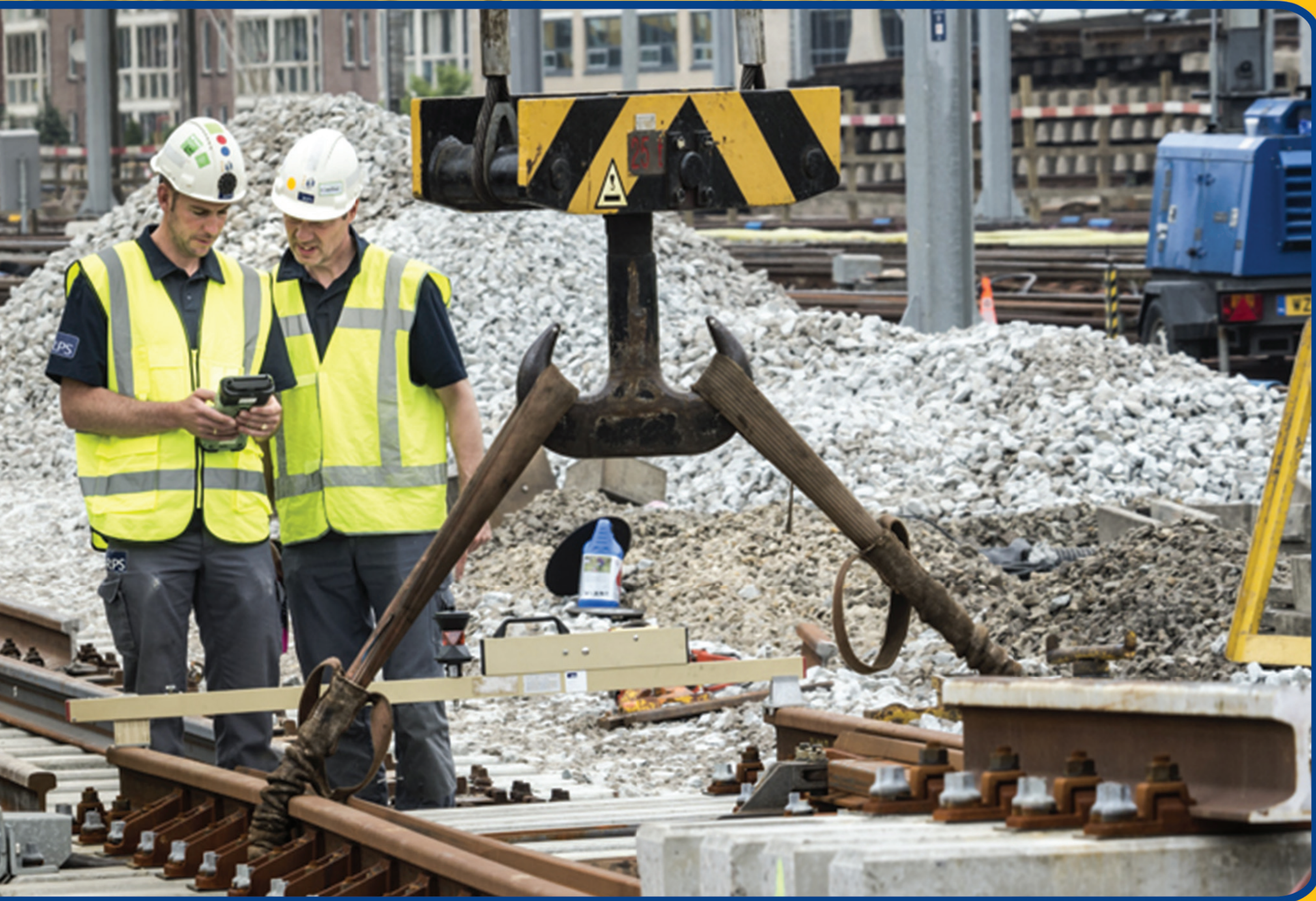
Process Analysis for Infrastructure Mutations and the Impact on Rolling Stock Deployment at the Dutch Railway Network

MSc. Thesis

T.W. Oudkerk



Process Analysis for Infrastructure Mutations and the Impact on Rolling Stock Deployment at the Dutch Railway Network

MSc. Thesis

by

T.W. Oudkerk

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Preface

Before you lies the report of my Master thesis. The research has been carried out at Nederlandse Spoorwegen (NS: Netherlands Railways), at the department Advies & Ontwikkeling/Integraal Product Ontwerp. The process of creating this report was not always easy, and therefore, I want to thank the following people for their assistance during this process:

- Jaap de Ruijter; as company supervisor he was the person who guided me through the complex organisation that is NS and supported me on various ways during the execution of my research. The freedom I've been granted by Jaap (and NS in general) was very delightful. Not only Jaap's professional approach and expertise was very helpful, also his humour and fun in the daily business helped me a lot during the process.

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- Boy Körver, Gerben Scheepmaker and Olger Siebinga: For taking the time to do the proof-reading of this thesis.

- My house-mates and family: for giving moral support and listening to all my complaints during the entire process.

- And last, but certainly not least; to all my friends, from which I received overwhelming support, especially during the final phase of my graduation. I couldn't have done it without you.

To conclude, I can only wish you a pleasant reading of this thesis report.

T.W. Oudkerk
Rotterdam, September 2017

Glossary

A&O Advice & Development *-NL: Advies & Ontwikkeling-*

AM Asset Management

Amfs station Amersfoort Schothorst

API Production and Infrastructure Council *-NL: Afstemoverleg Productie en Infra-*

BD Base Days *-NL: Basis Dagen-*

BDU Base Day Update*-NL: Basis Dagen Update-*

BU Base Hours *-NL: Basis Uren-*

BUP Base Hour Pattern *-NL: Basis UurPatroon-*

C&O Commerce & Development *-NL: Commercie & Ontwikkeling-*

CEG Civil Engineering and Geosciences

Circulation Combination of activities for a train in a specific time period, also referred to as 'rotation'

Composition Combination of a single type of carriages or a combination of one or more trainsets (Electric Multiple Units (EMUs)/Diesel Multiple Units (DMUs)) that forms a train.

Contractsector Lines, other than the 'hoofdrailnet' that are operated by NS, which have been obtained by public tenders

CRS Customer Requirement Specification

Daily plan Department responsible for making the daily plan *-NL: Dagplan-*

DMU Diesel Multiple Unit

Donna Planning software, used for (amongst others) allocation of capacity on the Dutch railway network. Originally developed by ProRail and NS.

DONS Software for studies on and design of timetables. Acronym for Design Of Network Schedules or DienstregelingOntwerp NS

Drp timetable-location *(NL: Dienstregelpunt; Drp)*

DSSU DoorStroomStation Utrecht

EMU Electric Multiple Unit

EPD Shunting Yard Diagram *-NL: EmplacementsDiagram-*

Es station Enschede

FIFO first in, first out

Follow-up train driver Train driver who is awaiting an inbound train on a station to board the rear driver cabin, so the inbound train driver does not have to walk to the other end of the train and therefore, the train can have a shorter turn-around time *-NL: Wisselmachinist-*

Gvc station Den Haag Centraal

Hoofdrailnet Dutch main railway network, operated by NS

ICM InterCity Materieel: single-deck rolling stock type for intercity services

I en M Ministry of Infrastructure and the Environment

IC Intercity

IM Inframanagement

IPO Integral Product Design *-NL: Integraal ProductOntwerp-*

K&M Customer & Market *-NL: Klant & Markt-*

KPI Key Performance Indicator

LIFO last in, first out

LOS Level of Service

LP Linear Programming

LT long-term

MAS Multi-actor Systems

MLT middle-long-term

NedTrain Subsidiary of NS, responsible for maintenance of rolling stock

NO Network Development *-NL: NetwerkOntwikkeling-*

NO Network Development and Design *-NL: Netwerkontwikkeling & Ontwerp-*

NS Netherlands Railways *(Nederlandse Spoorwegen)*

NSR NS Reizigers

OPG Stabling Plan Generator *-NL: Opstelgenerator*

OSC Order Service Centre

OV-SAAL Lijn Schiphol, Amsterdam, Almere, Lelystad

OVT Public Transport Terminal *-NL: Openbaar Vervoer Terminal-*

PAST Database used for the **P**lanning of **A**ssets and her **S**ervice-resources in favour of the **T**rain services. Used for keeping track of asset related matters and projects.

PHS Program for high-frequency railway traffic *-NL: Programma Hoogfrequent Spoorvervoer-*

PI Process quality and innovation *-NL: Processkwaliteit & Innovatie-*

ProRail Infrastructure Manager of the Dutch railway network

SBD Platform Occupation Diagram *-NL: SpoorBezettingsDiagram-*

SD Specific Days *-NL: Specifieke Dagen-*

SSM Soft System Methodology

Stabling yard collection of switches near a station to accommodate movements between multiple (platform-) tracks

Stabling yard collection of trakcs to park and/or service trains

T&P Transport & Planning

Tafel van Vergroting Council, where Train Operating Companies, Contractors and the Infrastructure Manager discuss developments for the railway infrastructure

TAM Optimisation tool for the adaptation of rolling stock duties *-NL: Tool voor de Aanpassing van Materieeldiensten-*

TB Transport Control *-NL: Transportbesturing-*

TDO Train Service Development *-NL: TreinDienstOntwikkeling-*

TIL Transport, Infrastructure and Logistics

TOC Train Operating Company

TOP Schedule Development & Planning *-NL: TreindienstOntwikkeling & Planning-*

TPM Technology, Policy and Management

Train series Collection of train compositions that are operated on a certain line in a certain time path. The number of the series determine the line, the time and the direction

Train Diagram Train Diagram/Time-Space Diagram (Tijd-Weg Diagram) Diagram indicating the course of a train in time and its followed path

Turn-around-time Amount of time a train needs between the end of the service on one line and the commencing of service on another line

Ut station Utrecht Centraal

VIRM Verlengd InterRegioMaterieel: double-deck rolling stock type for intercity services

VO Pre-design *-NL: Voorontwerp-*

VPT Vervoer per Trein

VSD Preparation of Specific Days *-NL: Voorbereiding Specifieke Dagen-*

Summary

NS is the largest train operating company on the Dutch railway network. With a growing demand in train movements, the railway infrastructure is subject to changes. These infrastructural mutations are a collaboration between NS, as Train Operating Company, and ProRail, as infrastructure manager. Various complexities arise due to the close relationship between the railway infrastructure, the timetable of the train services, the deployment of rolling stock and crew scheduling. This thesis discusses the complexities in the process of infrastructure mutations, that arise within NS as a result of such mutations. This is done by means of a process analysis and the assessment of a tool that is used within NS for the creation of rolling stock circulations.

The process (of infrastructure mutations) can be seen as a system, in which the subsequent planning processes for the timetable, rolling stock and crew are regarded as subsystems. To be able to catch the vaguely defined process at NS within the systems engineering definition, a "soft approach" of systems engineering is used. In this approach, the normative situation is analysed and reconstructed (the as-is situation). This normative situation is then compared with a real-life situation.

Similar to other actors in the railway sector (of which ProRail is one), a four phased process is described, which is illustrated in Figure 1. The four phases are defined as:

1. The initiative phase; in which the plan is initiated. Various actors may have various reasons to issue a mutation. This phase has little relation to the planning processes at NS and is out of the scope of this thesis.

2. The exploration phase; where the possibilities of implementing the initiated plan are explored. In this phase, functional specifications of the project are listed by the various actors.

3. The plan study phase; in which the specifications are translated to a number of alternatives for the mutation. From these alternatives, one final alternative is selected which then is realised in the fourth phase.

4. The realisation phase is the final phase. Here, the actual realisation of the mutation takes place and consists for NS of the most detailed planning in terms of the timetable, rolling stock and crew.

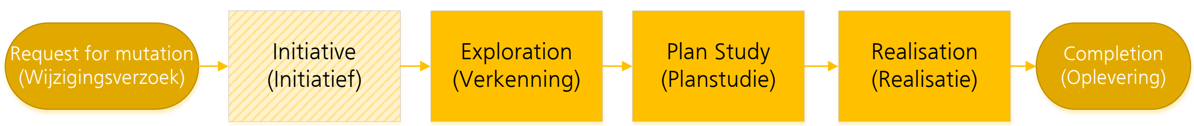

Figure 1: Illustration of the four phases of the infrastructure mutations process at NS

In the different phases, the roles of the various departments within NS, that are responsible for working out infrastructure mutations, differ. Nevertheless, a fixed pattern can be discovered. The Infrastructure Management department is the final responsible for the mutation in nearly the entire process. The commercial department is responsible for the specifications of the mutation and the effects in the timetable. The long-term planning department checks for feasibility of the plans and creates the blueprints for the planning products, like the base-hour pattern. Temporary decommissioning of the infrastructure is handled by the Order Service Centre. The operational implementation is done by the daily planning department.

Next to the reconstruction of the process and an identification of the roles, bottlenecks in the normative process are identified. These bottlenecks can be subdivided in the following categories: problems with information management, unclear definition of the process and its roles, and a lack of top-level management for (larger) mutations.

Subsequently, the same is done for a real-life situation. In this thesis, the DSSU project is used for this purpose. The DSSU project is a comprehensive renewal of the shunting yards at the central station of Utrecht, in the heart of the Dutch railway network. The project is chosen in this thesis, due to its size, complexity and since it has been realised recently, which ensures that a lot of information can be found on the topic. During this project, various factors, like governmental intervention and rescheduling of the project, introduced implications in the course of the project. Looking at the planning process at NS, the following bottlenecks can be identified: Unclear definition of the process and the definition of its roles, time limitations, a lack of planning resources, a lack of top-level management and issues with the realisation of the train service after the completion of the construction works. For these bottlenecks, various improvements are suggested in this thesis, based on experience from within NS, as well as from literature. The key finding of the process improvement is that using a more integral approach in the process of infrastructure mutations, both in information housekeeping and collaboration between actors, can avoid bottlenecks and result in better solutions in terms of timetable products and rolling stock deployment.

For the solution to the latter bottleneck in the DSSU process (the use of extensive planning and simulation tools), an evaluation of TAM is performed. TAM is a tool, that is used by NS for a relatively short period of time and is made to create and manipulate rolling stock circulations. The tool has shown its use for the planning of rolling stock, but the use in situations where the infrastructure is changed is rather unknown. Therefore this thesis focuses on evaluating the merits of this tool in the process of infrastructure mutations. To evaluate which factors in rolling stock planning are important for the various actors in the process, a questionnaire has been made. First, the questionnaire asked in open form which factors were considered important. Subsequently, the available outputs of TAM were scored in closed form. From the results it can be concluded that the required information differs per actor, but most of the requested information can be supplied by TAM (like carriage kilometres, number of shunting movements, seat-kilometres and other indicators that can be derived from these).

To evaluate the use of TAM in practical situations, three cases were assessed. All of the three cases were linked to one phase in the infrastructure mutations process, which have been discussed in the process analysis. This way, the use of TAM is evaluated for the entire process. The first case had an exploratory nature, in which the adding of an extra stop on the line between Dordrecht and 's Hertogenbosch. No exact specifications for the planned situation were provided, therefore fitting the description of an exploratory case. One of the main findings was the need of an extra composition to execute the service.

The second case related to the plan study phase, in which various alternative needed to be compared. For this case, the power limitations between Meppel and Zwolle was used. Four scenarios were discussed in a comparative analysis. The results indicated two favourable alternatives, of which one had a slight advantage, since it required zero extra train sets in total.

The last case had a relation with DSSU. It considered the effects of swapping the rolling stock types of two lines, which were combined at Utrecht due to the works in one of the construction phases of the DSSU project. By swapping the stock types, TAM indicated that the amount of driven kilometres where the patronage exceeded the capacity norm decreased. However, this decrease resulted in an increase in shunting activities and attachments and detachments of train sets and a comprehensive increase in driven carriage kilometres.

From the assessments it can be concluded that the tool indeed can give useful information on the effects of an infrastructure mutation on the rolling stock planning, but the results are highly dependent on patronage-prognoses and inputs from other parts of the planning process, like the (altered) timetable. Or in other words; the tool needed external input for every case, so a straight forward use of the tool is not possible in most situations. Besides this, the tool is (in its current form) not able to make optimal solutions, due to pre-defined turn-around patterns that constrain the model. Another shortcoming of TAM is the lack of insights in local (shunting) planning. Since TAM is a made to generate circulations, the (microscopic) shunting planning is not part of the tool. Since one of the bottlenecks of the process analysis was the lack of insights in feasibility of the plans on microscopic level, more research on this topic is recommended. Conclusively, TAM is a useful tool to obtain insights in the impact of infrastructure mutations, but it does not cover all effects and does not necessarily provide optimal alternative circulations.

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1 Introduction

Netherlands Railways *(Nederlandse Spoorwegen)* (NS) is, as Train Operating Company (TOC) on the main railway network (Hoofdrailnet), by far the biggest player in the field of rail bound passenger transportation in the Netherlands. With 159 million train kilometres on 7219 kilometres of track in 2016, the Dutch railway network can be considered as a very intensely used network [1]. Combined with a high societal pressure on the performance and interference by the government, this results in a complex organisation to keep the trains running.

In addition to this, ProRail has been split off from NS in 2003 as an independent manager of Dutch railway infrastructure. This introduced an extra interface in the already complex playing field of rail bound transportation in the Netherlands.

Thirdly, there is the necessity for NS to optimise its operation and to improve customer experience. This is a requirement to be able to operate the Hoofdrailnet after 2025, when the current concession period ends. The above mentioned collaboration between NS, ProRail and possible other parties induces complications in the process of acquiring new infrastructure or changing current infrastructure. Also the large number of internal departments within NS, that are involved in this process, introduces complexities. Earlier attempts to visualise and improve this process have been frustrated by reorganisations and at the moment there is ambiguity on who is responsible for what. One of the outcomes of this complex environment is that there is uncertainty on what the impact of infrastructure mutations is on the planning/deployment of rolling stock.

1.1. Problem Definition

NS is a large company, where around 35.000 [2] employees work together to keep the complicated process of running trains going. This varies from long-term planning to real-time operation. This thesis focusses on mutations made in the railway infrastructure and their impact on the planning process within NS. At the moment, this internal process is vague and rather undocumented. This leads to an inefficient way of planning for the changed infrastructure. Furthermore, the effects of such mutations on the various resources are not clear and, therefore, impede the decision making process for the planners. Additionally, this thesis evaluates if the currently used tool for rolling stock circulations can be used to provide insights in the effects of infrastructural mutations, which can support decision making in the planning process.

In more detail, the problem can be specified as follows; the first part of this thesis aims to give insights in the internal processes behind mutations in current infrastructure from the viewpoint of NS and to provide recommendations to improve this process. To obtain more insights to a real-life situation, a recent project; DoorStroomStation Utrecht (DSSU) is analysed as well. Additionally, NS states that it appears that there is a lack of knowledge on the impact an infrastructure mutation has on rolling stock deployment and, more specifically, the lack of possibilities to perform long-term studies. This has resulted in unexpected outcomes of projects in which the infrastructure was changed drastically, of which the DSSU project is an example. A study on the use of TAM (a rolling stock planning and optimisation tool) is performed to evaluate the merits of this tool in the planning process.

Interdisciplinary nature of TIL-programme

The thesis guidelines for the Master Transport, Infrastructure and Logistics (TIL) prescribe coverage of at least two of the three ”domains” of the TIL programme. Therefore, this thesis will cover the fields of study of the department of Multi-actor Systems (MAS) at the faculty of Technology, Policy and Management (TPM) and the department of Transport & Planning (T&P) at the faculty of Civil Engineering and Geosciences (CEG). The process analysis will cover the TPM MAS part and the evaluation of rolling stock tool TAM will cover the T&P part.

1.2. Research Questions

Due to the complexity of the problem it is important to divide the problem into various sub problems, with corresponding sub questions. The sub questions can be derived from one main question, which is stated below. With this main question and, subsequently, the sub-questions, the aim is to capture the problem of the unstructured current process and the assessment of the rolling stock planning tool.

Main Research Question

What problems occur in the planning process at NS when the infrastructure changes and can the effects of these changes on rolling stock circulations be assessed with the use of current tools?

Sub-questions

1. How is the current process of planning for infrastructure mutations set up?
2. What bottlenecks in this process are encountered in practice?
3. What factors determine the effects of infrastructural mutations on rolling stock circulations?
4. Is TAM able to provide these factors and give relevant outputs that can be used in the planning process?

1.3. Scope

The scope of the thesis is defined to ensure focus on the main topic and to prevent drifting off. The following boundaries are set:

- The research is limited to processes within NS and the interface between NS and ProRail.
- The geographical scope is determined by the operational area of NS Reizigers (NSR), which can be defined as the Hoofdrailnet.
- The assessment of the effects of the infrastructure mutations on planning is focused on rolling stock circulations. Other factors, like timetabling, will only be taken into account for as much as it is necessary to get a view on rolling stock circulations. Crew planning will not be taken into account, since this is a separate sub process of railway planning and will make the scope of this thesis too wide.
- The initial plan or initiative for an infrastructure mutation is considered as the starting point of the process. The reason or motivation for the mutation is outside the scope of this thesis.
- The process analysis focuses mainly on large-scale, project-based infrastructure mutations. *(The term "large-scale" is defined in Section 4.3.5)*
- The lack of possibilities to perform long-term studies on rolling stock circulations in the case of infrastructure mutation is considered as a given.
- The assessment of the effects on rolling stock circulations aims to give insights on the possible merits of the use of the tool TAM exclusively. Other tools might be useful as well, but are not considered in this thesis.

2
Research Methodology

In this chapter, the used method of the research is explained. It gives an impression of the steps that are taken to form an analysis of the problem, the methods for developing solutions for the identified problems and the methods for analysing the tool TAM. This chapter starts with explaining a 'soft systems method' that is used as initial approach for the research. Subsequently, the method for the process analysis and improvement is explained. In Section 2.3 the method for the evaluation of TAM is used. The chapter concludes with a summary of the method.

2.1. Systems Engineering Approach

As mentioned in the introduction of this thesis, the process of infrastructure mutations can be considered as a complex process. Therefore, it is wise to substantiate the process analysis with some notions from literature. The definition by Sage and Armstrong Jr [3] of a system seems to fit the purpose: *"A system is defined as a group of components that work together for a specified purpose."* The process of planning the main assets of the Railway System; infrastructure, rolling stock and crew is a system can be seen as 'the purpose'. In this system, the subsequent elements are interrelated. The main (sub)systems of the railway planning process at NS and their relations are shown in Figure 2.1 and are discussed more detailed in Section 3.1. Every element in this figure relates with its neighbour and many elements are dependent on another. For example the timetable; which can only be created, based on a certain infrastructure lay-out.

According to the Systems Engineering Book of Knowledge (SEBoK) [5], Systems Engineering can be defined as: *"[...] an interdisciplinary approach and means to enable the realization of successful (engineered) systems. It focuses on holistically and concurrently discovering and understanding stakeholder needs; exploring opportunities; documenting requirements; and synthesizing, verifying, validating, deploying, sustaining and evolving solutions while considering the complete problem, from system concept exploration through system disposal."*

This definition is very broad and the practical interpretation may vary, depending on the way the 'systems thinking' is implemented. Systems engineering usually requires a well defined and structured problem. The vague and undocumented situation, in which the process is set-up at NS, asks for a rather "soft approach". This approach is mentioned in the work of Checkland [6]. This approach is expected to suit the uncertainties within the process better than a hard application of systems thinking. Furthermore, the method can be seen as a proper Problem Structuring Method as defined by Mingers and Rosenhead [7]. It must be mentioned that the method will not be used 'as is', but again; it will be used as a guideline to formulate the process steps and the problems (or 'bottlenecks') in the infrastructure mutations process at NS. The main method, derived from the Soft System Methodology (SSM), is the comparison of a real-life situation with a normative situation. This means that the normative process is figured out (the as-it-should-be situation) and, subsequently, a real-life situation is considered to identify deviations from the normative process.

Another reason to apply Systems Engineering to the process analysis is that other actors in the railway sector use the method as well. So is the most important actor in the infrastructure process, besides NS; ProRail. ProRail applies System Engineering methods in their projects, following a self-made handbook [8]. To ensure proper collaboration, sector-wide, it might be wise to use elements from this handbook for processes

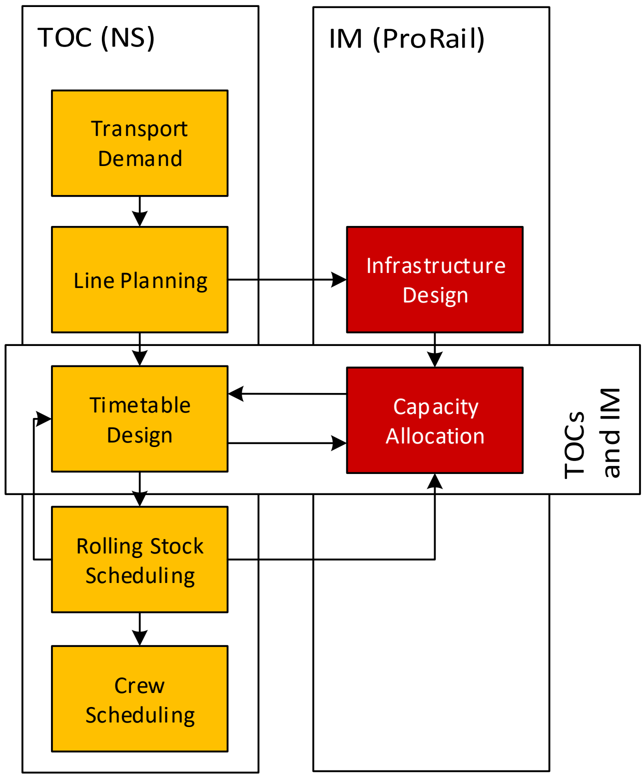


Figure 2.1: Railway system planning framework [4]

within NS as well.

To apply a Systems Approach, first a formulation on the 'who' and 'what' of the system has to be found. Next, the process has to be formulated and its bottlenecks have to be identified. Finally, some solutions are provided to tackle the identified problems. Summarising, the combination of system thinking and SSM will be done by following these steps:

- Determining how the end-product of the system can be defined
- Determining the sub systems
- Analyse the stakeholders (who is responsible for which subsystem?)
- Analyse how the stakeholders work together to realise the subsystems and the system as a whole (normative and in a real-life situation)
- Figure out what went wrong in the process
- Provide solutions for the identified problems

2.2. Process Analysis and Improvement

In the introduction it was mentioned that the process of planning for infrastructure mutations is rather undocumented. Besides that, the process of planning railway capacity, rolling stock and crew can be considered as rather complex. The first step to provide insights in this process is to use a process analysis on the normative planning processes for infrastructure mutations. In this analysis, the process is treated as a system, described by systems theory. Parallel to the analysis on the process, it is attempted to point out the bottlenecks that occur within the process. Subsequently, the same method is used to analyse the process as it is followed for the project "DSSU" to identify deviations from the normative process. In this way, deviations from the normative approach in a real-life situation are identified.

For the found deviations between the normative process and the process executed for the DSSU project, solutions are proposed. These solutions are based on outcomes of the collected data and, wherever applicable, on literature.

2.2.1. Data Collection

The process is analysed by means of documented interviews with relevant actors within the processes. The interviews are supported by additional data and information, found in information sources within NS. Undocumented, informal interviews or information from employees outside the (formal) interviews can be a rich data source as well, but are not documented and, therefore, are not fit to be used as a formal source of information.

The use of interview data as main source of information is used for two main reasons: the lack of consistent physical data (hard-copy or digital) on the process and the different perspectives of the various actors, which causes ambiguity. The interviews aim to capture trends or patterns, which can be considered normative when the amount of sources is significant. For this reason, interviewees from various departments are selected. Additionally, the interview data can be supported by physical data, if it can be considered valid enough (e.g. not outdated). The validity of the sources can be a point of discussion, due to the limited amount of interviewees and the subjectivity of the interviews, but due to the nature of this thesis and the 'soft nature' of the processes, the approach used is considered to be enough to reach the goal of the thesis.

Interview Framework The main method of gathering information is by conducting interviews. A known pitfall of using interviews as a research technique is rushing into the data-collection before having a clearly specified set of questions [32]. In addition to this, an important goal of the research is to make a proper, objective analysis, which is not biased by (in this case) the company's opinion or wishes. This trap has to be avoided as well. To do so, a well structured interview approach must be set up, in which the required data is well formulated in the questions. Therefore, a prescribed set of questions is formulated, which will function as guideline in the interviews.

The framework has been set up in cooperation with the company supervisor and two other NS-employees, to ensure that a broad enough selection of topics was formulated to cover the entire process, as discussed by Gillham [32]. The entire set of questions can be found in Appendix A. Summarised, the questions are formulated in order to obtain the following information:

- The role of the interviewee in the organisation and process
- The inputs and outputs the interviewee (or its department) needs and/or generates
- The bottlenecks (and/or positive points) in the process
- The aspects that determine the size of a mutations

The latter is asked, since this is given by NS as a known bottleneck. More on this bottleneck will be discussed in Section 4.3.5.

In practice, sometimes it is difficult to stick to the interview framework, since every interviewee might want to draw the main focus of the interview to their particular stakes. Literature refers to this type of interview mostly as unstructured interviews, due to their relatively small amount of structure. This semi-structured interview can be seen as the counterpart of the well-structured questionnaire for example, which is used more in cases where specific patterns or qualitative data is required [33]. The interviewer has to try to maintain the 'course' of the framework as much as possible, to obtain answers to the required questions. The semi-structured approach was attempted as much as possible during the course of the interviews.

Selecting Interviewees Besides constructing the framework for the interviews, it is important to gather information from various aspects of the process. Together with the company supervisor, a list was put together with people who are considered to be a good fit for interviewing due to their relationship with the process.

Every research requires a significant amount of data sources to obtain relevance of the data. The usage of semi-structured interviews impedes this requirement. Since the usage of this type of interviews is time consuming, a reduction in the amount of interviewees is needed. The choice is made to interview one person per company-division/section that is related to the process. This will result in limited detailed data on the different viewpoints within a certain division, but will ensure a broad vision on the entire time horizon and scope of the process. The findings from the interviews can be supplemented with information by other persons, that is not given in the context of an interview. This data can be considered as the obtained expertise within the subject by the author of this thesis.

Transcribing To make the translation from spoken word to written text, the interviews are transcribed. This means that the recordings of the interviews are written down. In this process some interpretation and selection of the words is made to ensure that only relevant information is derived from the interviews. For the transcription process, several guidelines mentioned in the 'Interviewing guide' by Gillham [32] are used. To ensure the summaries/transcripts concur with the intended information of the interviewee, the summaries are sent to the interviewee for confirmation, after which the interview is considered a valid data source.

