ProRail

UNIVERSITY OF TWENTE.

# Developing a methodology for train free period clustering using an opportunity-based methodology

Report Master Thesis

SEPTEMBER 19, 2017
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| Track: | Transport Engineering and Management<br>Construction Engineering and Management |
| Study year: | 2016/2017 |
| Version: | Thesis |

# Preface

"Ladies and gentleman, due to engineering works between Hilversum and Utrecht train services are replaced by busses. Please follow the signs to the bus platform to take a bus to Utrecht."
(Broadcast Utrecht Centraal, 2016)

In front of you lies the master thesis 'Optimization of train free period clustering using an opportunity-based methodology.' This research is conducted for ProRail to investigate how train free period clustering can be improved as my final assignment for completion of my master Civil Engineering at University of Twente. From August 2016 to June 2017 I have been working on researching and writing of this thesis.

I sent an open application to ProRail and with former mentor Ron, and we developed the thesis proposed and its research questions. Due to his opportunity to work for NS mentorship switched halfway from Ron to Harmen and Marco. After an extensive and intensive period of research I am 7able to answer the research questions and help ProRail further in reducing hinder. During this research, Ron, Harmen and Marco from ProRail and Andreas and Cuong from the University of Twente were always available to help when I had questions. My questions were always reflected to challenge me to improve my research and myself.

I thank my mentors for their support during this research and all other people I, regularly, asked for advice and further insight. Without their time and dedication, I could not have made it this far.

I would also like to thank all colleagues at ProRail for their warm welcome and their support. Multiple moments occurred when they pushed me to think a step further. I would also like to thank my friends and family for their advice and moral support I received.

I hope you enjoy your reading.

Thom Commadeur

Utrecht, September 19th 2017

# List of abbreviations

This research contains several abbreviations and some of them are Dutch abbreviations and are not translated into English to prevent confusion. The English translation is given after the Dutch explanation.1

BBV: "Bovenbouwverniewing" (Superstructure renewal)

BTD: "Buitendienststelling" (Possession)

FH: "Functie handhaving" (Maintain function)

FOT: "Functionele Ontrekkings Tekening" (Functional Extraction Drawing)

FW: "Functie wijziging" (Change of function)

GO: "Gebruikersoverleg" (User consultation)

INV: "Investering" (Investment)

LPO: "Landelijk Platform Overleg" (National platform consultation)

LVO: "Landelijk Verbeterprogramma Overwegen" (National Improvementprogramma Level crossings)

MJPG: "Meerjaren Programma Geluidssanering" (Multiannual Program Noise Mitigation)

MJPO: "Meerjaren Programma Ontsnippering" (Multiannual Program Defragmentation on nature)

OW: "Omgevingswerken" (Local projects)

P76: "Perronhoogte 76" (Level boarding entry)

PGO: "Prestatie Gestuurd Onderhoud" (Performance Based Maintenance)

PHS: "Programma Hoogfrequent Spoorvervoer" (Program High Frequency Rail)

RGO: "Regionaal Gebruikers Overleg" (Regional user consultation)

SAAL: "Schiphol – Amsterdam – Almere – Lelystad" (Program to improve rail service on that corridor)

TRS: "Tijdruimteslot" (Time space slot)

TVP: "TreinVrije Periode" (TrainFree Period)

[1] The entire report will be written in English but most abbreviations are used in Dutch to prevent miscommunication.

# Management summary

Clustering of train free periods (TVPs) has become more important in recent years as the number of possession requests grew and the capacity for possessions is limited. Currently, TVP clustering is performed on a loose basis and no process or technical support is provided. This research aims to provide a solution to the question how clustering of TVPs can be improved in order to decrease infrastructure unavailability. Problems related to clustering are identified and a clustering methodology is developed wherein evaluations and a new process are integrated.

TVPs are requested using Functional Extraction Drawings (FOTs), a drawing wherein duration of TVP and a schematic view of tracks is given. This drawing is made by Project Managers and shows which tracks are required in a TVP. A methodology is developed to assess the impact of a project within a TVP as it is unknown wherein a FOT work is performed and location relation between FOTs is important. Development started by determining what the main activities are that ProRail performs in a TVP. A list of twenty project activities has been determined and assessed using five criteria influencing TVP clustering. These five criteria are logistics of maintenance vehicles, interference during execution, movement of project, space occupation and importance to primary function. Each project activity is scored one to five and sum of these scores results in a final score of each project activity.

