	Commission status (ID)	Renewal status
2010	R_A_1036_1610	Rail60_UIC 2-4	Voie	0	0	0	Renewal not necessary
2018	R_A_1036_1610	Rail60_UIC 2-4	Voie	8549	1	0	Renewal in progress
2030	R_A_1036_1610	Rail60_UIC 2-4	Voie	0	0	0	Renewal not necessary

Figure 30: Overview of maintenance and renewal logs for Rail60

7.2.3. RESIDUAL LIFETIME COMPONENT AT THE END OF SIMULATION PERIOD

Figure 31 shows the relative ages of all components, where 1 equals 100% in terms of time, the end of lifetime. The most visible link between the Figure 27 and Figure 31 can be seen in the year 2016, where a huge investment of 5 million Euros in CAPEX is made. This investment

²⁹ Figure derived from (LGV Rhine Rhone, 2014)

³⁰ Figure derived from (Sersa Group, 2013)

yields to a renewal of components; the lifetime of these renewed components is reset to a relative lifetime of zero.

Figure 31 is useful for getting an insight in the costs of maintenance and lifetime of the components on a macroscopic level. However, a railway track can be regarded as a set of components which are all mutually dependent. In other words, if just one unit fails, the whole system (the ability to operate the railway line) will be out of order. Therefore, it is more valuable to look after that component, which is the most critical at time t . Critical can be defined as near the end of its lifetime, where (in a non-deterministic distribution environment) the probability of failure rises.

RESULTS : AVERAGE AGE OF ASSET																						
Year	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	
Relative age (technical)	0,456	0,481	0,499	0,522	0,546	0,546	0,195	0,196	0,210	0,234	0,235	0,252	0,274	0,300	0,326	0,345	0,360	0,367	0,386	0,401	0,303	

Figure 31: Numerical representation of relative average age of all components

7.3. OBSERVATIONS OF COMPUTER TOOL STRATEGO

The case study, used in this chapter, shows the functionality of StrateGo in practice. In this chapter the focus was on the output of StrateGo. However, during the process of simulations observations with StrateGo were noticed. The most striking observations are:

Positive points

- ◇ StrateGo enables to assess long-term strategies for maintenance in infrastructure
- ◇ StrateGo is applicable to many infrastructural areas
- ◇ Oxand possess different databases of infrastructures with details of different components
- ◇ StrateGo takes into account the costs and performance
- ◇ StrateGo makes use of a structured process approach to enter projects and databases
- ◇ Not a very microscopic level for the data is required to come to calculations

To be improved

- ◇ Short-term, hands-on maintenance policies are not possible to simulate (minimum timespan is years)
- ◇ No standardized maintenance strategies are possible to choose for simulation
- ◇ No combination of risk and costs can be used in order to make maintenance decisions
- ◇ Output is only shown in a numerical way
- ◇ No explanation of results in terms of bottlenecks or sensitivity analysis
- ◇ No other distribution possible than deterministic
- ◇ Slow if number of components exceeds 200
- ◇ Only experience with conceptual strategic planning, not yet implemented

In the next chapter, the observations as described above are to be elaborated. Furthermore, as in Chapter 4 the design requirements were stated, in the next chapter, these requirements are to be confronted with the functionality of StrateGo.

8. EVALUATION OF COMPUTER SIMULATION TOOL STRATEGO

In this chapter the case study of Chapter 7 is used as input for an assessment of StrateGo. The observations, as discussed in paragraph 7.3, are elaborated in this chapter. First, its strengths and weaknesses are described and possible improvements are given. Second, the computer simulation tool is confronted with the design requirements, which were identified in Chapter 4. The last part of this paragraph is about possible improvements for StrateGo, which are brought up by the confrontation. These latter improvements are to be implemented on a long-term.

8.1. METHODOLOGY: FITNESS FOR PURPOSE

In order to match the type of computer simulation tool with the design requirements, a fitness for purpose test is performed. Fitness for purpose has been a widely used approach by quality agencies. As one of the five definitions of quality, Harvey and Green, (1993) state: *Fitness for purpose sees quality as fulfilling a customer's requirements, needs or desires. Theoretically, the customer specifies requirements* (Harvey, L. and Green D., 1993). The fitness for purpose in this field of research is to what extent the computer simulation tools match the requirements, which have been derived from the interviews with the experts.

The fitness for purpose in this research is to what extent the researched computer simulation tools match the requirements, which have been derived from the interviews with the experts. As concluded in Chapter 5 the most promising computer simulation tool within Oxand S.A. is StrateGo.

8.2. STRENGTHS AND WEAKNESSES OF STRATEGO

On first sight, StrateGo seems very well possible to simulate maintenance on the long-term. Therefore, strengths and weaknesses of the simulation tool can be drawn, as will be done in this paragraph.

8.2.1. STRENGTHS OF STRATEGO

Table 12 shows the strengths of StrateGo, with according explanation.

Table 12: Strengths of StrateGo with proposed improvements and priorities

COMPUTER TOOL STRATEGO
Strengths
StrateGo enables to assess long-term strategies for maintenance in infrastructure Output of StrateGo shows the evaluation of maintenance over multiple years.
StrateGo takes into account the costs and performance The computer tool does not only focus on cost or (technical) performance, but focusses on both.
StrateGo is applicable to many infrastructural areas In the case study StrateGo is used for maintenance of a railway line; it could be used for any infrastructural area.
Outcomes of StrateGo are comparable to those of other computer tools See research of Sophie FABRE (Fabre, S., 2011), who compared the outcomes of StrateGo with other computer simulation tools.
StrateGo makes use of a structured process approach to enter projects and databases Input in StrateGo is divided in civil systems, technical domain and component; in this way components can be compared.
Not a very microscopic level for the data is required to come to calculations On a component level, the maximum lifetime is required. StrateGo is able to calculate with assumptions about the degradation of the component.

StrateGo consists of commercial (costs) and technical (residual lifetime) output

Output is shown in CAPEX and OPEX, and residual lifetime, which could enable to make decisions on both variables.

Oxand possess different databases of infrastructures with details of different components

Databases about an electricity grid, a conventional railway line and a private railway line to a nuclear power plant are possessed.

Explanation of strenghts

Although it is claimed that StrateGo could be applicable to many infrastructural areas, it is recommended to exploit first the railway sector, before starting the quest for numbers in other sectors. Furthermore, the triangle risk-cost-performance should be introduced; the decision of performing maintenance is always dependent of these three factors. Improving the output for more communicative goals is less important, but still recommended to do. Simulating is all about getting the correct numbers as input; garbage in is garbage out. That is why it is recommended that correct data from different databases are derived in order to improve the reliability of StrateGo.

8.2.2. WEAKNESSES OF STRATEGO

In the case study, some weaknesses of StrateGo have been revealed. In Table 13, these weaknesses are listed. This list is made up by means of own experiences with simulating and requiring output in StrateGo. Moreover, this list was completed by some employees of Oxand, who had already worked with this computer simulation tool (Crouigneau, S., 2011) (Goy, R., 2011) (Le Drogo, J., 2011) (Putallaz, Y., 2011). In Table 13 for each weakness a possible improvement is proposed. This is derived from own experience with StrateGo.

Table 13: Weaknesses of StrateGo with proposed improvements

COMPUTER TOOL STRATEGO	
Weaknesses	Proposed improvement
No standardized maintenance strategies possible to choose for simulation	Introduce strategies as only CAPEX, budget cuts and minimal residual lifetime
No reliable experience with risk and cost module	Introduce reliable risk and cost modules and link the three modules
Short-term, hands-on maintenance policies are not possible and not reliable	Only focus on strategic maintenance planning; skip hands-on schemes
No explanation of results in terms of bottlenecks or sensitivity analysis	Split the outcomes in terms of components; find the critical one
No other distribution possible than deterministic and knowledge about other distribution lacks	Introduce as least a Weibul distribution for residual lifetime (see interviews)
Slow if number of components exceeds 200, due to Excel-based program	Build a stand-alone computer program, with improved performance and interface
StrateGo has only been used for cases in France (electricity) and Switzerland (rail)	Gain more experience in other areas, sector wise and geographically
Only experience with conceptual strategic planning, not yet implemented	Exchange return of experiences with a client on a regular basis and gather details of spare parts from RAMS databases
No personal assessment of risk-treatment possible	Introduce a risk module, where risks can be mitigated to preferences of client

Explanation of weaknesses

It is a real lack that no standardized maintenance strategies can be chosen in StrateGo. It is recommended to introduce maintenance strategies, like budget constraints, minimum level of service (standardized buffer in residual lifetime), budget cuts and only using CAPEX.

Although StrateGo is regarded as a maintenance planning tool on a strategic level, it is recommended not to generalize its outcomes. By finding the most critical component, the

outcomes could have a real impact, rather than showing the state of the assets on a generalized level. Introducing probabilistic distribution functions for the residual lifetime is regarded as necessary, also by the experts, who were interviewed.

Building a stand-alone program, rather than using Microsoft Office Excel is not recommended in this stage. One could rather exchange return of experience (are the simulated predictions of StrateGo in line with the practice?).

The proposed improvements of these weaknesses are in line with the general recommendations for railway maintenance of the UIC (UIC, 2010), namely:

- ◇ Exchanges of Return of Experiences on a regular basis
This matches the weakness and proposed improvement that only experience with conceptual planning exists, and no implementation of strategic maintenance planning by means of StrateGo is done.
- ◇ An effort to stabilize the technology of some subsystems as the interfaces are becoming more and more difficult to manage.
This matches the proposed improvement that a risk module should be introduced in StrateGo, where risks can be mitigated to the preferences of the client.
- ◇ Common research for the development of a RAMS databank to assist in choosing components and in the management of spare parts.
One of the proposed improvements is to acquire correct data from different databases in order to improve the reliability of StrateGo

8.3. CONFRONTATION OF STRATEGO WITH DESIGN REQUIREMENTS

In Chapter 3, design requirements for a type of computer simulation tool have been identified. Two types of requirements were shown: organizational and technical. In order to test the fitness for purpose of StrateGo, the technical design requirements are assessed in Table 14.

Table 14: Scoring of StrateGo on the technical design requirements

Design requirements vs. StrateGo	
Technical requirements	Suitability StrateGo
Existence of a well-performing ex-ante life-cycle-cost simulation tool	+
Overview of historical data of previous high-speed railway maintenance projects	+/-
Possibility to change model distribution of the life-time of an asset to the reality	--
Possibility to alter data and parameters in the simulation model during operations	+
Be able to simulate long-term and short-term contract periods	+/-
Simulate an efficient maintenance planning, with use of budget constraints	+
Technical information about wheel/rail interface for new types of trains	--

Derived from Table 14 it is clear that StrateGo is an ex-ante LCC simulation tool, of which data and parameters during operations can be altered and budget constraints can be introduced. StrateGo does not perform well on changing model distributions, having a reliable historical database, being able to simulate for short-term periods and having technical data information.

8.4. OTHER PROPOSED IMPROVEMENTS FOR STRATEGO

Regarding the strengths and weaknesses of StrateGo, possible improvements have been proposed. Besides these improvements, other recommendations could be given as well,

also derived from its confrontation with the design requirements. The proposed improvements, which are to be discussed in this paragraph, are to be implemented on long-term. It is recommended to first look after the possible improvement to solve the weaknesses of StrateGo.

Add graphical representations

The output of StrateGo only consisted of numerical representations. It is hard to interpret the data by numbers, and it could cause misunderstanding. Therefore, it is proposed to introduce graphical representations of the data output. Moreover, when different graphical representations are combined, new in-sight information can be required.

Figure 32 shows the fragment of output of the case study, used in Chapter 7. It suggests the average residual lifetime of components. Derived from this numerical representation, no conclusions can be made easily.

Figure 33 shows the numerical output of Figure 32 in a graphical way. One can immediately see that in 2015 a lot of maintenance is performed, since the residual average lifetime of the components is extremely decreased. Figure 34 shows a graphical overview of the CAPEX, OPEX and total costs during the simulation period. The link between Figure 33 and Figure 34 is clearly visible: in 2015 the average residual lifetime decreases and simultaneously the total costs of maintenance rise.

RESULTS : AVERAGE AGE OF ASSET																					
Year	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Relative age (technical)	0,456	0,481	0,499	0,522	0,546	0,546	0,195	0,196	0,210	0,234	0,235	0,252	0,274	0,300	0,326	0,345	0,360	0,367	0,386	0,401	0,303

Figure 32: Numerical representation of average residual lifetime of components

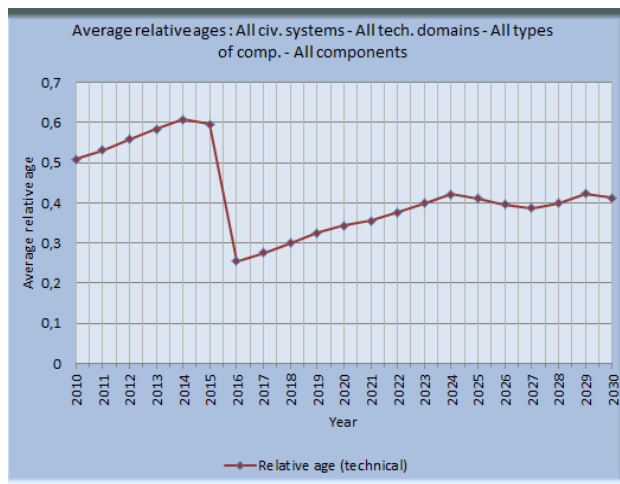


Figure 33: Graphical representation of relative age of all components

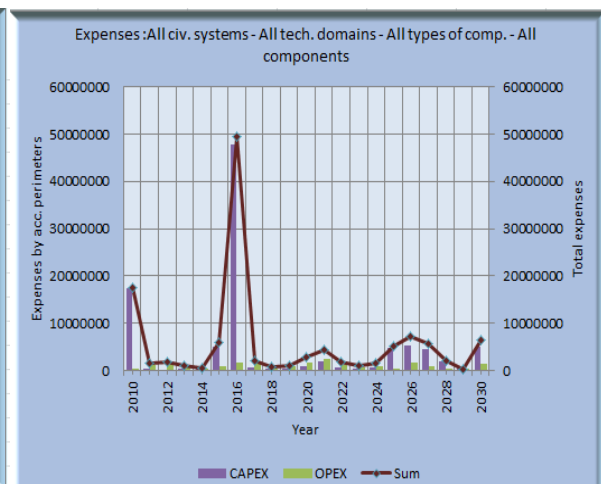


Figure 34: Graphical representation of CAPEX, OPEX and total costs

Do not generalize the outcomes

Output of StrateGo is shown on a generalized level. This means that all components are combined together, to get an average residual lifetime. For example, Figure 33 shows this relative age of all components.

Figure 35 has been constructed manually and shows the breakdown of the different types of components in terms of their lifetime. It is still on an aggregated level, since for example one type of switches consists of 99 actual switches, which all mostly differ in lifetime. This figure is made manually by numerical output data of StrateGo and is not shown automatically. It is clearly visible that in this figure, the catenary is the most critical

type of component; it is the bottleneck in this railway system. In 2015 it nearly reaches 1 (=100% of used lifetime), which means at the end of its lifetime. In 2016, when a CAPEX maintenance action for the catenary system is performed, its average lifetime drops to exactly zero. Since a (relative) lifetime cannot be negative, this means that all catenary components are renewed in 2015.

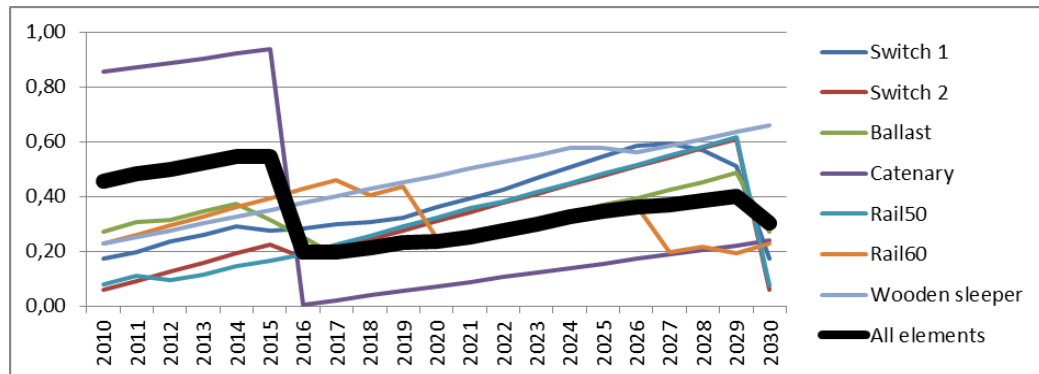


Figure 35: Breakdown of average residual lifetimes of all components

Other improvements

Besides adding graphical representations and not to generalize the outcomes, some other improvement can be given. These improvements are derived from interviews with employees and from experiences with other computer simulation programmes. It is recommended to first improve the weaknesses, as discussed previously. Later on, the following improvement can be implemented.