2.3. Evaluation of TAM

The lack of possibilities to assess the impacts of infrastructure mutations on rolling stock deployment has been given by NS as a starting point of this thesis. Therefore, an evaluation of the use of a rolling stock planning tool is performed. NS uses various tools to plan rolling stock and the currently used approach differs from the techniques used during the DSSU project. The implementation of modern optimisation tools resulted in new possibilities to quickly and well substantiated develop a rolling stock circulation.

This thesis aims to determine if the optimiser 'TAM' is a useful tool that can provide the proper insights and information on rolling stock circulations to support decision making. To prove the 'usefulness' of the tool, first an evaluation of relevant outcomes is done, based on the perspective of various actors in the process. This is done by a questionnaire and is described in Section 5.1. In the questionnaire, the first question is an open one and is meant to figure out which rolling stock related Key Performance Indicators (KPIs) the surveyed department requires, without being told what the capacities of the tool are precisely. Secondly, a list of KPIs that TAM can produce is presented. For each KPI, a score can be assigned between 1 and 5. In this way, the relevance of the various KPI for each department can be figured out. Since the person that is surveyed now knows what the possible KPI-outputs are, he or she can submit factors/KPIs that are found to be absent. With this information, it can be considered if the tool is relevant for the given KPIs. Thirdly, based on the KPIs that are missing, shortcomings in the tool can be identified. The results of these questionnaire is discussed in Section 5.1.

After evaluating relevant outcomes, the practical use of the tool has to be evaluated. To do so, a couple of scenarios (or cases), based on the outcomes of the process analysis of Section 4, are evaluated with use of TAM. The cases focus on situations where rolling stock circulations have to be adapted, due to changes in the infrastructure. The 'cases' are described in Section 5.2. Based on the questionnaire and the results of the cases, conclusions are drawn on the use of TAM in the infrastructure mutations process.

2.4. Cases

In the previous sections, various real life situations (or cases) are mentioned. Such cases are used both for the process analysis as for the evaluation of TAM. The DSSU project is chosen as representative real-life situation for the process analysis. This project is recently finished and has shown various areas that can be improved, hence making this project a suitable case to use for comparing the normative situation. More information on this project will be given in Section 3.4.

For the evaluation of TAM, three cases are used as well. One of these cases is related to DSSU as well. The other two are discussed are not. All three cases, used for the TAM evaluation, and the reasons to choose them are discussed in more detail in Section 5.2.

2.5. Methodology Summary

The methodology of the thesis research can be summarized in the step-by-step overview listed below. To support this, a visualisation is given in Figure 2.2. Summarizing, the first three blocks (Chapter 1 to 3) provide the foundation of the research with an introduction, elaboration on the methodology and literature review. Based on this foundation, in Chapter 4 the process of infrastructure mutations is analysed. This analysis is done for both the normative situation as for the DSSU-case. From this analysis, bottlenecks are identified and, subsequently, suggested improvements for these bottlenecks are given. For the bottleneck *"Lack of possibilities for rolling stock studies"* the TAM evaluation is performed in Chapter 5. This evaluation is set up in a part where the relevance of outcomes are determined and a part in which three cases are assessed. Both the process analysis as the TAM evaluation are concluded in Chapter 6.

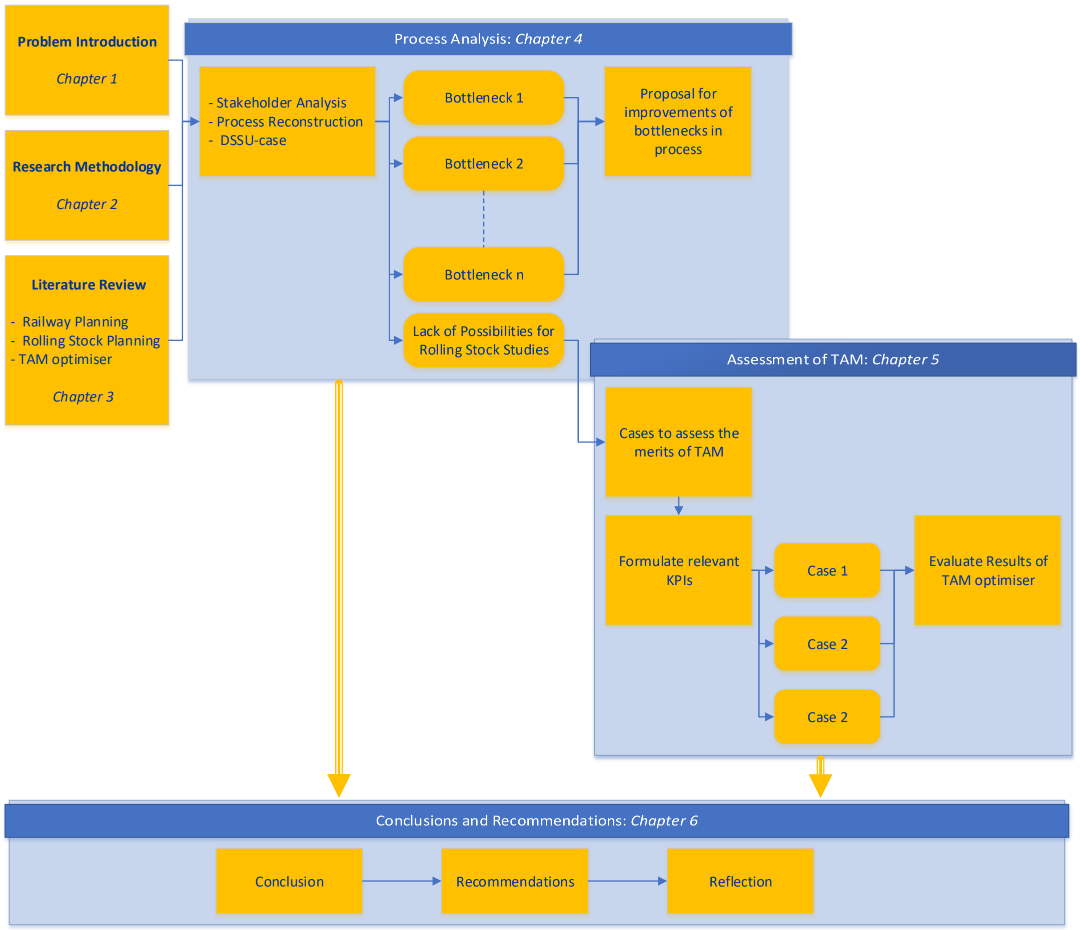


Figure 2.2: Research framework

Process Analysis & Improvement

1. Collect data on the current practice of the process used for infrastructure mutations within NS
2. Formulate the (normative) common practice of the process and the actors involved
3. Identify bottlenecks and problems in this process
4. Gather information on the DSSU project
5. Formulate the DSSU-specific process flow
6. Identify DSSU-specific bottlenecks and problems
7. Suggest improvements on the process (normative and DSSU)

TAM Evaluation

1. Identify relevant KPIs per actor in the planning process
2. Formulate cases to assess the use of TAM
3. Run TAM to evaluate the cases
4. Formulate findings with the results of TAM on the cases
5. Draw conclusions on the applicability of TAM for the given problems

3
Literature Review

This chapter provides information from literature on the various topics that are discussed in this thesis and gives context to the report. The literature review starts with a description of the railway planning process. Section 3.1 gives information on the planning framework for the train services at NS, with a focus on the timetable planning. This gives context on how the infrastructure mutations process is embedded within this planning framework. Additionally Section 3.2 gives backgrounds on the current practices of rolling stock planning. The background of the TAM optimiser is discussed in Section 3.3. Conclusively, Section 3.4 provides information on the DSSU project and gives insights in the choice for this project to use in the comparative analysis. The structure of the literature review is shown in Figure 3.1.

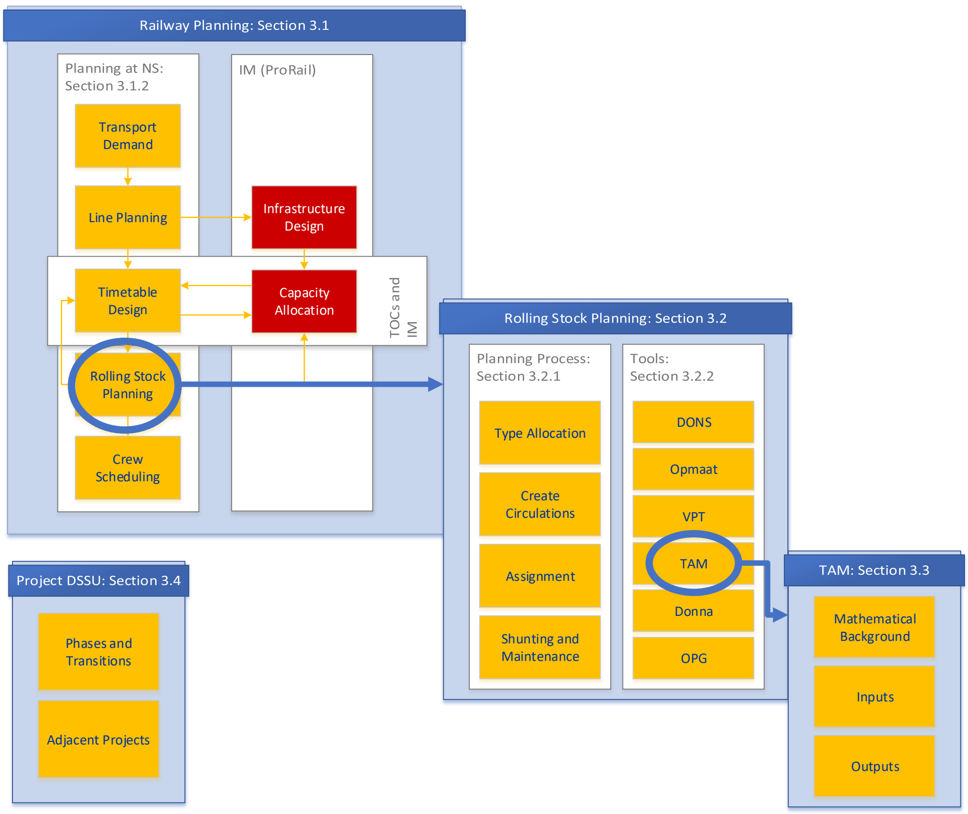


Figure 3.1: Framework of the literature review

3.1. Railway Planning Framework

A railway system is based on three main "assets": Infrastructure, Rolling Stock and Crew. The capacity of the infrastructure is allocated by means of a timetable and allocated train paths. The rolling stock and crew allocation is subsequently based on this timetable. The diagram of the planning framework for a railway system is shown is Figure 2.1. As can be derived from the figure, NS is partially responsible for the timetable (in cooperation with ProRail and other TOCs) and fully responsible for the rolling stock- and crew planning. The following sections provide a background on the planning framework for the timetable, and subsequently, rolling stock and crew. This information is vital to understand the planning and the impact of infrastructure mutations on this process.

As an addition to Figure 2.1 it must be mentioned that the "infrastructure design" seems to be exclusively done by ProRail, but in practice, there are multiple interactions between the TOC (NS in this instance) and ProRail, as this is the topic of this thesis. The final responsibility for this part of the planning framework lies with ProRail.

3.1.1. Planning Horizons

To gain clear insight in the different planning stages, as displayed in Figure 2.1, first, the various planning horizons in railway planning are discussed. These planning horizons can be defined as Strategic Planning, Tactical Planning and Operational Planning, according to the framework, proposed by Anthony [9] and used by Abbink [10] to describe the planning at NS.

Strategic The strategic planning can be seen as the long-term planning of the objectives of the organisation, the resources needed to attain these objectives and the policies on these resources. In practice, this involves line planning and development of the network, as well as decisions on acquiring new infrastructure or rolling stock. The strategic planning is done, amongst others, based on models on the development of transport demand, managerial decisions and governmental decisions.

Tactical The tactical planning comprises of the middle-long-term planning. This can be defined as the process that assures that resources are used effectively and efficiently in the accomplishment of the organisation's objectives, as planned on strategic level. Practically it involves the detailed planning of timetable and, subsequently, rolling stock and crew.

Operational The operational level focusses on the execution of the plans, made on tactical level. It involves the rescheduling of trains, rolling stock and crew to mitigate deviations in the original timetable. Changes in the actual deployment of trains or involved rolling stock and crew are made to mitigate disruptions that occur during operation of the train service. The latter is often identified as a fourth level and referred to as 'operational control'.

The X-## form

To give notion of the time span of a certain planning element, the "X-##"-form is common, where the hashes resemble the amount of time (usually weeks, but dependent on the specified time horizon) until the start of the project, timetable or whatever the expression is related to. For example: a certain plan is made 50 weeks before that plan is implemented in practice, this uses the expression 'X-50 weeks'.

3.1.2. Timetable Planning at NS

Parallel to the three planning horizons, indicated in the previous paragraph, NS has its own planning phases for timetable planning. The planning process is described with the main focus on its deliverables, i.e. the resulting timetable product per planning phase.

Long-term planning The timetable planning starts many years before the start of a timetable, up to around X-15 years. [10] In the years before actual planning is performed, studies are carried out on the long-term, strategic development of the infrastructure network (by ProRail) and the applied lines that are operated on the network (Line System; by NS). Within NS, these studies are performed by the commercial department (Train

Service Development *-NL: TreinDienstOntwikkeling-* (TDO)) in cooperation with Advice & Development *-NL: Advies & Ontwikkeling-* (A&O). These studies comprise of the development of new lines, new stops/stations and projects that span a large time horizon. [11] Examples of incentives for these plans can be:

- Development of transport demand, e.g. due to spatial developments, new station are opened or passenger amounts increase on a certain line
- Managerial decisions or wishes from the NS management, e.g. the decision to improve frequencies on a certain line to improve customer experience
- Governmental decisions, e.g. the construction of the HSL-zuid, to connect the Netherlands with the European high-speed network

VO and BU Around X-2 years, the long-term studies are being implemented in actual timetable plans. This process starts with the Pre-design *-NL: Voorontwerp-* (VO). In this pre-design stage, an concept timetable is produced, which is the base for the next stage; the design of the Base Hours *-NL: Basis Uren-* (BU) (X-1,5 years). The BU is a predetermined pattern that forms the basis of all detailed planning. It contains the paths of all planned train services. The pattern of the BU on the network is called a Base Hour Pattern *-NL: Basis UurPatroon-* (BUP). The BUP is designed every year and forms the blueprint of the timetable. This is the first timetable design step in which the infrastructure-layout is formalised in the plan [12]. The main responsible departments for the BU-phase are TDO and A&O, with support of Transport Control *-NL: Transportbesturing-* (TB). [12]

Train Diagram

The graphical representation of a collection of train paths on a certain stretch of infrastructure is called a train diagram or time-space diagram (*In Dutch: Tijd-Weg Diagram (TWD)*). Figure 3.2 shows a train diagram from Donna, the planning software of ProRail and NS. It contains regular paths (dark green) for passenger trains, grey lines for reserved freight-paths, light green lines for confirmed freight paths. In the figure, the infrastructure layout is shown on the vertical axis and gives basic information of the track layout of different sections. The horizontal axis represent time.

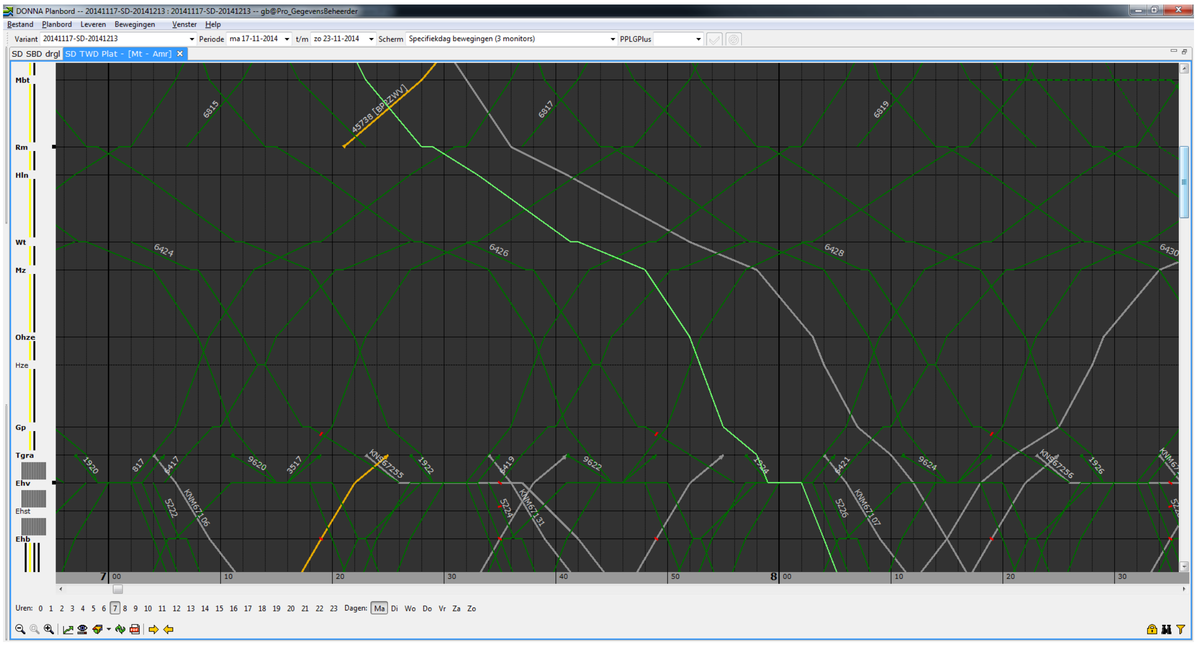


Figure 3.2: Train Diagram from planning software Donna, with time on the horizontal axis and the track sections, with layout and stations, on the vertical axis

BD and BDU Around X-1 year the BUP is made into Base Days *-NL: Basis Dagen*-s (BDs). This pattern is formed by expanding (or 'roll-out') of the BUP over a single day and, subsequently, over a week. The BD therefore has a size of 7x24 times the BU and, therefore, is commonly called as 7x24 timetable planning. [10] The BD plan is a combination of hour patterns in which the density of train services might vary over the day. In off-peak hours, less trains operate, due to lower transport demand. The combination of peak and off-peak BUPs makes the 24 hour plan. This plan is rolled-out to a full week (the actual 7x24 plan), in which there is (usually) only a distinction between weekdays and weekend-days, again due to differences in transport demand.

During the year that a timetable (BD) is used, inconsistencies or infeasibilities may occur, for example due to unforeseen circumstances or changes in the infrastructure. Therefore a revision of the BD is done six times per year (in the months dec-feb-apr-jun-sep-oct). These adaptations are called Base Day Update*-NL: Basis Dagen Update-* (BDU) and are planned for around X-16 weeks.

SD The most detailed planning phase, is that of the Specific Days *-NL: Specifieke Dagen-* (SD) (X-9 weeks). This is a pattern, with the size of 12 weeks, originating from the BD-pattern, but with specific conditions for specific days (e.g. holidays) implemented. The SD-plans form the blueprint for the daily operational planning.

Figure 3.3 shows the visual representation of the framework by means of Train Diagrams. Figure 3.4 shows the planning steps on a time line, based on the generic planning phases from Section 3.1.1.

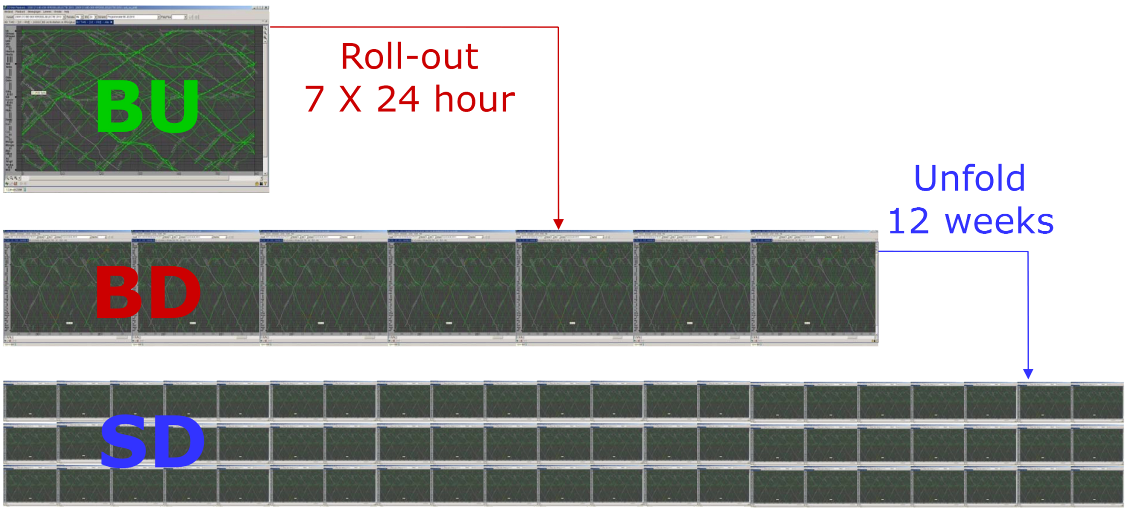


Figure 3.3: Visual representation of the planning framework by means of Train Diagrams, with in green the combined BUPs of a single day, in red the 'rolled-out' 7x24 BD-plan and in blue the 12-week SD roll-out. [13]

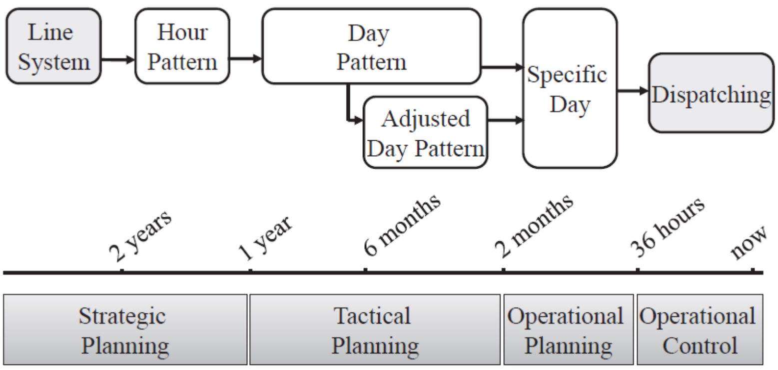
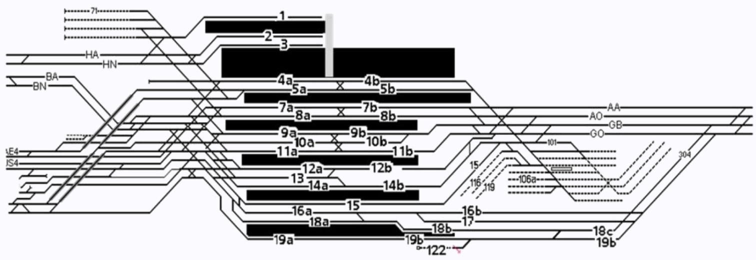


Figure 3.4: Planning steps for the timetable planning [10]

Network Topology [14]

Planning of railways is done in different detail levels. In this report, two levels are distinguished; macro- and microscopic. A macroscopic representation of a piece of a network includes nodes and the interconnecting arcs, without any information on the track lay-out in the nodes, i.e. the node is represented as a 'black-box'. In the Donna planning software, the Train Diagram can be seen as a macroscopic representation. It shows only the presence of a node and has limited information on the lay-out of the connecting arcs. (See the vertical axis of Figure 3.2)
A microscopic representation gives detailed information on the track lay-out. It shows the location of switches and shows every separate track. The Shunting Yard Diagram *-NL: EmplacementsDiagram-* (EPD) is an example of a microscopic representation. (See Figure 3.6)
The following images show, respectively, the macroscopic and the microscopic representation of a station.



3.1.3. Local Planning

The previously discussed planning products are designed mainly in macroscopic form. The macroscopic network representation is a simplified version of the railway network, where detailed track lay-out is not displayed. More on this, so called, network topology can be found in the grey context box above. The detailed planning of stops at a station is done on microscopic level. Graphically, this is displayed in a so-called Platform Occupation Diagram *-NL: SpoorBezettingsDiagram-* (SBD); a diagram showing the occupation of station tracks. In this diagram, the planner can see the trains stopping at a certain platform, or if a platform track is reserved for a passing train or shunting movement. The representation of train movements on track level and shunting movements is done with EPDs; a diagram showing the lay-out of a certain section of the network. Figure 3.5 and 3.6 show, respectively, a SBD and an EPD of Utrecht central station. Local planning at NS is performed on tactical level. [10] Adjacent to the microscopic planning for train lines, node- or shunting plans have to be made to plan train movements from stabling yard to platform track, or platform to platform, in the case a train departs from a different platform than its preceding service terminates. Also local planning for servicing and maintenance is necessary. Local planning is often referred to as the shunting plan and comprise of shunting movements. [10]

3.1.4. Link With Infrastructure Mutations

The process of infrastructure mutations does not occur parallel with the time horizons of the planning framework at NS. Depending on the time scale and size of the mutation, the time span of the mutation process might vary. For example; the removal of a single switch on a secondary line might be suggested, elaborated and physically removed in the time-span of a single year and therefore occur within the running year of a single timetable. A large scale mutation, like DSSU spans multiple years and therefore multiple timetables. This makes an unambiguous description of the infrastructure mutation even harder. More on this difference is given in Section 4.3.

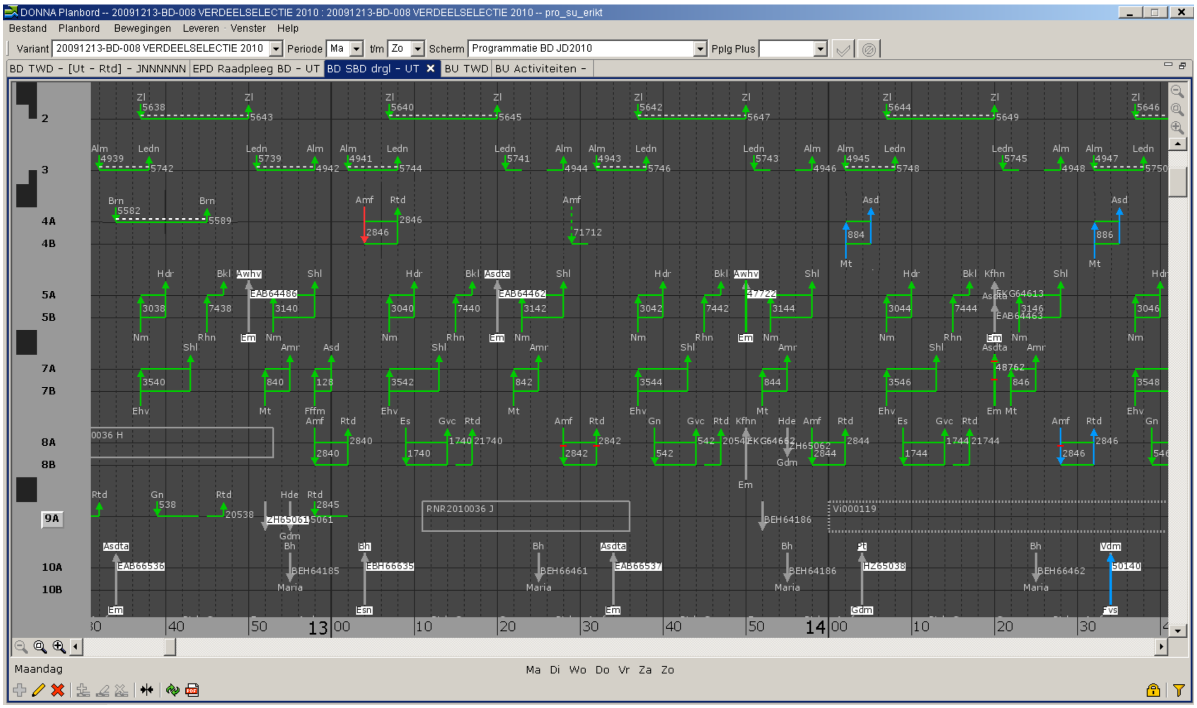


Figure 3.5: Track Occupation Diagram (SBD) in Donna of Utrecht Centraal

3.2. Rolling Stock Planning

Since this thesis focusses in particular on rolling stock planning, this section gives a background on this process in general and on the current practices at NS. The general description gives theoretical insights in the planning structure, the requirements and the factors that influence the planning. The description of the current practices in rolling stock planning at NS is performed, based on literature and experiences from NS employees. To get insight in the current practices, introductions in the tools have been given by Jan de Bruijn (Architect) on OpMaat and Ruud Drabbe (Study leader Rolling Stock A&O) on VPT/TAM. The tools that are used are each used for their own purpose; i.e. Opmaat is used for long-term studies, and VPT/TAM is used for the actual planning of rolling stock.

3.2.1. Planning Process

Earlier research on the rolling stock planning process at NS is performed by (amongst others) Abbink [10], Abbink et al. [15], Nielsen [16] and Kroon et al. [17]. The following summary of rolling stock planning is based on their work.

In retrospect to the planning horizons of Section 3.1, the rolling stock planning consist roughly of four steps:

1. Allocate (preferred) rolling stock type per line (Tactical)

2. Create circulations (Tactical)

3. Assignment of specific trains to the circulation (Operational)

4. Shunt planning and maintenance scheduling (Operational)

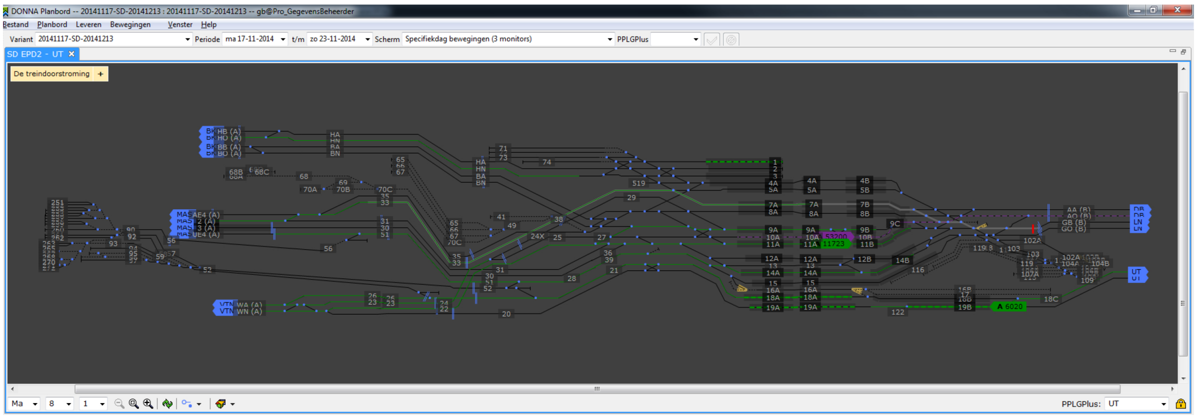


Figure 3.6: Track layout diagram (EPD) in Donna of Utrecht Centraal, with unoccupied tracks in black and planned train paths in green

Eight o'clock cross section

The eight o'clock cross section is a normative time period for which the required rolling stock capacity is determined. The cross-section consists of an overview of all trains that are used at 8:00 o'clock in the morning. This moment is chosen since it occurs in the peak of the morning rush hour. If the allocated capacity is enough for this time of the day, it can be assumed that it is sufficient for the entire day. This way, the maximum amount of trains can be calculated, which can assist the decision making process in the allocation of train types to lines. In some occasions, a 17 o'clock cross section is made to determine the amount for the afternoon peak.