The acquired scores are used to assess the combination of different TVPs. Three factors influencing the in-between relationship between TVPs are used to determine a score which dictates the ability to cluster. These three factors are number of tracks, TVP duration and geography. Each factor has three options wherefrom must be chosen based on the information in FOTs. The factors are used to generate a final score of clustering between TVPs and based on that score an advice is given. That advice ranges from do not cluster to easy clustering as it is not possible to give a strict yes or no result as it remains to be an approximation. A cluster of TVPs will then form a possession.

An Excel tool is developed wherein the two evaluations are incorporated to improve the usability of the evaluations. ProRail currently develops a new possession management system called BTD-planner wherein TVP clustering could play a large role. Therefore, preconditions are defined which must be met by the software to take full potential of clustering. Most important part is the distinction between work shell and safety shell which is currently missing and is necessary to be known. This results in a yes or no methodology and is more reliable to predict clustering than the opportunity-based methodology.

The methodology is applied on real data and compared with the realized possession planning for 2017. The case-study area is the triangle Utrecht – Leiden – Rotterdam and all track sections within and opportunities for improving clustering were found. On some corridor parts the result was the same as for 2017, meaning the possession planners performed good on clustering and on some corridors a reduction was possible. Leiden – Den Haag for example showed a reduction of 60% in total possession duration. In total for the entire case-study duration decreased from 2945 hours to 2144 hours, a 27% reduction. The number of possessions decreased from 49 to 28, a 43% reduction.

Costs and benefits of postponing or advancing TVPs are identified when the total number of possessions is reduced on a corridor part. Advancement costs extra as end-of-life of an asset is not reached and value deficit is made. Such costs are not present when postponing as end-of-life is reached and through daily maintenance quality of asset is guaranteed. Benefits are for travellers less hinder due to less possessions on a corridor part.

Clustering of TVPs requires a new process as it was not properly embedded into the current possession planning process. Therefore, an addition to the current process is developed wherein clustering of TVP is captured and integrated. When clustering should be performed, how it should be done and how the result will help creating a better possession planning. ProRail should implement the proposed methodology to structure the clustering process and improve the clustering. Furthermore, additional software should be developed that improve clustering and can assess hundreds of TVPs automatically without human assistance.

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# 1 Introduction

Rail infrastructure managers are under a constant pressure to facilitate as many train paths per day and to improve maintenance scheduling to keep infrastructure available. Travellers requiring more trains and often later departures in the evening decreases the available time for maintenance and therefore influences infrastructure availability. Maintenance is executed mainly during periods with less travellers, mostly nights and weekends, and costs are rising every year, up to €510 million per year in 2011 (EIM-EFRTC-CER Working Group on Market Strategies, 2012). Every time maintenance is executed, tracks are not available or a reduced number of tracks and trains cannot run, an optimum is required to increase infrastructure availability but still enough time to perform maintenance. This is called the dependency between capacity and maintenance and renewal (M&R), illustrated in Figure 1. Maintenance of public infrastructure becomes complex due to various factors such as technical, economic, environmental, political and social (Schraven et al., 2011).

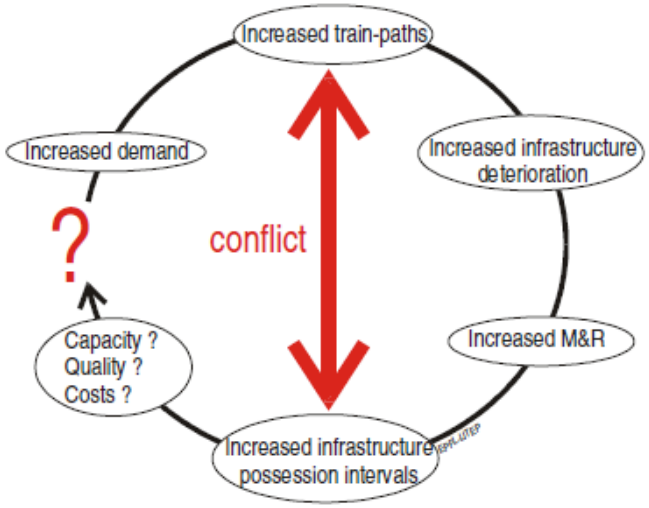



Figure 1: Dependency between capacity and M&R (IMPROVERAIL, 2003)