- ◇ **Implement (extended) project management triangle** (see Figure 36³¹); the decision for performing maintenance should not only be driven by the maximum lifetimes. The risks and available budget should be taken into account. Moreover, a schedule to combine different maintenance actions could be introduced, as well as the consideration for components of better quality versus higher costs.

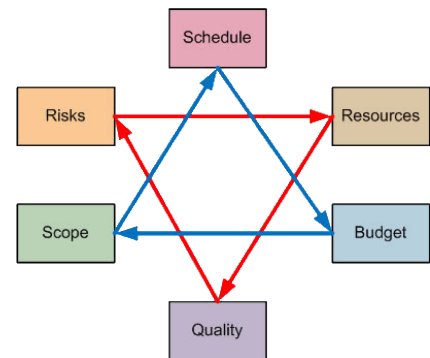


Figure 36: Extended project triangle

- ◇ **Verification of input data**; in order to avoid input errors, verification is needed of:
 - form of input data (number or letter)
 - validity (lower and upper bound for field)
 - consistency with other data

The simple verifications should be done automatically and an icon could indicate if the verification is done correctly or not (red cross, green tick)

- ◇ **Import of data for description of components in asset** from other sources, like ERP (SAP, Maximo) and other software (Access, Oracle).

- ◇ **Navigation within StrateGo**

In order to (de)activate some parts of the system, a navigation tree is proposed. In this tree one may activate entire systems, different domains, specific components and the maintenance actions.

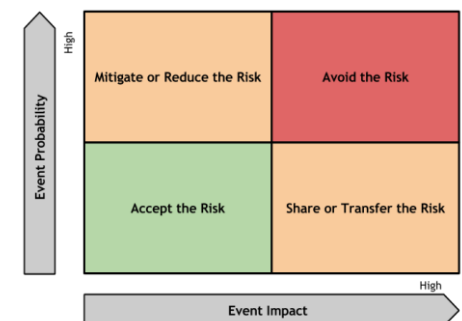


Figure 37: Overview of risk mitigation strategies

³¹ According to PMBOK (Project Management Institute, 2008)

- ◇ **Introduction of risk mitigation strategies;** in this way the client could decide itself whether some risks regarding residual lifetime are accepted, mitigated, shared or avoided (see Figure 37³²).

8.5. CONCLUSION OF COMPUTER TOOL STRATEGO

StrateGo is an Excel-based tool and described as a Strategic planning tool that enables the long-term technical and economic assessment of investment and maintenance policies. By means of a case study, its strengths and weaknesses were identified.

StrateGo could not be used for operational maintenance planning in practise yet. This is due to the reliability of the data and simulation. Experience with maintenance planning for real cases is non-existent, which causes risks. Moreover, a limited number of databases with details of components is possessed. Therefore, reliability of the data is at stake.

It is a real lack that no standardized maintenance strategies can be chosen in StrateGo. By the interviewed actors (see Chapter 3) maintenance strategies are demanded. It is recommended to introduce maintenance strategies, like budget constraints, minimum level of service (standardized buffer in residual lifetime), budget cuts and only using CAPEX.

Confrontation with design requirements showed that StrateGo is well-performing on a meta-level, but recommended is to improve mainly the reliability of data and simulation. Moreover, there is still room for other improvements, like adding graphical representations, more detailed outcomes, implementation of the project management triangle and introduction of risk mitigation strategies.

³² Figure derived from OWASP (OWASP, 2013)

9. CONCLUSIONS

In this report, the (latent) problems behind maintenance for high-speed railway infrastructure have been researched. The recommendations of the Dutch parliamentary survey about railway maintenance served as a starting point.

Overall, the parliamentary committee has come to the conclusion that the focus on long-term investment strategy for maintenance of Dutch railway infrastructure lacks. The part in the report about efficiency of maintenance is weak. It states that the real evidence for proving that improvements could be made, have not been researched. The rationales of which improvements can be made in order to improve the efficiency of railway maintenance remain still unclear after having read the final report of the survey. All in all, the conclusions and recommendations give rise to more research.

The first part of this report provided an comprehensive overview of the important problems and issues, mentioned by actors. The second half of this research provided directions to solve (a part of) these problems. Three research questions have been answered in this report.

1) *What are lacks of knowledge in strategic maintenance planning for high-speed railway infrastructure in The Netherlands and France?*

In order to gain more knowledge about the lacks of knowledge in the field of maintenance of high-speed railways, seven semi-structured expert interviews have been performed. The interviewees are originated from The Netherlands and France, and work for public and private parties. All interviews listed yield to five groups of lacks of knowledge:

Table 15: Overview of five groups of knowledge in field of railway infrastructure maintenance

1	Model and data lacking of railway infrastructure assets	Distributions Monitoring	Track records No standard LCC-model
2	Financial aspects of railway infrastructure projects	Complementary functions Influence of banks	Business case existence Quality after transfer
3	Organizational structures of railway projects	Cultural aspects Requirements vs wishes of RIM	Adaptions during operations Maintenance at start of project
4	Emphasis on efficiency with new railway projects	Risk management neglected EU norms of TSIs	French long-term PPP-contracts Dutch short-term contracts
5	Technical and organizational interface problems	Rail/Infrastructure Public/Private	International traffic RIM/operator

These five groups lead to two types of design requirements:

- ◇ technical design requirements
- ◇ organizational design requirements

2) *In order to solve the mostly mentioned lacks of knowledge, what design requirements should a computer simulation tool for strategic maintenance planning for high-speed railway infrastructure have?*

Due to the expert interviews, two types of design requirements have been unveiled: technical and organizational requirements.

Technical design requirements

A computer simulation tool:

- ◇ should exist of a well-performing ex-ante life-cycle-cost simulation tool for railway infrastructure maintenance;
- ◇ should own an overview of historical data for all components, which are taken into account, derived from previous high-speed railway maintenance projects;
- ◇ should have the possibility to change the model distribution of the life-time of an asset to its degradation;
- ◇ should have the possibility to alter data and parameters in the simulation model during operations;
- ◇ should be able to simulate long-term and short-term contract periods and come up with reliable results;
- ◇ should simulate an efficient maintenance planning, with use of (budget) constraints;
- ◇ should contain technical information about interface issues, like wheel-rail for new types of trains.

Organizational design requirements

A railway infrastructure maintenance organization:

- ◇ should take into consideration the strategic maintenance planning during the phase of design and build;
- ◇ should regarding the quality of the assets, focus on the period around transfer of the infrastructure and balance the discrepancies in expectations of different actors;
- ◇ should mix project teams with employees from public as well as private companies and parties;
- ◇ should invest in risk management from an operational and maintenance point of view;
- ◇ should use an holistic approach during the whole concession period, with feedback loops when needed;
- ◇ should be able to work in different countries and with different cultures;
- ◇ should do as much as possible in-source; minimize outsourcing

These requirements are used as criteria for existing computer simulation tools for strategic maintenance, which are researched due to the next research question.

3) *To what extent are existing computer simulation tools able to meet the design requirements, as stated in the second research question?*

After having analysed all available computer simulation tool within Oxand, computer simulation tool StrateGo seems mostly suitable for strategic maintenance planning. StrateGo is an Excel-based tool and described as a Strategic planning tool that enables the long-term technical and economic assessment of investment and maintenance policies. By means of a case study, it strengths and weaknesses were identified.

StrateGo could not be used for operational maintenance planning in practise yet. This is due to the reliability of the data and simulation. Experience with maintenance planning for real cases in non-existent, which causes risks. Moreover, a limited number of databases with details of components is possessed. Therefore, reliability of the data is at stake.

It is a real lack that no standardized maintenance strategies can be chosen in StrateGo. By the interviewed actors (see Chapter 3) maintenance strategies are demanded. It is recommended to introduce maintenance strategies, like budget

constraints, minimum level of service (standardized buffer in residual lifetime), budget cuts and only using CAPEX.

Table 16: Scoring of StrateGo on the technical design requirements

Design requirements vs. StrateGo	
Technical requirements	Suitability StrateGo
Existence of a well-performing ex-ante life-cycle-cost simulation tool	+
Overview of historical data of previous high-speed railway maintenance projects	+/-
Possibility to change model distribution of the life-time of an asset to the reality	--
Possibility to alter data and parameters in the simulation model during operations	+
Be able to simulate long-term and short-term contract periods	+/-
Simulate an efficient maintenance planning, with use of budget constraints	+
Technical information about wheel/rail interface for new types of trains	--

Confrontation with design requirements showed that StrateGo is well-performing on a meta-level, but recommended is to improve mainly the reliability of data and simulation. Moreover, there is still room for other improvements, like adding graphical representations, more detailed outcomes, implementation of the project management triangle and introduction of risk mitigation strategies.

10. RECOMMENDATIONS

In this last chapter, the recommendations will be stated. Two types of recommendations will be discussed: those derived from this research and recommendations for further research.

10.1. RECOMMENDATIONS DERIVED FROM RESEARCH

- 1) **Take strategic maintenance planning into consideration even before the phases of design and build**
When maintenance is taken into consideration from the start of a project on, more focus will be on efficient renewal and maintenance of the assets.
- 2) **Mix project teams with employees from public as well as private companies and parties**
Knowledge about components and the required maintenance is often not shared to other parties; if so, it could improve the (societal) benefits.
- 3) **Use an holistic approach during the whole time of the concession period, with feedback loops when needed**
Often in contracts maintenance is specified for a very long period of time. Experts recommend to be able to alter the information about the components in the contracts.
- 4) **Combine technical and organizational points of view in maintenance planning**
The design requirements show that organizational and technical requirements together will lead to a more efficient maintenance planning.
- 5) **Adapt computer simulation tool StrateGo to the wishes of the interviewed experts**
In Chapter 8, improvements for StrateGo were done, like not to generalize the outcomes and to have graphical representations.
- 6) **Collect a database with details about components, in order to ensure the reliability of the outcomes**
Extended databases with information about components will contribute towards more reliable data and in the end a more reliable simulation.
- 7) **Let StrateGo be able to simulate maintenance planning for short-term and long-term contract periods**
Currently, StrateGo can only simulate in terms of years. The interests between short-term and long-term contracts differ in terms of maintenance.
- 8) **Introduce maintenance strategies for strategic maintenance planning**
Maintenance strategies help to find a balance between the risks (in terms of residual lifetime) and costs

10.2. RECOMMENDATION FOR FURTHER RESEARCH

1) Elaborate on the organizational design requirements

This report has elaborated on the technical requirements. Due to scoping reasons only little attention was paid to the organizational design requirements, which are as important.

2) More actors to be interviewed

Mainly due to confidentiality reasons, only seven actors agreed on being interviewed. In order to get a more coherent vision of the actual problem statement, more expert could be interviewed.

3) Assess other computer simulation tools

In this research many computer simulation tools within Oxand were taken into account. However, a lot more tools exist. Further research could reveal their strengths and weaknesses.

4) Compare findings to other infrastructural areas

Other infrastructural areas, other than railways, are interesting to be researched. One can think about maintenance of highways and maintenance of buildings.

5) Compare findings to other geographical areas

Only France and The Netherlands were taken into account in this research. Countries which are famous for their high-speed rail are Germany and Japan. Further research could elaborate on these countries.

6) Get more in-sight information how maintenance is currently planned

As stated, due to confidentiality reasons it was only allowed to get more information on the current performance of maintenance on a superficial level. One could try to get more in-sight information in the high-speed railway maintenance organizations about their performances.

11. REFLECTIONS

All analyses are done, conclusions and recommendations were drawn; so what remains is reflections. In this chapter a research reflection and a process reflection will be given.

11.1. RESEARCH EVALUATION

Although valuable conclusions were drawn in this report, some remarks can be summed up in the research itself. Firstly, it was hard to find a focus in the research. Since company Oxand required a commercial, hands-on, operational report, the university asked for a scientific, more reflective report. Combined with the differences in the French and Dutch culture, this field of tension caused different visions of the desired product. After all, the commercial and scientific focus have been split: a final presentation as the end of my internship concerned the commercial possibilities in the field of railway infrastructure; this report described scientifically the research process and went beyond just a focus on the company Oxand.

The interviewing process was harder than expected. A lot of actors have been contacted, but only seven agreed on being interviewed; a hit rate of just 10%. It was hard to get the right information in the interviews themselves, due to confidentiality reasons and the actors being suspicious. All in all, most information gathered from this interviews are on a more macroscopic level; too bad that no actor wanted to unveil databases or methodologies.

In this report, scoping was very much required to get a focus. However, scoping also means that some subjects get less attention. This mainly counts for the organizational requirements; only the technical design requirements were elaborated.

11.2. PROCESS EVALUATION

This Master Thesis has required much more time than the initial six months, mainly due to personal reasons. The adventure started in May, 2011 when I began an internship at Oxand SA in France. Soon, it became clear that the topic of my Master Thesis was so loose that I needed to scope it, which was a lot harder than I previously expected. Moreover, it turned out that the company did not have much experience in the field of railways, which caused some problems in getting the right and needed information.

During my stay in France, I contacted many persons who I wanted to interview for the actual problem statement. However, only seven actors agreed on being interviewed and just after persuade them with maximum efforts. All in all, my motivation decreased and I chose to spend most of the time on my second internship topic: nuclear power plants. Knowledge about this topic was more present at Oxand and I was able to deliver three reports, all written in French.

After my stay in France, I had to finish two courses for my Master studies. This was all done in time, but personal problems arose. Between May 2012 and September 2013 I was not able to study or to work for my thesis. In September 2013, I restarted the research for my thesis, and with the help of my graduation committee I was able to scope my research. Between September 2013 and January 2014, I gradually speeded up my working process; resulting in being able to graduate in January 2014.

Despite of (or due to) these obstacles, I have learnt a lot from writing this Master Thesis. I regard *time management* and *expectation management* as crucial: a clear focus about the required time and its scope is to be defined in the very beginning of the project. I regard both points as lessons learnt in this project.

It took a while, but after all I am happy that this report could be handed in. My last project at Delft University of Technology and I must say that cannot totally suppress a feeling of proudness. I extremely thankful towards the members of my graduation committee, the medical specialists and my friends and family.

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15. ANNEX 1: GLOSSARY

English	Nederlands	Français
Public private partnership	Publiek-private samenwerking	Partenariat public-privé
Network	Netwerk	Réseau
Partnership	Partnerschap	Partenariat
Concession	Concessie	Concession
Concessionaire	Concessiehouder	Concessionnaire
	Concessieverlener	Concédant
Management	Management / Leiding	Gestionnaire
Partner	Partner	Partenaire
Joint Venture / Alliance	Alliantie	Alliance
Penalties	Boetes	Pénalités
Contractor	Hoofdaannemer	Maîtrise d'œuvre
Subcontractor	Onderaannemer	Sous-traitant
Infrastructure owner	Infrastructuurbeheerder	Maître d'ouvrage
State	Het Rijk	L'Etat
Maintenance	Onderhoud	Entretien
Investments	Investerings	Investissements
High speed line	Hogesnelheidslijn	Ligne à grande vitesse
High speed train	Hogesnelheidstrein	Train à grande vitesse
Freight / cargo transport	Vracht	Fret
Passengers	Personen	Passagers / Voyageurs
Train	Trein	Train
Track	Spoor	Voie
Catenary / Overhead line	Bovenleiding / Rijdraad	Caténaire
Train path	Treinsporen	Sillons
Life cycle	Levenscyclus van assets	Cycle de vie du patrimoine
Life cycle costs	Levenscycluskosten	Le coût du cycle de vie
Net Present Value (NPV)	Netto Contante Waarde (NCW)	Valeur Nette Comptable (VNC)
Replacement costs	Nieuwwaarde	Valeur à Neuf (VAN)
Finance	Financieringen	Financer
Construct	Construeren	Construire
Design	Ontwerpen	Concevoir
Develop	Ontwikkelen	Développer
Operate	Exploiteren	Exploiter
Maintain (ad hoc)	Onderhouden (ad hoc)	Entretenir
Maintain (periodically)	Onderhouden (periodiek)	Maintenir
Software	Computerprogramma / software	Logiciel
File	Bestand	Fichier
Model	Model	Modèle

16. ANNEX 2: OXAND FRANCE

The in 2002 founded French-based company Oxand is active in the field of asset, ageing and risk management for industry. Over years, Oxand has gained large experience with risks which arise along infrastructure and industrial equipment life cycle (design, construction, operation and maintenance, decommission). It advises companies with Go/No go support for new investments, Maintenance master plans, Infrastructure fleet maintenance policy optimization, Ageing and reassessment expertise and Project-risk management. Oxand is specialized in the fields of Energy (mainly Nuclear energy and Geosciences with CO₂ sequestration problematic) and Transportation (mainly ports, roads and railways). Geographically, Oxand has its focus on France, Switzerland and The Netherlands.

The company used to be only active in that part of a project, where the infrastructure would be fully operational and need diagnosis/prognosis to identify the best maintenance actions to control the risks linked to their ageing or justify their further operation. The last years, a shift to cover the full DBFMO-chain has been attempted to be achieved. In the upcoming years, Oxand wants to improve its position on the known markets as well as to discover new markets in Europe in the field of transportation, in particular railways. In railway field, Oxand already regularly works for Réseau Ferré de France (Finance and Strategy, Infrastructure), SBB/CFF (Maintenance policies), and Infrabel. Those clients are attracted by Oxand's support based on both financial and technical skills.