Step 1: Type Allocation

As mentioned earlier, the timetable forms the basis of the rolling stock planning process. In the timetable, the times of events of all train services are described. Based on the timetable (i.e. the eight o'clock cross section) and the line plan, one or more (preferred) types of rolling stock are assigned to each line. The following factors determine the choice of a specific type of rolling stock for deployment on specific line:

- Service type (Intercity (IC)/Sprinter)
- Infrastructural limitations (e.g. power supply or platform lengths)
- Driving characteristics (Maximum speed, acceleration, deceleration)
- Capacity (seats per trainset, single deck vs. double deck, possibility to combine train sets)
- Proximity to maintenance location (not every rolling stock type can be serviced at every maintenance location)

The choice for the assignment of rolling stock types to train lines is made by the commercial department of NS and might be influenced by some commercial stakes (e.g. the customer experience of a certain train type).

NS Rolling Stock

NS has an comprehensive rolling stock fleet, with various train types, with various characteristics. Most of the fleet consists of Electric Multiple Units (EMUs); self-propelling, fixed compositions of carriages that can be quickly combined with other EMUs to create a train that has the desired length. The use of EMUs gives the opportunity to tailor the deployment of the specific rolling stock type to the predicted patronage on a specific route. For the few non-electrified track lines that NS operates, the company owns Diesel Multiple Units (DMUs). The counterpart of the EMU/DMU is the classical train composition with a locomotive in the front, combined with carriages. One of the disadvantages of these type of trains is the requirement of shunting, to bring the locomotive to the front of the train in cases the train has to turn around. Recently, NS created train compositions of so called 'ICR carriages' with TRAXX-locomotives on both ends of the train (sandwich-operation) to operate a classical composition in a way that resembles an EMU. This ICR-composition is shown below. A separate train unit is called a 'train set'. A combination of train sets is called a 'composition'.

Another distinction in train types can be made between IC-stock and Sprinter-stock. IC-stock has, on average, lower capacity per train length, due to a higher comfort level (e.g. seat pitch). Sprinters usually have better acceleration and deceleration characteristics, due to the higher stopping frequencies on the services they operate. Also, sprinters usually have more doors to speed up te (de-)boarding process.
Within the IC and Sprinter train types, there are single and double decks types.
Most of the rolling stock types that NS owns, various lengths are an option. This means that various lengths of a train can be made, with a single rolling stock type. An example is shown below, where two lengths of a IC-double decks train type is shown (DDZ4 & DDZ6).

[18]

Step 2: Create Circulations

After a rolling stock type is assigned to a certain line, a circulation has to be made. A circulation is the combination of trips a train set makes per day. A train can only be deployed at location 'A' if the train is actually available on location 'A' on the desired time. A proper circulation makes sure that all rolling stock is distributed over the network in such a way, that every train is at the correct location at the correct time. To prevent the (costly) relocating of empty trains over the network, the planning aims to make the end-point at night the same as the starting point of the service the next day, which is called balancing. The combination of circulations makes up for all rolling stock for the entire service on the network and should match the required capacity on every line(-section). Figure 3.7 shows an example of a part of a circulation for 8800 series between Leiden and Utrecht by means of a Train Diagram. The dashed lines represent the train service, with its corresponding train service number denoted on top. The solid lines (displayed at the terminal stations only) represent the amount of deployed train sets for the specific services. In this figure, it can be observed that the 8822 train from Ut to Ledn runs with four train sets and a train set is detached after arrival in Ledn, which will be redeployed on the 8863 series. Next to this, a visual representation of the 8 o'clock cross section can be observed. The train services through the vertical line at '**8**' (i.e. 8820, 8822, 8829 and 8831) all run with 3 train sets. Therefore, the amount of train sets required in the cross section in this example is $4 * 3 = 12$.

An efficient rolling stock circulation maximises the use of the available rolling stock by deploying train sets in such a way that it fits passenger demand as good as possible, while minimising the running times of the train sets. This can be done by changing the assigned composition on a certain line on intermediate parts of the line, by attaching or detaching train sets to/from the composition. For example: the train services between Rotterdam/The Hague and Leeuwarden/Groningen used to run combined from Utrecht to Zwolle. Figure 3.8 shows that the services from The Hague to Utrecht and from Rotterdam to Utrecht (each consisting of 2 train sets) are combined in Utrecht to form a train of 4 train sets. In Zwolle the train is split up in a separate train to Leeuwarden (1 train set) and a train to Groningen (2 train sets). One train set stays in Zwolle and can be used on another service, be put on stand-by or be serviced/maintained (in the case a service- or

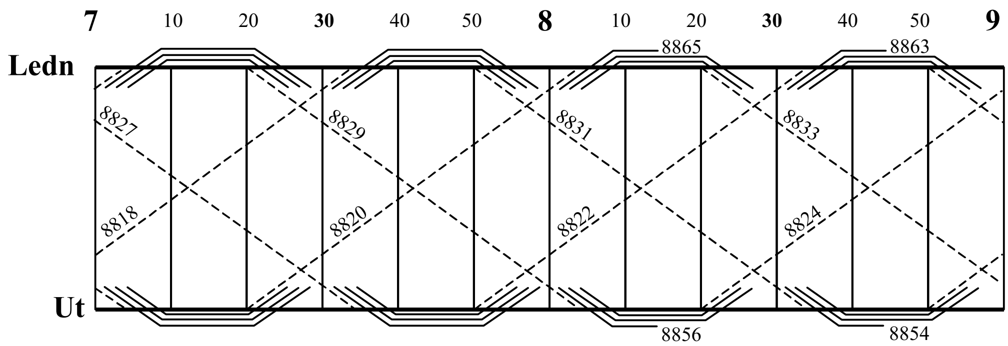


Figure 3.7: Part of the rolling stock circulation of the 8800 series between Ledn and Ut, between 7 and 9 o'clock [15]

maintenance location is present). This process requires shunting movements, which are time consuming, depending on how the composition is changed (i.e. (de-)coupled from the rear or the front of the train). The difference in train types, used in this example also indicates that the order of the train sets is important for the shunting planning. More on the use of different compositions on a line for efficient circulations is described by Alfieri et al. [19]

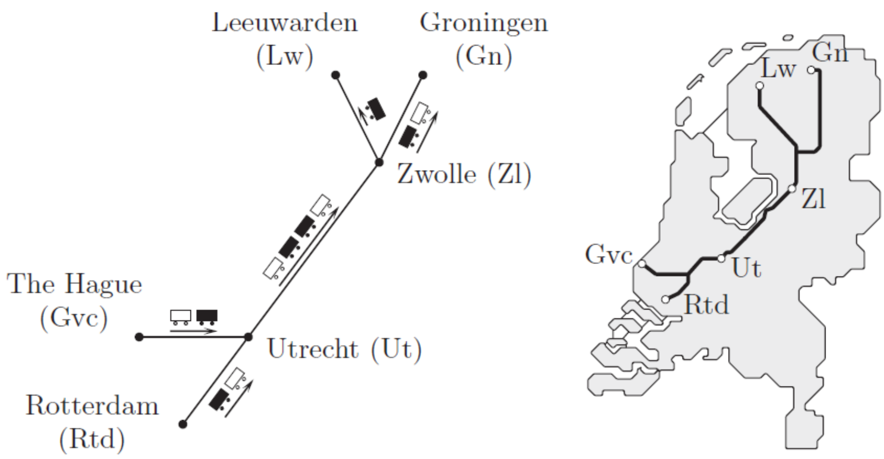


Figure 3.8: Combination of train services and compositions, where a white carriage represent a three-car-EMU and a black carriage an EMU with four carriages [15]

The required capacity is determined by so-called "counting figures" *(Telcijfers)* on "counting sections" *(Teltrajecten)*. These numbers represent the counted patronage per section of the network, per time of day. In combination with the applied comfort level for the particular train service, the required capacity can be calculated. More on the comfort level is given in Section 3.3.

Station Abbreviations

Within the Dutch railway sector it is common to use abbreviations for stations. These abbreviations are used in literature, tooling and documentation. Examples of these abbreviations are:

- Gvc: Den Haag Centraal
- Ut: Utrecht Centraal
- Amf: Amersfoort
- Amfs: Amersfoort Schothorst
- Rtd: Rotterdam Centraal
- Zl: Zwolle

Step 3: Assignment

After the circulations are made, actual train units have to be assigned to these circulations. The set of services in the circulation of a train set of a certain type is assigned to a deployment number *(Dienstnummer)*. At the operational planning department, this deployment number is assigned to a specific train set. This means that every rolling stock type has its own deployment number which consists of 2 alphabetic characters; corresponding to the rolling stock type, and 2 numerals; corresponding to the specific service (i.e. a VIRM4 = AD##, VIRM6 = AO##, ICM3 = OH##, ICM4 = OC##). The assignment of a specific train is illustrated by means of the following example:
Train series 1700 and 11700 are operated by VIRM. Figure 3.9 below shows the circulation of (virtual) VIRM6 train set OA37 on a tuesday between the start of the service, until around 11.00h. The service starts at station Enschede (Es) as train 1718 on place 1 (second train set in the composition) and runs to station Utrecht Centraal (Ut). Here, the front train set is detached and the OA37 runs toward station Den Haag Centraal (Gvc) as a single train set. At Gvc, the train set turns around and runs toward Ut as train 11727, where it is combined with another VIRM train set (OA37 runs at the front, hence train number 11727.0). In this combination the train runs to station Amersfoort Schothorst (Amfs). Here the train turns around onto the 11728 to Gvc and so on.

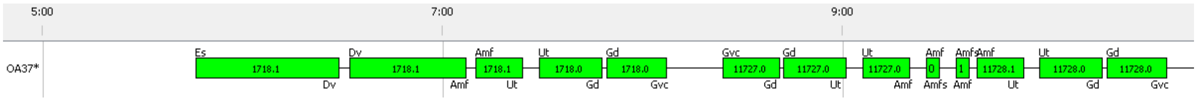


Figure 3.9: Circulation of OA37 (time on horizontal axis), with the operated services displayed as a green box and the start station at the top left and terminal station at the bottom right of each service.

The assignment is done on operational level and is done on a daily basis. Factors that influence the assignment process are: availability of the train sets, maintenance needs for trains, place of the required train sets in the stabling yard. In special occasions, train compositions can be chosen to differ from the original plan, due to e.g. events. An extra train set can be added to a composition due to a football match for example. Again, these measures are limited to the availability of the correct rolling stock types.

Step 4: Shunting and Maintenance

After the (physical) train units are assigned to the services, a shunting plan has to be made. This plan specifies where a train is parked (stabled), how the trains are routed from and to stabling yards. As mentioned in the assignment-step, trains have maintenance needs. If a train set is planned for maintenance, it must be ensured that it is at a workshop and that it is routed to that workshop so that it can be serviced. Maintenance can vary from cleaning to small check-ups to large overhauling. Each maintenance task has its own needs in terms of facilities and location and therefore requires accurate planning. With an increasing intensity on the network and at the nodes, a lot of work is in progress at NS, related to local planning. More details on node planning/shunting can be found in the work of Freling et al. [20].

3.2.2. Tools

For the process of rolling stock planning, NS uses a couple of tools. These tools can be used for study purposes or for the actual rolling stock planning. Since timetable design is the preceding step in the railway planning framework (as can be seen in Figure 2.1), timetable tool 'DONS' is discussed briefly as well. At this moment, the rolling stock planning is done with the following tools: Opmaat is used for coarse, long-term studies, VPT is used for the actual planning, TAM is used in combination with VPT to make an optimised planning and in the future, Donna will be used. These tools will be described in the following section.

Timetable Studies: DONS

DONS is a tool which can be used to perform studies on the timetable. It is able to construct timetables, given the railway infrastructure, trains and their paths and frequencies, and constraints expressing commercial wishes and technical limitations [23]. Although DONS has little relation to rolling stock planning, it is an important tool in the entire planning process since outcomes of the tool can form the foundation of rolling stock studies.

Studies: Opmaat

As mentioned in the section on the planning framework, different time horizons exist, each with its own purpose. On the long-term, plans like new lines, higher frequencies, additional stops, changes in the infrastructure etc., have to be checked for impact on the rolling stock deployment and more specific; the amount of trains required to execute certain plans and timetables. Since the level of detail of this planning stage is limited, there is no direct need for rolling stock circulations, train assignment and other planning-features. For this reason the 'Opmaat'-tool was developed. Opmaat is an Excel based tool that evaluates the required amount of carriages per type of rolling stock, occupancy rates and train-/carriage-kilometres on train series-level. Opmaat is used for the business planning (determining financial impact of line plans) and determines its results on BU-level (with eight o'clock cross section) and 7x24-level.

Input Opmaat uses input parameters from various sources, most of which are logistic. This means that they are based on the desired timetable, the available resources (rolling stock and infrastructure) and other planning decisions. Other parameters have a more commercial nature and are chosen from the customers perspective. The following logistic parameters are used by Opmaat:

- Rolling stock related parameters like carriage capacity per rolling stock type
- Infrastructure- and train related parameters, which are merged in the travel time per track section
- Time of day parameters; if a train runs in the peak hours or off-peak
- Turn-around-times
- Line intensities (patronage per line); these are provided by the Customer & Market *-NL: Klant & Markt-* (K&M) department (the so-called counting figures)
- Line frequencies

These logistic parameters are supplemented by some commercial specifications/parameters, like:

- Desired type of rolling stock
- Accepted Level of Service (LOS)

Calculations The tool calculates for the selected scenario (this can be a certain timetable, e.g. the BU of a certain year) the peak line intensities for the eight o'clock cross section. Based on the capacities of the selected rolling stock types and the prescribed LOS, the tool calculates the required carriages per type per line. The tool uses carriage capacities and various empirically determined multiplication factors to calculate the normative peak intensities from the patronage prognoses.

Output After performing the calculations, the tool delivers the following outputs:

- Estimate of the amount of carriages per rolling stock type. This can be filtered by train type (Sprinter/IC), operation area (Hoofdrailnet/contractsector)
- The amount of carriage-kilometres *(NL: bak-kilometers)*, which is a relevant indicator for the commercial- and maintenance departments.

Calibration The tool is mainly used for future planning, which means that predicted line intensities are used. The tool is calibrated with use of the actual intensities, as they have been measured in real-life. The empirical factors are redetermined and calculation methods are refined regularly to ensure that the results of the tool remain valid with each new timetable or situation that is calculated.

Planning: VPT

For the actual rolling stock planning, NS uses Vervoer per Trein (VPT). VPT has been used for the entire planning of the timetable, rolling stock and crew and the link to traffic control, but is being replaced by newer systems, like Donna, piece by piece. The rolling stock planning part of VPT is still in use. It makes the actual planning for rolling stock based on time- and route data of trains from the timetable. This data determines the train movements. Specific train compositions are assigned to these train movements. The process is done manually. In its current form, VPT does limited calculations or other operations to the rolling stock planning and is merely a tool to communicate with the timetable-software (Donna) and traffic control system. For this reason, no detailed functionality will be discussed in this thesis.

Optimised Planning and studies: TAM

One of the latest tools for rolling stock planning at NS is TAM. TAM is an optimizer that is designed to create and adjust rolling stock circulations using an optimiser, and to inspect rolling stock circulations. The tool can be used to adjust a current circulation to new specifications (e.g. in case of a BDU). For temporary changes, like an event, the tool can be used by the daily planning department (*dagplan*). In case a current circulation does not fit the new specifications, TAM can be used to create a new circulation that keeps the deviations from the original plan to a minimum. This way, other areas of planning are affected minimally (node planning, crew planning) [21].

The functioning and use of TAM is discussed extensively in the work of Fioole et al. [22] and Nielsen [16] and will be explained in more detail in Section 3.3.

Node Planning: OPG

For the microscopic planning on node level, i.e. the planning of routes and capacity on stabling yards, a tool is developed called Stabling Plan Generator *-NL: Opstelgenerator* (OPG), which can be used to do integral node planning. This includes; planning on stabling track level, shunting movements, treatment (cleaning and maintenance). The tool itself is being developed such that it can be implemented as a module in Donna. Since node planning is not in the main focus of this thesis, OPG will not be discussed in more detail.

Future Development: Donna Integration

Donna is introduced as integral planning system for the entire Dutch rail network. Initially it is used by ProRail and the users of the network to allocate capacity and make the timetable (Donna PTI). The planning of other assets, next to the rail infrastructure/capacity, nowadays is done by different tools. The aim is to bundle these features in Donna, to create an efficient and integral planning environment. NS already does the timetable planning in Donna , but aims to have the rolling stock- and crew planning modules (respectively Donna PM and PP) operational within short notice. This means that some older applications will be discontinued or that they are integrated in Donna. This is the case for TAM, where the entire application will be integrated as a module in Donna and with that, discontinuing VPT.

3.3. TAM: Tool for Rolling Stock Circulations

One of the goals of this thesis is to verify if TAM is a useful tool to assess the impact of changes in the infrastructure on the rolling stock planning, with a focus on rolling stock circulations. Therefore, it is necessary to explain what the tool does and how it works.

TAM is a rolling stock circulation tool, based on the work of Fioole et al. [22] and has been developed internally at NS. The foundation of the model is a cost function, which is minimised with the use of the CPLEX optimiser. In the following section, a summary of the mathematical background of the tool is provided and, subsequently, a more practical description of the program is given. The following model formulation is a summarised version of the model and is derived, or in some cases taken directly from the work of Fioole.

3.3.1. Mathematical Background

The total cost function, or objective function, used by TAM is formulated in Equation (3.1). One of the main building blocks is the set of trips T; a sequence of consecutive train movements in which the train composition cannot change. Trips are characterised by their departure station $s_d(t)$, arrival station $s_a(t)$, departure time $\tau_d(t)$ and arrival time $\tau_a(t)$. Another building blocks are the set of train unit types, denoted by M and compositions; a combination of train sets or carriages (elements of M) that form a train, denoted by p. The objective function consists of the following main decision variables: $X_{t,p} \in (0,1)$; whether composition p is used for trip t, $Z_{t,p,p'} \in (0,1)$; whether trip t has composition p and successor trip $\nu(t)$ has composition p', and $N_{t,m}$ denotes the number of train units of type m that are used on trip t. The 'inputs' are denoted by the set of stations: S and the set of train unit types M. Since the amount of available train units is finite, n_m denotes the amount of available train units of type m. $n_{p,m}$ is the number of train units m that is in composition p.

$$min\, F(X,Z,N) \tag{3.1}$$

The three variables of the objective function can be converted to more practical metrics in the following way: Variable $N_{t,m}$ can be converted to the amount of carriage kilometres (CKM) by means of Equation (3.2), where l_t is the length of trip t and c_m is the number of carriages in a train unit of type m.

$$CKM = \sum_{t\in T} \sum_{m\in M} l_t \cdot c_m \cdot N_{t,m} \tag{3.2}$$

Variable $X_{t,p}$ can be rewritten to the seat-shortage kilometres (SKM) as in equation (3.3), where P_t is the set of allowed compositions for trip t, and $s_{t,p}$ represents the expected number of seat shortages when composition p is used for trip t. "The shortage is computed by comparing the predicted number of passengers to the capacity of the train compositions." [22]

$$SKM = \sum_{t\in T} \sum_{p\in P_t} l_t \cdot s_{t,p} \cdot X_{t,p} \tag{3.3}$$

The third variable; $Z_{t,p,p'}$, represents the number of shunting movements (SHM) as in Equation (3.4). In this equation, Γ_t is a parameter that denotes if a certain composition change is allowed between two consecutive trips. The shunting possibilities are described in the set Γ_t. The term $\beta(p) \neq \beta(p')$ indicates that a composition change is not possible in this simplified version of the model. Fioole et al. [22] gives the extended model in which the splitting and combining of trains do is allowed.

$$SHM = \sum_{t\in T} \sum_{\substack{(p,p')\in\Gamma_t: \\ \beta(p)\neq\beta(p')}} Z_{t,p,p'} \tag{3.4}$$

From Equations (3.1) to (3.4) it can be concluded that the predominant rolling stock parameters to be minimised in TAM are carriage kilometres, seat-shortage kilometres and shunting movements. By means of varying other parameters, like penalising carriage kilometres of certain rolling stock types or seat-shortage kilometres for first class passengers more, variations of the model can be made. Such variations are discussed in more detail in the work of Fioole et al. [22].

Model Constraints

The model uses various constraints to model real-life conditions properly. The following constraints are used: Constraints (3.5) ensure that, for each trip, exactly one composition is used. Constraints (3.6) and (3.7) make sure that compositions are linked correctly to consecutive trips. In these constraints, T_1 denotes the set of trips without a defined successor trip. Constraints (3.8) describe the relation between the used composition for a trip and the amount of train units of the different types. Constraints (3.9) to (3.12) specify the number of coupled and uncoupled train units. In these constraints, $C_{t,m}$ denotes the number of train units of type m that have been coupled to the composition right before trip t, and $U_{t,m}$ expresses the number of train units uncoupled right after trip t. T_0 expresses the set of trips that have no preceding trip defined. Constraints (3.13) correctly allocate the available train units to the initial inventories at the various station. Constraints (3.14) are related to the inventory of train units at the various stations. In these constraints, $I^0_{s,m}$ denotes the number of train units of type m that start from station s and $I_{t,m}$ is the number of train units m, stored at station $s_d(t)$, after trip t has departed. $\varrho(s)$ denotes the re-allocation time at a station (or: waiting time). The last constraints ((3.15) to (3.18)) describe the binary or non-negative nature of the variables.

$$\sum_{p\in P_t} X_{t,p} = 1 \qquad \forall t \in T \tag{3.5}$$

$$X_{t,p} = \sum_{p'\in P_{\nu(t)}:(p:p')\in\Gamma_t} Z_{t,p,p'} \qquad \forall t \in T\setminus T_1; p \in P_t \tag{3.6}$$

$$X_{v(t),p'} = \sum_{p \in P_t : (p:p') \in \Gamma_t} Z_{t,p,p'} \qquad \forall t \in T \setminus T_1; p' \in P_{v(t)} \tag{3.7}$$

$$N_{t,m} = \sum_{p \in P_t} n_{p,m} X_{t,p} \qquad \forall t \in T; m \in M \tag{3.8}$$

$$C_{v(t),m} = \sum_{(p,p') \in \Gamma_t : n_{p',m} > n_{p,m}} (n_{p',m} - n_{p,m}) \cdot Z_{t,p,p'} \qquad \forall t \in T \setminus T_1; m \in M \tag{3.9}$$

$$U_{t,m} = \sum_{(p,p') \in \Gamma_t : n_{p,m} > n_{p',m}} (n_{p,m} - n_{p',m}) \cdot Z_{t,p,p'} \qquad \forall t \in T \setminus T_1; m \in M \tag{3.10}$$

$$C_{t,m} = N_{t,m} \; and \; U_{t,m} = 0 \qquad \forall t \in T_0; \; m \in M \tag{3.11}$$

$$U_{t,m} = N_{t,m} \; and \; C_{t,m} = 0 \qquad \forall t \in T_1; \; m \in M \tag{3.12}$$

$$\sum_{s \in S} I^0_{s,m} = n_m \qquad \forall m \in M \tag{3.13}$$

$$I_{t,m} = I^0_{s(t),m} - \sum_{\substack{t' \in T' : s_d(t') = s_d(t), \\ \tau_d(t') \le \tau_d(t)}} C_{t',m} + \sum_{\substack{t' \in T' : s_a(t') = s_d(t), \\ \tau_a(t') \le \tau_d(t) - \varrho(s_d(t))}} U_{t',m} \quad \forall t \in T; \; m \in M \tag{3.14}$$

$$X_{t,p} \in 0,1 \qquad \forall t \in T; p \in P_t \tag{3.15}$$

$$N_{t,m}, C_{t,m}, U_{t,m}, I_{t,m} \in \mathbb{R}_+ \qquad \forall t \in T; \; m \in M \tag{3.16}$$

$$I^0_{s,m} \in \mathbb{Z}_+ \qquad \forall s \in S; \; m \in M \tag{3.17}$$

$$Z_{t,p,p'} \in \mathbb{R}_+ \qquad \forall t \in T; \; (p,p') \in \Gamma_t \tag{3.18}$$

Some (physical) limitations in the deployment of trains are incorporated in the model with the use of additional (derived) variables, like the limitations on train lengths, which are derived from the train composition variable $X_{t,p}$. More details of the TAM model are given in the work of Fioole et al. [22].

In the next part, a more practical description of the TAM software is given. Some links between practice and theory will be made.

3.3.2. Inputs

This section describes the practical operation of the program. The program is loaded with data and parameters in a couple of consecutive steps. Initially, the train series can be selected that are evaluated in the model run. In this stage, claims on rolling stock for cleaning or maintenance can be made as well. The following inputs, which are used by the optimiser to make a circulation, are shown in Figure 3.10 and are discussed below.

Reference Plan Since TAM can be used to adjust current rolling stock plans/circulations as well, a reference plan can be added to the selection. The results of the optimiser are compared with the reference plan to see what the changes to this original plan are.

Timetable To start a new study or to make a new plan, a timetable has to be loaded. This timetable is imported from the planning tool VPT and contains all the trains planned with Donna and consists of all the trips t.

Prognosis With the selection of the timetable, also the prognosis (counting figures) can be loaded. By default, the numbers are used from VPT, which originate from the TDO/K&M department, but also other prognoses can be loaded. The prognoses are the (estimated) patronage per section of the network between two stations.

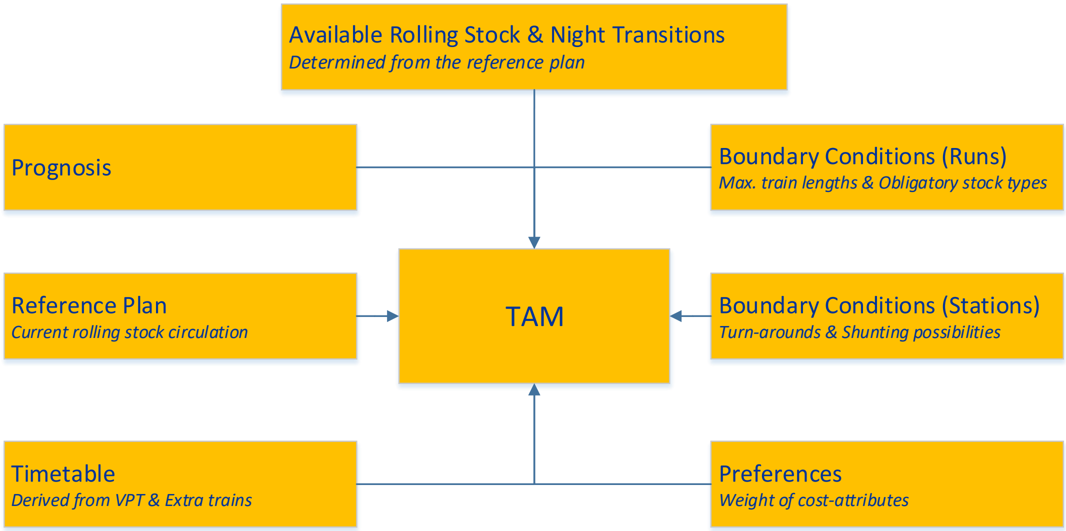


Figure 3.10: Requirements for TAM [21]

Available Rolling Stock The rolling stock plan can be made, based on the available rolling stock. Per train type, the amount of train sets (n_m in the model), that are available for the solver, can be selected. The program displays the amount of train sets that start and end in the reference plan at a certain station (i.e. the rolling stock inventory).

Boundary Conditions (Trips) The boundary conditions for the trips specify the limitations, on train movement level (i.e. per section of a trip). These conditions comprise of infrastructural constraints, like maximum train lengths (i.e. amount of carriages per network section), but also the comfort standard per track section, which is described in the grey box below.

Boundary Conditions (Stations) The boundary conditions on station level specify the conditions for turn-arounds and shunting (Γ_t). Based on these conditions one train series can be turned around on another series. These values also incorporate the re-allocation times; the minimum time a train set needs after decoupling from an arriving train at a certain station before it can be deployed again (in the model denoted as $\sigma(s)$).

Preferences The preferences determine how the solver runs to produce a solution. As mentioned before: the program minimises a cost function. The model preferences determine how the costs are evaluated and can specify the weights of certain cost-attributes. In this way, the solver can find a solution which, for example, assigns higher costs (i.e. the prior mentioned 'penalty') to carriage kilometres, and therefore results in a solution that has a lower amount of carriage kilometres. Penalties can be assigned to, for example:

- Carriage kilometres
- Kilometres exceeding comfort standard
- Used compositions
- Changes in the original plan (capacity, stock type, composition) (based on the reference plan)
- Changes in shunting activities (based on the reference plan)

CAV Comfort Standard [24]

NS uses comfort standards (norms) to plan rolling stock according to prognoses. A comfort norm is the specification of a comfort class, which a train has to comply to on a certain route, depending on the train type or time of day (peak or off-peak). NS uses three norms: C= Comfortable, A= Acceptable and V=Full *(NL: Vol)*. The three norms calculate the available capacity of a train in the following ways:

- $C = \#\ of\ Seats + \#\ of\ Folding\ Chairs$
- $V = \#\ of\ Seats + \#\ of\ Standing\ Places$
- $A = \frac{C+V}{2}$

For first class passengers, the C-norm is used, regardless of the time or train type. For second class in the off-peak hours, the C-norm is used as well. For second class passengers in the peak hours, the following classes are assigned:

Train type	Travel Duration	Applied norm
IC	$\leq 15min$	A
IC	$> 15min$	C
Sprinter	$\leq 15min$	V
Sprinter	$> 15min$	A

With the provided inputs, TAM can make plans for a desired selection of days in the week or for a specific day in the week only. It creates a workable input for the Linear Programming (LP) solver CPLEX, which minimises the cost function (Equation (3.1)).