Maintenance and renewal are executed during a period without train traffic, called a 'Possession' (Buitendienststelling). These periods are available for three different types of maintenance, daily maintenance, renewal maintenance or construction of new infrastructure. During daily maintenance, the daily required maintenance is executed ensuring a proper safety level of the system, daily maintenance is not considered in this research. Renewal maintenance focus on the renewal of assets when they reach their end of life or are for other reasons required to be renewed. Construction of new infrastructure comprehends every aspect where extra infrastructure is added, new switches, tracks or dive-unders. Daily maintenance is mostly executed during weeknights, from Sunday nights until Thursday nights. Renewals and constructions are mostly executed during weekends as a longer work period benefits efficiency of renewal as starting and ending activities takes a significant amount of time.

ProRail is the Dutch rail infrastructure manager and is responsible for construction, maintenance, safety and capacity management of the rail network. With the reorganization of NS in 1995, three departments were created, NS Railinfrastructure Management, Railned and NS Traffic Control. These departments were placed under NS Railinfrastrust in 2000 and with the removal of Railinfratrust out of the NS Holding in 2002, a formal different organisation was created which was renamed first of January 2003 *ProRail*. These three departments merged in 2005 to *ProRail B.V.* and its main goals are to deliver train paths and to provide reliable and safe infrastructure.

ProRail is responsible for the maintenance of 7021 km of track, 7071 switches, 405 stations and 2589 level crossings and does so with 3958 employees (ProRail, 2016b). Figure 2 is a graphic display of the network that ProRail is responsible for safe and reliable transportation. Maintenance of these assets requires an extensive knowledge on their current state and deterioration to improve maintenance activities. ProRail is constantly improving on forecasting the state of infrastructure and how to maintain them with as less hinder as possible.

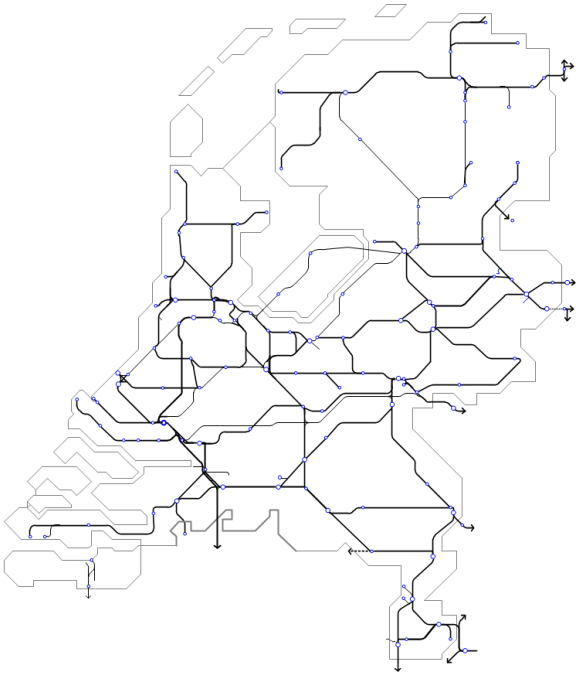


Figure 2: Dutch Rail Network

Capacity management is important for ProRail as it is the consideration between maintenance and operation. Choosing between longer lasting possessions, more than four hours, and operations of train services during weekends became a more difficult task. Optimization of maintenance periods is currently underperformed and too many maintenance periods are scheduled onto the network. Both maintenance and train operation are growing and clustering of train free periods is one of the possible solutions to reduce maintenance hinder. More specific, clustering of train free periods is one way of solving the problem and is the incentive for this research as it is an undocumented step in possession planning.