Currently, their existing computer tools allow risk management policies to be implemented in a practical and useful way and facilitates communication about the policies within an organization. Oxand has developed different tools, which are applicable to specific markets. Those tools are combined in a platform called SIMEO. All Oxand's tools do have the prefix SIMEO.

17. ANNEX 3: RECOMMENDATIONS OF PARLIAMENTARY SURVEY “SPOOR”

This reports shows the recommendations of the Parliamentary Committee Spoor of the Dutch house of Representatives. Only the recommendations regarding railway infrastructure maintenance are shown.

Aanbeveling 1

De minister moet zorgen voor aansturing van de spoorsector op basis van een integrale langetermijnvisie en -strategie op zowel de inrichting en het gebruik van het spoor als op onderhoud, vervanging en aanleg. Daarbij is het niet voldoende om alleen te leunen op de abstracte doelen zoals die geformuleerd zijn in bijvoorbeeld de Nota Mobiliteit. Deze doelen moeten geoperationaliseerd worden, zodat ProRail en NS weten welke concrete prestaties van ieder van hen verwacht worden om die overkoepelende doelen te realiseren.

a. Deze langetermijnvisie en -strategie dienen zo snel mogelijk te worden ontwikkeld. De commissie is van mening dat daarvoor nu reeds voldoende aanknopingspunten beschikbaar zijn.

b. De focus van de sturing van de minister moet verschuiven van korte termijn en kortetermijnfinanciën naar langetermijndoelstellingen, waarbij veiligheid, kwaliteit en capaciteit een belangrijke rol moeten krijgen.

c. Huidige en toekomstige plannen voor inrichting en gebruik van het spoor, alsmede voor onderhoud, vervanging en aanleg, dienen te worden getoetst aan deze integrale langetermijnvisie en -strategie. Dit geldt ook voor de departementale begrotingen.

Aanbeveling 24

Voorkom dat oplopende leeftijd van de infrastructuur tot onveiligheid leidt, door te sturen op resterende levensduur.

a. Investerings voor vervanging en vernieuwing van het spoor moeten passen in een strategie voor de lange termijn. Maak toekomstig beheer en onderhoud een onderdeel van deze afweging.

b. ProRail dient uit te gaan van de life cycle cost door onder meer direct bij investeringen inzichtelijk te maken welke materialen (nieuw, tweedehands) er met welke levensduur gebruikt gaan worden.

c. Haal de negatieve prikkel uit het systeem door bijvoorbeeld een prestatie-indicator te ontwikkelen die uitdrukt wat de life cycle cost per treinkilometer zijn.

Aanbeveling 26:

ProRail dient het inzicht in de kwaliteit van het spoor (de «staat van het spoor») te verbeteren en haar verantwoordelijkheid als infrabeheerder waar te maken.

a. Een actueel en betrouwbaar activaregister moet helderheid geven over de kwaliteit van de railinfrastructuur en gegevens over de resterende levensduur en een integrale planning van vervanging te omvatten.

b. Geef bij aanbesteding van toekomstige onderhoudscontracten aannemers vooraf inzicht in dit activaregister en maak deze informatie onderdeel van de aanbestedingsopdracht (juridische binding tussen ProRail en de opdrachtnemer).

c. Creëer een jaarlijks visueel overzicht van «de staat van het spoor» voor de belangrijkste systeemelementen en locaties en vul dit aan met een samenhangende analyse en zend dit naar de Tweede Kamer.

Aanbeveling 27:

Laat een onafhankelijke partij in het kader van kwaliteitsborging één keer in de vijf jaar standaard de fysieke kwaliteit van het spoor controleren, aanvullend op de kwaliteitsborging van ProRail.

Aanbeveling 28:

ProRail dient de bestaande onderhoudsketen te optimaliseren en te zorgen voor de juiste prikkels voor onderhoud.

- a. Maak de onderhoudscontractgebieden voor klein onderhoud groter en laat deze waar mogelijk (bij het hoofdnets lastiger) synchroon lopen met de gebieden van de verschillende vervoerders.
- b. Bezie hoe het onderhoudsproces efficiënter georganiseerd kan worden. Hier valt bijvoorbeeld te denken aan een andere inrichting van buitendienststellingen en de bredere toepassing van technologische innovaties zoals een mobiele werkplaats.
- c. Spreidt de projectmatige opdrachten (groot onderhoud en vernieuwing) gelijkmatiger over het jaar.

Aanbeveling 29:

Laat een onafhankelijke partij over drie jaar (2015) de effecten van de PGO's op de aspecten kwaliteit, kosten en doelmatigheid toetsen en informeer de Tweede Kamer halverwege 2012 over een nulmeting.

18. ANNEX 4: ORGANIZATIONAL FORMS OF PUBLIC-PRIVATE PARTNERSHIPS

This Annex described the six forms of public-private partnership.

Design and construct

With a Design and Construct (DC) contract, the public party asks private parties to design and/or construct a (phase of a) large engineering project. It is an input-driven contract: the specifications for the project have already been decided in detail by the public party. The ownership of the object remains of the public party. With a DC-contract, the private party is mainly remunerated in an unit price contract, which means that the public party pays the actual made costs made by the private party.

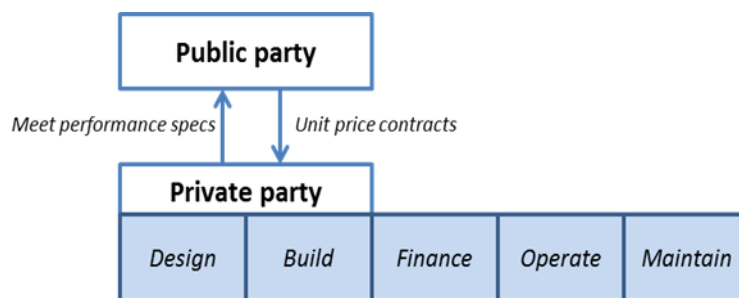


Figure 38: Organizational structure of Design and Construct

Main risks for public party	Main risks for private party
◇ Cost overruns ◇ Time overruns ◇ No focus on process life-cycle	◇ Not so many risks ◇ Too strict input specifications or quality control

Short-term services

Short-term service contracts are comparable to DC-contracts, but only apply to the phases of operations or maintenance. An example of a short-term service is the maintenance of the vegetation along highways: the task is clear and bounded and the private party could execute it on a short-term time scale. The public party still owns the infrastructure object.

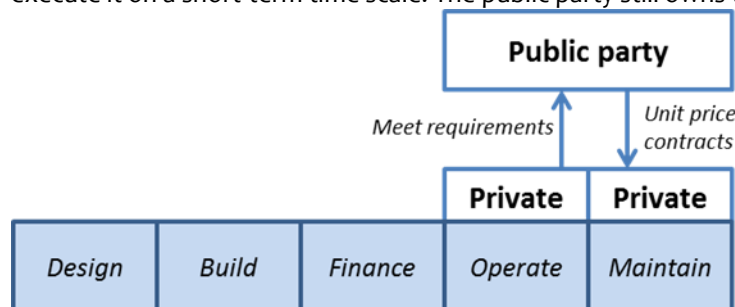


Figure 39: : Organizational structure of short-term service contracts

Main risks for public party	Main risks for private party
◇ Strict quality control is required, due to ownership ◇ No focus on process life-cycle	◇ In case of remuneration <i>per unit</i>: ○ Too strict requirements ◇ In case of remuneration <i>lump sum</i>: ○ More risks, like: ○ Cost overruns ○ Time overruns

Concession

A concession is the first organizational form, which can be regarded as public-private partnership. In the countries where a so-called concession has been applied, some different forms exist. In this research, however, a contract is regarded as a concession when the operation phase is in. Figure 40 shows that the operation phase is in a concession contract. The concession contract, however, can also be extended with other phase of the process life-cycle. Concessions are also called licenses or in case of fully integrated contracts: DBFOM. It is mainly based on required output performances. These contracts last 5 to 15 years. During the concession phase, the ownership of the infrastructure is with the private party. At the end of the concession period, the ownership is transferred to the public party.. The role of the public party during the concession changes into a regulator, who takes care of the quality control of the object. A common example of a concession is the right of a private party to operate on a certain railway line for a limited number of years. This private party is then directly remunerated by the sold tickets to the travelers.

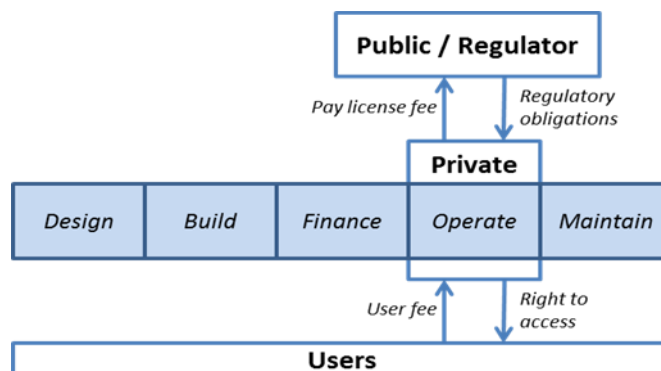


Figure 40: Organizational structure of concession

Main risks for public party	Main risks for private party
◇ Only steering due to output possible ◇ Output requirements with large consequences should be determined on beforehand ◇ State of infrastructure when it is transferred ◇ Being financial responsible as back-up for societal projects, in case of bankruptcy of private partner	◇ Uncertain actual demand ◇ Intra-SPV relationships ◇ Uncertainty about (too?) strict output performance parameters ◇ Cost overruns

Partnership

A partnership is defined as integrated process life-cycle approach contract, where the DBFM-phases are included. So, the operation of the infrastructure is no responsibility of the private party. With partnerships mainly a consortium of private parties comes into play, since multiple phases of the process life-cycle should be served: the construction, financing and maintenance. These contracts last for a very long time, since the private party should be remunerated for its investments during the construction phase: with a maximum of 50 years, as can be seen in examples later on. The ownership is at the private party, but transferred to the public party at the end of the contract period. The role of the public party is in this case a regulator, who performs quality control and may give penalties, which have been determined before the project had started.

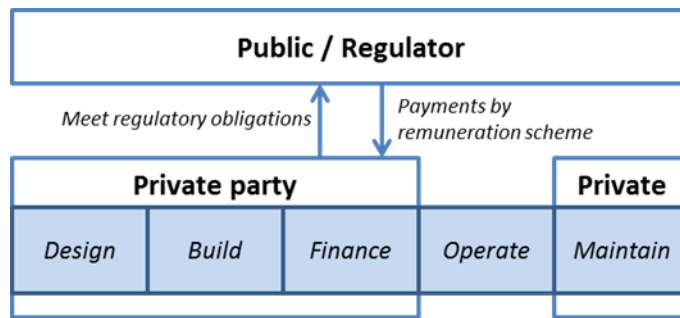


Figure 41: Organizational structure of partnership

Main risks for public party	Main risks for private party
- Supervision is only based on predefined performance indicators - Less supervision due to no ownership - Commercialization of societal infrastructure	- Cost overruns - Income depends on demand - Long-term obligations - Intra-SPV relationships - Many disciplines to be covered

Alliances

If a contract is formed as an alliance, it could mean every organizational structure between public and private parties. As Figure 42 shows, every phase of the process life-cycle could be taken into account. The ownership with alliances is equally divided between the public and private party, so a shared ownership. In case of railway infrastructure is hard to create organizations like alliances, due to this shared ownership. The users of the infrastructure may be in contact with the private party, as well as with the public party.

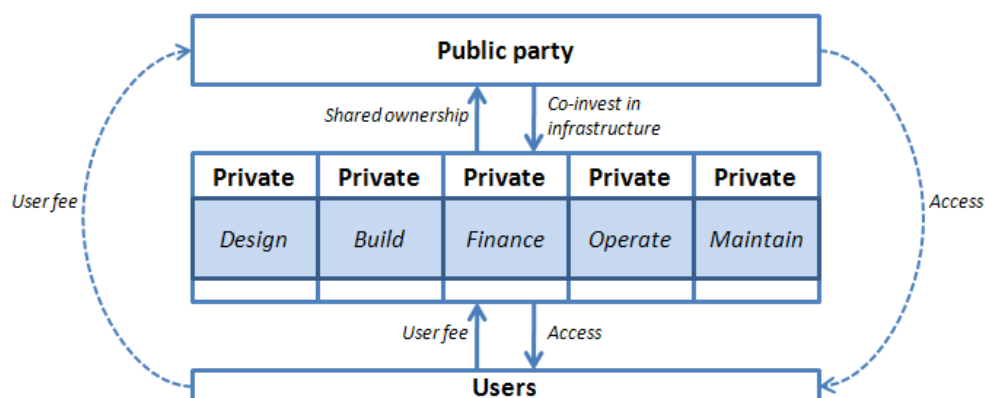


Figure 42: Organizational structure of alliances

Main risks for public party	Main risks for private party
- Shared ownership at all times - Cherry picking by private parties - Lack on focus of life cycle costs - Strict contract required to arrange the relations	- Strict requirements possible - Dependant on the public party - Lack on focus of life cycle costs as well

Privatization

With privatization, the ownership of the infrastructure is in hands of only the private party. The infrastructure is mainly sold before to this private party. It means that the private party is responsible for the whole process life-cycle and has a direct remuneration by its users. The public party is only a regulator in this case, who may only perform quality control on output parameters. Within the field of railways some forms of privatization exist. For instance, in Switzerland some railway infrastructure has been privatized. However, as one may see later

on, it is still the question if this may be regarded as real privatization. Since the ownership of the infrastructure is mainly in hands of regions, so by definition a public party, it is not a straight form of privatization. Most telephone markets, however, have been privatized in the past.

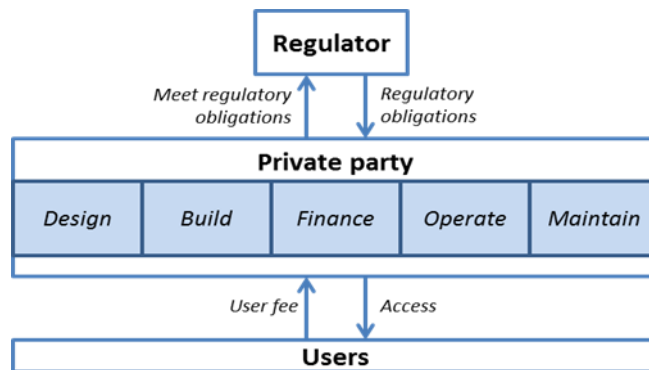


Figure 43: Organizational structure of privatization

Main risks for public party		Main risks for private party	
◇	All responsibilities for infrastructure	◇	Lack of real supervision, only steering on output
◇	So, all risks involved	◇	Entirely private ownership

19. ANNEX 5: DEFINITIONS OF PUBLIC-PRIVATE PARTNERSHIPS

In order to come to a definition of public-private partnership, different sources have been researched. In this Annex, these resources are shown, resulting in a comprehensive proposed definition of public-private partnerships.

A proper definition of public-private partnership

Different institutions, like national governments, investment banks, the European Union and large private players all have their own definition about PPP. Hoge and Greve describe in their book *The challenge of public-private partnerships* different definitions (Hodge, G. & Greve, C., 2005), which are described in scientific science papers. The overall definition of PPP, where everyone agrees on, is: *Public-private partnerships are cooperative institutional arrangements between public and private sector parties*. To the opinion of the authors this definition is too loosely formulated.

A more likely definition is derived from Dutch scientists from Delft University of Technology. They state that *PPP is a cooperation of some sort of durability between public and private actors in which they jointly develop products and services and share risks, costs and resources which are connected with these products* (van Ham, H. & Koppenjan, J. , 2011). This definition seems to make more sense. It emphasizes the joint-development of products of services, which goes beyond an ordinary cooperation: those two parties together develop products or services. Moreover, not only costs – also financial reasons – but also resources and risks in general are mentioned. The term *risks* in their definition could be regarded as an overall family of risks; it is a compilation of many different risks, like financial, construction and democratic risks. Remarks can also be stated to this definition: nothing is said about investments (for example the private party should take part in at least a part of the investment costs) and remunerations (for example payments from the public to the private party are mainly done on output, performance-based criteria).

PPPs are also applied outside the European Union, like in India. The Indian ministry of finance has compiled different views on PPP in their report *Approach paper on defining public private partnerships* (Government of India, 2010). Nineteen visions of different institutional bodies, as the European Union, the European Investment Bank, International Monetary Fund, nine different countries and investment banks as Standard & Poor's have been compared, in order to come to an overall definition, which is compiled out of the main leads in the existing visions. It states:

PPP means an arrangement between a government or statutory entity or government owned entity on one side and a private sector entity on the other, for the provision of public assets and/ or related services for public benefit, through investments being made by and/or management undertaken by the private sector entity for a specified time period, where there is a substantial risk sharing with the private sector and the private sector receives performance linked payments that conform (or are benchmarked) to specified, pre-determined and measurable performance standards.