3.3.3. Output

After running the solver, an output is returned. Various graphical and numerical outputs can be generated. A selection of outputs that are relevant for this thesis, is discussed here. Other, more detailed outputs are available as well (e.g. detailed spreadsheets with composition information per route section), but since these can all be derived from the outputs discussed below, they are not discussed.

Graphical

TAM can provide a graphical representation of the determined services in the circulation. In this view the colours can be chosen to display various comparisons with a reference plan. Figure 3.11 shows a part of a generic circulation of VIRM train sets for a day in 2016. In this view, the difference of the calculated plan with a reference plan is shown. Figure 3.12 shows the same circulation, but now with the colour scheme that visualises the capacity norms (CAV-norm) and the exceeding of the applied norm. Other views that can be selected are: Composition, seat shortages, amount of train managers, amount of carriages, train set surplus.

Another graphical output is the shunting-activities-view, of which an example is shown in Figure 3.13. In this overview, all shunting activities are displayed, varying between starting and ending, combining, splitting and turning around.

A third way of displaying the outputs of TAM is by means of Train Diagrams. This TWD is similar to the ones displayed in Figure 3.2. In TWD-representation, outputs like the used composition, capacity, shortages etc. are projected on the on the lines in the TWD. In Figure 3.14, the seat shortage is shown on the TWD of VIRM train sets between Zwolle (Zl) and Leeuwarden (Lw). This figure also shows clearly the turn arounds in Leeuwarden (the curved lines).

Numerical

TAM returns a lot of numerical values as well. Next to a numerical report of all separate activities (trips t), various KPIs are produced. Table 3.1 gives an overview of the KPI-summary by TAM. From this overview it can be concluded that most of the presented metrics can be reduced to the main decision variables mentioned earlier (eq. (3.2), (3.3) and (3.4)). Some of the metrics are related to crew planning; for example 21 and 22 mention duties of train managers. Although crew planning is not in the scope of this thesis, TAM is able to deliver (rough) indicators/estimates on crew usage of a circulation. The last column of the table indicates the

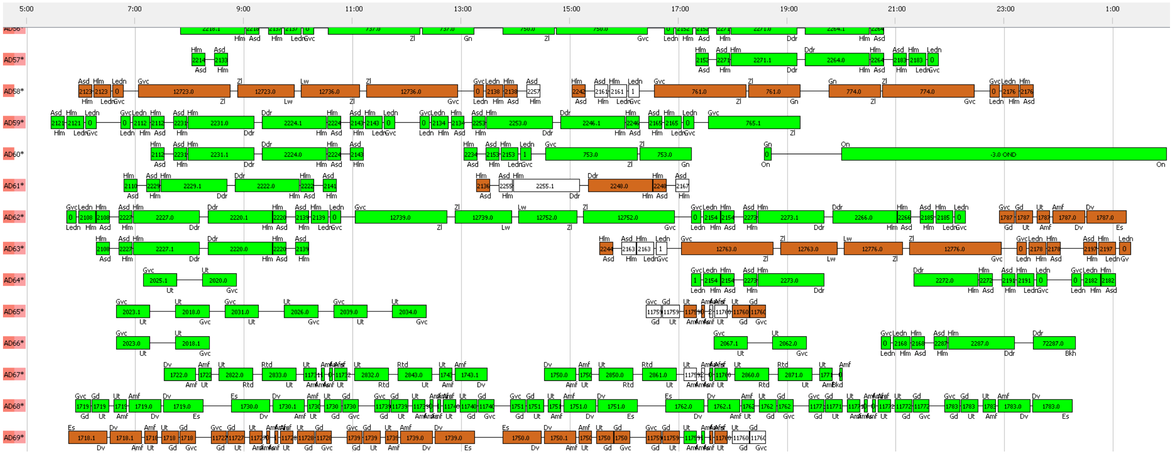


Figure 3.11: Services view for VIRM train sets (BDU feb. 2016) for one day; comparison on train type. Green= same train type, brown= different train type (same rolling stock type) white= new in plan

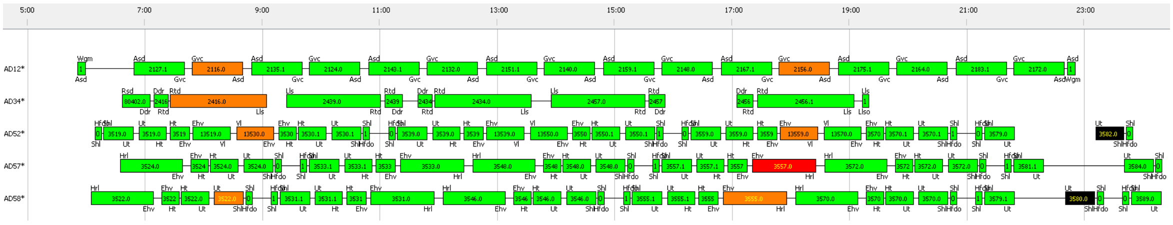


Figure 3.12: Services view for a selection of VIRM train sets (BD 2016) for a Tuesday; comparison on CAV-norm. Green= C-norm, Orange= A-norm, Black= V-norm, Yellow-font= exceeding the applied norm

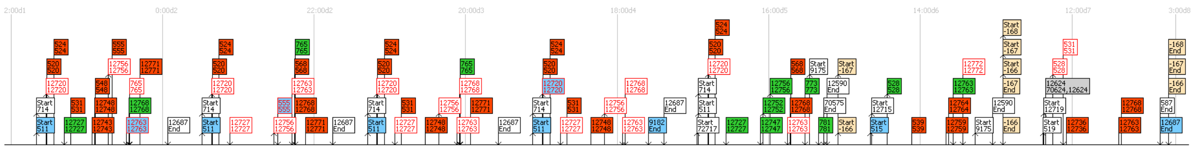


Figure 3.13: Shunting activities at Zl for VIRM train sets (BDU feb. 2016) for an entire week. Starting and ending services denoted with, respectively, 'start' and 'end'. Red= new activity, blue/grey= changed activity type, green= cancelled activity, beige= new turn-around, red font/grey= splitting/combining

category in which the indicators are assigned to. The indicators are divided in three groups: Train; for indicators that are merely related to the train itself, Pax; indicators that are related to the transported passengers and crew; merely related to crew planning. This grouping will be used in Section 5.1.

Attachments and detachments *(NL: Aftrappen/bijplaatsen)* refer to the attachment of an extra train set to an operating train (service), or the detachment of a train set from a service. The 4%, mentioned in '10' and '12' is a predetermined value of exceeding a norm, it functions as a margin. If a norm is exceeded by, for example, only 5 passengers the train should ideally be extended. Since this extension with an entire extra train set is a costly measure for only these 5 passengers, the 4% margin is agreed upon.

Currently, there is a debate among NS staff on how to handle trip sections in which the CAV-norm is exceeded. In the past, the actual hindrance of the capacity being exceeded was counted by means of passenger kilometres of the passengers that exceeded the norm. A new method suggests that in a case of capacity exceeding; all the passengers experience hindrance because of this. Therefore the entire patronage of that train is counted as 'experience hindrance'. This is explained in Figure 3.15. The left bar indicates the capacity of a train, with the 4% margin on top. The middle bar indicates the past situation, in which only the 15 passengers (in red) are counted as 'experiencing hindrance'. In the right bar, all passengers experience hindrance. Due to this new method, exceeding capacity is considered to be more disadvantageous.

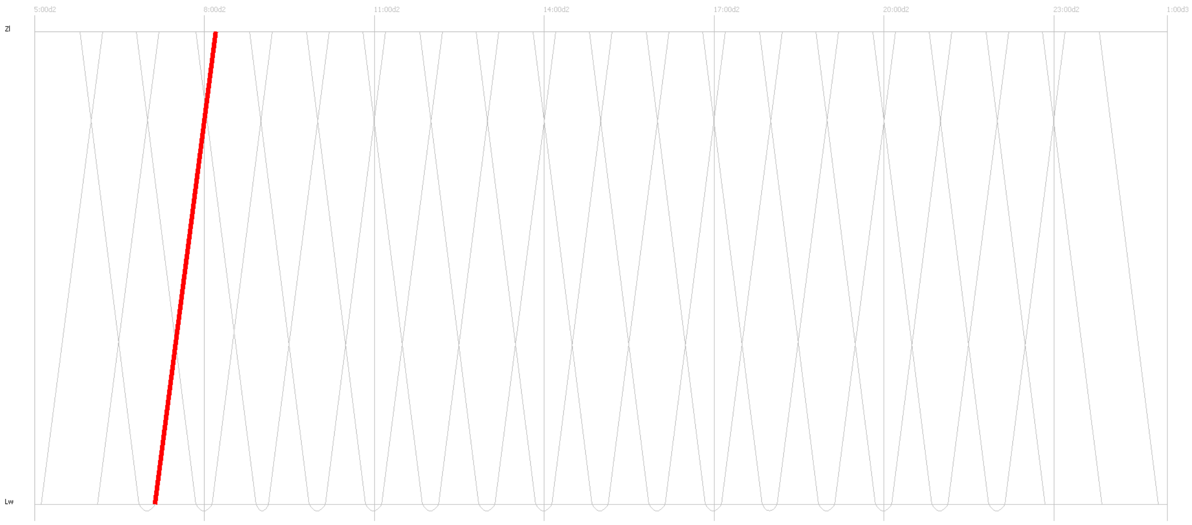


Figure 3.14: Time-space diagram/Train Diagram of VIRM series between Zl and Lw. The red line indicates a seat shortage on the service starting at 07:08 in Lw, heading to Zl

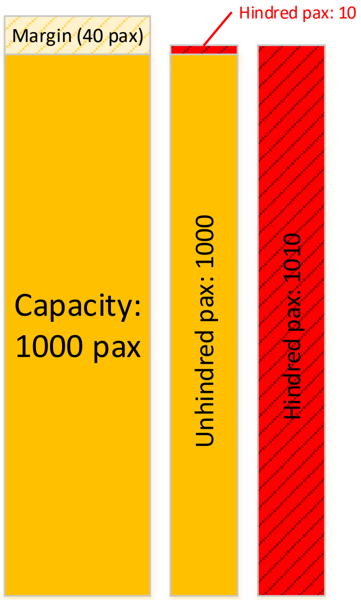


Figure 3.15: Example of the old and new way of treating a capacity exceeding. Assumed patronage: 1010 passengers. Left bar= capacity of train, middle bar= old situation, right bar= new situation

Table 3.1: Numerical outputs from TAM

	Metric (Dutch)	English Translation	Category
1	Aantal Rangeeractiviteiten	Number of shunting activities	Train/Crew
2	Aantal starters/eindigers	Number of starters/enders	Train/Crew
3	Aantal keer bijplaatsen/aftrappen	Amount of detachments/attachments	Train/Crew
4	Rit kilometers	Trip kilometres	Train/Crew
5	Bak kilometers	Carriage kilometres	Train
6	Passagier bak kilometers	Passenger carriage kilometers	Train
7	Leegmat bak kilometres	Empty car kilometres	Train
8	Totale reizigers vraag	Total passenger demand kilometres	Pax
9	Totaal geboden plaatsen	Total supplied seat-kilometres	Pax
10	Totaal geboden plaatsen (4%)	Total supplied seats-kilometres (4%)	Pax
12	Totaal tekort plaatsen	Total shortage seats-kilometres	Pax
12	Totaal tekort plaatsen (4%)	Total shortage seats-kilometres (4%)	Pax
13	1e klas zitplaatstekort km's	First class seat shortage kms	Pax
14	2e klas zitplaatstekort km's	Second class seat shortage kms	Pax
15	Aantal passagiers ritten	Amount of Passenger trips	Pax
16	Aantal ritten boven comfortabel norm	Trips above C-norm	Pax
17	Aantal ritten boven acceptabel norm	Trips above A-norm	Pax
18	Aantal ritten boven vol norm	Trips above V-norm	Pax
19	1e klas zitplaatsoverschot	First class seat surplus	Pax
20	2e klas zitplaatsoverschot	Second class seat surplus	Pax
21	Totale rijtijd conducteurs	Total travel time train mangers	Crew
22	Aantal conducteursdiensten	Train manager duties	Crew
	Afwijkingen van bestaand plan:	*Deviations of current plan:*	
23	Nieuwe rangeeractiviteiten	New shunting activities	Train
24	Bijplaatsen wordt aftrappen	Attaching becomes detaching	Train
25	Aftrappen wordt bijplaatsen	Detaching becomes attaching	Train
26	Verandering in aantal/type stellen bij bijplaatsen	Change in composition for attaching	Train
27	Verandering in aantal/type stellen bij aftrappen	Change in composition for detaching	Train
28	Starter met verandering in aantal/type stellen	Starter with change in composition	Train
29	Eindiger met verandering in aantal/type stellen	Ender with change in composition	Train
30	Aantal ritten met gewijzigde samenstelling	Trips with changed composition	Train
31	Aantal ritten met minder capaciteit	Trips with less capacity	Pax
32	Aantal ritten met meer capaciteit	Trips with more capacity	Pax
33	Aantal ritten met extra hc op service norm	Trips with extra train manager on service norm	Crew
34	Aantal ritten met extra hc op veilig norm	Trips with extra train manager on service norm	Crew

3.4. Project DSSU

This section is not actual literature review, but provides background information on the DSSU project. The backgrounds are required to get context on what the contents of this projects are. As mentioned in Chapter 2, an analysis is carried out on a real-life situation to see how it deviates from the normative process. The project DSSU is chosen, since it is finished relatively recent (at the end of 2016). Knowledge on the project is still 'fresh' and most of the involved actors still work at NS. Furthermore, it is a comprehensive project, in which a lot of planning disciplines are involved and which spans a broad time horizon. Based on these factors it can be concluded that the project is representative as a case study for assessing a real-life infrastructure mutation process.

The DSSU project is a large-scale project at the central station of Utrecht. The goal of DSSU is to enhance the capacity, quality and robustness of the railway infrastructure around Utrecht Centraal in the coming years [25]. Utrecht is an important and central node in the Dutch railway network. In 2015, 176.552 travellers started and ended their journey in this station [26] and due to the central position in the network, around 285.000 people use the station on a daily basis. It is expected that this number will rise to 360.000 per day in ten years [27]. To cope with this growth, various plans have been introduced to increase capacity of this node. This includes the expansion of the station itself, by converting the building into a Public Transport Terminal (OVT), where various modes are integrated in a single building. Furthermore, the capacity on the rail-side is increased, this is done with the flow-through philosophy of DSSU. The project is also part of Program for high-frequency railway traffic *-NL: Programma Hoogfrequent Spoorvervoer-* (PHS), a program that is introduced to intensify the traffic on main corridors of the Dutch railway network.

The works that were included in the DSSU project are: [25]

- Relocation and replacement of tracks;
- Removal and/or renewal of switches;
- Realisation of a new (8th) platform at Utrecht central station and construction of two extra platform tracks (track 20/21) (*Part of project OVT, which is mentioned later*);
- Platform adaptations at station Utrecht Centraal, including the adaptations of passenger tunnels and (re)placement of platform canopies;
- Construction of various technical buildings and emergency track-crossings;
- Temporary works, like construction yards and a soil depot.

Before the start of the project, the way the station was used differed significantly from the way it is used nowadays. Train services started and ended at Utrecht, resulting in the turning around of trains. Also compositions of trains were changed at the station, making use of the adjacent stabling yards: Cartesiusweg (North-west of the station), Landstraat (North-east of the station), Opstelterrein Zuid (OZ: South of the station). To accommodate the shunting movements, a lot of switches where present at the station, resulting in a high accessibility from the platform tracks to the stabling yards. The high amount of possibilities to manoeuvre across the switch yard can be seen in Figure 3.16.

Programma Hoogfrequent Spoorvervoer

PHS is a large project that aims to intensify the frequencies on some major corridors. At the latest in 2028, 6 ICs and 6 Sprinters per hour, per direction should operate on these corridors. This means that passengers are no longer required to consult the timetable for their journey. The program is developed to adapt to the growing number of passenger- and freight trains on the network [28]. With PHS, in total 50% more passenger trains will run from and to Utrecht Centraal, compared with the situation in 2013. Also, the main freight flow between Amsterdam / Breukelen and Geldermalsen / Betuweroute (2 freight paths per hour) and the freight flow between Amersfoort – Houten/Betuweroute will be facilitated [25]. To make this increase in capacity possible, some infrastructural changes will have to be performed. These changes include: extra tracks, larger stations and removal of level-crossings (both rail-rail, as road-rail).

To comply with PHS, station Utrecht Centraal is converted to a so called "flow-through station" *(NL: doorstroomstation)*. This means that train services will no longer end or start at this station (or at least limited to a minimum). Turn-arounds are done at satellites (i.e. peripheral stations). To do so, the current, highly tangled track lay-out is converted to an untangled lay-out, where the tracks are separated in bundles per corridor. This has the additional advantage that disruptions will be limited to the specific corridor and do not propagate over the entire network.

One of the main features of the project is the significant reduction of the amount of switches. This reduces the risk of disruptions due to switch failure and separates the corridors. Also the allowed speed at the station will rise from 40 km/h to 80 km/h. However, the removal of the switches also limits the possibility of adjusting the timetable in the case of a disruption by diverting to another platform for example. It also limits the accessibility of the shunting yards. Figure 3.16 shows the vast amount of switches in the old situation. In Figure 3.17, the corridors are shown in different colours. The reduction of switches is clearly visible in this figure [29].

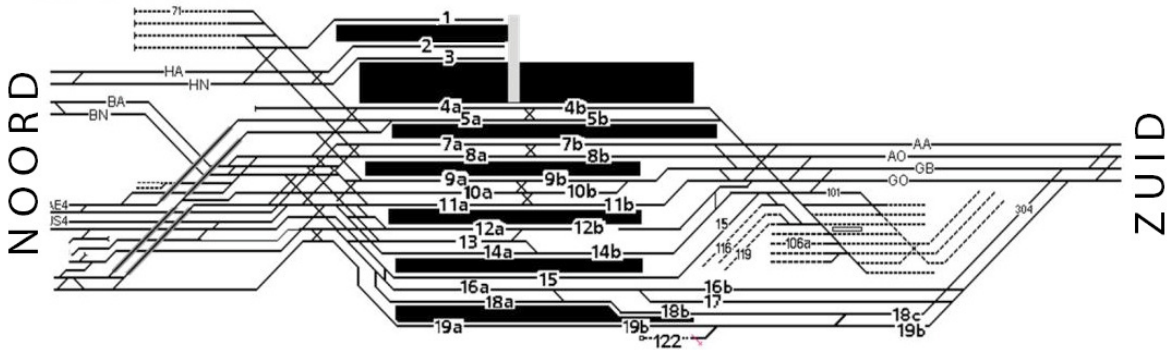


Figure 3.16: Old track lay-out of Utrecht Central station [30]

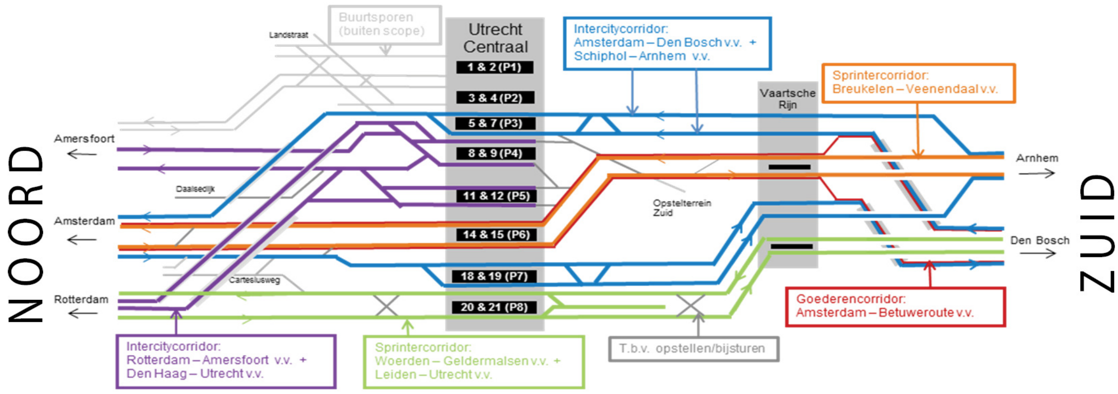


Figure 3.17: New track lay-out of Utrecht Central station [30]

3.4.1. Phases and Transitions

Due to the size of the project, the construction works have been parted in phases. One of the requirements for the project was to "keep the shop open", i.e. the station had to be (partially) operational at every time. In every phase, a part of the construction works was performed, while at the other parts of the station, operation could continue. Figure 3.18 shows the drawing of a phasing plan, in which the construction works of a particular step are displayed and in which the infrastructural limitations of that phase are displayed.

Every transition between two consecutive phase was 'stitched together' by temporarily decommissioning a part of the infrastructure. During these transitions, various infrastructure elements were taken out of service to connect the newly built tracks to the rest of the infrastructure. During these decommissioning-periods, various services were cancelled, rerouted or operated by buses. Figure 3.19 shows a schematic overview of a big decommissioning step.

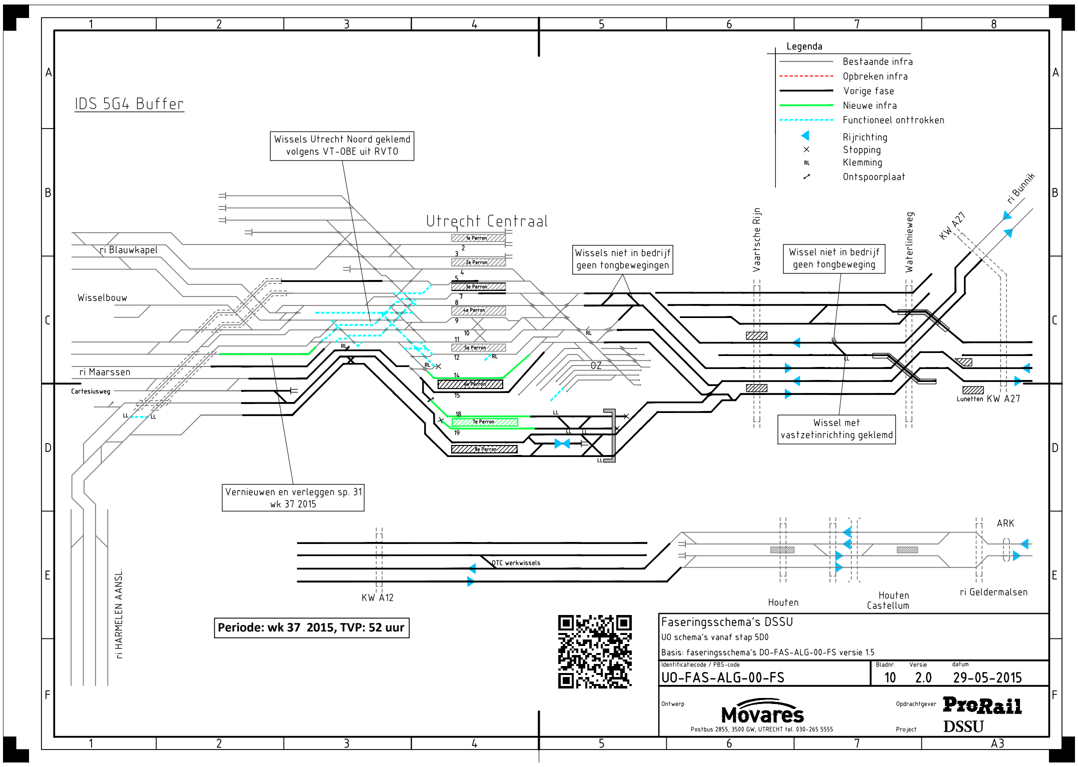


Figure 3.18: Example of the drawing of a particular phase of the DSSU-project

3.4.2. Interfaces with Adjacent Projects

During the realisation of DSSU, various other projects were carried out at or nearby Utrecht central station, next to PHS. The following sections give an overview of these projects in, so called, "Groot Utrecht". The impact and/or overlap varies between the projects. The amount of overlap is indicated at each project.

OVT

One of the main influencing co-projects for DSSU was project Public Transport Terminal *-NL: Openbaar Vervoer Terminal-* (OVT). This project comprised of the overhaul of the old station building above the tracks of Utrecht central station into a state-of-the-art public transport terminal (OVT). The old station building had capacity issues for years and therefore receives a capacity upgrade that is able to cope with 100 million passengers per year (from 2020), in comparison with the 35 million the old building was built for. The new terminal houses train, tram, bus, taxi and bicycle under one roof and connects the east and west side of Utrecht's city centre [25]. This project was the predecessor of DSSU and was initially scheduled before the works of DSSU were planned to commence. The Dutch government had requested ProRail to combine the works of DSSU and OVT to reduce the amount of years that the people would experience nuisance [31].

Randstadspoor

Another large scale project in the Utrecht region was Randstadspoor. Since 2005, an integral regional public transport system in the region of Utrecht is being developed. Randstadspoor is an urban mobility concept that uses conventional train tracks for the accessibility of a couple of suburban areas (VINEX-expansions) around Utrecht. By means of duplication of certain tracks, Sprinters and ICs are untangled, so ICs are not hindered by (delayed) Sprinters. The new services replace the national Sprinter services in the region. Utrecht Centraal will not be a terminal station, but an intermediate stop. This means that multiple destinations can be accessible without a transfer at the busy central station of Utrecht. The program is part of the long-term programme infrastructure, environment and transport (MIRT), and with that, is an independent project with its own planning and budget [25].

The use of Utrecht as an intermediate station instead of a terminus coincides with the flow-through philosophy of DSSU.

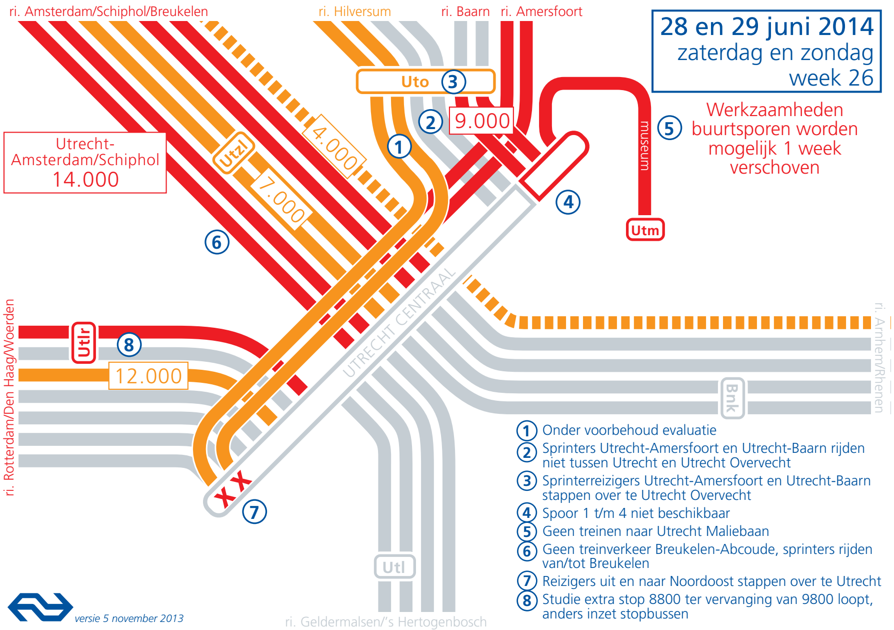


Figure 3.19: Example of a passenger impact-diagram of a particular transition, which shows cancelled routes in red and limited routes in orange. The numbers on the routes indicate the amount of passengers hindered by the transition.

Randstadspoor consist of the construction of seven new stations, the renewal of three existing stations, the expansion of the amount of tracks on four sections of the network, the construction of turn-around tracks at three locations and the removal of level-crossings. Figure 3.20 gives an overview of the works. The expansion of certain track sections and the method of operation of Randstadspoor has many overlaps with DSSU.

Figure 3.20: Overview of the catchment area of project Randstadspoor (Source: ProRail)

Stadskantoor

The construction of the new office building for the municipality and city of Utrecht took place directly next to the platforms of Utrecht Centraal. The building has been built partially over the OVT and, with that, is entangled with the construction of the terminal building. Since there is no direct relation of this project with the railway system, the overlap with and impact on DSSU is considered limited.

Moreelsebrug

As a part of the zoning plan of the municipality of Utrecht, the Moreelsebrug (or formerly known as "Rabobrug") was built as a connection for cyclists and pedestrians between the inner city and the western side of the city. The bridge has a length of 275 metres and runs over the tracks and platforms of Utrecht Centraal [29] Except that the actual placement of the bridge is above the tracks, no further relation with the railway system exists. Therefore, the overlap with DSSU is considered limited.

Renewal Hoog Catharijne Shopping Mall

Hoog Catharijne is the shopping mall that is located between Utrecht Centraal and the city centre. The mall handles a large part of the passenger flows from and to the station and therefore plays a big role in the accessibility of the station. The renovation of the mall forms a large part of all the renovation projects in the centre of Utrecht, and has large influences on the flows of people in the station area. Nevertheless, the direct overlap with the rail system is limited, and with that the overlap with DSSU is considered limited.

3.5. Conclusion of Literature Review

The literature review gives context to the thesis by means of explaining the railway planning process. The planning can be subdivided in three groups, related to the three 'railway assets': infrastructure (or capacity), rolling stock and crew. The planning for these three assets is done subsequently, since every step of the planning process is dependent on its predecessor. The level of detail of the planning products (like the BUP, BD etc.) increases as the implementation date of the specific timetable product approaches.

For rolling stock planning, various tools exist, based on the level of detail and the time before implementation of a plan. TAM has been introduced to automate the process of creating rolling stock circulations, which has been done by hand in the past. It has various possibilities of optimising a circulation on various parameters. For example to focus on the minimising of the amount of carriage kilometres.

DSSU has been a comprehensive renewal project in the centre of the Dutch railway network. The project has been subdivided in various construction phases, since the station had to be kept operational at all times. Besides the scale of the project itself, it had a lot of adjacent project which had interfaces with DSSU, making the project even more complex.

4

Process of Infrastructure Mutations

The introduction already mentioned that the process of infrastructure mutations is a complex project with various actors and that the interfaces between these actors are a source of impedance of the process. A 'soft systems approach' is used to analyse the process, its stakeholders an bottlenecks, as mentioned in Section 2.1. The chapter starts with determining the system of the thesis in Section 4.1. After having determined the system, the actors in the system are discussed. This is done in Section 4.2, where the organisation structure of the planning departments within NS (in relation to the infrastructure mutation process) is discussed. In this stakeholder analysis, the involved departments and their roles in the process are mentioned. Subsequently, a reconstruction of the process is made (Section 4.3) and bottlenecks in the process will be identified (Section 4.3.5). These results will conclude the analysis of the normative process that is carried out when infrastructure mutations are issued.