In Figure 3 an organogram of ProRail is given wherein it is visible where in the organization this research is conducted. The dotted line shows difference between where research is conducted and for which part of ProRail this research is meant. Difference between divisions is smaller than seems in this organogram and they are closely related. This research is conducted at staff department of infrastructure availability and facilitates possession department.

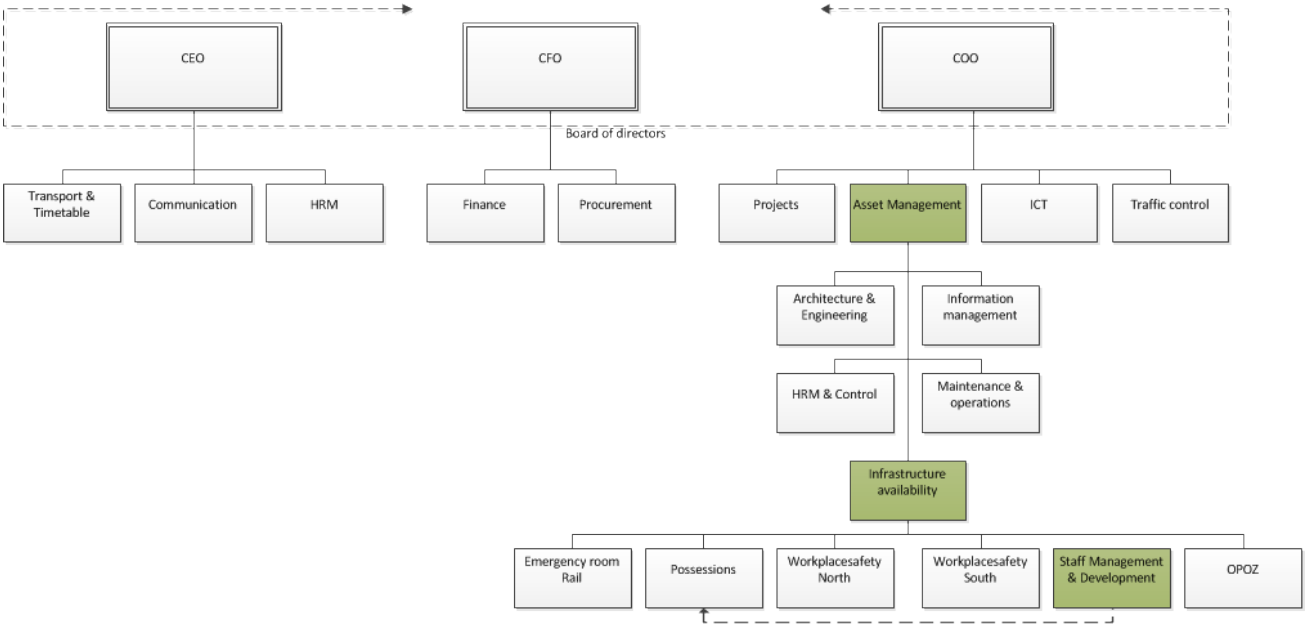



Figure 3: Organogram ProRail

## 1.1 Problem definition

The ever-growing need for maintenance as train intensities and demand for transport increases puts more pressure on an efficient balance between maintenance and operation. The number of required possessions for maintenance and construction has reached a level that it is no longer possible to plan in the appropriate year. This number of planned possessions also results in more hinder for travellers and cargo transporters. A reduction in possessions is necessary and clustering of TVPs is one opportunity to reach that goal. This will also reduce hinder for operators and freight transporters and will decrease infrastructure unavailability. No methodology exists for clustering of TVPs, no software support or a process what steps need to be made to perform clustering at ProRail.

Every year, there is a lot of negotiation in the process of dividing capacity and in 2016 a dispute occurred between ProRail and NS Reizigers, the major Dutch rail operator. The number of planned possessions required for maintenance and construction was unexpectedly high and influence on the timetable 2017 was large. Several lines are unavailable for several weekends and it occurs that on both ends of one line maintenance projects have to be performed but their possessions are not clustered. For example, several periods with different durations between two and four days are planned on Gouda and Den Haag in 2017 and these possessions create several periods with a lot of nuisance that could have been prevented according to operators. One recommendation from this dispute is to assess how the number of possessions can be reduced to improve the process for creating a timetable and to improve the relationship with stakeholders as they are convinced not all these periods are necessary.