This definition seems to be the most complete definition. Although, two main remarks can be made:

- ◇ Often more private or public entities are combined in a consortium, instead of only one entity
- ◇ PPP-partners are involved in participation in different stages in a project

Private or public entities and consortia

In the definition above a public party is considered as (multiple) national or regional institution(s) with a vision to maximize the total welfare of the people the institution represents. Total welfare is defined in quantifiable and non-quantifiable factors, as well as intangible factors. On the other hand, a private party (consortium) has a strong belief in maximizing its profit: its performance is defined on quantifiable output figures.

In PPP-projects, often many different private companies join in a single overall limited private entity, which is called a Special Purpose Vehicle (SPV). In a book of American National Bureau of Economic research, a definition of SPVs and their characteristics are provided (Gorton, G. & Souleles, N., 2007). *An SPV is a legal entity created by a firm by transferring assets to the SPV, to carry out some specific purpose or circumscribed activity, or a series of such transactions.*

It has to be mentioned that, as described above, an SPV can also exist out of multiple firms. According to Gorton & Souleles (2007), characteristics of an SPV are:

- ◇ SPVs are thinly capitalized.
- ◇ SPVs have no independent management or employees.
- ◇ Their administrative functions are performed by a trustee who follows pre-specified rules with regard to the receipt and distribution of cash; there are no other decisions.
- ◇ Assets held by the SPV are serviced via a servicing arrangement.
- ◇ SPVs are structured so that, as a practical matter, they cannot become bankrupt.

In short, SPVs are essentially robot firms that have no employees, make no substantive economic decisions, have no physical location, and cannot go bankrupt.

For its definition, it is important to realize that PPP-projects are always initiated by a public party. Subsequently, private party or parties can participate in the project proposed. Only projects with an ownership of at least 51% of the shares for the public party can be regarded as PPP. If a private party owns more than 51% of the shares, the project is constructed as private entity (Government of India, 2010).

Proposed definition

The additions in the previous sub-paragraphs are added to the existing definition, as described in section 4.1. This definition for public-private partnership will be used in the rest of this research.

Public-private partnership means an integrated process life-cycle arrangement between a public entity on one side and one or more private sector entities (often joined in a special purpose vehicle) on the other. It is performed for the provision of public assets and/ or related services for public benefit, through investments being made by and/or management undertaken by the private sector entities for a specified time period. A substantial risk sharing with the private sector exists and the private party receives output-performance linked payments that conform to specified, pre-determined and measurable performance standards.

20. ANNEX 6: LIST OF CONTACT DETAILS OF PROPOSED EXPERTS TO BE INTERVIEWED

Table 17 shows a list of contact details of experts to be interviewed. As one can see, many persons have been contacted. However, only seven experts agreed on being interviewed.

Table 17: List of contact details of proposed experts to be interviewed

NAME	COMPANY	FUNCTION	PROGRESS
Cécile Brandao	Vinci Concession	Project manager	<i>Contacted, no response</i>
Maxence NAOURI	Vinci Concession	Press contact	<i>Contacted, no response</i>
Philippe Chadeyron	LISEA (Vinci)	Press contact	<i>Contacted, closed</i>
Laurent Cavois	MESEA (Vinci)	President MESEA	<i>Invitation received</i>
Gilles Malavallon	Eiffage Concession	Directeur de Projets PPP	<i>Contacted, no response</i>
Frederique Alary	Eiffage Concession	Porte-parole des projets de TGV d'Eiffage	<i>Contacted, no response</i>
Arnaud CLARISSOU	TP Ferro	Responsable Qualité et Environnement	<i>Invitation received</i>
Ramón Conde	TP Ferro	Directeur Commercial	<i>Contacted, no response</i>
Jean-François PESCADOR	TP Ferro	Responsable Exploitation	<i>Contacted, no response</i>
Pierre Thomassin	TP Ferro	Responsable Unité Signalisation, ERTMS, Communications et Courants Faibles	<i>Invitation received</i>
Julien LAMBELET	Colas Rail (Bouygues)	Ingénieur voies ferrées	<i>Contacted, no response</i>
Cécilia Mélé	Colas Rail (Bouygues)	Ingénieur	<i>Contacted, no response</i>
Riccardo Zampieri	Colas Rail (Bouygues)	Director PPP Projects	<i>Contacted, no response</i>
Patrick Montigny	Colas Rail (Bouygues)		<i>Invitation received</i>
Maxime Robin	Egis Rail	Bid manager	<i>Contacted, closed</i>
Jean-Eric BREDEL	Egis Rail	Responsable Développement / Directeur de Projets	<i>Contacted, no response</i>

Julien Blanc	Egis Rail	Ingénieur d'études en infrastructures ferroviaires	<i>Contacted, no response</i>
Raphael HYENNE	SNCF	Ingénieur travaux maintenance infrastructure transport	<i>Contacted, closed</i>
Alexandre BUNIAK	SNCF	Maintenance et travaux Directeur des Ressources Humaines, SNCF, Infrapôle	<i>Contacted, no response</i>
Olivier ARMAND	SNCF	Languedoc Roussillon	<i>Invitation received</i>
Pacale DUMONT	SNCF + Inexia	Projet SEA	<i>Invitation received</i>
Jean-Xavier ROCHU	T&D International	Directeur	<i>Invitation received</i>
Emmanuel Desplanches	Currie & Brown France	PPP Technical Adviser	
Aurélie ALTENBURGER	Arcadis	Ingénieur Infrastructures et transports	<i>Contacted, no response</i>
Jean-Marie Howe	Réseau Ferré de France	Contrôleur de Gestion Grands Project	<i>Contacted, no response</i>
Manon Hérail	Réseau Ferré de France	Press contact	<i>To be contacted</i>
Makeda Jahanshahi	Réseau Ferré de France		<i>Contacted, closed</i>
[anonymous]	Réseau Ferré de France	Financial department	<i>Invitation received</i>
Khaled Amri	Ernst & Young	Project manager PPP at RFF	<i>Contacted, response, in progress</i>
Taco Fens	Dutch Ministry	Member of PPP-team	<i>Invitation received</i>
Willem-Jan Zwanenburg	SBB / CFF	Life Cycle Manager Track at SBB	<i>To be contacted</i>
Joël VELASQUE	Vinci Concessions	Démolition et préparation des sites	<i>Contacted, no response</i>
Jérôme FURGE	Bouygues Travaux Publics	Construction d'autres ouvrages de génie civil	<i>Contacted, no response</i>
Hervé LE CAIGNEC	SNCF	Transport ferroviaire interurbain de voyageurs	<i>Contacted, no response</i>
Paul van Straten	Ministerie van V&W		<i>To be contacted</i>
Michel Croc	Réseau Ferré de France (RFF)	International Projects Development Director	<i>To be contacted</i>
Jean-François KERSALÉ	SNCF		<i>To be contacted</i>
Roel Hartman	Infraspeed Maintenance	COO	<i>Invitation received</i>

Ruud Schellekens	Infraspeed Maintenance	Directeur (CEO)	<i>To be contacted</i>
Jaap Hagestein	ot. Infraspeed Maintenance	ot. Directeur (CEO) until 2007	<i>To be contacted</i>
Mark Oldenziel	ProRail / NS Hispeed	ot. Maintenance planner ProRail / ht. Alliance manager NSHispeed	<i>To be contacted</i>
Nicolas Auvin	INEO SCLE FERROVIAIRE	Responsable projets étude	
Camiel van der Burg	Strukton Rail bv		
Linda de Jong	Strukton Rail bv	Communicatieadviseur	<i>Contacted, closed</i>
Arnoud van Rossum	Strukton Rail bv	Tender manager	<i>Invitation received</i>
Arjan vd Paalen	ProRail	Management Trainee	<i>Contacted, no response</i>
Thijs Rottier	ProRail	Business Information Manager	<i>To be contacted</i>
Arjen Zoeteman	ProRail	Manager of Technology Policy	<i>Invitation received</i>
Auke van der Pal	ProRail	Tendermanager	<i>To be contacted</i>
Dick Nederveen	Movares		<i>Contacted, no response</i>
Mark Modderkolk	Movares	Afdeling onderhoudsmanagement	<i>Invitation received</i>
Rene vd Vooren	Movares		<i>Invitation received</i>
General	SETVF	Société for Track Maintainers	<i>Contacted, no response</i>
Eléonore BRUNEL	Inexia	Chef de Projet Infrastructures Ferroviaires	<i>Invitation received</i>
Bjorn Paulsson	UIC	Senior Advisor	<i>To be contacted</i>
Libor LOCHMAN	CER	Deputy Executive Director	<i>To be contacted</i>
Michael ROBSON	European Org. Infrastructure Managers	Secretary General	<i>To be contacted</i>

21. ANNEX 7: SPECIAL PURPOSE VEHICLES

In PPP-projects, often many different private companies join in a single overall limited private entity, which is called a Special Purpose Vehicle (SPV). In a book of American National Bureau of Economic research, a definition of SPVs and their characteristics are provided (Gorton, G. & Souleles, N., 2007). *An SPV is a legal entity created by a firm by transferring assets to the SPV, to carry out some specific purpose or circumscribed activity, or a series of such transactions.*

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In short, SPVs are essentially robot firms that have no employees, make no substantive economic decisions, have no physical location, and cannot go bankrupt.

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22. ANNEX 8: OVERVIEW OF HSR-PROJECTS

Table 18 shows an overview of high-speed railway projects in The Netherlands and in France. For each project, the route, length, public and private partners and the total costs have been specified. Moreover, the financial agreements and type of contract have been researched.

Table 18: Overview of HSR-projects in The Netherlands and France

Project name	Route	Length (km)	Construction period	Public partners	Private partners	Total costs ³³	Financial arrangements	Phase(s) of design cycle
France								
HSL Est européenne³⁴	Vaires-sur-Marne - Beaudrecourt	300 km	2002 – 2007	RFF, French state, European Union, Grand Duchy of Luxembourg, SNCF and 17 local authorities	For construction: Eiffage, Arcadis, Bouygues TP, Roger Martin, SNCF	M€ 3125 ³⁵	100 % financed by public authorities	DB
	Baudrecourt – Vendeheim	106 km	2010 – 2016	RFF, French state, European Union, Grand Duchy of Luxembourg and 16 local authorities	For construction: Eiffage, Arcadis, Vinci, Dodin, Cegelec	M€ 2010 ³⁶	100 % financed by public authorities	DB
HSL Sud Europe Atlantique	Tours – Bordeaux	340 km	2012 – 2017		For financing: LISEA (Vinci, Caisse des Depots and Axa Private Equity). For construction: COSEA (Vinci, Eurovia, BEC, NGE, TSO, Ineo, Inexia, Arcadis and Egis Rail) Maintainance: MESEA (Vinci and Inexia)	M€ 7800 (M€ 6200 for construction)	49% by LISEA, 38% by public authorities, 13% by RFF	Concession contract (DBFMO) for 50 years ³⁷
HSL Nîmes – Barcelona	Nîmes – Montpellier ³⁸	71 km	2009 – 2016	French State, Regional authorities, RFF, European Union	Candidates: Bouygues TP, Eiffage et Vinci Concessions	M€ 1620	To be determined	Partnership for 25 years (DBFM)

³³ Total costs of project, estimated at the time the contract was signed.

³⁴ Source: www.lgv-est.com

³⁵ Price level of 1997

³⁶ Price level of June 2008

³⁷ Dans ce contrat de 50 ans, de type concession, c'est le groupe de BTP qui percevra lui-même sur l'exploitation de la ligne des péages qu'il déterminera.

	Perpignan – Figueras	44 km	2004 – 2011	European Union, French State, Spanish State	Financing: TP Ferro (Eiffage and ASc Dragados); construction: TP Ferro, Arcadis, Ingérop, Sener, TUC Rail	M€ 1100 (of with M€ 540 by public authorities)	320 M€ by French State, 320 M€ by Spanish State, 160 M€ by European Union and 300 M€ by TP Ferro	Concession contract for 53 years (DBFMO)
HSL Bretagne - Pays de la Loire	Rennes – Connerré	214 km	2011 – 2017	French State, Regional authorities, RFF, European Union	Eiffage,	M€ 3400		Partnership for 25 years (DBFM) ³⁹
The Netherlands								
HSL Zuid	Nieuw-Vennep – Belgium border (construction + maintenance)	125 km (HSL: 85 km)	2001 – 2007 – 2031	Prorail, Dutch State	Infraspeed (Fluor, Siemens, BAM, Innisfree, HSBC)	M€ 1320 ⁴⁰	M€ 800 by syndicate of Banks, M€ 400 by European Investment Bank	Partnership for 5 + 25 years (DBFM) ⁴¹
	Amsterdam – Belgium border (operations)				High Speed Alliance: Nederlandse Spoorwegen, KLM	M€ 160 ⁴²	HSA (NS + KLM)	Concession for 15 years (Operations)

³⁸ Final contract between public and private parties is expected to be signed in autumn 2011.

³⁹ Comme la future LGV Sud Europe Atlantique, cette LGV va être réalisée dans le cadre d'un PPP. Ainsi, suite à un appel d'offres, Réseau ferré de France a désigné, le 18 janvier 2011, le groupe Eiffage pour construire et entretenir la LGV[16]. Le partenariat courra sur une durée de 25 ans. Eiffage avancera le tiers de l'investissement et touchera en retour pendant 25 ans des loyers fixes de RFF, qui exploitera la ligne et encaissera les péages versés par l'opérateur[17].

<http://www.latribune.fr/depeches/reuters/eiffage-retenu-pour-la-lgv-bretagne-pays-de-la-loire.html>

⁴⁰ <http://www.buildingbusiness.com/awards2011/ingezonden/details.asp?id=247>

http://www.omegacentre.bartlett.ucl.ac.uk/studies/cases/pdf/NETHERLANDS_HSL_ZUID_2P_040511.pdf

⁴¹ Five years (2001 – 2006) for Design and Construction of superstructure , 25 years (2006- 2031) for Maintaining of superstructure and substructure.

⁴² Price level of 2010

23. ANNEX 9: OVERVIEW OF COMPUTER TOOLS OF OXAND FRANCE

Table 19 shows an overview of computer tools of Oxand France.

Table 19: Overview of available computer simulation tools of Oxand France

		Main areas of application	Level of detail	Level of decision making	Kind of risk to be mitigated	Project example	Possible application in other areas	Applicability to railway and railway maintenance
SIMEO Consulting		Aging assessment of civil works (mostly reinforced concrete)	Microscopic	Operational	Technical risks during life-cycle	Corrosion problems of bridges	yes	--
SIMEO Maintenance	SIMEO AMP	Civil engineering for nuclear power plants						+ ++ ? Airports (surveillance plan for buildings) Wide range, e.g. pipelines, roads, buildings
	SIMEO IPA	Actual state of nuclear power plants	Microscopic	Operational	Technical risks during life-cycle			
	SIMEO Ports	Large seaports	Mesoscopic	Tactical	Operational risks (e.g. budgets, human resources)	Maintenance plan plus software for port of Le Havre		
	SIMEO Voie navigable	Inland waterway transportation	Mesoscopic	Tactical	Operational technical risks	Maintenance plans for VNF		
	SIMEO Ferroviaire	Railway transportation networks	Mesoscopic	Tactical	Operational risks (e.g. budgets, human resources)	CFF		
	SIMEO ITE	Branch railway lines to and inside nuclear power plants	Mesoscopic	Operational	Technical lifecycle and operational budget risks	Maintenance methodology for Électricité de France (EDF)		
SIMEO StrateGo		Maintenance policies for railway assets	Macroscopic	Strategic	Financial risks driven by technical risks	RFF (Asset management due to deregulation ⁴³)	Idem	++
SIMEO Risk		Graphic representations of risk assessments for industrial processes, mainly FMECA formalism	Microscopic	Operational	Criticality analyses	FMECA for infrastructure mgmt (eg: roads, tunnels, storage tanks...)	yes	+/-

⁴³ A project for Réseau Ferré de France (RFF), called Base d'Active Régulés (BAR)

SIMEO MC²		Research to risks and dependency of variables – probabilistic approaches for taking in account uncertainties	Micro to Macroscopic	Ope to strat	Financial, environmental, organizational, safety and maintenance risks	Project for securing arrival times of rail transport to nuclear power plants	yes	+
SIMEO ERM		Collaborative tool to manage the process of risk management implementations	Macroscopic	operational if project follow-up Strategic if help making some scenario decision	Cooperate risks: image, financial and human resources Operational follow up (risk owner, mitigation action...)	Rebuilding of neighborhood in Paris: 20 actors, ERM for board of project managers. Plus project for TSO (railways)	Many fields	+
SIMEO STOR		Critical aging analysis of pipe-lines	Microscopic	Operational	Leakage of geological storage of CO ₂	Geological storage of CO ₂	None	--

24. ANNEX 10: CLASSIFICATION OF SIMULATION TOOLS OF OXAND

In this annex the classification of the computer simulation of Oxand is discussed.