Besides the normative process, an analysis of the process for the DSSU project is carried out in Section 4.4. Here, the deviations from the normative approach and the possible causes for these deviations are identified. In Section 4.5, solutions for the identified bottlenecks are suggested.

4.1. Definition of the System

The first step of the approach, mentioned in Section 2.1, is determining what the end-product of the system is and what the sub systems are. For this thesis, the system that has to be designed is the 'train service'. This, in the case where the original infrastructure changed from the situation where the service was based on in the first place. This system comprises of all the sub systems needed to operate the train service and to transport passengers in a way that the passenger feels connected by NS [2]. Section 2.1 mentioned the relationship of the 'three main assets' of a railway system: Infrastructure, Rolling Stock and Crew. The optimal planning for these individual assets can be considered as the sub systems. Practically, this results in the following three sub systems:

- Infrastructure planning (and capacity allocation) and with that; timetable design. Elaborated in Section 3.1.2
- Rolling stock planning. Elaborated in Section 3.2
- Crew Planning. Out of the scope of this thesis, and therefore, not discussed further.

The next step is to determine the stakeholders of the system and their roles for the system. An overview of the relevant stakeholders (or actors), within the organisation of NS is given in Section 4.2.

4.2. Stakeholder Analysis

The following section discusses the departments within NS that are responsible for the planning of the timetable and rolling stock. To get a good and complete impression of the relations within the organisation, the organisational structure is mentioned from executive level to the level of implementation. At the moment NS is in the middle of various organisational reforms. The structure of the planning departments, often referred to as the 'logistic departments', is being rearranged. First, the current structure is mentioned. There is some ambiguity in the nomenclature of some departments, but the following section aims to give the best interpretation of the current structure. In Section 4.2.2, this new structure is discussed. To ensure applicability of the results of this thesis, the aim is to focus on generic roles, instead of specific names of positions or departments. As a reference for the occasions when this is not possible, Table 4.1 shows the names of the department in both old and new situation.

4.2.1. Current Organisational Structure

Below, the organisational structure of the departments, involved in the process of infrastructure mutations, is discussed in its current form. The organisational tree is displayed in Figure 4.1. The description is done in a top-to-bottom way, i.e. from management level to implementation level (top to bottom).

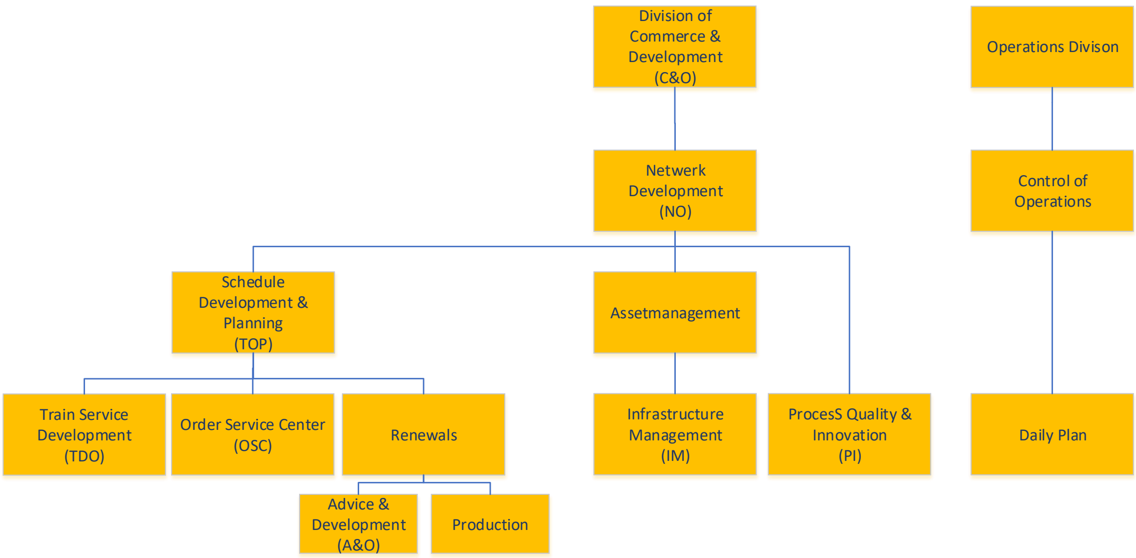


Figure 4.1: Organigram related to infrastructure mutations (current situation)

Division of Commerce & Development Most of the planning (or: 'logistic') departments fall under the responsibility of the division Commerce & Development *-NL: Commercie & Ontwikkeling-* (C&O). The division C&O is responsible for the development-, sales-, and marketing activities of NS. The goal is to "provide an executable and profitable supply of transport from "a single hand" and to make clear promises that are realisable." [34]

C&O is the management division responsible for the commercial viewpoint on infra mutations, in cooperation with the Operations division *(Directie Operatie)*. This management branch will be responsible for the department Network Development *-NL: NetwerkOntwikkeling-* (NO) as determined in the new management structure, proposed in a letter to the Central Works Council (Centrale Ondernemingsraad; COR) in March 2016. [34]

Operations Division The Operations division is responsible for the operational business of NS. This includes the transport activities, as well as the maintenance activities (formerly named NedTrain). By introducing this management branch, the control of all operational activities is bundled. [34]

From 2017, the section of operations management is responsible for the departments 'control of operations' *(besturing operatie)* and, subsequently, 'daily plan' *(Dagplan)* (Right branch in organigram of Figure 4.1).

Network Development Network Development *-NL: NetwerkOntwikkeling-* (NO) is the overarching department responsible for the specification and design of the timetable and the planning of available assets. NO ensures that all necessary assets are available; in terms of infrastructure, rolling stock, crew and energy. Additionally NO is responsible for maintaining railway safety, quality of the process and innovation.

Schedule Development & Planning The department of Schedule Development & Planning -*NL: Treindienst-Ontwikkeling & Planning*- (TOP), is specifically responsible for the planning of timetable and allocation of rolling stock and crew in all aspects and time horizons.

Train Service Development The TDO is the commercial part of the TOP-department and produces the specifications (or boundary conditions) for timetables and the development for new train services. These specifications comprise of determining train-lines to be operated, frequencies on the lines and stops. These specifications can be seen as the boundary conditions of the timetable. They are supported by the section K&M, which provide the models and numbers on which the plans for the timetable are based.

Order Service Centre The Order Service Centre (OSC) handles incidental changes in the service on a short- and medium-long timespan. They are responsible for changes in the yearly timetable within the present year in case of decommissioning *(buitendienststellingen)* of infrastructure (e.g. construction works) and requests for extra capacity, for example in case of large events. [35]

Renewals The section called "Renewals" (*Nieuwbouw*) is responsible for the design of new timetable products. This section is divided in two subsections; A&O *Advies & Ontwikkeling* and production.

The A&O section performs studies on new train products. Based on the specifications of TDO, studies are performed and blueprints are made for the timetable, rolling stock planning and crew planning. A&O also performs studies on specific topics, for example the practical effects of certain changes in the assets (infrastructure or rolling stock). From a more practical perspective; A&O is responsible for working out the yearly plans and creating the blueprints for the new yearly timetable. [35] After the blueprints are made by A&O, the 'production' subdivision works out the blueprints in more detail.

In the rest of this thesis, 'Nieuwbouw' is referred to as A&O, unless specified otherwise.

Asset management/Infrastructure Management The department of Asset Management (AM) and, subsequently, Infra Management (Inframanagement (IM)) is the central actor within NS regarding infrastructural mutations. They are responsible for all infrastructure related matters, from the perspective of NS. They also assess environmental permits, process complaints with relation to the environment, monitor the reliability of the infrastructure together with ProRail and make long-term plans for capacity improvements in cooperation with ProRail.

Process Quality & Innovation The department of Process quality and innovation -*NL: Processkwaliteit & Innovatie*- (PI) is an integral part of the NO-department and ensures quality and supports innovations in the processes of the entire TOP department. PI develops tools for the other planning departments. They do not play an active role in the process of infrastructure mutations.

Control of Operations: Daily Plan The department of Control of Operations (Besturing Operatie) and subsequently the section Daily Plan (dagplan) are responsible for the development of the plans onto a time scale of a day, based on the plans provided by the departments renewals and OSC, in the various tools (VPT/Donna etc.). [35]

Control of Operations: Transport Control - Not displayed in organigram Another department which has a role in infrastructure mutations is TB. This department is responsible for the operational handling of the train services and, with that, have to keep train services operational in case of disruptions.

Production and Infrastructure Counsel - Not displayed in organigram The Production and Infrastructure Council -*NL: Afstemoverleg Productie en Infra*- (API) is a council, formed by representatives of various departments that are related to the planning for infrastructure mutations and also includes parties like NS Stations, NedTrain. They approve proposals created by the various development departments.

4.2.2. New Organisational Structure

A reform of the logistic department is planned to be implemented somewhere mid 2017. In this new structure, various departments are rearranged or replaced. This reform is carried out to place the department of Network Development and Design *-NL: Netwerkontwikkeling & Ontwerp-* (NO) in the role of "asset user", which means that NO has the ability to combine the available resources (in terms of infrastructure, rolling stock and crew) to create a realisable and feasible plan to realise client requirements, KPIs and efficiency. The organisation tree is shown in Figure 4.2.

In this reform, a clear distinction between development and planning is made, which makes sense from chronological perspective; long-term plans and design of train services is done by the development branch. The planning branch works on shorter-term development and implementation of the designed plans.

Under the new development branch, new plans are specified and an integral design is made (Integral Product Design *-NL: Integraal ProductOntwerp-* (IPO)), which lines up with the current asset strategy. Large projects (like the renewal of (the switch yard of) Amsterdam Centraal) have separate project organisations which operate apart from the bottom-level departments.

Under the Planning branch, the planning on a shorter-term basis is carried out. This means the implementation in the base day or a specific day plan.

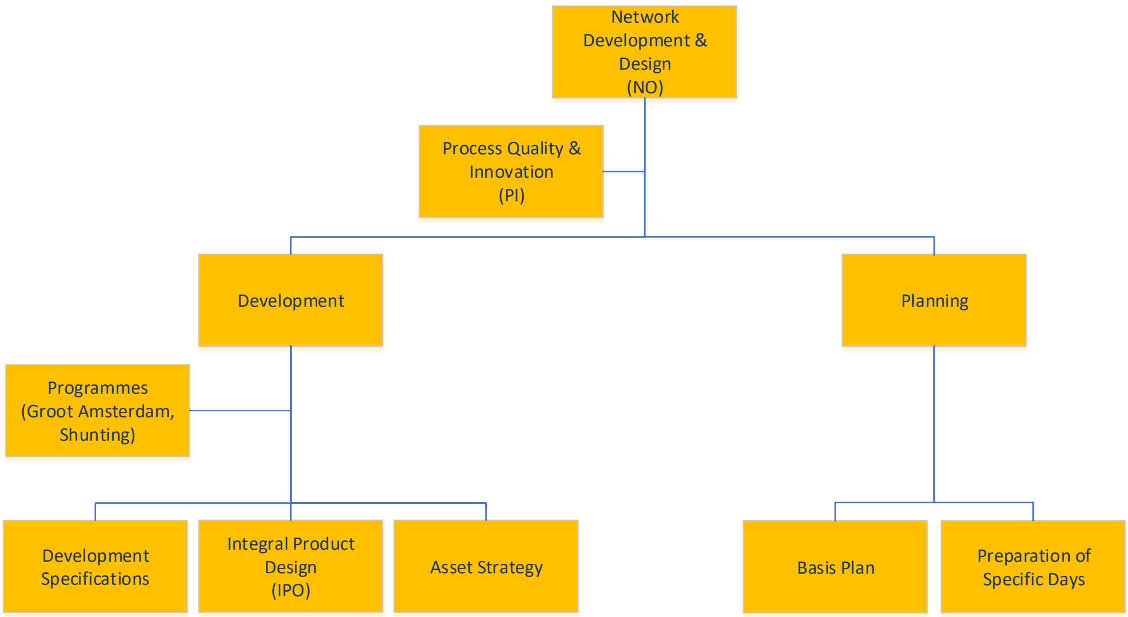


Figure 4.2: Organigram related to infrastructure mutations (new situation)

Table 4.1 shows the transition of the departments from the old to the new structure. This cannot be done accurately for every department, since roles change in some cases. Therefore, an overview of roles is given in Table 4.2 at the end of the next Section, where the planning framework is discussed.

Table 4.1: Transitions of departments

Old situation	**New Situation**
TDO	Development Specifications *(-NL: Ontwikkelspecificaties-*
TDO	IPO
OSC	Preparation of Specific Days *-NL: Voorbereiding Specifieke Dagen-* (VSD)
Renewals A&O	IPO
Renewals Production	Basisplan
IM	Asset Strategy
PI	PI

4.2.3. Generic Role Description

Now the actors in the process are listed, the link can be made between the actors in the process and the planning for infrastructure mutations. Table 4.2 states the roles and tasks within the process. The overview gives the responsible department in the old and the new situation, i.e. the situation prior to and after the reorganisation of the NO department.

Table 4.2: Overview of roles and responsible departments

Role	Old situation	New Situation
Main responsible for handling of infra mutation	IM	Asset Strategy
Drafting specifications	TDO	Ontwikkelspecificaties/IPO
Checking feasibility & realisability (long-term)	A&O	IPO
Checking feasibility & realisability (short-term)	Dagplan	Dagplan
Making phase plan (large projects)	A&O	IPO
Perform impact studies on rolling stock	A&O	IPO
Perform impact studies on crew	A&O	IPO
Creating BU-plan	A&O	IPO
Creating BD-plan	Nieuwbouw Productie	IPO/Basisplan
Creating SD-plan	OSC/Dagplan	VSD/Dagplan
Daily operational planning	Dagplan	Dagplan
Innovation and process quality	PI	PI

Now the system is defined and the stakeholders are identified, the questions of ’who?’ and ’what?’ are answered. In the next section, the describing, or analysis, of the process is carried out.

4.3. Normative Process Analysis

This section illustrates the normative process regarding infrastructure mutations. The various involved actors and their roles in the planning process have been discussed in Section 4.2.

In the past, several attempts have been carried out to visualise the project. These attempts functioned as the starting point for the reconstruction of the process. An example of such an attempt is the process drawing of the infrastructure mutations related to the Lijn Schiphol, Amsterdam, Almere, Lelystad (OV-SAAL) project. The drawing, made by DHV, is shown in Figure 4.3. This drawing is outdated and lacks a clear description of the process and the involved actors with their roles and. The drawing clearly indicates the complexity of the process and confirms the need of a better description.

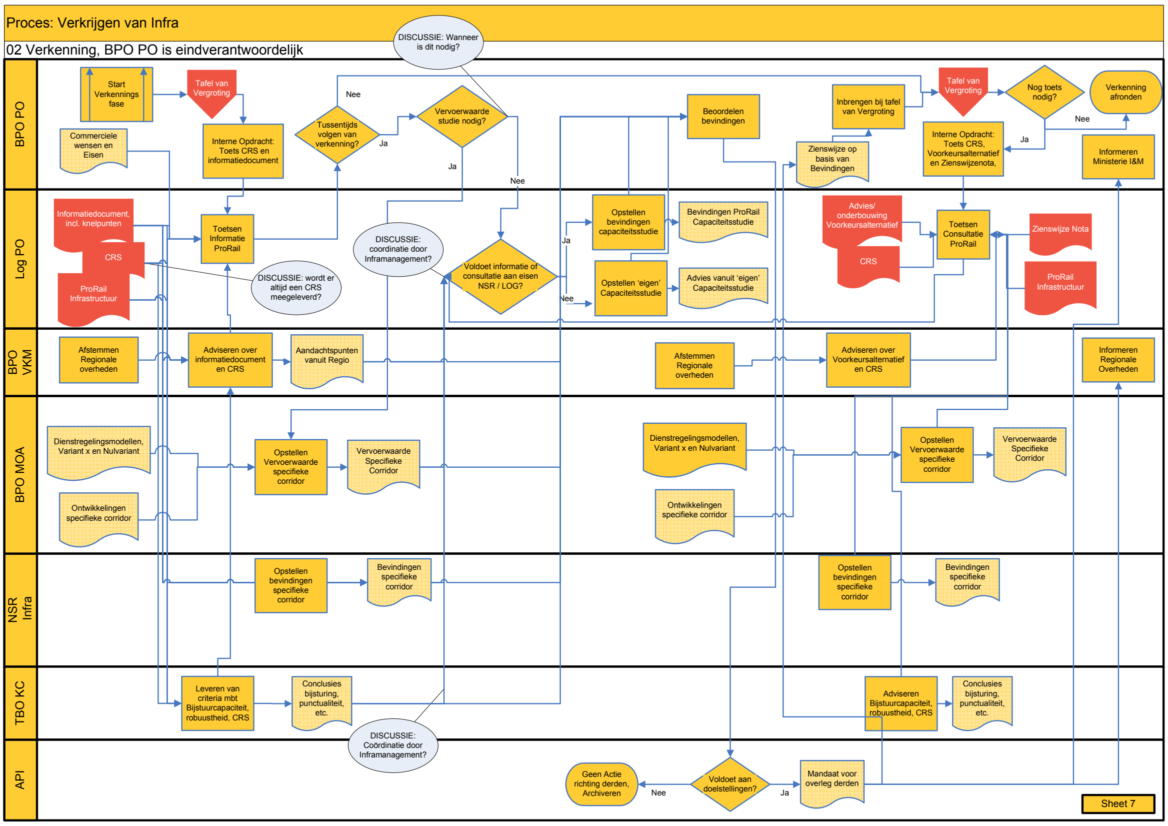


Figure 4.3: Process drawing of OV-SAAL

The process is split up in four sub processes or phases. This way, better interaction with the parallel processes of the two main actors, i.e. ProRail (kernproces [8]) and the Ministry of Infrastructure and the Environment (I en M) (MIRT [36]) can be ensured, which both have their infrastructure mutation process divided in four phases as well. This forms the base of the description of the process as a system, in according to the other sector parties. A comparison of the four-phase frameworks is illustrated in Figure 4.4. The following list gives an overview of the four phases and their core goals within NS. The following section describes the phases in more detail.

1. Initiative: In this phase a plan is initiated. This can have various reasons and can be performed by various actors. *Since the reason for the mutation is considered fixed, this phase is out of the scope of this thesis, and therefore will only be discussed briefly.*

2. Exploration: In this phase the possibilities of implementing the initiated plan are explored. Also, the (functional) specifications of the project are formulated.

3. Plan study: In the plan study phase the specifications are translated to a number of alternatives for the mutation. From these alternatives one final alternative is selected which is realised in the fourth phase.

4. Realisation: The final phase comprises of the actual realisation of the mutation and ends when the project is finished.

In the following sections, the four phases are described. This description consists of the main work(flows), the (plan)products that are produced in the phase, and the roles of the involved departments.

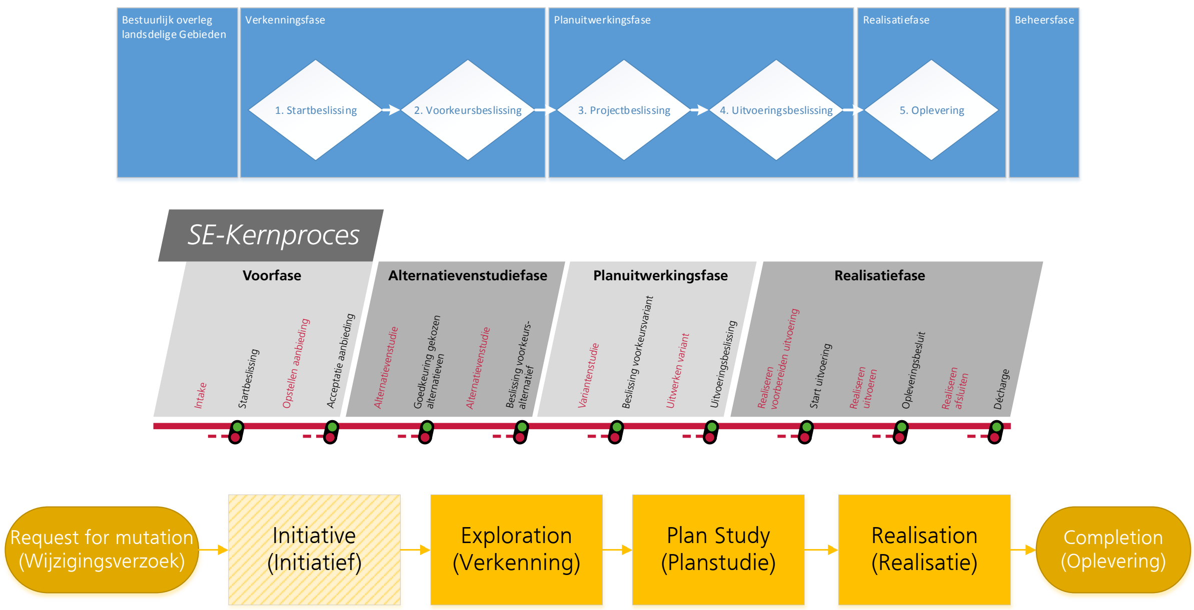


Figure 4.4: Comparison of the process structure at I en M [36], ProRail [8] and NS

4.3.1. Phase 1: Initiative

N.B. *this phase is out of the scope of this thesis. To provide some context, a short description of this phase is given here.*

A mutation of the railway infrastructure can have many reasons; for example to enhance the capacity of a certain track section, adding a new section to improve connectivity of the network, remove switches to reduce the chance of malfunctions or to improve the flow of trains. Each reason may have a different initiator (NS, ProRail, I en M, another TOC), but the key player and decision maker in the process is always ProRail.

4.3.2. Phase 2: Exploration

Based on the request or initiative from phase 1, ProRail drafts the so-called Customer Requirement Specification (CRS). Therefore, the second phase is also referred to as the CRS-phase. This document defines the functional specifications of the mutation. It does not contain detailed drawings, but sketches the functional specifications and requirements the mutations must comply to. This document is used as a reference for further developments of the plans.

The concept CRS is sent by ProRail to all actors involved in the mutation to form their vision on the CRS. At NS, the department of IM is responsible for the intake of the concept CRS and to forward it to the relevant departments. IM makes a selection of the departments which the concept CRS will be sent to, depending on the size of the project, but normatively the document is sent to all of the following departments:

- Commercial department; to see if the proposed CRS is desirable from the perspective of the customer, the timetable and long-term (LT).
- Inframanagement department; to check whether the CRS is compliant with current plans and visions on infrastructural resources.
- Logistic-/Integral-design department; to see if the proposal is executable from a perspective of middle-long-term (MLT) plans.

The flowchart in Figure 4.5 shows the simplified version of the process that is performed within NS in this phase. The diagonal arrows indicate that internal consultation is performed between the commercial- and logistics departments.

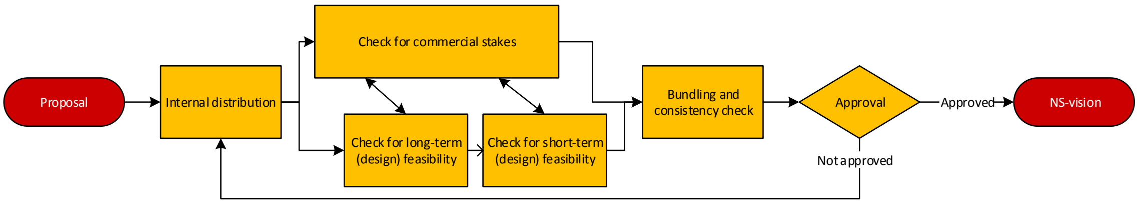


Figure 4.5: Generalised internal process steps for checking of proposal. Red= hand-over from/to ProRail, Yellow= Internal NS process

Within the departments, there are designated employees who function as the central person for acceptance and distribution of request. These people determine which experts should be consulted to assess the CRS. This happens mostly on the judgement of this responsible person. The selection of experts is based (among other factors) on the size and time scale of the mutation. If the mutation is project based (for example like DSSU), a specific team of planners can be assigned to be responsible for the assessment of the plans of the project. In this stage the initial studies are performed for desirability of the proposal. Due to the functional nature of the CRS, there are limited possibilities to perform detailed studies.

The consulted departments send their visions on the mutation request back to IM. IM bundles the responses and produces a combined vision, which resembles the vision of NS as a company. This company vision is sent to the API for a final check. After this, the vision on the CRS is formally signed by IM and returned to ProRail. The vision is discussed in the next session of the 'Tafel van Vergroting' (council for infrastructure developments). If there are major disagreements that cannot be solved at the Tafel van Vergroting, the issue can be reconsidered within NS internally.

ProRail uses the visions of all actors involved in the process to create a final CRS. These actors are: TOCs, contractors and freight operators. The final CRS is used as the formal guideline of the project and is the main output of the exploration phase. Based on this final CRS, ProRail creates various alternatives for the plan, with a preferred alternative, which are the inputs for the third phase.

Roles

- In this phase, IM is in the lead. They are the main responsible department for the correct execution of the process and the delegation of tasks.

- Due to the level of detail A&O is the main responsible department of the check for logistic feasibility of the proposed CRS. Depending on the size of the project, other departments, like OSC might be consulted.

- TDO is responsible department to verify if the proposed CRS is desirable, from the perspective of the long-term plans of NS.

4.3.3. Phase 3: Plan Study

In the third phase the proposed alternatives are assessed. The process structure has large resemblance with the second phase. The input for phase 3 is a set of proposals on how the mutation will take shape (i.e. alternatives). A similar iterative loop as in phase 2 is used (like Figure 4.5). The main difference is the level of detail. Where the vision of NS in the second phase is formed on the functional specifications, the vision in the third phase must be formed on actual alternatives. The relevant departments within NS check for the desirability and feasibility of the alternatives and form their vision on these alternatives. Due to the presence of more detail on the mutation, in this phase, more detailed and elaborate studies can be performed.

After the visions are formed, they are bundled again by IM and sent (via the API) to the Tafel van Vergroting after which ProRail can make the final decision on the plans (i.e. ProRail uses the visions of related actors for consultation only, the final decision is made by ProRail itself). The output of this phase and input for the next phase is the decision on a specific alternative which is selected for realisation.

If a (preferred) alternative is made definitive, a financing proposal is filed at the ministry (I en M). After this proposal is approved, the project can be realised and moves on to the next phase.

Roles

The roles of this phase are mostly identical to the previous phase.

- In this phase, IM is in the lead again. Just like in phase 2, they are the main responsible department for the correct execution of the process and the delegation of tasks.

- The main responsible actor from the logistic studies is A&O again. They check the alternatives with the relevant timetable products and effects on rolling stock plans and crew planning. In which timetable products the mutation has effect depends on the size and time span of the mutation (e.g. BU for long term, or BDU for shorter term). Other relevant departments, like OSC might be consulted, for example in the case of decommissionings.

- TDO is responsible to verify if the proposed alternatives are desirable from the perspective of NS.

4.3.4. Phase 4: Realisation

In the fourth and final phase, the proposed plan is realised. This comprises of the detailed planning and implementation of the plan, as well as the physical execution (construction). For NS, this includes the development of the actual timetables, rolling stock and crew deployment plans for the train services that are affected by the mutation, both during construction and after finishing the mutation. This means that in this phase, the processes of the planning of the timetable and the infrastructure mutation get intertwined, resulting in an extra interface. For smaller projects this might not have a large impact, but especially whenever the plan is large enough to be approached project-based, the need for phasing of the project will occur. This results in a more complex planning process.

The starting point of this phase is the alternative that is chosen by ProRail. The process that follows can be considered twofold, since a large-scale, project-based mutation has a different approach than a small-scale mutation. More on the definition of the scale of a mutation is discussed in Section 4.3.5.

Small Scale Mutations

A small scale mutation is usually handled as an integral part of the infrastructure maintenance cycle. The realisation of this kind of mutations is planned in a way similar to regular maintenance tasks. It is planned in such a way that it is performed at a time that it is most opportune in terms of time and money. An example can be; the removal of a switch, which is planned simultaneous to track renewal works on the same or adjacent track section. The appointed council, responsible for the planning of such works is the regional user council *(regionaal gebruikersoverleg)*. This council is chaired by ProRail and comprises of the users of the infrastructure in the discussed region.

Although the impact of the realisation can be kept to a minimum and the mutation can be classified as small-scale; the impact on the timetable or the 'controllability' of the operation can be comprehensive. Depending on the time of the year in which the mutation is executed, various planning departments have to act. For the permanent impact on the timetable (i.e. on BU-, BD or BDU-level) A&O has to implement the mutation in the 'blueprints' for the timetable. If the mutation is carried out in a currently 'active' timetable, OSC has to adjust the plan to implement it in the current plans and/or has to implement measures to mitigate the consequences of the mutation.

The outcomes of the structural and the temporary implementation are embedded in the daily operation by 'Daily plan'.

Large Scale Mutations

This type of mutation follows a far more complex process. The realisation phase starts with setting up a project-specific user council *(gebruikersoverleg)*. In this council, the first steps of phasing plans are made. This part of the process is done by IM, TDO and A&O. Where IM was in the lead in the previous phases, A&O is in the lead in the realisation phase. The phasing plans are developed by the contractor, in cooperation with A&O. This cooperation goes via ProRail, since they are the client of the contractor.

After making the phasing plans, A&O assesses the impact of the phasing on the timetable and in most cases (depending on the length of the construction phase) creates blueprints for the adjusted timetable. For the transition between two consecutive phases, OSC creates the blueprints for the adjustment.

Construction Phases in the Timetable The way a construction phase is embedded in the timetable depends on the length and the start date of the phase. The various timetable-stages (BD/BD/BDU) have fixed starting dates within the year, whilst construction projects or phases have not. The aim is to align the starting date of the timetable-stages with the construction phases. Since construction works are usually intertwined with other processes and projects this is hardly realisable in practice and therefore, results in overlap of the construction phase with a timetable stage. This will, subsequently, lead to overlapping responsibilities of the various planning departments.

This situation can be illustrated by an example: A certain construction phase runs from January until March. As stated in Section 3.1 a new BDU is started in December, February and April in which comprehensive changes to the timetable are made. This means that the construction phase overlaps partially with the BDU of December and April, whilst BDU February has complete overlap (see Figure 4.6). The timetable changes, required by the partial overlap, are made by OSC. Depending on the length of the partial overlap and the agreements between OSC and A&O, two possibilities occur:

1. The construction phase is implemented structurally in the BDU with full AND partial overlap (in this case in BDU December and/or April) by A&O. The time span outside the regarded construction phase is modified by OSC

2. The construction phase is implemented structurally only in the BDU with full overlap (i.e. BDU February) and the time span in which the construction phase overlaps adjacent BD/BDUs, the adjustments of the timetable are modified by OSC

Figure 4.6 shows the situation where a construction phase has a minor overlap with BDU December and a major overlap with BDU April. In this situation, a reasonable choice would be to let A&O create the BDU of December, where the construction phase is not implemented and to let OSC add the adjustment of the construction phase to this BDU on a temporary basis. For BDU April the situation is the opposite; A&O implements the construction phase in BDU and OSC adjusts the timetable to remove the adjustments for the last days of May. The blue bars on the bottom of the Figure show the tasks that have to be performed by A&O and OSC to implement this specific construction phase into the timetable.

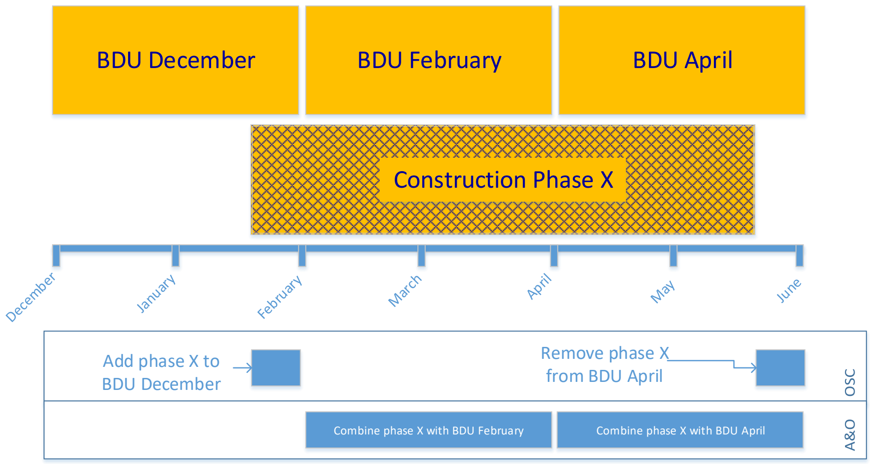


Figure 4.6: Schematic representation of overlap between BDUs and construction phases, including responsible departments

Incidental Mutations of the Plan Large-scale, project-based mutations are often subject to disruptions in the planned work schedule, due to unforeseen circumstances, changes in the original plans and other factors. These changes have to be captured by the planning departments, depending on the impact of the disruption. Since these disruptions inflict all involved parties (contractor, TOC, ProRail), tailor made solutions have to be found. These solutions are discussed at the user council *(gebruikersoverleg)*.

Workflow of Planning for Mutations

As briefly mentioned in Chapter 3, A&O is responsible for making blueprints on BUP- and SBD level, which form the groundwork of the timetable, based on the specifications of TDO. These blueprints are handed over to the production department of *Nieuwbouw*, which elaborates the blueprints in more detailed BD-/BDU level. These products are handed over to Daily plan, where the plans are further elaborated into SD plans. A second flow consists of the blueprints made by OSC of incidental changes in the groundwork. OSC hands over these blueprints to Daily plan. Daily plan combines the two input flows to a workable daily plan. The final plan is used by the executive parts of the organisation (traffic control, TB etc.) to operate the service, based on the provided timetable.

This workflow is displayed in Figure 4.7.

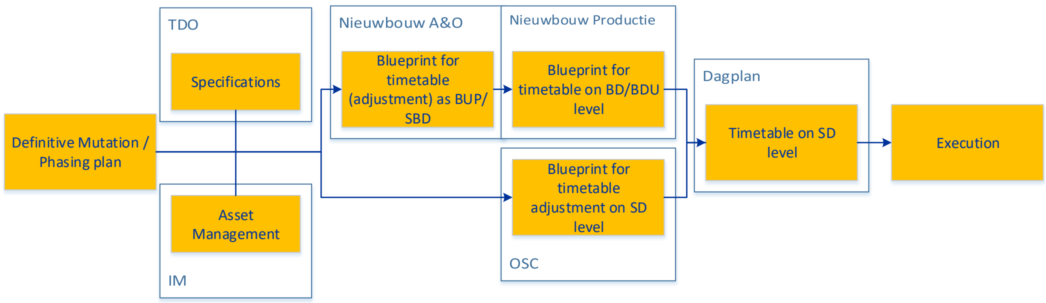


Figure 4.7: Schematic representation of the workflow

Roles

- IM fulfils the role of advisor in the process and acts as the main responsible party from NS regarding the project.
- A&O is in the lead in this phase. They try to serve the interest of providing a feasible and achievable plan for the project. The main focus for A&O lies at the phasing plans, which they develop in cooperation with the contractors of the project. The developed plans (phases) are elaborated by the departments *'nieuwbouw productie'* and Daily plan
- OSC produces the orders for the transitions between the phasing steps, since most of the (short-term) decommissions take place during these transitions. The developed orders are elaborated by Daily plan
- TDO serves the commercial interest and, therefore, have their focus on the desirability of the plans. This can be summarized by the wish to operate as many trains as possible and to reduce nuisance for passengers as much as possible.

It can be concluded that every individual mutation has its own nature and requires its own approach. This makes it hard to describe the process unambiguously and in detail. In the following section, problems that impedes clear description of the process are stated.

4.3.5. Bottlenecks in the Normative Process

From the information, provided by the interviewees, it can be concluded that problems occur at various steps in the process (i.e. process bottlenecks). The following section lists the bottlenecks that have been identified in the normative process and discusses these in more detail. If not specified otherwise, these bottlenecks occur (or have effect) in every phase of the process.

N1 There is no proper administration of current projects and their execution. [37] [38]

N2 No centralized information source for keeping track of data. [39] [38]

N3 No clear and formal formulation of the process and its responsible actors. [40] [39]

N4 No central responsible person for large projects. [38] [41]

N5 No clear distinction between "small" and "large" projects [40]

N6 Not all mutations requests are provided for consultation by ProRail nor are they discussed internally [38] [11]

N7 NS has a weak position in the process of "giving and taking" during the realisation phase; most of the solutions for problems can only be provided by NS.[38]

Problem N1 & N2: Information Management

Since problem N1 & N2 are closely related, they are discussed together.

The planning of a mutation in the infrastructure and the consequences for the train service can be considered rather complex. To mitigate these complexities it is vital to have enough information on the (available) assets and on how these can be used to run the services as proper as possible. Therefore, it is necessary to have information on other ongoing projects, that (might) influence the mutation considered (Problem N1). Also it is important to have up-to-date information on the current state of the infrastructure and rolling stock (Problem N2). Centralising this data and making sure it is up-to-date and accessible for all involved actors is an important aspect. If different actors use different sources for their information, miscommunication and other implications might occur. A continuous source of misinformation is the lack of an up-to-date list of platform lengths. A current example for this is the situation sketched in the box below.

Miscommunication example: Platform length at Driebergen-Zeist

For the construction works that are currently carried out at station Driebergen-Zeist (Db), the contractor placed a fence that limited the length of the platform. This obstruction was not known at NS, but could have major implications for the train service. If a train had stopped at Db, with the maximum amount of carriages possible, a safety issue would have occurred, since passengers would not be able to disembark the train, because there would be a fence on the platform, or there would be no platform at all (at the end of the train). If situations like this would have been communicated through an up-to-date database of platform lengths, this problem can never occur.

Problem N3: Process Description and Responsibilities

The infrastructure mutation process is not new within NS. Nevertheless, it has never been documented and formalised, and therefore, the process is carried out depending mostly on the experience of involved employees. Especially since the railway sector (and NS in particular) is changing constantly (from the separation of NS and ProRail in 1993 to the reforming of the logistic departments that is happening at the moment), this results in implications, since there is no clear description of responsibilities during the process. One could say that problems lack 'ownership'. This results in a suboptimal execution of the process.

Problem N4: Project Management

Especially for larger, project based mutations, there is limited management on the top level. This bottleneck occurs in all process phases, but its effects occur for the majority in the realisation phase, due to the increasing complexity of the process. According to the process description, drafted in the previous Section, the main responsible actor for the process is IM, and for some part also A&O. For these larger mutations, complexity increases and the stakes become higher for NS. Therefore, a dedicated project manager becomes essential.

Problem N5: Scale of Mutation

The scale of the mutation has an effect on how the process is shaped. As mentioned before, a small mutation does not require phasing, where a larger one does. Also the impact of a larger scale mutation usually is bigger than the impact of a small one, although not necessarily. A small scale mutation can have a big impact; for example the removal of a single switch might result in a situation where the current timetable becomes infeasible and requires a complete renewal of the current timetable. The other way around is possible as well; for example a change of the 'Zeeuwse Lijn' (line from Roosendaal to Vlissingen) [42], which might be closed for many days and the service is operated by buses to replace trains. This seems like a large mutation, but has little impact on the rest of the network, and the amount of passengers influenced by the works is also limited.

The indistinctness on the scale also results in ambiguity in the question of responsibility. It is not clear who is responsible for the planning of different scales of mutations.

Problem N6: Not all Mutations are Consulted

In addition to the previous problem, the ambiguity on scale also results in another problem; small scale mutation tend to be overlooked in the process. It happens that smaller scale mutations do not follow the entire process, since it is expected that the mutation does not have a large impact. Sometimes, the impact of a mutation cannot be foreseen if it has not been planned and/or simulated first to assess the magnitude of its impact.

Problem N7: Weak Position of NS for Negotiating

Incidental problems in the realisation phase are usually simpler to be solved for NS than for another actor. For example: if there is more time required to complete a construction phase in which trains cannot run on certain track sections, the easiest solution is to extend the decommissioning period of this particular track section and therefore create more nuisance for passengers and less operated trains for NS. Other solutions, like scheduling another decommissioning, can be more costly for ProRail or the contractor, but indirectly also for NS. For (among others) this reason, NS usually is obligated to take inconvenient measures to avoid a new decommissioning. As can be derived from the description, this problem occurs mostly in the realisation/-construction phase.

4.4. Process Analysis of DSSU Project

After having a better overview of the normative process and its bottlenecks, the process of the DSSU project is analysed. It will give a brief overview of events that were typical within the project and deviations from the normative process. After this, an overview of bottlenecks and positive points is given. In Section 4.5, improvements for these bottlenecks are suggested. The same information gathering method is used as for the normative process, i.e. the information is based on interviews with actors and internal data of NS.

DSSU was a unique project in the Netherlands. A rigorous reconstruction/reduction of a shunting yard, while keeping the station operational, had not been done before on this scale. This resulted in a lot of uncertainties due to this unique nature of the project. Furthermore, the project was carried out parallel to other projects in the Utrecht region (see Section 3.4.2), making it even more complex.

In the initial phases of the process there were not a lot of noticeable problems and it can be stated that the normative process was followed quite well. It must be added that because of the unique nature, not every step has been followed completely as desired, but that can be considered impossible for a project of this scale. Nevertheless, the project was approached as 'business-as-usual' by ProRail and NS, and there seemed no need to handle it differently.

In the later stages of the project, approaching the realisation phase, the course of the DSSU process can be considered abnormal. Due to a rescheduling of the project, the project started to be a race against the clock. Initially, the project was planned to be the successor of the OVT project at the station of Utrecht, but due to a decision of the management of ProRail (as a request of the Dutch national government, resulting from the financial crisis), the project was carried out earlier than planned and due to this, parallel to the OVT project.

The resulting plan of combining the two projects was elaborated by ProRail, without consulting other actors. This resulted in friction in the process of making the phasing plans. While the friction persisted and decision making progressed slowly, the project was tendered and the contractor needed to start the works.

Still, the project was handled as 'business-as-usual', which meant that it was not being discussed on directional level, whilst it had national impact. Due to the lack of mandate of the project organisation (within ProRail and NS), the project stalled. [31] To overcome this, programme managers (for both ProRail as NS) were assigned to the project at the beginning of the realisation phase. With this, the conclusion was drawn that collaboration and transparency was vital to bring the project to a good end. This was something the programme managers had to take care of.

By using a more integral approach for the project, with an intensive collaboration between NS and ProRail, clear top-level management structure and a transparent way of sharing information, it was possible to complete the project successfully in the short time span. This integral approach meant, for example, that project meetings were held with TOCs, contractors and ProRail together. This, instead of the usual communication chain, where every actor has its own 'island', where communication between actors was limited. Using this approach introduced the advantage that every party could openly discuss its wishes and needs, with explanatory arguments, resulting in solutions for problems that were accepted/understood by all actors.

Not only the internal matters and processes were done jointly, also the external communication was done by NS, ProRail and other actors together, resulting in a clear flow of information to passengers and other external actors [31].

On the field of the logistics departments, the effects of moving the completion date forward resulted in various implications. Because of this, the possibility to perform long-term studies was deprived, and therefore, the studies on the project were caught up by the actual planning. In an already vaguely defined process, this resulted in even more uncertainties and vagueness. In practice, this led to entangled work flows, where one department was doing the work of another. Next to ambiguity in responsibilities and tasks, the information flows were distorted as well. This lead to the situation that one department was requesting information from another department which was not responsible for this information.

After introducing the 'integral approach', the collaboration within NS improved, but the unclear process remained an issue. In the end, the conclusion of various actors within the logistics departments is that the project was finished properly [43] [42] [31] , but various lessons learned should be implemented in future processes.

4.4.1. Bottlenecks in DSSU Process

Next to the bottlenecks in the normative process, some bottlenecks can be identified in the DSSU-specific situation. The following list gives the bottlenecks that were identified from the interviews on the DSSU process. Some of these problems are only noticeable in the DSSU case, but some of them have overlap with the normative situation.

- D1 Unclear definition of roles within the process; (i.e. who is responsible for what and where?) [44]
- D2 Insufficient or improper allocated resources for planning (i.e. people; planners) [42] [44]
- D3 Time restrictions (late start) [45] [44] [11]
- D4 No detailed planning in early stages, therefore troubleshooting instead of proper planning [46]
- D5 Lack of vision for the long-term future [46]
- D6 Initially, there was no clear top-level management on the process [38]
- D7 Problem with accessibility of stabling yards. [47] [48]
- D8 Unclear effects of the mutated infrastructure on the realisability of the train service [48] [47]

Problem D1: Improper Role Definition

During the DSSU project, there were a lot of uncertainties within the logistic departments on who was responsible for which part of the planning. Especially during overlaps of construction phases and BDUs. There were also uncertainties on the 'products' that the various departments needed to deliver. For example: at some part in the process, A&O was asked to deliver details on the rolling stock planning (night transitions of trains), while this was not their task. [45]

Problem D2: Insufficient Planning Resources

A frequent problem within DSSU was the lack of planning resources. At various stages of the process there were not enough planners to perform studies and to make timetables during construction. This also resulted in the lack of possibilities to perform extensive studies on certain infrastructure lay-outs. Not only the absolute amount of planners was the issue, also the allocation of resources was not always done properly. During the process some departments of NS did the job of other departments. For example: at some stage of the process, A&O made the blueprints for a decommissioning, which actually is the task of OSC. [43]

Problem D3: Time Restrictions

Due to the mentioned change of the planning of the project, DSSU is realised in a relatively small time frame. Usually, a project of this size is planned years in advance, but since the DSSU-project was realised far earlier than scheduled, the planning is executed in way shorter period of time. This resulted in a rushed way of working and this was one of the reasons why extensive studies could not be performed. [45] [44] [43]

Problem D4: Lack of Detailed Planning in Early Stages

There were no detailed studies performed for the DSSU-project. Partially because of lack of time, also partially because of the lack of planning capacity, but also since it has not been common to do so. Like in other projects, detailed planning (like the elaboration on the timetable during the construction phases) is done only in the realisation phase. Only pattern-checks were performed for DSSU, while no 7x24 checks had been performed. [11] This means that it was only checked if the timetable was feasible during the day, i.e. checked if the train paths do not result in conflicts. Other activities, like movements from and to the stabling yards (at the beginning and, respectively, ending) of the service, are not taken into account with such a check. This led to the detection of infeasibilities on a very short notice in some cases.

Problem D5: Lack of a Long-term Vision

In relation to problem D4, the lack of long-term vision is given as a problem in the process as well. It is stated that it is not always assessed if a mutation in the infrastructure will still be relevant in ten years. [11] Sometimes the ”spot on the horizon” is missing, resulting in an unstructured way of planning (for) mutations. [46] An example, related to DSSU, is the application of the flow-through station-concept. Now the project is realised, the concept is not completely used in practice. One of the reasons is that the satellite stations are not prepared to be used as intended. The concept turned out not to be very practical, and therefore, the planned capacity increase is not realised.

Another factor, that can be identified as a cause or as an effect, is that the processes of changing the infrastructure and planning a timetable (on this mutation) are carried out as two separate processes. First a mutation is suggested and in a late stage (the realisation phase) an actual timetable is created for that mutation. This results in an suboptimal connection between the timetable and the infrastructure, since the mutation might not fit to an ’ideal’ timetable.

Problem D6: Lack of Top-Level Project Management

Overseeing the project and handling conflicts was initially the task of IM. But since they did not have the mandate (or a direct line to the management of NS) to make fundamental decisions, it was hard to perform this task. This led to complicated situations, for example at meetings with the contractors. Later in the process, more top-level management was requested and this request was answered with the appointment of the programme manager ’Groot-Utrecht’, who had the central responsibility for the project. A similar programme manager was appointed at the side of ProRail.

Problem D7 & D8: Problem with Realisability of the Service, Based on Rolling Stock.

These two problems have a combined nature. With the DSSU-project, the effects of the changed infrastructure were insufficiently known during the planning stages, which led to inconvenient surprises. The following causes were derived from the interviews:

- The capacity of the three stabling yards at Utrecht was treated as a whole (i.e. the capacity was summed and the total was used as the capacity for the entire station). This led to problems in the execution of the service.

- The accessibility of the stabling yards was significantly reduced, due to the untangling of the corridors and the removal of switches. This results in situations where some platform tracks cannot be accessed from certain stabling yards. [47]
- The renewed infrastructure lay-out was tested with the, so-called, pattern-checks. These checks made sure that the timetable was feasible during the day, but it did not incorporate the starting and end of the service, which turned out to be not feasible in some cases. [11] [48]
- The flow-through concept was designed to use stations in the periphery of Utrecht (so called satellites) to handle the turn-arounds of trains, but these stations were never set-up for this kind of service (i.e. no stabling yards were built on these satellites). [48]

These problems can be summarised by a lack of detailed planning and a lack of insights in the effects of certain changes in the infrastructure for all resources (timetable, rolling stock and crew).

4.4.2. Positive Aspects in DSSU Process

1. The appointment of the programme managers and the subsequent integral way of working in the later stages of the project resulted in a constructive and proactive course of the project. [31] [46]
2. Due to time restrictions; the planning departments became creative with the allocation of planning capacity, since the plans had to be delivered anyhow. Despite that the process was not carried out as it should be, this resulted in an organic allocation of planning capacity. [45] [43] [46]
3. The joint execution of the plans, between ProRail and NS, in the later stages of the project also resulted in cooperation in the information flow towards passengers. As a result, a clear and unambiguous stream of information was produced for the passengers. [31]
4. A positive side-effect of DSSU was the development of passenger-nuisance-diagrams *Klanthinderkaarten*. The development of these diagrams was done on request of TDO, to have a clear image of the hindrance per decommissioning. The diagrams turned out to be useful for other actors in the process, since a proper indication of nuisance was not available before. [38]

4.5. Proposal for Improvement

As the list of bottlenecks is compiled, the following section links these problems to possible solutions. These proposals can be based on either literature, or from lessons learned from earlier projects (like DSSU).

4.5.1. Problem D1 & N3: Process Description and Role Definition

Due to the unclear definition of the process and the roles of its actors, a lot of ambiguity occurs. This can be solved by clearly documenting the process, for which this thesis can be a starting point. First, a description of the sub process, with their in- and outputs is made. [49] Based on this description, the process can be made clear and understandable. An even more desirable effect is that it makes the process measurable and/or controllable. After identifying the sub process, each sub process is assigned to a process owner. By making somebody responsible and accountable for (the in- and outputs of) each sub process, it is ensured that the sub process is carried out in, hopefully, an optimal way. The merits of process ownership have been researched by Kohlbacher and Gruenwald [50] for manufacturing companies, but in general, the technique can be considered applicable for the infrastructure mutation process as well.

It must be added that most of the infrastructural mutations ask for tailor-made solutions, which make it harder to clearly describe the process. Some flexibility of the process owners is required to cope with variations in the process.

4.5.2. Problem N1 & N2: Housekeeping on Information

Proper access to information is vital to ensure a proper process flow. Especially when planning in the complex Dutch railway infrastructure is considered. To keep track of ongoing infrastructure mutations, PAST is set up within NS. [37] PAST is an internal database within NS for keeping track of ongoing infrastructure projects and development of other assets, that focuses on the long term. The project was started by the department of IM to overcome the deficiencies in the internal communication. The database is operational, but at the moment, it is not yet implemented in the organisation.

The process ownership mentioned in the previous paragraph can be integrated in the PAST database as well; for every entry in PAST, an owner can be assigned who is responsible for that specific project.

Besides the internal 'housekeeping' of information, a lot of up-to-date information is missing from the side of ProRail. Actively managed information on the rail infrastructure can reduce a lot of uncertainties and frustrations in the planning process.

4.5.3. Problem N5: Size of Mutation

A lot of ambiguity in the process is the consequence of the lack of definition on the difference between a small and a large mutation. To make sure that a project is handled by the correct people and/or department, a clear and widely supported definition must be formed. Due to the unique nature of infrastructure mutations, forming a clear and unambiguous definition is difficult. Nevertheless, a suggestion for this definition is given below.

From the interviews, a twofold definition can be identified. A distinction that forms the first part of the definition is whether the mutation is project based or not. If there is a project organisation set-up for the mutation, like there was with DSSU, the mutation can be handled as being 'large'. Another indicator of this definition is the presence of phasing-steps within the project. Otherwise, if a project is implemented in the regular maintenance routine, the mutation can be considered small-scale.

The second part of the definition is based on (passenger) nuisance. The nuisance, caused by a mutation, can be subdivided in a selection of indicators. The following indicators are derived from the interviews:

- Qualitative passenger nuisance: This method of classifying nuisance is used by OSC for decommissionings and is subdivided in the following levels: 'Hinder-free': no implication on the train service or train product, 'Low Hindrance': small timetable adjustments, no cancellation of trains, 'High hindrance': Cancellation of trains, and 'Extraordinary high hindrance': in which the decommissioning takes longer than 52 hours. [44]

- Quantitative passenger nuisance: Amount of passengers affected by the mutation (amount of passengers in total, amount of hindered passenger kilometres, amount of shortages etc.

- Infrastructure reductions: Amount of available platform tracks, accessibility of stabling yards, accessibility of platforms, amount of possibilities for simultaneous arrivals through the shunting yard. [11]

A lot of the above mentioned points are related and can be derived from each other. The passenger-related indicators have a good connection with the company vision of 'putting the passenger at the first, second ánd third place'. The relevance of each indicator will differ for the various departments, so a precise definition should be chosen in practice. Related to the company vision, a customer oriented definition like the second is recommended.

4.5.4. Problem N6: Consistently Follow Process

From the results of the interviews it can be concluded that it happens occasionally that a mutation is not taken into account by certain departments within NS or by NS as a whole. Usually this is the case because the responsible party considers the mutation as 'not relevant enough' or does not submit the mutation for consultation. This can happen internally at NS or even more upfront in the process, at ProRail. If the process is arranged in such a way that every mutation can flow through the process, but a small mutation can omit some steps, it can be ensured that all relevant aspect are assessed by the involved departments and no seemingly irrelevant aspect can be overlooked. This also requires a proper implementation of the process at both NS and ProRail.

4.5.5. Problem N7: Position of Negotiation

Since this issue originates from the way the playing field in the rail sector is set-up, no easy solution is presentable. This problem is considered unsolvable within the scope of this thesis.

4.5.6. Problem D2: Planning Resources

The issues with planning capacity (human resources) have had their impact on various stages in the process. The solution to this problem can be seen as twofold. As a first, when the planning process for a mutation is started earlier, the necessary studies can be spread out over a larger time span so the load on the planners can be distributed more evenly than in the ad-hoc way the studies tend to go nowadays. Secondly, a more flexible set-up of the logistics departments might reduce a lot of the planning capacity issues. By allocating planners to the departments where they are needed, instead of the fixed teams that are used nowadays, capacity can be distributed over all planning departments more evenly. For example in the quiet period, during summer, less manpower might be necessary for short-term (operational) planning, due to less patronage on the network. The operational planners can assist the long-term planning during this period and vice-versa. It must be added that there are differences in expertise that have to be considered for this solution.

4.5.7. Problem D3: Time restrictions

The inconvenient time span, in which DSSU was carried out, is caused by external influences (amongst others by influence of the government [43] [31] [51]). Therefore, the problem is considered unsolvable in relation to these circumstances. Nevertheless, the consequences could likely have been mitigated by performing more studies in advance on different possible outcomes to ensure flexibility during the construction process. Since projects of this scale have a lot of uncertainties, considering all 'variables' is a hard task and almost unachievable.

4.5.8. Problem D4: Plan Ahead

As the previous two paragraphs already mentioned, there is a lot to win by doing more of the planning in advance. The lack of insights in the effects of a mutation in the deployment of rolling stock also exists. By being able to assess these effects, better feedback can be provided on the plans can be provided to ProRail and surprises can be avoided. As will be elaborated below, various simulation tools might be used to make these assessments.

4.5.9. Problem D5: Develop a Clear Vision

By developing and advertising a clear vision for the long term, planners (tactical and strategic, i.e. both infrastructure and timetable) can collaborate in a better way by developing 'products' that fit the passenger demands better. Besides the formulation clear vision, decisiveness is necessary as well to implement the vision properly. This has the advantage that NS has better arguments to defend its stakes, because discussions on mutations become more clear and explicit. [46]

The second part, mentioned in this problem, is the improper connection between the infrastructure and the timetable, based on the mutation. Ideally, a timetable would be formed that suits all commercial stakes. In practice this timetable is not realisable, but based on an ideal timetable, new infrastructure can be planned. This way, a better connection between the infrastructure and the (desired) timetable can be provided. [46]

4.5.10. Problem D6 & N4: Project Management

The lack of central project management also played a role in the uncertainties in relation to the 'who does what?-question'. By assigning a programme manager, as has been done late in the DSSU project, central responsibility is assured and better communication between NS and ProRail can be achieved. It is recommended to assign such a programme/project manager to every larger scale mutation.

4.5.11. Problem D7 & D8: Extensive Microscopic Planning and Simulation

By removing switches, the accessibility of the stabling yards at Utrecht was drastically limited. Not all platform tracks were directly accessible from the stabling yards. This resulted in issues with realising the train services and in particular; the starting and ending of the services. With use of microscopic simulation, most of these issues likely could have been avoided. Software packages like OpenTrack or RailSys are able to perform microscopic simulations of a planned timetable and can give a better view on the feasibility of the planned timetable. Details on the use of simulation tools are discussed by Nash and Huerlimann [52] (OpenTrack) and more extensively by Quaglietta [53]. Additionally, Planting [12] has performed research with RailSys on the Dutch timetable.

Also in the field of local shunting planning and maintenance planning there are a lot of uncertainties. [47] With use of tools like OPG, a more detailed planning of the local rolling stock processes can be done. A more detailed description and elaboration on the problem has been made by Kroon et al. [54] and Freling et al. [20].

Through further integration of planning tools in the Donna planning environment, as mentioned in Section 3.2.2, a more integral approach for the planning of all resources can be achieved. It is expected that this will also reduce the blind spots' in the planning, which have occurred in projects like DSSU, since it reduces the amount of interfaces between the individual tools.

For rolling stock planning, and in particular, rolling stock circulations, TAM is considered to be a useful tool to do more extensive studies on the effects of mutations in the infrastructure on rolling stock. More details on the use of TAM in these situations is given in section 5.

4.6. Conclusion on Process Analysis

As can be concluded from the process analysis, various issues impede the process. Some of these are not directly solvable, like the weak position NS has in the negotiations during the process. This is mainly due to the way the playing field between NS and ProRail is organised. Other problems are solvable by clearly describing the process (the lack of clarity on roles and responsibilities) or a different allocation of resources within the process.

By describing the process clearly, and by making use of a central place for information, where the information on assets and project is kept up-to-date, a lot of implications can be avoided. NS started with the use of the PAST-project-database and ProRail has the 'Logistiek Portaal' for infrastructure related information, but there is still a lot of improvement possible on this matter. Getting a clear picture on who is responsible for what kind of information and to act likewise will help the information void.

For one problem; the problem of planning on a relatively short term, a lot can still be improved. Nowadays, various tools exist to make extensive simulations of alternatives for the timetable. These computerised simulations use less planning capacity (manpower) and are relatively cheap to use, in comparison with manual techniques. At NS, some of the tools that can help with doing extensive studies already exist or are being developed. Next to the simulation, the actual planning also has to be done in microscopic form. In this way, conflicts on this level of detail can be identified in the planning stage as well. One of the main outcomes of the DSSU-case is the lack of knowledge on the impact of the project on the deployment of rolling stock. TAM is one of these tools and can be used to assess the impact of certain changes in the infrastructure, and with that the timetable, on the rolling stock deployment. In the next chapter of this thesis, the use of TAM in the planning process is assessed.

Further conclusions are given in Chapter 6.

5

Evaluation of TAM

Following from the bottlenecks in the normative process (Section 4.3.5) and in the DSSU process (Section 4.4.1), the lack of insights in the effects of infrastructural changes on the planning of rolling stock becomes evident. In Section 3.2.2 tools were presented for this planning, but the application of these tools in practice was limited on earlier projects (like DSSU). This section tries to verify if it is possible to get a better insight in the effects of the infrastructure mutations on rolling stock circulations and to show the applicability and merits of the use of TAM. This is done by identifying what are relevant outcomes of the tool, according to stakeholders in the process, and subsequently, by evaluating cases from practice. The focus of this evaluation lies on the first two steps of the rolling stock planning framework from Section 3.2: Tthe assignment of rolling stock types and the planning of circulations. .

The three cases in this section are each linked to one of the three[1] phases in the infrastructure mutations process, as mentioned in Section 4. This way, the use of TAM can be evaluated independently for each of the discussed phases.