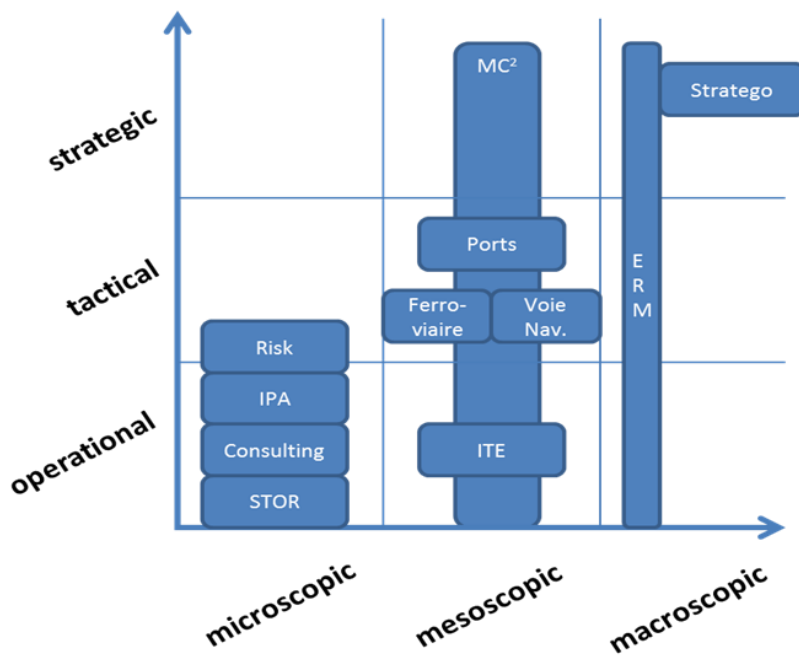


Figure 44: Graphical overview of tools of Oxand

The different tools are combined in Figure 44. Based on the two scales mentioned before, the different tools are placed in this figure. Some remarks/conclusions:

- At first sight, SIMEO Ferroviaire seems to be fully suitable for railways, since *ferroviaire* is the French word for railways. This tool is part of the family of tools *Maintenance*. By means of different scenarios, this tool uses the state of maintenance of a railway track to define state-related risks, associate necessary maintenance actions and costs, priorities at a fleet's scale the needed maintenance actions. The tool is only

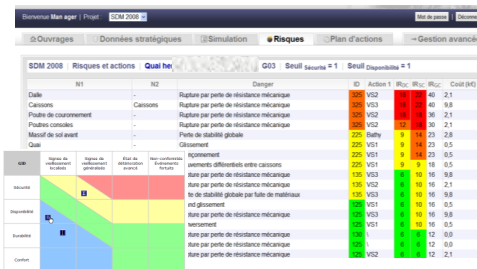


Figure 45: Outcome of SIMEO
Ferrovaiare

suitable for medium-term maintenance planning, so from 3 until 5 years. This tool has been developed for CFF needs, regarding the maintenance management of its tracks, civil works, electrical and signalization components. A lighter version has also been developed for EDF railway junction management. Due to its scoped applicability and its medium-term approach, it may not be applicable to the future European railways, regarding PPPs. However, to some extent it may be interesting to look in-depth if this tool may be altered.

- ◇ In Figure 44, SIMEO MC² and ERM are both placed on a strategic, tactical and operational level. This is due to the loose structure of both tools, which make them able to be implemented in many areas. MC² is a more scientific tool, which makes use of Monte Carlo-simulations and Markoff-chains. It is able to calculate different output parameters by means of intermediate variables, where different distributions can be assigned to. In simple terms, it quantifies a causal diagram. In fact, MC² does not fit well in Figure 44, since it may be placed over all horizontal and vertical axes.
- ◇ ERM is a real different tool, compared to MC² and StrateGO. It is a collaborative tool to manage risk registers, edit risk mapping and list risk mitigation plans with associated risk owners. It leads to a wide range of outcomes, from mitigation actions (operational) to the state of the human resources (more strategic).
- ◇ A possible combination of StrateGO and MC² has been researched by Sophie Fabre, an intern at Oxand. She researched different maintenance policies and their risks, with an example of the Dutch highway-tunnel Coentunnel. It turned out that the combination of both StrateGO and MC² could be valuable for these future policies.

25. ANNEX 11: INTERVIEW RFF

Table 20 shows the filled template of the interview with Réseau Ferré de France.

Table 20: Filled template of interview with RFF

Interview	Master Thesis Menno van der Kamp	Confidentiality Recording Feedback	
Interviewee:	Name known to interviewer	Date:	27-09-2011
Company:	RFF	Place:	Paris, France
Function:	Head of financial department	Start time:	10.00
		End time:	12.00
High speed rail			
Top 3 most successful known HSR projects in Europe? For what reasons? What are the key-elements making a new HSR project a success?			
- To prepare well the first phase of a tender (in terms of documentation). - To be very well prepared within the company internally (in terms of organization). All departments and divisions of the public party have to work very close to each other. - For the public side: decision and approval process. You have to be prepared that decisions take a lot of time.			
What are the top-3-lessons learnt from the constructed high-speed lines in the world?			
No top-3 lessons, because there is so much to learn. We are now currently in “retour d’expérience” period. No conclusions have been drawn yet. Precision: each participant has drawn his conclusions, but RFF has not drawn it on a consolidated basis.			
What are the main differences between countries where high-speed railway lines have been constructed?			
Are there any differences between the different phases of a project? What are the most risky phases? For what reasons? Which players do support those risks? How do they control them? And between other fields (buildings, highways etc.)?			
Of course, it depends on the project. But for SEA it will certainly be the construction and ramp-up period. The latter, because in that period payments are dependent of traffic and revenues generated by traffic. During the construction period, unpredicted accidents are very risky as well as who manage the consequences of such accidents (if it happens). For example, are stakeholders able to invest more money? Or when the construction has to be stopped for several months: the company has still to pay interest. Regarding the traffic risk: private parties have to subscribe guarantee as well. On the market is EIB (European Investment Bank), which propose LGTT (loan guarantee instrument for trans-european transport projects).			
Do you think it could be improved?			

My opinion: if the public party wants the private parties to participate, the public party and banks should be more tolerant for their criteria of approval.

Which players do support those risks?

It depends on negotiations. For example traffic risks: it is logically a risk for private. But you have to be vigilant if the costs in the end are not paid by the public party due to sophisticated mechanisms. This takes time, that's why (among others) Tours-Bordeaux took so long.

How to control?

Information transparency for all companies.

PPP investments

Which PPP-scheme is most suitable for high-speed railway PPP-investments? (Concession – Licensing – PPP). Why? Specific per country? If so, which element has to be considered? (tradition, actors, regulation, existing infra...)

In my opinion, best scheme is PPP-PFI (DBFM). For concessions (i.e. DBFMO), the revenues (toll) are directly paid to the private concessionary. In railways, toll is very different from highways. For the train you do have a choice for alternatives.

For Tours-Bordeaux we signed contract for 50 years. It is thus very difficult to imagine that the private concessionary will take the whole traffic risk during this period.

Who is in charge to predict costs for PPP-Investments? (key-player, entity, skill – eg: infra's owner, accountancy service)

What is the most difficult to predict (CAPEX, OPEX, maintenance costs, legal issues, insurances, etc.)? On which time

We have experience in CAPEX and OPEX. But for maintenance costs it is very difficult, because hardly any track record in high-speed rail exists. Moreover, the technology improves and is renewed.

What is the most used methodology to predict costs for PPP-investments? Top 3

What are the top-3-risks for private parties in PPP-investments? What are the main needs of private parties when answering a PPP tender? When carrying out the PPP?

- Management of control (maîtrise) risks: which party takes the risk after that there is a cost for each risk.
- Traffic risk

Needs for these risks?

these risks have to be managed internally or with advisors.

What are the top-3-risks for public parties in PPP-investments? What are the main needs of public parties when answering a PPP tender? When carrying out the PPP?

To check we pay good price for good risk. Banking fees Traffic revenues
The role of the public party during concession period: conflicting interests?
Remuneration schemes and cooperation
What are the experiences with Special purpose vehicles, or consortia? Conflicts? It is in fact the main shareholders of the SPV. We have experiences with them to negotiate. Collaboration between public party and SPV? During negotiations, SPV wants to transfer the costs of the risk to the public side. The more shareholders in a SPV, the harder the collaboration. Vinci, Bouygues and Eiffage have all their own approach. Vinci works with investment funds and industrial shareholders. Bouygues works mainly with financial shareholders and equity. Eiffage does a lot in-house, they fully cooperate with SPV. All three, they've got their own process and stick to it. What remuneration scheme is most preferable and most used (user fee / shadow toll / lump sum) Why? Advantages-Inconvenients of each? Depends on project and its nature. PPP-DBFM is the best, in my opinion. A DBFMO-concession contract is very difficult; you've to manage risks during the negotiation process for the whole period (in that case 50 years) that you can not anticipate on. Why is for some projects chosen for DBFM and others concession? Depends on time of decision, management of the company, budget constraints, time constraints and decisions process within RFF. RFF is 100% public party; we just want to improve and extend the network depending on the strategy defined by our shareholder – the French State. No common opinion about the future of just 1 model? No. We have to evaluate later on. For sure, it will be a mix of everything in the future. We can not say that we will have 1 model. Why can't you say that? We have to wait before deciding new PPP-schemes. As far as I know there is no preferred model for RFF, at this stage. That's why we don't have strategy plan for 10 years, but only for 2-3 years. Traditional contracting (D&C): still a 3rd option? We have to keep all options in hand. Traditional contracting could be more suited for some projects, for example for small parts of a line. It is a question of diversification of risks. What are the experiences with performance-based output schemes? For public party? For private party?
Maintenance

What kinds of models and methodologies during tender phase are used to predict maintenance costs? Definition and planification of maintenance actions (e.g.: feedback or risk-based approach)? Cost evaluations? Uncertainties management? Probabilistic/deterministic approaches? Monte-carlo?
What is the reliability of these models and methodologies?
What are the top-3-difficulties in predicting these maintenance costs?
What are the lacks in knowledge?
What is the most seen balance CAPEX/OPEX? What is a healthy balance? (eg: for France 1/3 CAPEX=renewal and 2/3 OPEX=maintenance, whereas in Switzerland other way around)
What are the main innovations during the last years in maintenance policies? And PPP-agreements?
Conclusion
Is PPP & Construction of high-speed rail a marriage made in heaven? Why so, or not? It might be a good combination. It is a very good experience for public companies. Nowadays, public parties only have a little experience with managing contracts, but it is still a very good option. Philosophy of RFF: first PPP after all? To my opinion, it is not good to do everything from start in PPP. We have to be pragmatic and rational. Every project is unique, but at the same time we can of course draw a lot of benefits from the previous projects we have closed. Study everything at all times. There will be learning effects.
If public parties or public parties could get 3 magic tools to help them managing PPP contracts, what would they be? - At European level data sharing between infrastructure managers in terms of costs, but also at the technical side: CAPEX and OPEX. - Use during negotiations the experiences of other countries. (This might be the role of EIB. We have to mix the culture. Not only on top management side, also on operation side). - The question is how to improve and make sure the project process. To be honest, right now it is too early to evaluate the effectiveness of all PPP-schemes.
Do private and/or public parts already get help from external entities (university / consultancy / suppliers...)? From who and for what? Specific for what parts?

26. ANNEX 12: INTERVIEW INFRASPEED

Table 21 shows the filled template of the interview with Infrasppeed.

Table 21: Filled template of interview with Infrasppeed

Interview	Master Thesis Menno van der Kamp	Confidentiality Recording Feedback
Interviewee:	Roel Hartman	Date: 13-09-2011
Company:	Infrasppeed Maintenance	Place: Dordrecht, The Netherlands
Function:	COO	Start time: 14.30
		End time: 16.00
High speed rail		
Top 3 most successful known HSR projects in Europe? For what reasons? What are the key-elements making a new HSR project a success? - DBFM-organizations are only valuable from an investment level of 300-400 million euros. Below this amount, lease-constructions are better. - According to a research in The Netherlands: all PPP-projects are cheaper and faster finished than estimated at the start - Try to fulfill the requirements by innovations on a long-term		
What are the top-3-lessons learnt from the constructed high-speed lines in the world? - Too little attention for risk management from a point of view of maintenance and operation. From the ERA, the TSI-norms are set for all vehicles on high-speed lines. These norms hold for measurement vehicles as well. They were rejected, since no toilet was on-board. Currently, from other countries, one comes and looks how this is solved at Infrasppeed.		
What are the main differences between countries where high-speed railway lines have been constructed? For high-speed lines in Europe, the same TSI-requirements apply. If in a country it has been proven that a requirement is valid, it will count for the rest of Europe. For example, the alignment of the track for the HSL South is an exact copy of the line in Germany.		
Are there any differences between the different phases of a project? What are the most risky phases? For what reasons? Which players do support those risks? How do they control them? And between other fields (buildings, highways etc.)? Maintenance and transfer. In the maintenance-phase you are faced with the choices which have been made in the design-phase. TP Ferro solved this by letting the maintenance team being a part of the organization, already during design and construction phase. On the other hand during the maintenance phase, all is about collaboration between the parties. You		

should achieve such a collaboration that both parties work by the means and goals of the contract, rather than by its strict letters. This holds for a large extent for maintenance during the day.
PPP investments
Which PPP-scheme is most suitable for high-speed railway PPP-investments? (Concession – Licensing – PPP). Why? Specific per country? If so, which element has to be considered? (tradition, actors, regulation, existing infra...) From a principal point of view: always DBFM. All risks are transferred to the other party. All responsibility should be in hands of one party, so that no problems like with the HSL South (interface problems between substructure and superstructure) exist.
Who is in charge to predict costs for PPP-Investments? (key-player, entity, skill – eg: infra’s owner, accountancy service)
What is the most difficult to predict (CAPEX, OPEX, maintenance costs, legal issues, insurances, etc.)? On which time The balance between CAPEX and OPEX, based on availability. Since we are a DBFM-organization we are responsible for the infrastructure for a long time. If we don’t invest in the infrastructure we may face the problems later on. After the period – at the transfer of the infrastructure – must transfer it in a good state, although this is loosely defined.
What is the most used methodology to predict costs for PPP-investments? Top 3
What are the top-3-risks for private parties in PPP-investments? What are the main needs of private parties when answering a PPP tender? When carrying out the PPP? - Investment of an amount of money and acceptance of certain risks - Due to 90-95 percent investment of banks, private parties are very dependent on financial institutions - Creditability of the public party
What are the top-3-risks for public parties in PPP-investments? What are the main needs of public parties when answering a PPP tender? When carrying out the PPP? - Well-specified requirements and specifications. For example: with the HSL South, one floor has to be swept clean, but it can’t be related to a norm. - Less attention for operational costs, which are at least equal to the investments costs
The role of the public party during concession period: conflicting interests? Collaboration or partnership is crucial with PPP-projects. If both parties search for solutions by the means and goals of the contract – instead of by its letter – both will succeed. For example: HSL South. Infrasppeed Maintenance has the right of 5 hours per night of doing maintenance. If one track is maintained, the maximum speed of the other track is decreased to 160 km/h, instead of 300 km/h. If Infrasppeed Maintenance forced this, then no testing train would run on the track.

Remuneration schemes and cooperation
What are the experiences with Special purpose vehicles, or consortia? Conflicts?
What remuneration scheme is most preferable and most used (user fee / shadow toll / lump sum) Why? Advantages-Inconvenients of each? The payment to Infrasppeed is divided into availability of the track (97%) and its condition (3%). If the availability is above 99,46% bonus minutes are rewarded. As maintenance you will come up with creative schemes. We may also buy more maintenance minutes, but this should be done 3 years in advance.
What are the experiences with performance-based output schemes? For public party? For private party? Over the last years, a better cooperation between the public parties can be observed. The role for the public parties change.
Maintenance
What kinds of models and methodologies during tender phase are used to predict maintenance costs? Definition and planification of maintenance actions (e.g.: feedback or risk-based approach)? Cost evaluations? Uncertainties management? Probabilistic/deterministic approaches? Monte-carlo? RAMS-calculations are used to meet the requirements. Based on these calculations, the maintenance schemes are made. It is remarkable that all models are based on normal distributions for disruptions and availability. The normal distribution often counts for element level as well. I would always prefer the Weibull distribution.
What is the reliability of these models and methodologies? Right now, we can't evaluate very well, since other vehicles than estimated use the infrastructure. On the other hand interface problems exist, while no TSI-norms exist. Every contract period, a new maintenance scheme is made. It is changed to its reality. The optimization of this scheme is bounded by the requirements and the assumptions in the safety case.
What are the top-3-difficulties in predicting these maintenance costs?
What are the lacks in knowledge?
What is the most seen balance CAPEX/OPEX? What is a healthy balance? (eg: for France 1/3 CAPEX=renewal and 2/3 OPEX=maintenance, whereas in Switzerland other way around) For infrastructure, OPEX is always larger than CAPEX. But, for every maintenance action you make new, separate decisions. The difference between Infrasppeed Maintenance and Strukton is that the latter is directed by Prorail. Strukton has no responsibility for availability and reliability. We have.