5.1. Determining Relevant Outcomes

The questionnaire, which was mentioned in 2.3, was sent to various actors in the process. Table 5.1 gives an overview of the recipients and their role in the process. NedTrain is added to the list, since they have an important stake in the planning of rolling stock, due to claims on train sets for maintenance and service. This, despite the fact that they are not discussed before. A crew planner is added to the list as well, since the crew planning is highly dependent on the rolling stock planning. The following sections discuss the three subsequent questions of the questionnaire.

Table 5.1: Recipient of the questionnaire

Number	Name	Department	Role
1	Arjan Kal	Asset Strategy	Infrastructure Advisor
2	Irene Hendrickx	IPO	Manager IPO
3	Sven Barmentloo	IPO	Expert Planner Crew
4	Marleen Wieten	NedTrain	Long-term planner service location (SB)
5	Roel Zijdemans	IPO	Timetable Architect
6	Johan Ohlen	VSD	Business Consultant
7	Dirk Dral	IPO	Product Market Manager
8	Shahin Chaleshtor	Daily Rolling Stock Plan	Rolling Stock Planner

5.1.1. Requirements

The first question stated: *"What aspects are relevant for you or your department, to judge whether a rolling stock circulation is desirable, in relation to your field of expertise?"* The answers can be summarised as follows:

[1] Three out of four phases; the initiative phase was disregarded. So the cases are related to the exploration phase, the plan study phase and the realisation phase.

- The infrastructure advisor from asset strategy indicated that he sees no direct involvement for him or his department in the rolling stock planning. The infrastructure is a boundary condition for the rolling stock planning; "whatever is possible can be deployed". Therefore, he scored all indicators as 'irrelevant'.
- The crew planner states that he needs the following indicators: Carriage norms, required crew-duties, empty-train-trips vs. commercial trips, number of starters per crew post *(Starters per Standplaats)*, size and occupation of stabling yard.
- The timetable architect requires: Total carriage demand, carriage kilometres per week, running-minutes (first crew and second crew), number of attachments/detachments.
- The OSC representative states that the number of deployed carriages is relevant for his work.
- Daily rolling stock plan: Patronage, CAV-norms, carriage kilometres, number of train managers, shunting movements, shortage and surpluses of rolling stock, rolling stock type, deviation in inventory, turn-around-times, follow-up train drivers
- From the perspective of design specifications: CAV-norms, number of carriages, carriage kilometres, compliance to train formulas (IC/Sprinter), future-proof rolling stock deployment, running time supplement
- The NedTrain representative requires: Length of trains vs. length of stabling tracks, rolling stock types, available time for servicing, amount of carriages, link between starters and enders over night first in, first out (FIFO)/last in, first out (LIFO).

5.1.2. Scoring of Outcomes

The second question was *"How relevant are the following parameters for your judgement (or the judgement of your department) on the desirability of a rolling stock circulation?"* The indicators, shown in Table 5.2, were scored by the respondents on a scale from 1 (not relevant) to 5 (very relevant). The list is based on the indicators in Table 3.1 in Section 3.3, but is somewhat condensed to ease filling in the questionnaire. The columns x_1 to x_8 refer to the scores of respondent 1 to 8. The last column is the average score per category. In this average, the scores of the asset strategy department (all scores '1') are not taken into account. The 'category' column indicates the category from Section 3.3; (T)rain, (P)assenger or (C)rew.

5.1.3. Additional Requirements

As mentioned in her answer on question 1, the NedTrain representative stated that night transitions (information on which train is where during the night), which are used for servicing of trains, are an additional requirement. The commercial department misses the opportunity to perform long-term, pattern based, studies. The daily rolling stock planner states that the chance for a passenger to have a seat *(Zitplaatskans)* is an issue that is missing at the moment. It can be reasoned that this is part of the CAV-norm. Additionally he states that an overview of compliance to the maintenance schedule could be added (i.e. checking if maintenance is performed on each train).

Conclusions on the KPIs

From the questionnaire it appears that there are a lot of different requirements per respondent. When looking at the qualitative and quantitative data (top 5), the amount of cars/train sets and (seat-)shortages appear to be important factors. When looking at the desired indicators from question 1, it can be concluded that TAM can provide a lot of the requested parameters. Based on question 3, two main deficits are seen; the link with microscopic rolling stock planning [2] is missing. The link to commercial specifications, as mentioned by the commercial department, is not defined specifically in TAM. Depending on what the commercial department means by this 'compliance', it might be obtained by deriving it from other indicators.

The indicator 'follow-up train drivers', is mentioned by the daily rolling stock planner. This is no direct indicator/result from TAM, but can be derived from the turn-around-times in combination with NS turn-around-time-norm-times (so-called Isidoor norms).

Based on the questionnaire and theoretical knowledge on TAM, it can be provisionally concluded that TAM is a comprehensive tool that has the ability to answer a lot of questions regarding the desirability of a

[2] Here defined as both local shunting planning and maintenance planning

Table 5.2: Scores of parameters

Parameter	Cat.	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	$\bar{x}_{2..6}$
Carriage-km Total	T	1	5	4	1	5	2	4	2	3,29
Carriage-km per rs-type	T	1	5	4	1	4	1	4	2	3,00
Amount of carriages per type	T	1	5	4	4	5	2	5	4	4,14
Train sets per type	T	1	4	4	4	5	1	4	5	3,86
Seat surplus kilometres	P	1	5	1	1	3	4	3	2	2,71
Seat shortage kilometres	P	1	5	1	1	5	4	5	5	3,71
Counting sections with shortages (Sections in which the CAV-norm is exceeded)	P	1	5	1	1	5	5	5	5	3,86
Total travel time train managers	C	1	5	5	1	4	3		3	3,50
Train Manager duties	C	1	4	5	1	4	4	3	3	3,43
Shunting movements	T	1	5	5	3	4	1	3	4	3,57
Offered capacity (in relation with demand)	P	1		1	1	4	4	3	5	3,00
Over-norm kilometres	P	1		1	1	4	1	4	3	2,33
Empty train kilometres	T	1	4	5	1	4	1	3	4	3,14
Capacity per counting section (demand and supply)	P	1	5	1	1	4	4	3	5	3,29
Exceeding norm per norm level (C, A or V)	P	1	5	1	1	3	4	5	5	3,43
8 o'clock cross section (rs-type, occupation, CAV-norm)	TC	1	5	5	1	5	2	5	1	3,43
17-o'clock cross section (rs-type, occupation, CAV-norm)	TC	1	4	5	1	5	2	5	1	3,29
Rolling stock duties	TC	1		5	3	3	2	3	5	3,50
Capacity Surplus (per train series, per counting section)	P	1	5	5	1	3	4	3	4	3,57

rolling stock circulation/plan. The following cases will verify if the tool functions as well in practice as it is assumed to do in theory.

5.2. Case Evaluations

For a good view on the merits of TAM in the process of rolling stock planning, it is important to reflect the three phases of the infrastructure mutations process (from Section 4.3) in the cases. Therefore the case have to fit the following requirements:

- *For the exploration-phase:* A case in which a mutation is proposed and the specification is only functional (i.e. no actual details are known yet). The re-opening of former station "Berkel-Enschot" is evaluated and the resulting implementation of this station in the 6600 sprinter series between Dordrecht (Ddr) and 's Hertogenbosch (Ht) fits this requirement.

- *For the plan study-phase:* A case in which there are various alternatives that have to be assessed and compared[3]. For this case the problem of adding a fourth train on the section Leeuwarden-Meppel vv. and the subsequent problems in the energy supply (as identified by ProRail) was selected. To solve the energy supply problems, a limit in the rolling stock length is instated. To comply with this limit, four scenarios are assessed and compared.

- *For the realisation phase:* A case which relates to a situation in which the infrastructure situation is known in detail and is preferably construction-phase related. This requirement resulted in the selection of the case where the combination of train series 1700 and 2800 at Utrecht is evaluated. In this case, limitations in platform occupation in Utrecht occurred, as a result of a phase in the DSSU project.

The solver is set to run with the default parameters of evaluations for the yearly plan. This comprises, in summary, that relatively low penalties for the parameters of the cost function, with the penalty for seat surplus set extra low. This results in a plan with a focus that is more on capacity aspects than on financial aspects. The penalties for changes in relation to the reference plan are set to zero.

[3]The alternatives in this case do not differ in terms of infrastructure, as this phase suggests. The selected case aims to approach such a situation by providing various alternatives for a single infrastructural problem.

The results of every case are compared with a base situation. These base situations are formed by calculating the conditions of the real-life situation. The actual planned (real-life) situation usually is manually altered a lot, and therefore, is not useful for comparison.

The indicators from TAM regarding first class sea ts are not used widely nor implemented correctly in all data and are likely to provide faulty results, therefore, these results are omitted in all cases. Seat surplus figures gave questionable outputs and therefore are omitted as well.

More practical details on the cases are discussed in each consecutive section.

5.2.1. Case 1: Re-opening Station Berkel-Enschot

The station Berkel-Enschot (Bke) is a former stop on the railway line Tilburg – Nijmegen. It was located between the current stations Tilburg (Tb) and ‘s-Hertogenbosch (Ht). The station was opened on the 4th june 1881 , but was closed again on the 15th of may 1938. Currently there are plans to reopen the station and to implement the stop in sprinter series 6600 between Dordrecht (Ddr) and Ht. This extra stop has an effect on the total trip time and therefore, might have an effect on the circulation.

The 6600 series operate with a frequency of 2 per hour (every 30 minutes in both directions) and it is operated by DDZ4 (LBM) double-deck rolling stock. The new situation is compared with the current situation (in BD2017) by adding a stop in the train series 6600 at the (planned) station Bke. The added time, due to this stop, is 2 minutes, which has been calculated with timetable study software 'DONS'. DONS is used, since this software can manipulate infrastructure data and therefore, has the ability to evaluate the effects of this case for the timetable. The calculations, performed with DONS, is shown in Table 5.3. Since the timetable is planned in full minutes, the results are rounded; here from 1,46 to 2 minutes. In this table, the running times are presented on the relevant drp. In this calculation Bke is represented by the drp 'Tilburg Industrie: Tbi', since this lies only 1 km from the location of Bke and Bke itself is not represented in DONS yet. The column 'stat' represents the stop times, for which a value of 0.7 minutes is used as a rule of thumb. The running times (t_r) are summed and the stopping times (t_s) are added for the situation with and without the stop. The difference ($t_r^0 - t_r^1$) is shown in the far right column.

Table 5.3: Added travel time calculation for the stop at Bke, time units in minutes

SP E6600 H.01 Ddr-Ht *(No stop at Bke)*				SP E6600 H.01 Ddr-Ht *(Stop at Bke)*				
Drp	Track	Stat	t_r	Drp	Track	Stat	t_r	$t_r^0 - t_r^1$
Tb	1 (901a)		0	Tb	1 (901a)		0	
Tba	LJ	0,7	1,56	Tba	LJ	0,7	1,56	
Tbi	955		1,79	Tbi	955	0,7	2,16	
Vga	768	0,7	7,02	Vga	768	0,7	7,41	
Ht	4a (704a)		3,18	Ht	4a (704a)		3,18	
		$\sum t_r$	13,55			$\sum t_r$	14,31	
		$\sum t_r + \sum t_s$	14,95			$\sum t_r + \sum t_s$	16,41	*1,46*

This case is evaluated for day 2 only (i.e. Tuesday) due to the repetitive nature of the timetable of this train series. Tuesday is used, since this day is considered normative. This is as a rule of thumb within NS.

The passenger prognoses are disregarded in this case, because there are no prognoses available yet for the adding of the new station. Since the timetable is roughly the same, except for the added 2 minutes at Bke, no large deviations in the seat demand are expected. Therefore, the case investigates if there are serious changes in the deployment of rolling stock, due to this added travel time.

Deadhead trips

A deadhead trip is a trip without passengers that transports a train or train set from one location to the other to make a more efficient schedule. In the numbering of train series, deadhead trips are indicated by the prefix '7'. For the 6600 series, the corresponding deadhead trips are indicated by the 76600 series. In TAM, these deadhead trips have to be added manually, but are displayed separately in the numerical result.

Figure 5.1 shows the circulation of the original 6600 series. From the figure it can be seen that the service requires 5 train sets (5 rows in the circulation diagram).

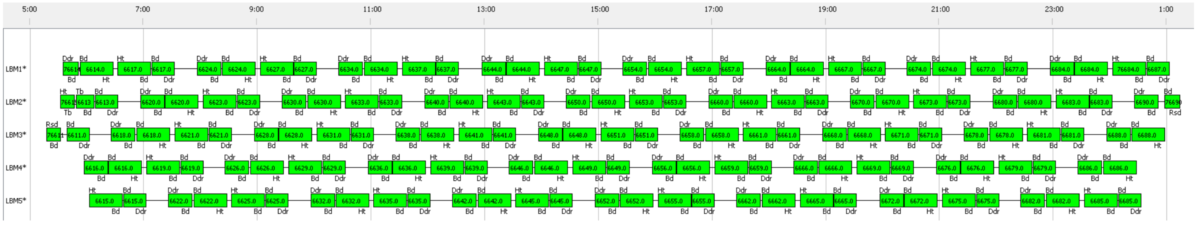


Figure 5.1: Rotation of the 6600 series (without adding of Bke), stops in Bd displayed for every service

Figure 5.2 shows the circulation of the 106600 series, which represent the 6600 series with the added two minutes. From this figure it can be seen that the TAM solution requires five train sets as well. Due to the longer trip times, the turn-around-times at Ht become very small (i.e. 3 minutes). One of the outputs of TAM is that the created circulation does not comply to the norms of NS (so-called Isidoor-norms) because the turn-around-times are too short. Therefore, a different turning pattern *(Keerpatroon)* has to be defined, which does not let an incoming train in Ht turns around on its direct successor, but on the next one. The resulting circulation is shown in Figure 5.3 and requires 6 train sets, as a result of the longer turn-around-time.

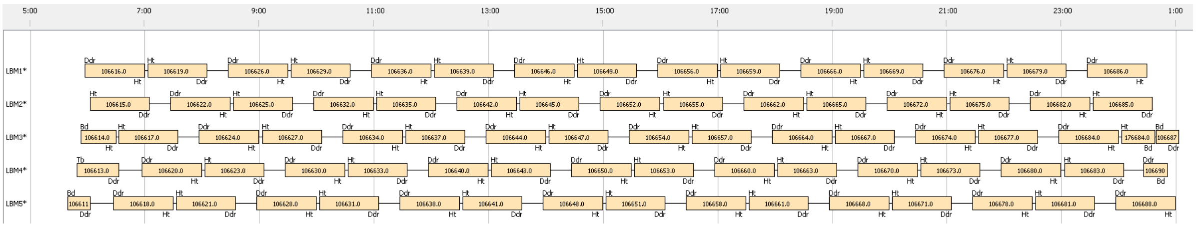


Figure 5.2: Rotation of the 106600 series (with stop at Bke), stop in Bd not displayed

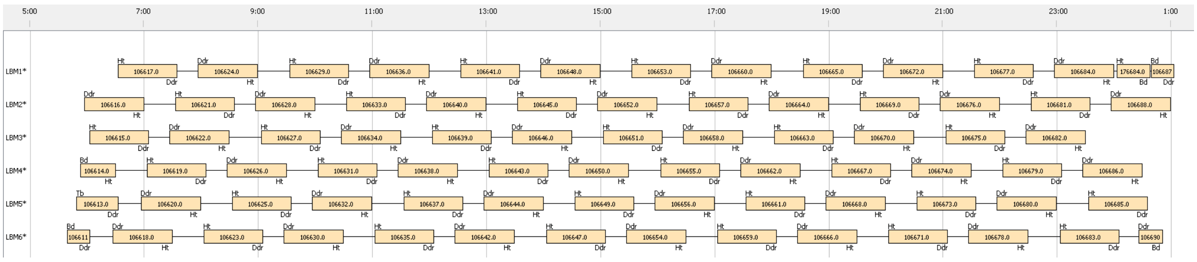


Figure 5.3: Rotation of the 106600 series (with stop at Bke) and extra turn-around-time

Table 5.4 shows the relevant indicators from the TAM calculation. Since there was no prognosis data available, all the indicators that are based on prognosis data are omitted (8, 11-20). The comparison of the 106600 is done with a calculation of the 6600 series, and not with the actual plan, therefore the comparative indicators (23-34) are omitted as well.

Discussion of Results

The most relevant outcome is the need of an extra composition to overcome the extra stop. The addition of two minutes resulted in a shortage in turn-around-time, which subsequently lead to the need of another train set. The amount of carriage kilometres and empty carriage kilometres did not change, since the amount of services does not change and the trip kilometres are spread over more train sets. This can give a biased view. Furthermore, despite the extra train set, the empty kilometres do not change, this is due to the fact that these empty kilometres only count for dead-head trips, not for shunting movements. In this situation, it is assumed that the extra train set is available at the station where the service starts. In real life, more 'empty kilometres' might occur due to extra relocation trips. Besides this, the solver does not take in to account platform occupation and possible shunting activities that are related to the platform usage at the stations, this can also lead to a biased view on the situation.

Table 5.4: Numerical results from TAM

#	Indicator	6600	106600	δ	
1	Number of shunting activities	10	12	+2	20%
2	Number of starters/enders	10	12	+2	20%
3	Amount of detachments/attachments	0	0	0	0%
4	Trip kilometres	5.585	5.585	0	0%
5	Carriage kilometres	22.520	22.520	0	0%
6	Passenger carriage kilometers	22.340	22.340	0	0%
7	Empty car kilometres	180	180	0	0%
9	Total supplied seat-kilometres	2.219.662	2.219.662	0	0%
10	Total supplied seats-kilometres (4%)	2.278.685	2.278.685	0	0%
21	Total travel time train mangers	74	78	+4	5,4%
22	Train manager duties	16	16	0	0%

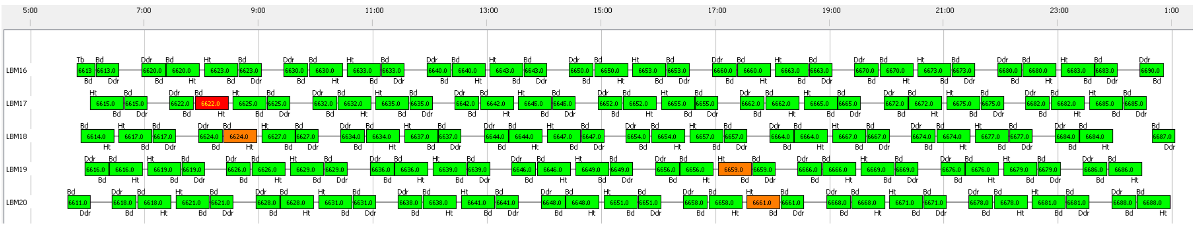


Figure 5.4: Capacity view of the circulation of the 6600 series. Green= C-norm, Orange= A-norm, Black= V-norm, Yellow-font= exceeding the applied norm

For the case, no prognosis data is used for the introduction of the new line. Thus the outcome is purely based on the added kilometres. With the patronage data of the original 6600 series an estimate can be made on the new situation. Figure 5.4 shows the capacity based on the norms. There are some services that experience capacity exceeding. Due to the addition of the new station, it can be expected that the amount of passengers will increase. This might result in the need of deploying more train sets or a different type of rolling stock.

The case focusses on an exploration situation. The results of the run with the added running time are relatively coarse, but do give useful information in this time window, and can be used for further development of the plans.

5.2.2. Case 2: Power Limitations Leeuwarden-Meppel

"In the pre-study phase of timetable 2017, a fourth train between Leeuwarden (Lw) and Meppel (Mp) has been planned. The desired timetable consists of two ICs and two Sprinters. For the 4$^{\text{th}}$ train, there is a good chance that there is a shortage in capacity of the traction-power supply." This can lead to power outages and dangerous levels of the return-currents in the rails. [55] At the moment the track is operated by the IC series 1800 (Lw-Mp-Zl-[..]-Gvc v.v.) & 600 (Lw-Hr-Stw-Zl-[..]-Rtd v.v.) and the sprinter series 9000 (Lw-[..]-Mp v.v.). The ICs operate once every hour. In the study situation the frequency of the sprinter is increased form 1/hour to 2/hour (i.e. the fourth train per hour).

To overcome the limitations in the power supply, caused by operating these trains, one solution is limiting the length of the compositions. NS investigated the option where the train lengths are limited to overcome the limits in the power supply. Four alternatives are evaluated in this case, of which the limitations L are shown in Table 5.5. In alternative 2 and 4, the turn-around is different, which is denoted in the last column. To ensure enough availability of VIRM train sets, in variants 3 and 4, series 2100 are changed from VIRM to ICM.

Since this case is comprehensive in terms of assessed train series, the focus lies on the numerical results. This is because the graphical representation gives little comparative information in this case.

Table 5.6 shows the obtained indicators for the base situation V_0). This base situation is a calculation with the five train series (600, 700, 1800, 9000 & 2100), based on the timetable of 2017 (BD2017). The results of the alternatives V_1 to V_4 is shown in Table 5.7.

Table 5.5: Limitations in compositions for the four alternatives and the base situation (V_0)

Alternatives	L_{1800}	L_{600}	L_{2100}	Turn-around
V_0	VIRM	ICM	VIRM	1800 → 700 & 700 → 1800 @ Gvc
V_1	max VIRM6	max ICM4	VIRM	1800 → 700 & 700 → 1800 @ Gvc
V_2	max VIRM6	max ICM4	VIRM	1800 → 1800 & 700 → 700 @ Gvc
V_3	max VIRM6	max VIRM4	ICM	1800 → 700 & 700 → 1800 @ Gvc
V_4	max VIRM6	max VIRM4	ICM	1800 → 1800 & 700 → 700 @ Gvc

Table 5.6: Base situation

#	Indicator	V_0 600,700, 1800	 9000	 2100
1	Shunting Activities	546	32	109
2	Starters/enders	300	32	66
3	Attachments/ detachments	246	0	43
4	Trip kilometres	190.480	8.395	27.082
5	Carriage kilometres	1.073.774	26.586	166.268
6	Pax carriage kilometers	1.068.124	25.251	165.106
7	Empty carriage kms	5650	1.335	1.162
8	Total demand [km]	41.887.823	476.731	6.502.057
9	Total supplied seat kms (based on norm)	101.452.655	2.082.953	17.580.694
10	Total supplied seat kms (based on norm, 4%)	105.127.601	2.140.803	18.094.070
11	Total seat shortage kms (based on norm)	29.234	0	1.649
12	Total seat shortage kms (based on norm, 4%)	17.503	0	621
15	Passenger trips	2.076	130	438
16	Trips exceeding C-norm	45	0	10
17	Trips exceeding A-norm	2	0	0
18	Trips exceeding V-norm	0	0	0
20	2nd class seat surplus kms	58.261.470	1.553.291	10.251.779
21	Total travel time train managers	2184	101	561
22	Train manger duties	470	21	120
AD	VIRM4 train sets	5	-	8
OA	VIRM6 train sets	11	-	1
OC	ICM4 train sets	3	0	-
OH	ICM3 train sets	11	3	-

Table 5.7: Results of the four alternatives

#	Indicator	V_1 600,700, 1800	V_1 9000	V_1 2100	V_2 600,700, 1800	V_2 9000	V_2 2100	V_3 600,700, 1800	V_3 9000	V_3 2100	V_4 600,700, 1800	V_4 9000	V_4 2100
1	Shunting Activities	539	40	109	509	40	109	473	40	127	448	40	127
2	Starters/enders	294	40	66	280	40	66	292	40	92	278	40	92
3	Attachments/ detachments	245	0	43	229	0	43	181	0	35	170	0	35
4	Trip kilometres	190.480	16.790	27.082	190.480	16.790	27.082	190.480	16.790	27.082	190.480	16.790	27.082
5	Carriage kilometres	1.051.341	50.370	166.268	1.058.033	50.370	166268	1.012.018	50.370	184.755	1.003.110	50.370	184.755
6	Pax carriage kilometers	1046713	48.945	165.106	1.052.889	48.945	165106	1.007.732	48.945	183.711	998.758	48.945	183.711
7	Empty carriage kms	4.628	1.425	1.162	5.144	1.425	1.162	4.286	1.425	1.044	4.352	1.425	1.044
8	Total demand [km]	41.887.823	16.315	6.502.057	41.887.823	16.315	6.502.057	41.887.823	16.315	6.388.990	41887823	16.315	6.388.990
9	Total supplied seat kms (based on norm)	99.390.272	4.132.260	17.580.694	99.951.349	4.132.260	17.580.694	103.153.003	4.132.260	15.311.203	102.253.270	4.132.260	15.311.203
10	Total supplied seat kms (based on norm, 4%)	102.990.298	4.248.345	18.094.070	103.575.377	4.248.345	18.094.070	106.898.117	4.248.345	15.702.887	105.965.795	4.248.345	15.702.887
11	Total seat shortage kms (based on norm)	104.722	-	1.649	100.570	-	1.649	28.036	-	7.690	25.798	-	7.690
12	Total seat shortage kms (based on norm, 4%)	73.067	-	621	71.260	-	621	16.876	-	5.518	15.556	-	5.518
15	Passenger trips	2.076	260	438	2.076	260	438	2.076	260	438	2.076	260	438
16	Trips exceeding C-norm	66	-	10	59	-	10	36	-	34	33	-	34
17	Trips exceeding A-norm	7	-	0	6	-	0	0	-	1	0	-	1
18	Trips exceeding V-norm	0	-	0	0	-	0	0	-	0	0	-	0
20	2nd class seat surplus kms	56.223.148	-	10.251.779	56.838.651	-	10.251.779	59.898.149	-	7.697.090	59.017.688	-	7.697.090
21	Total travel time train managers	2.159	203	561	2.134	203	561	2.184	203	569	2171	203	569
22	Train manger duties	465	43	120	460	43	120	470	43	122	468	43	122
AD	VIRM4 train sets	5	-	9	4	-	9	16	-	-	16	-	-
OA	VIRM6 train sets	11	-	0	11	-	0	11	-	-	10	-	-
OC	ICM4 train sets	7	-	-	7	-	-	-	-	0	-	-	0
OH	ICM3 train sets	6	4	-	6	4	-	-	4	12	-	4	12

Since the case aims to make a comparative assessment, Table 5.8 shows relative results. In this overview the results of every indicator are compared with the base situation (V_0) to see what the impact is on various aspects. The last four columns show the differences, expressed in percentages, colour coded from green (positive) to red (negative). These colour scales are not assigned to every indicator, since it is a matter of perspective if an indicator is positive or negative. For example: The amount of seats (and seat surplus) is negative in terms of costs, but positive in terms of customer experience.

Table 5.8: Relative results

#	Indicator	$\sum V_0$	$\sum(V_1 - V_0)$	$\sum(V_2 - V_0)$	$\sum(V_3 - V_0)$	$\sum(V_3 - V_0)$	δ_{V_1}	δ_{V_2}	δ_{V_3}	δ_{V_4}
1	Shunting Activities	687	688	658	640	615	+0,15%	-4,22%	-6,84%	-10,48%
2	Starters/enders:	398	400	386	424	410	+0,50%	-3,02%	+6,53%	+3,02%
3	Attachments/detachment	289	288	272	216	205	-0,35%	-5,88%	-25,26%	-29,07%
4	Trip kilometres	225.957	234.352	234.352	234.352	234.352	+3,72%	+3,72%	+3,72%	+3,72%
5	Carriage kilometres	1.266.628	1.267.979	1.274.671	1.247.143	1.238.235	+0,11%	+0,63%	-1,54%	-2,24%
6	Pax carriage kilometres	1.258.481	1.260.764	1.266.940	1.240.388	1.231.414	+0,18%	+0,67%	-1,44%	-2,15%
7	Empty carriage kms	8.147	7.215	7.731	6.755	6.821	-11,44%	-5,11%	-17,09%	-16,28%
8	Total Demand [km]	48.866.611	4,8E+07	48.406.195	48.293.128	48.293.128	-0,94%	-0,94%	-1,17%	-1,17%
9	Total supplied seat kms (based on norm)	1,21E+08	1,2E+08	1,22E+08	1,23E+08	1,22E+08	-0,01%	+0,45%	+1,22%	+0,48%
10	Total supplied seat kms (based on norm, 4%)	1,25E+08	1,3E+08	1,26E+08	1,27E+08	1,26E+08	-0,02%	+0,44%	+1,19%	+0,44%
11	Total seat shortage kms (based on norm)	30.883	106.371	102.219	35.726	33.488	+244,43%	+230,99%	+15,68%	+8,44%
12	Total seat shortage kms (based on norm, 4%)	18.124	73.688	71.881	22.394	21.074	+306,58%	+296,61%	+23,56%	+16,28%
15	Passenger trips	2.644	2.774	2.774	2.774	2.774	+4,92%	+4,92%	+4,92%	+4,92%
16	Trips exceeding C-norm	55	76	69	70	67	+38,18%	+25,45%	+27,27%	+21,82%
17	Trips exceeding A-norm	2	7	6	1	1	+250,00%	+200,00%	-50,00%	-50,00%
18	Trips exceeding V-norm	0	0	0	0	0	0,00%	0,00%	0,00%	0,00%
20	2^{nd} class seat surplus kms	70.066.540	6,6E+07	67.090.430	67.595.239	66.714.778	-5,13%	-4,25%	-3,53%	-4,78%
21	Total travel time train managers	2.846	2.923	2.898	2.956	2.943	+2,71%	+1,83%	+3,87%	+3,41%
22	Train manager duties	611	628	623	635	633	+2,78%	+1,96%	+3,93%	+3,60%
AD	VIRM4 train sets	13	14	13	16	16	1	0	3	3
OA	VIRM6 train sets	12	11	11	11	10	-1	-1	-1	-2
OC	ICM4 train sets	3	7	7	0	0	4	4	-3	-3
OH	ICM3 train sets	14	10	10	16	16	-4	-4	2	2
	$\sum_{Train\ sets}$	42	42	41	43	42	0	-1	1	0

Discussion of Results

Based on the relative results, shown in Table 5.8, in general, alternative V_3 & V_4 outperform the first two. Since V_4 performs better or equal for most indicators and costs zero extra train sets (after summation of the total amount of train sets), it appears that this is the best alternative. Only indicators 21 & 22 show an increase in travel time and crew duties. Additional study of the logistic feasibility/desirability of the plan might give a reason to choose another alternative, but at first glance it seems that the limitations do not result in severe capacity issues (and even results in a lowering of A-norm exceeding trips) or changes in the total amount of required train sets.

5.2.3. Case 3: Changing Rolling Stock Type on the 1700/2800 Series

During construction phase 5d of DSSU, several switches were removed from the Utrecht switch yard. Due to limited platform length to turn-around the 2800 series, it was impossible to operate train series 1700 and 2800 as separate trains. Therefore, the two train series were linked together at Utrecht. Until BD 2015, the 1700 series were operated by double-deck VIRM trains and the 2800 with single-deck ICM trains. From the start of timetable 2015, both trains were operated with ICM trains. This was a requirement by the operational planning, since operating with mixed types results in operational complexities. The actual link was established at the main timetable change of December 2014 (when BD 2015 was introduced). As from the timetable (BD) 2016, the combined train service was changed to VIRM, to be able to cope with increased patronage on the lines.

Vleugeltrein

The 11700 is the parallel train series *(Vleugeltrein)* of the 1700 (hence the prefix '1'), this means that the destination alternates. The (1)1700 starts at Gvc and the destination alternates between Es and Amfs. The service is set up in such a way that a 1700 turns around in Gvc on the 11700 series and vice versa. When the 1700/2800-combo is mentioned, the combined 1700, 11700 and 2800 series are meant.

Table 5.9: Rolling stock types per train type

Series	Route	Sept. 2014	Sept. 2015
1700	Gvc-Gd-Ut-Amf-[..]-Es	ICM (OH&OC)	VIRM (AD&OA)
11700	Gvc-Gd-Ut-Amf-Amfs	ICM (OH&OC)	VIRM (AD&OA)
2800	Rtd-Rta-Gd-Ut	ICM (OH&OC)	VIRM (AD&OA)
3500	Shl-[..]-Ut-[..]-Hrl	VIRM (AD&OA)	ICM (OH&OC)

This case focusses on the question if the rolling stock switch was necessary. Since it is done in retrospect, patronage data is available. Initially, two separate runs with TAM are performed; one with only ICM available and one with only VIRM. From the results it will be investigated if changing to VIRM was necessary and what the impact was of using the VIRM train sets from the 3500 series. The results are shown in Table 5.10. BDU September 2015 is used, only stock types are changed, all other factors (turn-around patterns, length limitations etc.) are fixed. For clarity, deadhead trips are disregarded in this case. Therefore, indicator 6 and 7 are omitted.

Table 5.10: Results of TAM runs for train series 1700, 11700, 2800 and 3500 with differences (δ)

		1700,11700,2800			3500			
#	Indicator	ICM	VIRM	δ^{VIRM}_{ICM}	VIRM	ICM	δ^{ICM}_{VIRM}	$\sum\delta$
1	Shunting Activities	69	55	-14	45	54	9	-5
2	Starters/enders	23	23	0	28	28	0	0
3	Attachments/Detachments	46	32	-14	17	26	9	-5
4	Trip kilometres	13.926	13.926	0	12.644	12.644	0	0
5	Carriage kilometres	84.420	82.290	-2.130	77.560	89.656	12.096	9.966
8	Total demand (km)	3.790.091	3.790.091	0	3.705.520	3.705.520	0	0
9	Total supplied seat kms	6.676.221	8.532.415	1.856.194	7.918.484	6.922.664	-995.820	860.374
10	Total supplied seat kms (4%)	6.900.473	8.827.477	1.927.004	8.213.850	7.179.318	-1.034.532	892.472
11	Total seat shortage kms	152.931	59.348	-93.583	2.300	14.532	12.232	-81.351
12	Total seat shortage kms (4%)	134.572	50.294	-84.278	54	6.062	6.008	-78.270
14	2nd clas seat shortage kms	175.618	70.820	-104.798	2.547	15.680	13.133	-91.665
15	Passenger trips	320	320	0	236	236	0	0
16	Trips exceeding C-norm	13	11	-2	7	9	2	0
17	Trips exceeding A-norm	14	4	-10	0	0	0	-10
18	Trips exceeding V-norm	5	3	-2	0	0	0	-2
								0
21	Total travel time train manager	195	197	2	182	178	-4	-2
22	Train manager duties	42	42	0	39	38	-1	-1
OH	Train sets ICM3	21	0	-21	0	28	28	7
OC	Train sets ICM4	7	0	-7	0	6	6	-1
AD	Train sets VIRM4	0	13	13	15	0	-15	-2
OA	Train sets VIRM6	0	5	5	5	0	-5	0
	$\sum_{Train\ sets}$	27	18	-10	20	34	14	4

The results in the third and fourth column of Table 5.10 show that using VIRM for the 1700, 11700 and 2800 gives significant operational benefits; the amount of shunting movements and attachment/detachments was lowered and the amount of carriage kilometres was lowered, while offering significantly more (27,8%) seat kilometres. Additionally a decline in the amount of norm-exceeding trips is obtained. It is expected that the 3500 series, which was changed to ICM to provide the required VIRM train sets, counteracts these results, therefore, a similar run is done with the 3500 series. The results of these run are shown in column 6 and 7. The columns depicted with a δ show, respectively, the difference for the 1700/11700/2800 and the 3500. The last column gives the sum of these differences, resulting in the final results of the change.

From these results it can be concluded that:

- There is a slight decrease in shunting activities and attachments or detachments.
- There is a significant increase in total carriage kilometres.
- The supplied seat kilometres increased as well, resulting in a decrease of norm exceeding trips.
- There is little change in staff requirements.
- There is a total surplus in ICM train sets, although the four carriage type has a deficit, due to the change. The same is valid for the four carriage VIRM train sets.

Discussion of Results

To decide if the change of the rolling stock type is desirable depends on the willingness to 'pay' for the reduction in norm-exceeding trips with a significant increase in carriage kilometres and the deployment of four extra train sets. Other indicators show little differences. In practice, the deficit in ICM4 & VIRM4 train sets might be overcome by combining the train sets with other train series. To evaluate this, additional studies need to be performed (evaluating the total circulations of rolling stock series to determine the effect on the whole network). Since this 'willingness to pay' differs per departments and the 'network effects' are not determined, the results of this case give interesting insights, but a specific recommendation cannot be given.

5.3. Conclusions on TAM Evaluation

The questionnaire and the case evaluations showed that a lot of parameters that are used in rolling stock planning can be provided by TAM. The tool is able to give results in the various phases of the infrastructure mutations process. Nevertheless, it has some shortcomings; the tool is highly dependent on input data from other tools, like the timetable from Donna or DONS and prognosis data. Additional, more detailed conclusions on the tool are given in Section 6.3 of the next Chapter.

6

Conclusions and Recommendations

This thesis focusses on the planning process for infrastructure mutations in the Dutch railway network from the perspective of NS. There is a lot of vagueness and uncertainty on how the process is currently structured. The aim of this research is to analyse this process, identify bottlenecks and give recommendations for improvement. Subsequently, it aims to evaluate the benefits of optimisation tool TAM in the planning process, with a focus on rolling stock circulations. These aims are based on the following research question:

Which problems are encountered in the planning process at NS when infrastructural mutations occur and can the effects of these mutations on rolling stock circulations be assessed with the use of current tools?

In Chapter 4 the analysis on the process of infrastructure mutations is discussed and in Chapter 5 the use of TAM in this process is evaluated. Based on the findings of these chapters, the research questions are answered, conclusions are drawn and recommendations are given. These are given in the following sections. At the end of the chapter, a reflection on the research is given.

6.1. Answers to the Research Questions

As mentioned in the introduction in Chapter 1, the research question is very broad, which makes it hard to provide a unambiguous answer. Therefore the main question is split up into four sub questions to make sure a proper answer can be given. This section answers these sub questions.

How is the current process of planning for infrastructure mutations set up?

The process is set up as a four phased system, starting from the initiative for the mutation in the first phase. After the initiative phase, the functional specifications for the mutation are drafted in the exploration phase and assessed by NS. Subsequently, various alternatives are proposed and assessed as well in the third phase. The process is complete at the end of the realisation of the mutation in the last phase; the realisation phase. The first three phases have their main focus on the creation of the plans for the mutation and have a relatively straight-forward course. After the definitive alternative is established by ProRail at the end of the third phase, the detailed planning for the timetable, rolling stock and crew is done by NS. This is the phase in which the process is most complex. The exact course of the process is dependent on various variables, for example the size of the mutation.

What bottlenecks in this process are encountered in practice?

Due to the complexity of the mutation process, various bottlenecks occur. The bottlenecks, identified by means of interviews with actors within the process, have different causes. The identified bottlenecks in the normative process can be subdivided in the following groups: unstructured and limited information housekeeping, a lack of clarity in the description of the process, unclear role definition and a lack of process ownership. For most of the problems solution can be proposed, but for large projects, the problem occurs that NS is 'forced' to provide the solutions for incidental changes in the realisation phase. This can not be easily solved, since there are no formal regulations and this is mainly caused by the way the playing field between NS and ProRail is organised.

In the DSSU case, some additional bottlenecks are identified. During the process, in various stages of the project there were limitations on the available planning capacity. This was partly due to the time schedule of the project, but also due to the way the planning departments are organised. Another bottleneck is regarding the overall structure of the planning process for infrastructure mutations and the way a long-term vision is implemented in this process. Some of the solutions in this thesis are based on improvements that are being implemented by NS already, like the PAST project for information housekeeping. A final, major bottleneck is the lack of possibilities to perform long-term studies on the impact of infrastructure mutations. Especially the impacts on rolling stock. New tools are likely to solve this problem, but there merits are not evaluated yet. Therefore, the merits of rolling stock circulation tool TAM are evaluated.

What factors determine the effects of infrastructural mutations on rolling stock circulations?
To be able to evaluate the merits of TAM, it has been investigated what factors in the rolling stock planning are relevant for the actors that are involved in the process of infrastructure mutations. The overview of relevant factors has been compiled by means of a questionnaire. The various actors mentioned different factors that were considered relevant, depending on their involvement in the process. The infra management department had no direct interest in the use of TAM at all. The commercial department attached importance to the costs, in terms of amount of train sets and kilometres and the customer satisfaction (seat availability). The long-term planner stated that all the provided factors were important. The department responsible for the incidental changes in the service (OSC/VSD) stated that only cost-related factors, like amount of train sets, driven (empty) kilometres and amount of shunting activities are of no importance. The NedTrain representative only marked the factors relevant that are directly related to stabling and maintenance, like the amount of operated services per train set. The majority of the mentioned factors can be provided by the tool. To evaluate the practical use of the mentioned factors, three cases were evaluated with TAM.

Is TAM able to provide these factors and give relevant outputs that can be used in the planning process?
The three consecutive cases all related to one of the three discussed phases in the process of infrastructure mutations. The cases showed that TAM can give relevant information on the effects of an infrastructural mutation. Although, in most cases, the interpretation of the results is dependent on the perspective of the various actors, because every actor has its own interest. Besides this, the dependency of TAM on other tools (e.g. for the timetable or prognosis data) impedes the possibility to quickly analyse every kind of mutation, especially on the long term. A large share of the factors that TAM can deliver are related to patronage and, consequently, to prognosis. To get the complete view of the impact, prognosis data is a necessity for proper studies.

6.2. Conclusions on the Process Analysis

The analysis showed that the complexity of the process of infrastructure mutations introduces numerous factors that impede this process. Especially due to the vagueness of the current practice, there are a lot of uncertainties. A lot of these factors are being tackled already, like the centralisation of information (with PAST), the introduction of a programme manager for larger projects, more use of integrated and long-term planning with use of TAM, OPG and, eventually; Donna. Although some of these issues are not directly solvable, like the weak position NS has in the negotiations during the process. This is mainly due to the way the playing field between NS and ProRail is organised. For other issues, improvements can be made.

By describing the process clearly, and by using a central place for information storage, where the information on assets and project is kept up-to-date, a lot of implications in the process can be avoided. NS has started with the use of the PAST project database and ProRail has the 'Logistiek Portaal' for infrastructure related information, but there is still a lot of improvement possible on this matter. Getting a clear picture on who is responsible for what kind of information and to act likewise will help to prevent the information void.

For another problem, a lot of improvement is still possible as well. That is the problem of planning on a relatively short term. Nowadays, various tools exist to make extensive simulations of alternatives for the timetable design. These computerised simulations use less planning capacity (manpower) and are relatively inexpensive to use, in comparison with manual techniques. At NS, some of the tools that can help with doing extensive studies already exist or are being developed. One of the main outcomes of the DSSU-case, is the lack of knowledge of the impact of the project on the deployment of rolling stock. TAM is one of these tools that is developed and can be used to assess the impact of certain changes in the infrastructure, and with that; the timetable, on the rolling stock deployment.

One of the pitfalls of the improvements, that are currently carried out, is that they lack widespread support or continuity. Therefore, the lessons learned are not used to their fullest. This can be supported by the example of the renewal of the Amsterdam switch yard, which can be seen as a similar project as DSSU. In this project the programme manager has been appointed only recently, which is relatively late. If this central project responsibility is introduced earlier, some bottlenecks that were encountered with the DSSU project can most likely be avoided in this new project.

6.3. Conclusions on the Evaluation of TAM

Based on the problem formulation for this thesis by NS, it seemed that there was a significant lack of tooling to assess impact of infrastructure mutations in the planning of rolling stock. Contrarily, it appeared that there was tooling available. But since these tools only just have been implemented or are currently in development, the possibilities to assess these impacts will become larger over time. For creating and evaluating rolling stock circulations, TAM can be seen as a comprehensive tool within the NS planning framework. Besides the planning, it provides the possibility to perform extensive studies on rolling stock circulations. The cases in the previous section give a good view on the applicability of the tool in various situations.

The differences between the study purposes of the various actors (like in the cases) and the planning that is done in real-life are comprehensive. Or in other words: the differences between an actual plan in practice and a calculation, both based on the same conditions, are large, due to various small changes in the plan during the daily practice. This makes the comparison between reality and the studied cases hard. Something which has to be taken into consideration by the planner who performs studies.

To obtain realistic results and to create efficient circulations, it is necessary to perform macro-studies. These macro-studies comprise of the entire network and entire rolling stock series. This way, train sets can be used in multiple, adjacent, train series. This can result in a lower number of required train sets and, therefore, a more efficient use of the trains.

At the moment, the tool is mostly a 'stand-alone' programme and needs a lot of manual inputs to perform studies. To make it easier to perform studies, more integration with other tools and resources is desirable. The possibility to use study scenarios from the timetable study tool DONS would facilitate studies where the entire 'line of assets' (i.e. infrastructure, rolling stock, crew) is integrated. Now the underlying timetable is obtained from Donna and reduces flexibility for studies, since it cannot be manipulated easily. The same is valid for prognosis data; the cases showed that the lack of prognosis data in study situations seriously limits the amount of output parameters for TAM. At the moment, project 'KLAP' is set up to obtain a better integration between DONS, VISUM (prognosis tool) and TAM. This project can fill in this gap.

Another 'gap' in the planning with TAM is the one between the circulations and shunting- and maintenance planning. The only features of this matter in TAM are the claims that can be implemented when selecting train series and the inventories at stations, of which the latter do not actually constrain the model. Integrations with tools as the previously mentioned OPG-tool could overcome this limitation. Also the planned integration in Donna can provide solutions to this deficit.

Another opportunity for the use of TAM, based on the high amount of manual inputs, is to run the solver in a more 'organic' way. In current practice, a lot constraints are present in the model, for example the turn-around patterns *(Keerpatronen)* and the impossibility to let the solver plan deadhead trips by itself. By 'relaxing' the model in terms of the turn-around patterns and giving the opportunity to add deadhead trips, there is a chance that the solver returns a more efficient circulation. It must be mentioned though, that there are a lot of tactical, strategic and operational constraints to this, like fixed stock-types per route, geographical maintenance limitations, staff limitations, and controllability of the service that still limit the solution space.

There are a lot of degrees of freedom to steer the solutions of the solver (the created circulations). Examples are: strategic-financial considerations, like the use of more train sets; operational-financial: reduce carriage kilometres, tight planning to demand, reduce surpluses; more customer-oriented, like improving the chance of having a seat, and therefore increasing surpluses. These degrees of freedom give a lot of opportunities for making various kinds of circulations, but it also introduces uncertainties: there is not a specific circulation that is 'the best', it is a continuous consideration between various stakes.

Results of the Cases in Relation to the KPIs Most indicators are directly available from TAM and it can be concluded that TAM is a useful tool that provides relevant information on the rolling stock planning and the implications of infrastructure mutations for various actors in the process. There are two main shortcomings in relation to the requested KPIs. A lot of KPIs, (amongst them the 4th and 5th most important one, according to the quantitative results from the questionnaire) are related to prognoses and, therefore, need extra information to be fed into TAM, which is a shortcoming of the tool. Once prognosis data is available, this shortcoming can be overcome, but the lack of integration is a negative aspect of the tool.

The second shortcoming is the lack of (microscopic) details of the effects of the circulation on the shunting plan. The only information available is on inventory at each station and shunting event information (event time and type). Detailed information like routes within the stations, stabling locations, duration and costs of the shunting movements are not an output of TAM.

Aside from these two shortcomings, which can be solved by providing extra data, or by combing the tool with other tooling, it can be concluded that TAM is a useful tool to assess the impact of infrastructure mutations on rolling stock circulations.

TAM in Relation to the Research Questions In Section 5.1, the relevant KPIs were obtained from the perspective of various actors in the rolling stock planning process and, consequently, related to the infrastructure mutations process. From these results it can be concluded that the requirements differ per department, which could be expected, due to the various areas of expertise of the departments. The required indicators that were expected from the rolling stock circulation tool varied from strategic stakes; like complying to the delivered train products, tactical-financial stakes; like operating a cost efficient service by minimising travelled and empty kilometres and use surpluses in a smart way. But also more detailed information on the individual trains for maintenance purposes. It must be added, that a lot of the requested KPIs are related to regular planning of the rolling stock and do not seem to have a direct link with infrastructure mutations. This can be explained by the fact that the stakes for 'regular planning' and 'mutation planning' do not differ very much and therefore, the required indicators are similar. Therefore, it can be concluded that with the outcomes of this section, sub question 3[1] is answered and forms a basis for the answer to the 4th sub question[2].

By performing the cases in Section 5.2 and comparing the theoretical description of the tool (Section 3.3 with the requested KPIs from Section 5.1, some conclusions of the applicability of TAM can be drawn, in particular in relation to infrastructure mutations. As mentioned above, the requested KPIs appeared to be mostly related to regular planning, but the cases involved clear situations in which the infrastructure was being changed.

When looking at the most relevant indicators from the quantitative part of the questionnaire and most of the requested indicators from the qualitative part, it can be concluded that, overall, TAM gives a good insight in the differences that occur in a situation where the infrastructure is changed. Nevertheless, there is a large dependency on tools for changes in the underlying timetable (DONS or Donna) and on traveller prognoses (VISUM). If this input data is not provided, the use of TAM is limited.

It is obvious that TAM is an improvement in comparison with the previous manual practice, like used at the start of the DSSU project, since the tool is not only able to quickly provide the circulations, but also to change parameters and to evaluate different scenarios with limited resources, like planners and time.

The main pitfall is the direct comparison of a study scenario with a plan from practice. The manual changes in such a plan are often too much to make a proper comparison and therefore, a calculated base scenario must be made. This has as a shortcoming that one is comparing a fictional situation with a fictional base situation.

Also the lack of microscopic (shunting) planning is something TAM cannot overcome, since this is not part of the solver. Therefore, the use of TAM would not have prevented the issues, related to the shunting yards at the DSSU-project.

6.4. Recommendations

Some recommendations on improving the process were integral part of this thesis and some have already been mentioned in the conclusion. In this section, some specific or additional recommendations are given.

By starting with a definition of the internal processes, with their responsible persons, problem owners and in- and outputs, a lot of the ambiguity can be solved. The findings of this thesis can be elaborated and formalised in such a way that the process is easy to understand and usable for all actors. It is wise to ensure widespread support and acceptance of these process descriptions, so internal disagreement can be prevented. By stipulating the process in, for example a quality management system, the process steps are

[1] What factors determine the effects of infrastructural mutations on rolling stock circulations?

[2] Is TAM able to provide these factors and give relevant outputs that can be used in the planning process?

clear and unambiguous. Besides this, the progression of the process can be monitored, which can avoid inconvenient surprises.

Also, a different approach of the planning process for mutations is advised. Like mentioned in the proposal for the solution for Problem D5 in Section 4.5, it is wise to use a planning approach which starts from an ideal situation, instead of a planning for a sub-optimal situation in a later stage of the process. Besides this, a better spreading of the planning stages over the process of infrastructure mutations is recommended. In the current situation most of the planning for the timetable, rolling stock and crew is done in the realisation phase. Spreading the planning can result in a better allocation of planning capacity. This will require drastic changes in the entire process, including the processes of other actors (e.g. ProRail).

Evaluation of large-scale processes in the future might reveal more bottlenecks from which the process can be improved. It is recommended to draw conclusions from these bottlenecks and to implement improvements in the process; for example by using the integral approach of DSSU from the start of new projects and investigate if this approach can be useful on other projects or processes within the company.

Another recommendation is the further development of integrated tools for planning, with a main focus on long-term planning. TAM has proven itself to be a useful tool, but by integrating the planning steps before and after the development of circulations (i.e. timetable and local-/shunt planning), a complete image of the effects of infrastructure mutations can be formed. This will result in less surprises during the realisation of a mutation. A prioritisation in developing a method to (easily) obtain prognosis data for study cases is recommended. At the moment, this method is investigated by NS (project 'KLAP', as mentioned before in this chapter), so it is likely that this improvement is made in the near future.

Further developing TAM and integrating the tool in other planning tools, as is scheduled to be done in the future, also makes sure that TAM can be used even more easily. This results in faster decision making in the process and, therefore, speeding up the entire process of infrastructure mutations. Additionally, it gives the opportunity to evaluate more scenarios for a proposed mutation which results in additional robustness in case a project is not carried out according to plan.

6.5. Reflection

To be able to understand the context and the use of this thesis it is important to identify the limitations of the research approach. This section discusses these limitations and helps to better interpret the contents of the thesis. As a general remark, it can be stated that the thesis covers a wide range of topics, but due to the many topics, the discussion of the individual parts in this report is not done in-depth. This is not necessarily a limitation, but it does make it harder to comply to the proper academic standard. This can be explained by various changes in the scope and the goal of the research along the creation of this report. As a cause for this, the difference in expectations between NS and the university can be appointed, but also because extensive literature review lacked in the earlier stages of the research. A third cause is that the author has only involved the graduation committee in a small number of occasions. By involving the committee more during the research, the 'drifting' could have been prevented. Nevertheless, this thesis can be a good starting point for additional research to get an in-depth view on the various topics. In the following sections, the specific reflection is given on the process analysis of Chapter 4 and the assessment of TAM of Chapter 5.

6.5.1. Reflection on the Process Analysis

The 'soft approach' of systems thinking in the process analysis and the use of interviews for acquiring data for the identification of bottlenecks resulted in a major limitation. The reconstruction of the process and analysis of the system (in combination with the identification of bottlenecks) are done mostly within the same interview session. This makes it hard to obtain explicit results for the separate interview goals. By splitting the research in separate parts, it could have been more structured and therefore resulted in more explicit outcomes, which were better to validate. This could have been done by starting with interviews that give clear vision on the process, without pinpointing bottlenecks and, subsequently, perform interviews to obtain the bottlenecks. The same separated approach could have been done for the real-life situation (the DSSU case), which would likely have resulted in outcomes that could have been compared better for the normative and the real-life situation.

Besides the previously mentioned inadequacy of the research method, a more precise goal in the early stages of the research process (and mostly in the process analysis) would have been desirable. This would have prevented 'drifting' within the defined scope. By having a clearer research framework in an early stage, more verifiable and explicit results could have been obtained. A proven method from literature could have helped for this limitation. In other words; accurately using a known method from literature, or carefully sticking to the method of comparing the normative situation with the real-life situation would likely have given more explicit results.

There were also improvements possible in the way interviewing was used for data gathering. In this thesis, a relatively small number of interviewees has been used. Although the interviewees were selected from different departments, and therefore, providing a wide view on the process, the sample size of the interviews is relatively low. Due to this, a valid dataset is hard to obtain. Besides this, it easily results in a 'listing of personal complaints' of the respondents. This was attempted to be prevented by ranking outcomes on the amount of times it was mentioned by different respondents, but this turned out to be impossible to do with the limited sample size. Another shortcoming, related to the interviews, is the usage of semi-structured interviews for the 'soft system'. This leads to responses that contain a lot of subjective data, which can cause biased views on how the actual process is carried out. As mentioned by Gillham [32], interpreting someone's (biased) opinion as the truth is a risk. This aspect of the way of data gathering is inevitable. This effect has played a big role in this thesis, since the interviews were carried out in a stage of the research where the author did not have a clear enough view on the organisation, the process and work flows to be able to decide how information from the interviews could best be interpreted.

Nevertheless, the results of the process analysis give a good overview of the structure of the process, what the in- and outputs of the various phases are and which department is responsible for the various intermediate steps. The performed method might not be 'watertight' from an academic point of view, given the limitations mentioned above, but the results expose various points for improvement which, in the future, can lead to a more smooth process flow and less surprises.

6.5.2. Reflection on the Evaluation of TAM

The choice for assessing the merits of TAM in situations where the infrastructure is changed has been made in a later stage of the research to narrow the scope. By limiting to this specific tool, opportunities to assess the use of other tools was omitted. Despite this being a deliberate choice, it results in a limited view on other possibilities to assess the impact of infrastructure mutations on rolling stock deployment. On the other hand, the choice for TAM has been advised by NS, resulting in a more practical use of the results. Especially since the tool has not been in active use for very long time (i.e. the use during DSSU was limited) and documented research on the practical application of the tool is limited. From an academic perspective it was more desirable to consider more options for the assessments, based on literature.

Another limitation in the TAM evaluation is the lack of validation. The results could have been validated by sending the results of the different cases back to the respondents of the KPI questionnaire. In this way, it could have been validated if the results of the cases were indeed desirable and useful. Due to scope changes and the resulting time limitations, this has not been done but would have made the results and conclusions more substantiated and useful.

Despite the limits in the TAM evaluation, the research shows that various effects of infrastructure mutations can be determined with the use of TAM, and it has exposed points of improvements for the tool, like better integration with other planning tools. Therefore, the findings of this thesis can be a starting point for the further development of the tool.

6.6. Final Remark of the Author

The road towards the completion of this thesis has not been one without bumps. The limitations, indicated in the previous sections, could most likely have been avoided by making other choices during the research. Nevertheless, I still expect this thesis to be useful for NS to stimulate further improvement of the planning processes and for them to keep improving their services. Besides this I expect that, in the end, it is a proof of my acquired analytic- and engineering skills, obtained during my study in Delft.

A

Interview Framework

In this appendix, the interview frameworks are mentioned. In Section A.1 the format for the interview questions related to the normative process are listed. In Section A.2 the questions for the DSSU-specific interviews are listed. Both interview frameworks have been made in cooperation with the company supervisor.

A.1. Normative Process Interview Questions

1. What is your role within the organisation?
2. What is your role within your department/section?
3. What is the role of your department/section?
4. What is your definition of mutations in the infrastructure?
5. What makes the distinction between a small and a large mutation?
6. What is your role, regarding large-scale infrastructure mutations?
7. What is your experience on the current practice in relation to the infrastructure mutation process?
8. What is going well, what can be improved?
9. What do you need in the process to complete your task, why do you need this and when do you need this?
10. What will go wrong if you do not get your 'input'?
11. What is the output you deliver and to whom do you deliver this?

Question 1 to 3 are about the interviewee and its place within the organisation. Question 4 - 6 are aimed at infrastructure mutations and the size of mutations. Question 7 and 8 relate to the bottlenecks in the normative process. The final questions (9 to 11) are meant to give more information on the normative process flow.

Table A.1: Interviewees for normative proces

Interviewee	**Department**	**Role**	**Remark**
Paul van Buuren	AM	Staff member 'asset strategy and quality mgmt.'	Responsible for PAST
Erik van Weelden	IM	Staff member 'infrastructure and environment'	
Dirk Dral	C&O/TDO	Product manager	
Guus Kimpel	OSC	Customer representative	
Kees van der Wal	IM	Staff member	

A.2. DSSU Process Interview

The DSSU interview has been aimed directly at the bottlenecks in the process. Prior to the interview, the interviewees where given a summarised overview of the suggested normative process structure. This is done to answer the questions that try to lay the connection between the normative process and the DSSU process. The overview is shown in Figure A.1.

Orientation

1. What is your role within NS (or ProRail)?
2. How does your role relates to the process of infrastructural mutations?
3. What has been your role in the DSSU project?

DSSU Process

4. Do you recognise the normative process, as it has been sent to you, prior to the interview? If not, what are the abnormalities?
5. Does the normative process resemble the process as carried out during DSSU?
    - If not; where, when and why not?
    - If yes; was this an appropriate approach for DSSU?
6. What are the bottlenecks that occurred during the DSSU project?
7. How can these bottlenecks be avoided in your opinion?

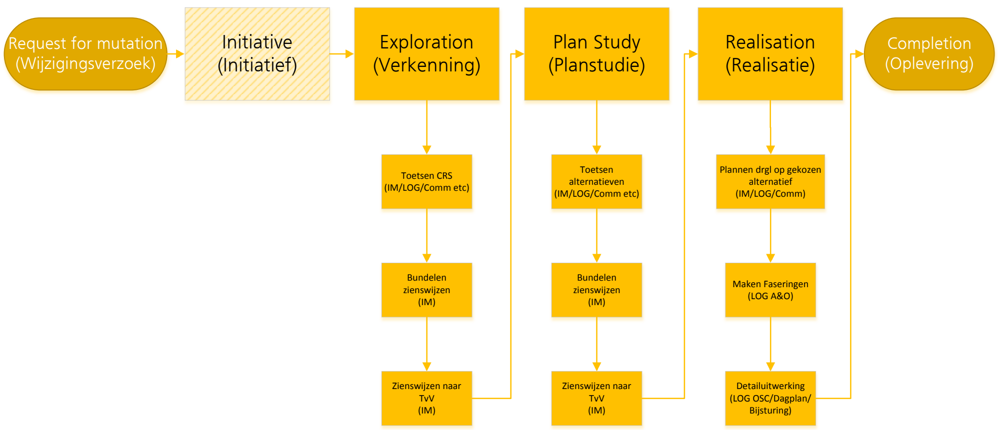


Figure A.1: Summarised overview of process structure

Table A.2: Interviewees for DSSU process

Interviewee	**Department**	**Role**
Erik van Weelden	IM	Staff member 'infrastructure and environment'
Wouter op ten Berg	C&O/TDO	Product manager
Mark Oldenziel	TB	Program manager "Groot Utrecht"
Jeroen Klinkers	ProRail	Program manager "Groot Utrecht"
Jaap de Ruijter	A&O	Architect
Guus Kimpel	OSC	Customer representative
Henrie Schut	A&O	(Former) planner for phasings

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