What are the main innovations during the last years in maintenance policies? And PPP-agreements? - Monitoring system for switches - High-speed grinding: invented at HSL South. It is another way of grinding the rails - On-board photo recognition at the measurement rail vehicle
Conclusion
Is PPP & Construction of high-speed rail a marriage made in heaven? Why so, or not? I don't think you can conclude this in this stage. The scope of responsibilities is larger, so you are forced to work in another way. Private parties look in another way to infrastructure than public parties. I regard the role of the private party as better and more mature.
If public parties or public parties could get 3 magic tools to help them managing PPP contracts, what would they be? - Involve the maintenance organization earlier in the PPP-process - Take the cultural aspects into account, conflict are mainly between private and public parties.
Do private and/or public parts already get help from external entities (university / consultancy / suppliers...)? From who and for what? Specific for what parts?

27. ANNEX 13: INTERVIEW PRORAIL

Table 22 shows the filled template of the interview with ProRail.

Table 22: Filled template of interview with ProRail

Interview	Master Thesis Menno van der Kamp	Confidentiality Recording Feedback	
Interviewee:	Arjen ZOETEMAN	Date:	23-09-2011
Company:	ProRail	Place:	Utrecht, The Netherlands
Function:	Strategic management of technology	Start time:	10.00
		End time:	11.30
High speed rail			
Top 3 most successful known HSR projects in Europe? For what reasons? What are the key-elements making a new HSR project a success?			
What are the top-3-lessons learnt from the constructed high-speed lines in the world? - Don't use non-proven technology (particularly not combined with highly punitive risk regimes, since market parties will have to cover for those risks with high margins) - Consider high-speed lines as 1 line, not as multiple projects (particularly the border is not automatically the right point to split between contacts e.g. NL/Belgium border needs to be crossed at 300 kph) - Construction according to finished European TSIs - Actual number of passengers for new projects becomes unrealistic according to prognoses, which may lead to bankruptcy of operator. This risk needs to be considered and managed by parties in a long term contract - HSL below 1.000km is regarded as a success. However, a minimum limitation should also be taken into account (note through operation on conventional network can be successful, e.g. TGV in France) - A solid business case should exist - PPP should consist of real collaboration			
What are the main differences between countries where high-speed railway lines have been constructed?			
Are there any differences between the different phases of a project? What are the most risky phases? For what reasons? Which players do support those risks? How do they control them? And between other fields (buildings, highways etc.)? In sense, every phase is risky. In terms of safety, the validation and operation phase is most risky. The validation phase is important, since trains with a lot of degrees of freedom must be tested. Quality of design and maintenance needs 120% of attention (LCC perspective). From PPP-point-of-view, maintenance is not an extra risk, since quality certifying is done in front of the project. The train-track-integration is very critical. It should be done in close cooperation.			

PPP investments
Which PPP-scheme is most suitable for high-speed railway PPP-investments? (Concession – Licensing – PPP). Why? Specific per country? If so, which element has to be considered? (tradition, actors, regulation, existing infra...) PPP is mostly interesting for the construction of the infrastructure. For the construction of a tram line, Build-Operate-Transfer is most successful. About concessions of more than 10 years, it could be interesting. About international traffic, PPP is not recommended.
Who is in charge to predict costs for PPP-Investments? (key-player, entity, skill – eg: infra’s owner, accountancy service) It is mainly the banks, since they decide to a large extent the amount of money that is invested. This counts for overall PPP-investments.
What is the most difficult to predict (CAPEX, OPEX, maintenance costs, legal issues, insurances, etc.)? On which time Lifecycle costs are difficult to predict when no database with historical data is available. Although, in a business case of a high-speed train line, the total LCC is just a minor part; migration strategies between conventional and new lines are more important.
What is the most used methodology to predict costs for PPP-investments? Top 3 Lifecycle cost calculations in excel-sheets. Not one specific model exists; it is mainly made again for each new project.
What are the top-3-risks for private parties in PPP-investments? What are the main needs of private parties when answering a PPP tender? When carrying out the PPP? - If maintenance costs and availability have been estimated wrongly. This is mainly a problem with shadow toll. (This went wrong in The Netherlands: Infrasppeed doesn’t suffer from the low amount of passengers, the government does) - The hunt for financing of projects with innovations. The private party pays the (innovation) risk. - Juridical risks. It could change over time - Risk in software: revision management and upgrading: uncertainty about future behavior Both parties should be able to adapt the contract, when the amount of passengers does not reach the predicted number.
What are the top-3-risks for public parties in PPP-investments? What are the main needs of public parties when answering a PPP tender? When carrying out the PPP?
The role of the public party during concession period: conflicting interests?

Remuneration schemes and cooperation
What are the experiences with Special purpose vehicles, or consortia? Conflicts?
What remuneration scheme is most preferable and most used (user fee / shadow toll / lump sum) Why? Advantages-Inconvenients of each?
What are the experiences with performance-based output schemes? For public party? For private party?
Maintenance
What kinds of models and methodologies during tender phase are used to predict maintenance costs? Definition and planification of maintenance actions (e.g.: feedback or risk-based approach)? Cost evaluations? Uncertainties management? Probabilistic/deterministic approaches? Monte-carlo? Ten years ago, hardly any model existed. Models have been made based on LCC-forecasts and expert judgments. For now, life-cycle models are tailor made programs. Within banks, more financial models exist. The problem for all models is more about the data itself and the estimations. Models often need finetuning, e.g. worldbank has standard software for LCC for roads
What is the reliability of these models and methodologies?
What are the top-3-difficulties in predicting these maintenance costs? - Knowledge for new technology does not exist: interaction train-infrastructure is often complicated and needs serious attention certainly with newly developed systems e.g. ERTMS - It is the European intention to create an open railway area, working according interoperable standards is more and more important. These standards still change frequently requiring updates. - Problem with open network and long term contracts is that new types of trains can lead to different wear patterns e.g. if freight would be allowed to run on a HSL this leads to additional wear out processes - I would say over a long term the exact traffic load is hard to estimate this needs flexibility in the contract
What are the lacks in knowledge? The main risks and lacks in knowledge are in safety / signaling systems of the track and train and in ICT systems. For these factors, a far larger dynamics in technology exists than on the track side. On the other hand, train vehicles develop / innovate as well, but less rapidly. In about 10 years, GSM-R will be succeeded by a new standard for mobile communication.
What is the most seen balance CAPEX/OPEX? What is a healthy balance? (eg: for France 1/3 CAPEX=renewal and 2/3 OPEX=maintenance, whereas in Switzerland other way around) For The Netherlands, it is somewhere 50/50. But, you cannot use the balance CAPEX/OPEX alone, you should also take into account the average lifetime and quality of the network. France has more regional and very infrequently used tracks than NL. Probably, Switzerland has invest more than we have done.

What are the main innovations during the last years in maintenance policies? And PPP-agreements? - Monitoring of assets online, everywhere - Health-monitoring - Simulation models to improve communication between parties - Proactive grinding of track. Wheel-rail contact to prolong the lifetime - Measurements of train material to compare to the agreements of the material on the line.
Conclusion
Is PPP & Construction of high-speed rail a marriage made in heaven? Why so, or not? It can be a good instrument for large projects but depends on the conditions, goals and way of setting risks and performance regime. E.g. HSL South seems not to have been managed to a very cost effective solution for the government e.g. the delay by several years and the high risk margins paid as well as the absence of traffic in the first years (still today). It is not a goal on itself. PPP is mainly suitable for new projects with point-to-point connections. PPP has as well advantages as disadvantages. Integrated management and a strong emphasis on construction to be done in time are key-points. A main disadvantage is that in this way parties are excluded, since they are too small to meet these key-points.
If public parties or public parties could get 3 magic tools to help them managing PPP contracts, what would they be? There are no magical tools or solutions in this, but helpful are - Models which are used during the time of a project and in which the assumptions can be adjusted to the state of the infrastructure of technology - A track record of the maintenance in the past. Specifically, it is about common databases to gain a common picture of the quality. Important in the case of existing systems as well as transfer of projects and monitoring the progress in existing contracts
Do private and/or public parts already get help from external entities (university / consultancy / suppliers...)? From who and for what? Specific for what parts? Banks, consultants, universities

28. ANNEX 14: INTERVIEW STRUKTON

Table 23 shows the filled template of the interview with Strukton.

Table 23: Filled template of interview with Strukton

Interview	Master Thesis Menno van der Kamp	<i>Confidentiality</i> <i>Recording</i> <i>Feedback</i>	
Interviewee: Arnoud van Rossum		Date:	13-09-2011
Company: Stukton Rail		Place:	Utrecht, The Netherlands
Function: Tender manager		Start time:	11.30
		End time:	13.00
High speed rail			
Top 3 most successful known HSR projects in Europe? For what reasons? What are the key-elements making a new HSR project a success?			
Key-elements for success: - Possibilities to plan whole life-cycle process of all elements of a project, by long-term DB(F)M-contracts - Do as much as possible in-house. Outsource only local or very specific tasks.			
What are the top-3-lessons learnt from the constructed high-speed lines in the world?			
What are the main differences between countries where high-speed railway lines have been constructed?			
Concerning maintenance contracts: - In United Kingdom, all maintenance was tendered separately. Right now, they do it less and less. - For the London Underground: PPP-maintenance contracts for 30 years: management and maintenance of infrastructure, stations and trains. - In Germany is everything in-house with Deutsche Bahn - In Scandinavia the same trend as in The Netherlands of a few years ago can be seen.			
Are there any differences between the different phases of a project? What are the most risky phases? For what reasons? Which players do support those risks? How do they control them? And between other fields (buildings, highways etc.)?			
PPP investments			
Which PPP-scheme is most suitable for high-speed railway PPP-investments? (Concession – Licensing – PPP). Why? Specific per country? If so, which element has to be considered? (tradition, actors, regulation, existing infra...)			

It depends on the type of train line. When always the same type of train runs on the line, DBFM(O)-contracts for 30-40 years are fine, like the HSL South and Regiotram Groningen. Problems occur at interference areas with conventional tracks. If so, PPP-contracts and a split in partial contracts could be good option. As maintenance company, you can take more risks. Smaller public parties have less knowledge and transfer a lot to private parties: this is a good start for PPP-contract. Large, rigid organizations are less suitable for PPP-contracts. Strukton believes to a large extent in comprehensive contracts.
Who is in charge to predict costs for PPP-Investments? (key-player, entity, skill – eg: infra’s owner, accountancy service)
What is the most difficult to predict (CAPEX, OPEX, maintenance costs, legal issues, insurances, etc.)? On which time
What is the most used methodology to predict costs for PPP-investments? Top 3
What are the top-3-risks for private parties in PPP-investments? What are the main needs of private parties when answering a PPP tender? When carrying out the PPP? - The unknown quality of the infrastructure, at moment of transfer - Don’t get any frameworks when preconditions change - The different train loads on the infrastructure, together with its unpredictability
What are the top-3-risks for public parties in PPP-investments? What are the main needs of public parties when answering a PPP tender? When carrying out the PPP? - Due to competition the private parties only do the most necessary maintenance - Requirements and specifications don’t respond with the wishes of ProRail
The role of the public party during concession period: conflicting interests? This is mainly faced when maintenance companies do their maintenance. Currently, this is done at night and weekend, but it could be interesting to maintain during the day or around 20.00 at night. This is driven by the desire of ProRail to run trains 24/7. For the main network in The Netherlands maintenance during the day is hard to introduce, since many parties are involved.
Remuneration schemes and cooperation
What are the experiences with Special purpose vehicles, or consortia? Conflicts?
What remuneration scheme is most preferable and most used (user fee / shadow toll / lump sum) Why? Advantages-Inconvenients of each?
What are the experiences with performance-based output schemes? For public party? For private party?

Maintenance
What kinds of models and methodologies during tender phase are used to predict maintenance costs? Definition and planification of maintenance actions (e.g.: feedback or risk-based approach)? Cost evaluations? Uncertainties management? Probabilistic/deterministic approaches? Monte-carlo? - FMECA's - Historical data for the infrastructure - Analogies with other field, for example for lighting or signaling
What is the reliability of these models and methodologies? It is an interactive process between the tender teams and operation teams. They are assisted by many computer tools, like: - RCMO (reliability centre for maintenance) for analyses. In this tool, a database of LCCs exists - SAP within Strukton for maintenance management system, linked to activities and objects
What are the top-3-difficulties in predicting these maintenance costs? - Weather conditions: hot summers, cold winters - Intensity of traffic / train paths - State of infrastructure (including installation and cables) Infrastructure wear is very dependent on the train paths: heavy bulk trains through switches contribute to an intense wear. The traffic controller has only the criterion of the shortest path, not the least maintenance.
What are the lacks in knowledge?
What is the most seen balance CAPEX/OPEX? What is a healthy balance? (eg: for France 1/3 CAPEX=renewal and 2/3 OPEX=maintenance, whereas in Switzerland other way around) For new "PGO-contracts", the expenditures in OPEX is much larger than in CAPEX. This is due to the fact that these contracts last for a maximum of 5 years. For that reason, pre-financing (CAPEX) is not efficient.
What are the main innovations during the last years in maintenance policies? And PPP-agreements? - Monitoring system - POSS: measurement of power at switches to detect preliminary degeneration; developed by Strukton - Video cameras: image recognition on inspection trains. - Improved mechanical tools. - Self-reflection and feedback for all errors or mentions.
Conclusion
Is PPP & Construction of high-speed rail a marriage made in heaven? Why so, or not?

If public parties or public parties could get 3 magic tools to help them managing PPP contracts, what would they be?

- Reliable information about the (technical) state of infrastructure
- On-board measurement system
- Reliable results to compare
- For operations: how could we interact quickly with the operator when a disruption occurs?

An on-board measurement system is a matter of finance and operations: the operator is not the company as the maintenance company, so it does not have any interest.

Do private and/or public parts already get help from external entities (university / consultancy / suppliers...)? From who and for what? Specific for what parts?

29. ANNEX 15: INTERVIEW T&D INTERNATIONAL

Table 24 shows the filled template of the interview with T&D International.

Table 24: Filled template of interview with T&D International

Interview	Master Thesis Menno van der Kamp	Confidentiality Recording Feedback	
Interviewee: Jean-Xavier ROCHU		Date:	08-09-2011
Company: T&D International		Place:	Paris, France
Function: Director / Railway Consultant		Start time:	14.00
		End time:	16.00
High speed rail			
Top 3 most successful known HSR projects in Europe? For what reasons? What are the key-elements making a new HSR project a success? - Utilize all three lines of transport: - o Pax - o Freight - o Messagerie: mail, parcels etc. - Take complementary functions into account: parking, buildings, building management. - Don't be too optimistic about the number of passengers. SNCF studies tell that the pax for rail will be multiplied by 4, but this is too optimistic. - o Road : Rail : Other ▪ Today: 60 : 20 : 20. ▪ For me, it should come to 45 : 45 : 10, with 5% for international railways. ▪ But what is going to happen: 60 : 30 : 10. - Involve operational team from start on About complementary functions: CDG Airport: 43 percent of turnover is out of the core business of managing planes. Stations should not be just a stop. For example: make a crèche in the station, parking and intermodal transport.			
What are the top-3-lessons learnt from the constructed high-speed lines in the world? - Regarding the HSL South, the only error is the separation in two companies: operation and tracks. Huge interface problems occurred. - Japanese HST is operated like a metro system. In France it is operated like a public service, where only 60 percent of the market is caught. The Shinkansen is about 40 times cheaper than EU trains. The secret is for me to have a management out of politics. I mean you have social benefits of which should be sold to the government. Politicians have no power than being a costumer among others. The high-speed trains are profitable in Japan. - Regarding the Eurotunnel: politicians decided that it should be a high-speed connection. A few months later, far after deadline private parties said: we are interested, but you have to change the specifics. The public party SNCF refused. Arrogance. Mistake. The private company was able to			

pay for it. Moreover, the operating team was hired 21 months after signature of contract. It should be there when it was signed. Finance, where you have a syndicate with 185 banks: it is like a casino! No one took the risk. Only the last year, Eurotunnel is going to make money. Now profitable. - You should think maximum utilization of the network. But, after all a business case should exist. For example, at night you can have freight and night trains in sleepers. These could be very profitable. I think that no market exists for a TGV A'dam – Madrid during the day. But at night: a business man may like it. There is a market for it.
What are the main differences between countries where high-speed railway lines have been constructed? It depends on the culture of a country. The idea in France of risks with public servant they have in mind a culture of tax-payer support. So this is why PFI in France is so little in high-speed. Regarding the HSTs in Japan, these trains are not as luxurious as in Germany or France. It's a state of mind. It is a normal, suburban train inside. They have reached a state that high-speed is fixed in the system. When you are in competition, do it on the right level. The right product to the right persons.
Are there any differences between the different phases of a project? What are the most risky phases? For what reasons? Which players do support those risks? How do they control them? And between other fields (buildings, highways etc.)? The real issue on private management: the schedule and costs should be kept. If you keep your budget, you will be able to reimburse the dept. In a traditional project, the operating people are too much there. They change everything over time. But in private industry, operating people know how to build what you want. And after then, you will adjust. But changing all the time the design costs a fortune. You can't do that in a public organization because there is no authority. In private organization you know what you want, you stick to it. Later on they have time to change. It is the only way to stick to budget and time.
PPP investments
Which PPP-scheme is most suitable for high-speed railway PPP-investments? (Concession – Licensing – PPP). Why? Specific per country? If so, which element has to be considered? (tradition, actors, regulation, existing infra...) I believe very much in high-speed. But you need agility. You can make money, like the Shinkansen does. But you really have to sell the social benefits.
Who is in charge to predict costs for PPP-Investments? (key-player, entity, skill – eg: infra's owner, accountancy service)
What is the most difficult to predict (CAPEX, OPEX, maintenance costs, legal issues, insurances, etc.)? On which time For me, on CAPEX you can win 40 percent; with OPEX 60 percent. For example, in operations in France we turn the train in 45 minutes; the Japanese turn it in 12 min. This means 3 trains more available, so 3 trains less to invest. In France we have a lot of switches, which need a lot of maintenance. It is stupid. We don't want to push a train, like the Japanese do.

What is the most used methodology to predict costs for PPP-investments? Top 3
What are the top-3-risks for private parties in PPP-investments? What are the main needs of private parties when answering a PPP tender? When carrying out the PPP?
I see three levels of risk: - Risks manageable by me or you. These should not be shared by anybody. - Risks which are very difficult to bear, but have been split. For example a large Total-project, where Total has 33% of the shares and dozens of colleagues has few percent. But Total manages that everybody is taking the risk. - External (or sovereign) risks, like earthquakes or fires. You saw with Eurotunnel, 6 months of no income: catastrophic for the shareholder.
What are the top-3-risks for public parties in PPP-investments? What are the main needs of public parties when answering a PPP tender? When carrying out the PPP?
The role of the public party during concession period: conflicting interests?
It is just a catalyst. To see there is business for development of area. To set up a fair competition
Remuneration schemes and cooperation
What are the experiences with Special purpose vehicles, or consortia? Conflicts?
That's the normal way of life of business. You have shareholders and they fight. But to a limit, because they have to stay profitable in the end. You don't have to be scared for conflict. Public or political conflicts have no boundaries. If it is delayed by 5 years, nobody cares at the public party.
What remuneration scheme is most preferable and most used (user fee / shadow toll / lump sum) Why? Advantages-Inconvenients of each?
It is a question of circumstances and cultures. If it concerns wealthy countries they will pay lump sum, if they are poor more user fee.
What are the experiences with performance-based output schemes? For public party? For private party?
Maintenance
What kinds of models and methodologies during tender phase are used to predict maintenance costs? Definition and planification of maintenance actions (e.g.: feedback or risk-based approach)? Cost evaluations? Uncertainties management? Probabilistic/deterministic approaches? Monte-carlo?
What is the reliability of these models and methodologies?

What are the top-3-difficulties in predicting these maintenance costs?
What are the lacks in knowledge? You have two strategies. Either you pay for innovation, or not. If you change something, you have to qualify it. You can't expect a prototype with the railways. You test on the go. We are now halfway the mature phase with high-speed rail. The profits are to gain. We should work on making more profit. For me, high-speed is a profitable business. We should work on productivity and efficiency.
What is the most seen balance CAPEX/OPEX? What is a healthy balance? (eg: for France 1/3 CAPEX=renewal and 2/3 OPEX=maintenance, whereas in Switzerland other way around) Maintenance costs are a big issue, it's 1/3 of operation expenditures. In a private ownership, maintenance is very important. In a public ownership you only do the maintenance when you have to. In PPP-organizations, for private parties it's a spiral. You don't do the maintenance, you don't get money etc. For me, that's why the French network is so poor. Because RFF doesn't receive that money, people were committed to give. For me the best thing is when you buy the equipment, you have with the supplier a commitment of the life-cycle of the equipment. The best way is have the supplier making the payment. Don't make it yourself. Outsource as much as you can.
What are the main innovations during the last years in maintenance policies? And PPP-agreements?
Conclusion
Is PPP & Construction of high-speed rail a marriage made in heaven? Why so, or not? The high-speed train could be a profitable tool. Agility in competitive markets is very important. It's a condition of life. If you are not agile, you're death. You have to survive. For me, for railways PPP like DBFMO is not very good, I'm more in favor of BOT. DBFMO is for activities with no income, for example for a jail; it is just a tool for civil servants to hide their poor ability to manage public projects.
If public parties or public parties could get 3 magic tools to help them managing PPP contracts, what would they be? - Shared understanding of capability of each party. - To meet the contract, including the market share, the schedule, the cashflow. - The public party should behave as fair authority; during the operation they should stick to the profit and loss statement. Nothing should be imposed by the public party.
Do private and/or public parts already get help from external entities (university / consultancy / suppliers...)? From who and for what? Specific for what parts? It depends. When you look at project in Taiwan, smaller, they put in Chinese, German and French players. They used an American consultant. They took the time. It was their first BOT, some kind of pilot. I think in USA they use a lot of consultants. In France not so much.

30. ANNEX 16: INTERVIEW MESEA

Table 25 shows the filled template of the interview with MESEA.

Table 25: Filled template of interview with MESEA

Interview	Master Thesis Menno van der Kamp Delft University / Sponsor: Oxand	
Interviewee:	M. Laurent CAVROIS	Date: 19 – 10 – 2011
Function:	Président de MESEA	Company: MESEA / LISEA
		PPP project: TGV SEA Tours-Bordeaux
	Work experience in PPP projects: Vinci Projects, development of railways. Projects as SEA, concessions.	Project phase: Maintenance MESEA consists of 6 persons right now, and gives advice to COSEA, which is responsible for Design and Construction of the line. Line will be operational at mid-2017, the real maintenance will start around mid-2016. MESEA is now involved to let COSEA work properly around the site and execute maintenance planning schemes in advance, with help of Inexia.
High speed rail		
Top 3 most successful known HSR projects in Europe? For what reasons? What are the key-elements making a new HSR project a success?		
Difficult to tell, because I don't know the projects from abroad very well. And what defines a success.		
Are there any differences between the different phases of a project regarding risk and responsibilities? What are the most risky phases? For what reasons? Which players do support those risks? How do they control them? Comparison of feedback between railway and other fields (buildings, highways etc.)?		
A lot. For concession holder, the phase of estimation of costs is very important. And during operations: information and experience needed. Most information is based on experience and data from Inexia. Most risky phase is that of renewal period, since risk of premature wear (unexpected, costly renewals) and risk of obsolescence (the norms of technologies change rapidly) are come into play.		
In railways is much regulated and it is not a sector which is very innovative.		
Many autoroute experience within Vinci.		
PPP investments		
Which PPP-scheme is most suitable for high-speed railway PPP-investments? (Concession – Licensing – PPP). Why? Specific per country? If so, which element has to be considered? (tradition, actors, regulation, existing infra...)		

This is a concession. It is the question if the traffic risk is easy to anticipate on. Traffic risks are not easy to learn and to evaluate.

What is the most difficult to predict (CAPEX, OPEX, maintenance costs, legal issues, insurances, etc.)? During which project phases?

What are the top-3-risks for private parties in PPP-investments? What are the main needs of private parties when answering a PPP tender? When carrying out the PPP?

- 1) Risks associated with interfaces (institutional environment and relationships between actors, connection with existing infrastructure).
- 2) Risks associated with integrating of systems (construction and operations of rail, catenaries, trains, signalation together is difficult).
- 3) Commercial risks, due to payment by number of traffic.

In terms of maintenance, the open use of the European rail network is not an extra risk. Even not, since you don't know the specifications of the trains. The trains have to comply themselves to the European standards, which define for example the maximum weight. It differs from a PPP of concession: for a concession more traffic means an opportunity in terms of revenues. For a PPP-party: more traffic doesn't mean more revenues, but may lead to more costs in maintenance.

Public parties

Not so many risks.

But:

- To negotiate once again, when necessary.
- The risk of having an accident after opening: bad choice for constructor, bad control, image etc.

Remuneration schemes and cooperation

What are the experiences with Special purpose vehicles, or consortia? Conflicts?

Vinci and Inexia work well together. Vinci is able to invest, Inexia has the knowhow. There are often conflicts with the investors (banks), since who pays, who decides.

What is the most used methodology to predict costs for PPP-investments? Top 3

Not really a methodology, but more per component to look for its specifications (life-time and costs). A maintenance plan will be made on short-term.

For end of concession period: transfer. The quality of the infrastructure should be the same as at the start of the concession. Ten years before the end of the concession, an audit will be executed to research if the quality of the line is still sufficient. No really specified indicators exist, but "it should be in the way it was there at the start of the concession period". It is not regarded as a problem. We will see after 50 years, we cannot predict the world by now.

Which regulations did/do you apply (conception/building/operation for signal, railroad clearance? Any

difficulties regarding this point?
What remuneration scheme is most preferable and most used (user fee / shadow toll / lump sum) Why? Advantages-Inconvenients of each? Traffic risks are large risks, still when SNCF is the monopolist. Today there are 32 trains Paris-Bordeaux, it should go to 48. But nothing obliges them to run the trains. CP = loyer fixe qu'est payé par publique (pas de risques, donc formidable) Concession = Shadow toll is interesting for autoroutes. User fee is suitable for railways. Lump sum does not exist in France.
Maintenance
What kinds of models and methodologies during tender phase are used to predict maintenance costs? Definition and planning of maintenance actions (e.g.: feedback or risk-based approach)? Cost evaluations? Uncertainties management? Probabilistic/deterministic approaches? Monte-carlo? Excel. Maintenance (courante..) is not planned, since it should be done by the agreements with the public parties. Renewal actions are planned. 2 strategies: - Maintenance courant: evaluating all assets with their specifications. Benchmarking by RFF (life-time, how to improve it, costs). - Renewals: experience, specifications given by constructors. It is estimated by their life-times, by Excel in a deterministic way. Probabilistic models have not been developed at all. For each component, a maintenance strategy exists. But there is no optimization made for an optimal maintenance regime, regarding all assets. The large renewal actions are done as latest as possible. For example, effects of and on ballast is unknown.
What are the top-3-difficulties in predicting these maintenance costs?
MESEA needs, if any
Inexia is part of MESEA and takes care of most factors above. SNCF (part of Inexia) gives also data input. All factors are regarded as difficult. An optimization of the penalties has not been done. Two big axes: to integrate maintenance within the design. In the beginning much preventive and correcting maintenance. We have pointed in the business plan to which level of performance we will go. The specifications, set by RFF are higher, but we don't think that we will face penalties. Indicators are made on the number of accidents per year, the number of trains, minutes of total delay. [minutes / paxkm] Advantage of a concession: the licensor grants a concession to a party with included the commercial traffic risks. So performance and penalty regimes exist on a more strategic level. We know very well our public client.

Describe the improvement needs in field of maintenance in general and for MESEA. Improvement of the tools. Maintenance in design phase To integrate more ambitious studies based on FDMS-approach in design phase More data of the work and structure in a more coherent way, location-free by a GMAO (Les logiciels de Gestion de la Maintenance Assistée par Ordinateur). Also to get historical data of the different components.
What are the main innovations during the last years in maintenance policies? And PPP-agreements? Mainly associated with the construct phase: catenaries, bitumen etc. Strategies for renewal.
Describe the lack(s) of knowledge in field of maintenance for MESEA.
How would you describe the internal competence of MESEA to come up with cost-performance efficient maintenance schemes? Is there a need of helping MESEA with this issue(s)?
Had you budgeted penalties payment provision? How/What tools? Is the prediction made during the tender phase accurate with the current happenings? Were in MESEA's point of view penalties defined in a fair way? Why/why not?
Conclusion
Is PPP & Construction of high-speed rail a marriage made in heaven? Why so, or not? It is difficult to make a fixed price for 40 years. But due to the fact that all phases of a project are done by one consortium, this consortium will optimize the total costs. On the other hand there are also problems with the public party, because often right after the process of bidding and granting the concession, the public party leaves the private consortium alone.
In your opinion: if public parties or private parties could get 3 magic tools to help them managing PPP contracts, what would they be? What in the case of MESEA? - A crystal ball - A big issue is reporting, from the licensor to the public party. - A well-organized management board for the whole site (300km, 5.000 employees) Due to a PPP-contract, many interfaces exist. That's why good communication between the public and private party is necessary, often by means of reporting.
Do private and/or public parts already get help from external entities (university / consultancy / suppliers...)? From who and for what? Specific for what parts/project phases?

31. ANNEX 17: INTERVIEW SNCF

Table 26 shows the filled template of the interview with SNCF.

Table 26: Filled template of interview with SNCF

Interview	Master Thesis Menno van der Kamp	
Interviewee:	Pascal DUMONT	Date: 27-10-2011
Company:	SNCF	Place: By phone
Function:	Operational director of Inexia, project SEA	Start time: 8.30
		End time: 9.45
High speed rail		
What are the top-3 most successful known HSR projects in Europe? For what reasons? What are the key-elements making a new HSR project a success?		
1) Paris-Lyon: first LGV-project in France. SNCF has learnt a lot about signaling, geometric design and configurations of vehicles. It was commercially also a success. 2) Paris-Brussels: a real competitor for airlines: fast and own infrastructure. 3) Lyon-Marseille: technically a very complicated project, due to many connections to the conventional railways.		
What are the top-3-lessons learnt from the constructed high-speed lines in the world?		
1) High-speed should be high-speed 2) Operating on its own infrastructure 3) Well-connected to other railway lines and integrated in European network.		
What are the main differences between countries where high-speed railway lines have been constructed?		
High-speed rail in France is constructed as a radial network, with Paris as the center for all connections. It means that everyone should make a transfer in Paris, but it turned out that it has been a real competitor to the airlines.		
Are there any differences between the different phases of a project? What are the most risky phases? For what reasons? Which players do support those risks? How do they control them? And between other fields (buildings, highways etc.)?		
Every project is risky until the last day of construction, just before the operation starts. Even during the operations the maintenance phase is risky. Nowadays only 3 to 4 persons work for MESEA, the company		

which is responsible for maintenance. The frequency of trains passing on the route (traffic risk) is still a large risk. It is a matter of economics.

You can't say which phase is the most risky one, since every phase has its own risks. For example with the construction part of signaling, the safety system ERTMS is risky as well.

PPP investments

Which PPP-scheme is most suitable for high-speed railway PPP-investments? (Concession – Licensing – PPP). Why? Specific per country? If so, which element has to be considered? (tradition, actors, regulation, existing infra...)

The state of France has decided the type of contract. RFF didn't have the money to renew the infrastructure to meet the requirements for high-speed trains or even construct new infrastructure. So the State has asked different parties to construct this new infrastructure.

Right now three lines will be constructed by means of PPP: Tours-Bordeaux, Bretagne-Pays de Loire, Nimes-Montpellier (to be constructed).

BPL and Nimes-Montpellier are contrat partenariat. And SEA is a concession: DSP: Délégation de Service Public for a time frame of 50 years. It is all new in France and the interviewee assumes that RFF wants to try different methods.

Who is in charge to predict costs for PPP-Investments? (key-player, entity, skill – eg: infra's owner, accountancy service)

The private party is mainly involved in predicting the costs, since they carry a lot of risks in the PPP-project.

What is the most difficult to predict (CAPEX, OPEX, maintenance costs, legal issues, insurances, etc.)? On which time

What is the most used methodology to predict costs for PPP-investments? Top 3

What are the top-3-risks for private parties in PPP-investments? What are the main needs of private parties when answering a PPP tender? And when carrying out the PPP?

- 1) Traffic risks (in case of PPP and a concession)
- 2) Security risks (mainly signaling)
- 3) Organizational risks: who is responsible?

What are the top-3-risks for public parties in PPP-investments? What are the main needs of public parties when answering a PPP tender? And when carrying out the PPP?

- 1) Traffic risks (in case of PPP)

2) Interface problems: connections to the conventional railways and to vehicles
3) Overruns in time and budget
The role of the public party during concession period: do you see conflicting interests?
During the SEA-project the majority of the companies which invested in the project, had extensive knowledge about autoroutes, but didn't have any knowledge and experience of trains. So the train safety was a huge issue to overcome by The State.
Remuneration schemes and cooperation
What are the experiences with Special purpose vehicles, or consortia? Conflicts?
Only contractual agreements exist, for example between LISEA and the constructor COSEA and they all work in respect to the contract.
What remuneration scheme is most preferable and most used (user fee / shadow toll / lump sum) Why? Advantages-Inconvenients of each?
In the SEA-project an user fee is paid for the service used, like a plane at an airport. Or like a toll paid on autoroutes.
What are the experiences with performance-based output schemes? For public party? For private party?
Maintenance
What kinds of models and methodologies during tender phase are used to predict maintenance costs? Definition and planification of maintenance actions (e.g.: feedback or risk-based approach)? Cost evaluations? Uncertainty management? Probabilistic/deterministic approaches? Monte-carlo?
What is the reliability of these models and methodologies?
What are the top-3-difficulties in predicting these maintenance costs?
1)
2)
3)
What are the lacks in knowledge?

What is the most seen balance CAPEX/OPEX? What is a healthy balance? (eg: for France 1/3 CAPEX=renewal and 2/3 OPEX=maintenance, whereas in Switzerland other way around)
What are the main innovations during the last years in maintenance policies? And PPP-agreements?
Conclusion
Is PPP & Construction of high-speed rail a marriage made in heaven? Why so, or not? I propose you will call me in 50 years.
Do private and/or public parts already get help from external entities (university / consultancy / suppliers...)? From who and for what? Specific for what parts?
If public parties or public parties could get 3 magic tools to help them managing PPP contracts, what would they be? 1) Risk management 2) Interface management 3) Contract management and legal requirements

32. ANNEX 18: LONG-LIST OF CONCLUSIONS OF ALL INTERVIEWS

The long-list in this Annex shows the conclusions of all interviews. Moreover, specified for RFF, Strukton and MESEA party-specific conclusion are given.

Long-list of conclusions of all interviews

- ◇ Not enough focus on period around transfer of infrastructure [Infraspeed]
- ◇ Cultural aspects are as important as technical aspects [Infraspeed]
- ◇ Project teams for operation and maintenance should be involved in the project from the start on [Infraspeed, Rochu, RFF].
- ◇ Monitoring of the state of infrastructure is done by locomotive, switches, cameras and license plate registering.
- ◇ Due to small period of concession (5-6 years for conventional track) maintenance policies should be very efficient.
- ◇ Risk management from a operation and maintenance point of view is a neglected aspect. Hardly any feedback loops exist. [Infraspeed, Zoeteman]
- ◇ Models are needed which can be used to alter the preliminary assumptions.
- ◇ All models of (possible) disruptions and availability of infrastructure make use of normal distributions; this must be changed into reality, for example Weibull distributions [Infraspeed]
- ◇ Interface problems in an organizational context are more and more important. For example, interface problems between different countries in international traffic. It should be considered as just one project.
- ◇ More emphasis on standardized European TSI-norms.
- ◇ Previous HSL-projects were a success; the projects to come will be less successful in terms of amount of passengers [Zoeteman]
- ◇ Banks make huge investments in projects; their influence is very large.
- ◇ Non-proven technology should not be used for new lines.
- ◇ A PPP-project is nowadays very juridical. More emphasis should be on partnership and shared responsibilities.
- ◇ Banks do have their own LCC-models for PPP-projects.
- ◇ No standardized LCC-model exists [Zoeteman]
- ◇ In the models, for new technology no knowledge exists; the interaction train-infrastructure is unknown.
- ◇ You can't only consider the balance CAPEX/OPEX, but you should also take into account the mean lifetime.
- ◇ Everything in maintenance policies is about monitoring. In special: health-monitoring.
- ◇ The success of a HSL is due to its business case. You must take into account the complementary functions as well.
- ◇ For CAPEX and OPEX, also look to solutions out of the box; like turning a train faster means less trains to invest.
- ◇ Relatively, car use will stay the same in the future (60%) train traffic will rise a little bit (20% → 30%)

RFF

- ◇ To be very well prepared within the company internally. All departments and divisions of the public party have to work very close to each other [RFF].
- ◇ During the construction period, unpredicted accidents are very risky.

- ◇ if the public party wants the private parties to participate, the public party and banks should be more tolerant for their criteria of approval.
- ◇ maintenance costs it is very difficult, because hardly any track record in high-speed rail exists. Moreover, the technology improves and is renewed.
- ◇ Generally there are no persons from private parties who work at a public party. So, sometimes misunderstanding. Within RFF it is difficult to convince them that – for example – the banks do not always tell the truth. I would recommend to mix. Integration of people.
- ◇ it will be a mix of everything in the future. We can not say that we will have 1 PPP-model.
- ◇ Traditional contracting could be more suited for the project, for example for small parts of a line.
- ◇ At European level data sharing between infrastructure managers in terms of costs, but also at the technical side: CAPEX and OPEX.
- ◇ Use during negotiations the experiences of other countries. (This might be the role of EIB. But it is difficult because the majority at RFF don't speak English. We have to mix the culture. Not only on top management side, also on operation side).

Strukton

- ◇ Do as much as possible in-house. Outsource only local or very specific tasks.
- ◇ Due to competition the private parties only do the most necessary maintenance
- ◇ Requirements and specifications don't respond with the wishes of ProRail
- ◇ Currently, maintenance is done at night and weekend, but it could be interesting to maintain during the day or around 20.00 at night.

MESEA

- ◇ Traffic risks are not easy to learn and to evaluate.
- ◇ Risks associated with integrating of systems (construction and operations of rail, catenaries, trains, signalation together is difficult).
- ◇ No really specified indicators exist, but "it should be in the way it was there at the start of the concession period". It is not regarded as a problem. [MESEA]
- ◇ Renewals: experience, specifications given by constructors. It is estimated by their life-times, by Excel in a deterministic way. Probabilistic models have not been developed at all. [MESEA]
- ◇ An optimization of the penalties has not been done. [MESEA]

Improvements:

- ◇ To integrate maintenance within the design. [MESEA]
- ◇ To integrate more ambitious studies based on FDMS-approach in design phase
- ◇ More data of the work and structure in a more coherent way, location-free by a GMAO (Les logiciels de Gestion de la Maintenance Assistée par Ordinateur). Also to get historical data of the different components.

Needs: [MESEA]

- ◇ A big issue is reporting, from the licensor to the public party.
- ◇ A well-organized management board for the whole site (300km, 5.000 employees)
- ◇ To communicate the interfaces between the different (private) parties [COSEA/Inexia]
- ◇ To let stick every party to the strict deadlines. (holds mainly for public parties) [COSEA]

33. ANNEX 19: CATEGORIZATION OF INTERVIEW CONCLUSIONS

Table 27 shows an overview of the categorization of the conclusions which have been derived from the interviews with experts.

Table 27: Categorization of conclusions derived from interviews

	Organizational	Efficiency	Interfaces	Data	Financial
No focus on period around transfer		X			X
Cultural aspects mostly neglected	X				
Involvement of operation and maintenance in design	X				
Focus on efficiency at short concessions		X			
Monitoring of state of infrastructure				X	
No feedback from operation				X	
Need for computer models				X	
Adaption of model distributions				X	
Interface problems rail/infrastructure			X		
International traffic			X		
Standardized TSI-norms needed	X	X			
Future HSL-projects are less successful					X
Large influence of banks					X
No use of non-proven technology		X			
Shared responsibilities are neglected	X				
Banks own LCC-models					X
Train-infrastructure interaction unknown			X		
Mean lifetime of assets				X	
Health-monitoring of railway assets				X	
Complementary functions of HSL					X
Out-of-the-box solutions for CAPEX/OPEX					X
Close cooperation between company's departments	X				
Be aware of unpredicted accidents		X			
Be more tolerant about criteria of approval	X				
Hardly any track record in HSR exists				X	
Misunderstanding between public and private parties	X		X		
Integration of employees is not standardized	X				
Not just one PPP-model be dominant	X	X			X
Traditional contracting can still be used	X	X			X
Data sharing between RIMs needed			X	X	
Use experiences of other countries				X	
Outsource only very specific tasks	X	X			X
Only most necessary maintenance is done		X			X
Ambiguity between specifications and wishes of RIMs	X		X		
Maintenance is mainly done at day-time	X	X			X
Traffic risks are hard to evaluate				X	X
Integrating system's risks are neglected		X			X

	Organizational	Efficiency	Interfaces	Data	Financial
Specifications for transfer lack					X
Lack of specifications for transfer not regarded as problem	X				X
Renewals are estimated in a deterministic way				X	
Probabilistic models have not been developed				X	
Optimization of penalties not been done				X	X
Maintenance to be integrated with design	X	X			
Studies of FDMS-approach to be integrated with design	X	X			
To get more historical data of assets				X	
Better reporting of licensor to public party needed	X				
A comprehensive management board for whole project	X		X		
Communication of interfaces between parties	X		X		
Incentive to let parties stick to deadlines		X			X

34. ANNEX 20: HANDOUT WORKSHOP STRATEGO

Workshop StrateGo 15/12/2011



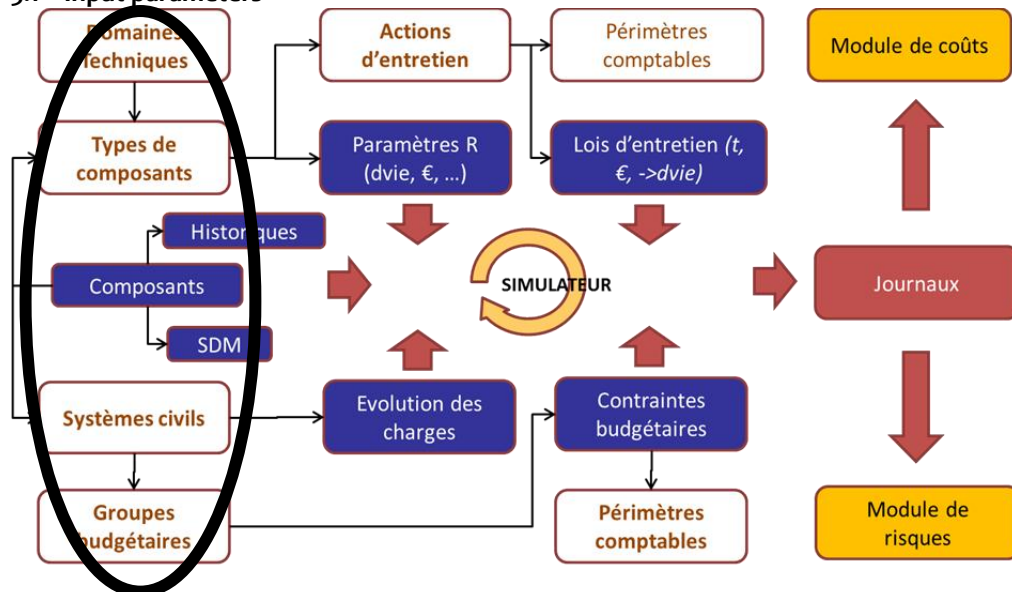
1. Maintenance action

- Represents an engineering intervention in the assets
 - o Extending of lifetime of component
 - Preventive, corrective, palliative
 - o Ensuring the availability of asset
- In StrateGo it is defined as:
 - o Sensitive to delays or not
 - o Impact of the lifetime or not
 - o Palliative or not

2. Main description

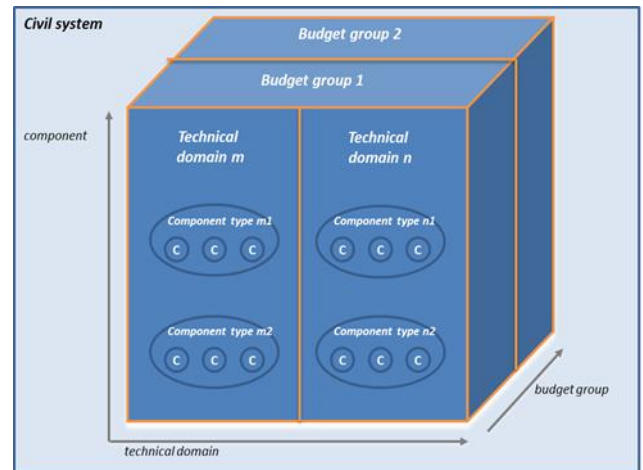
Strategic planning tool that enables the **long-term technical and economic assessment** of investment and maintenance policies. The tool suggests, based on **probabilistic simulations** with or without **budget constraints**, the **predictable evolution** of the selected assets' state and **associated risk levels**, as well as **potential evolutions** of technical and financial volume.

3.1 Input parameters



3.2 Input factors

- **Civil system**
 - ◇ Is an often geographically defined project.
- **Technical domain**
 - ◇ All major parts within the civil system; they are distinguished by the differences in lifecycles.
- **Budget groups**
 - ◇ Who pays for the different components? CAPEX and OPEX.
- **Components types**
 - ◇ A group of components, which are small enough to have homogeneity inside, but are also big enough not to be too detailed.
- **Components**
 - ◇ The physical assets, which belong to a group of components. A single component.



- ◇ **Civil system**
Is an often geographically defined project. It is the highest level in the hierarchy of StrateGO. Examples: “Railway line Lausanne-Vallorbe” or “Entire electricity grid in city X”.
- ◇ **Technical domain**
It can be considered as the second breakdown in the hierarchy. These are all major parts within the civil system; they are distinguished by the differences in lifecycles. Examples: “Signaling” or “Track”.
- ◇ **Budget groups**
This defines who pays for the different components. Also a maximum in the available yearly budget of CAPEX and OPEX can be determined.
- ◇ **Components types**
A group of components, which are small enough to have homogeneity inside, but are also big enough not to be too detailed. Examples: “Railway track type 5” or “Transformer 220kV”. Maintenance activities are defined for component types, since it is assumed that independently of the location, the activities will stay the same.
- ◇ **Components**
These are the physical assets, which belong to a group of components. One unit or object is defined as a single component. Examples: “Railway track type 5 between 100.2km and 108.3km” or “Transformer 220kV in city X”

4. Output

- An overview of assets, expressed by their relative age
- The amount of renewal and maintenance actions per year
- The amount of money allocated to renewal and maintenance.

5. Three modules

- An asset module, which simulates the evolution over time of the assets.
- A cost module, which makes it possible to integrate the remuneration of the infrastructure manager.
- A risk module, which takes into account the risks associated with the proposed maintenance strategies, and estimates the necessary provisions for the risks.

6. Outline of program

Info database

Results database

Languages

Input

Horizon

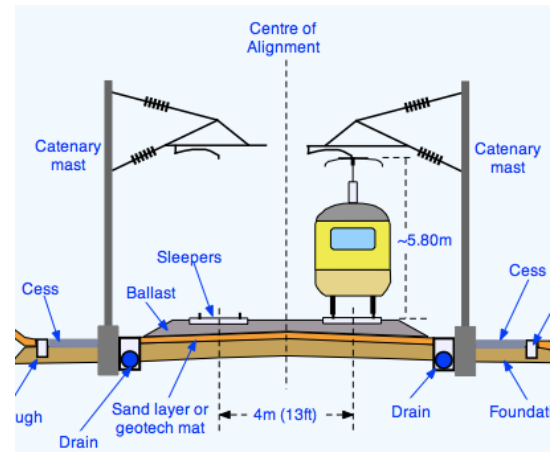
Simulator per module

Asset: 5 extra options

Risk and Costs: 0 extra options

7. Database

- Railway track
- Switch
- Wooden sleeper
- Ballast
- Catenary system



	Number of locations	Number of units	Life time of component	CAPEX		OPEX		
				CAPEX Action	Costs	OPEX Action	Costs	Maximum number of actions
AdV_UIC 2-4	26	99 x	25 years	Replacement	100000 €	Stuffing	70 €	6 x
						Replacement of mechanism	90 €	1 x
AdV_UIC 7-9	5	8 x	30 years	Replacement	80000 €	Stuffing	45 €	7 x
						Replacement of mechanism	90 €	1 x
ballast_UIC 2-4	6	14.755 m	30 years		250 €	Stuffing	40 €	6 x
Ligne type A	36	120.969 m	60 years		400 €	Painting	10 €	1 x

<i>Rail50_UIC 2-4</i>	19	55.180 m	30 years		150 €	Grinding	15 €	2 x
<i>Rail60_UIC 2-4</i>	9	63.314 m	30 years		170 €	Grinding	15 €	2 x
<i>TraversesBois_UIC 2-4</i>	13	81.583 m	40 years		280 €			

8. Examples of results

Results in numbers and graphs

Asset:

Renewal log: per (type of) component

Expenses: in total or in detail

Average age: overall mean or in detail

Maintenance log: per maintenance activity per component

Budget: per budget group, takes into account constraints

Costs:

External factors for costs

Risks:

Provision for risks

NPV = net present value (=degradation of value of asset over years)

VAN = Valeur à neuf

Strategies assessment

Different strategies to be compared. Copy – paste.

9.1 Difficulties, mentioned by Chiara

- Excel-based: slow if number of components exceeds 200
- Short-term maintenance policies are not reliable
- Less experience with risk- and cost-module

9.2 General difficulties, mentioned by Menno

- No experience with other distributions than deterministic distribution
- No standardized maintenance strategies possible
- No explanation of results in terms of bottlenecks
- No personal assessment of risk-treatment possible

10. Improvements

Graphical: Jean and Aimerick: A stand-alone program. Without Excel. Better user interface.

Compatibility problems with Microsoft Excel XP

Costs and risk module only well known by Yves

Strategy assessments