An early result from preliminary discussions with ProRail employees shows that a clear process might be available for creating and requesting TVPs but is not clear. ProRail department of Transport & Timetable is responsible for allocating capacity for the timetable in a next service year and department of Possessions is responsible for programming of possessions. Initiatives to projects however come from local production planning, architecture and engineering, operators and local governments and currently lacks a process to centre these activities and there is also no consultation between these parties where they will work. Appendix A shows the origin of maintenance activities and who is responsible for their part. Operators, local governments, architecture and engineering and local governments are treated as different parties and the first gathering is at the operations office. These activities come from five ProRail regions: North, South, Randstad-North, Randstad-South and central when activities have a nationwide impact. All activities are transferred to the department Projects, where a project manager will request the TVPs based on information delivered by the different origins. During capacity allocation, a rough check is made on locations but the missing connection in the earlier process is a possible barrier for even more clustering of TVPs. The different parties mentioned before do not specifically define what their projects are about and such information is crucial to perform clustering.

Several maintenance and renewal projects are executed during possessions but not every TVP can be combined with each other. Several projects limit other projects to be executed such as ballast renewal preventing execution of catenary works on the same location. Clustering is limited because information on which projects have the potential to be combined is unknown. Also, there is a lack of overview between large and small projects as they have different project managers who have no detailed information what their counterpart is working on.

Large projects, both maintenance and construction, have a long preparation time, up to four to five years. Before execution, a lot of coordination is required with local stakeholders such as public transport companies, major event organisers and airports. Several commitments are made with these stakeholders regarding the time of execution. However, it often occurs two years before execution, other renewal works on nearby corridors are added and thus the planning could be interfered due to reachability issues. This leads to conflicts between stakeholders and ProRail and within ProRail as long-planned possessions might be moved to other dates. Currently barely any insight exists to have an overview on renewal of assets for several coming years. Most renewal work is gathered per year and treated on a yearly basis and limited clustering of projects for coming years is made. Each year the same process is executed in the same way, gathering information, which switch, what tracks and what catenary parts need to be renewed.

Due to the large number of possessions requested for 2017 and not being able to program them throughout the year, several possessions are moved to first quarter of 2018. The risks that come with this decision are, however, not known and a new bottleneck in the planning of 2018 might be resulted. A multi-year view, that could prevent the bottlenecks is missing. Clustering with work already planned in 2018 may have benefits and reduce the number of planned possessions. No process is designed to cope with this issue. Beneficial, however, is the number of scheduled possessions in the first two quarters of each year. At the end of August, a definitive number and design of possessions are set and the procurement of works can start. To start execution of works in the first quarter of the next year is difficult as it is too close from procurement to execution. Available maintenance capacity in the first and the second quarters is underused and this result to tensions within the organisation as third and fourth quarters are heavily used. The postponement of possessions results in problems for the planning in the next year, depending on when the decision on postponing is known. Before or after the planning for the next year is finalized.

Clustering of TVPs is not properly implemented within ProRail and requires more knowledge on when it can be performed and under what constraints. A multiannual planning is currently missing and results in sub-optimal possession clustering and planning. Also, limited support on clustering is available for possession planners. Every step is performed manually and steps are made in this research towards a more automated clustering. Main problem is clustering of TVPs for multiannual planning is not used in its full potential and clustering is not integrated within current possession planning process.

## 1.2 Objectives

The objective of this research is to investigate the possibilities and constraints for clustering of TVPs in order to help reduce the number of planned possessions. Evaluations and a new TVP clustering process to be able to implement clustering within current possession planning process requires development. At last, the evaluations and process are evaluated in a case-study to show their practical value.

## 1.3 Research questions

The main research question is based on the objective elaborated in the previous section and is as follows.

*'How can ProRail cluster plannable maintenance possessions in order to decrease infrastructure unavailability?'*

Several steps are required to answer the main question and to develop the methodology sub-research questions are formulated to achieve the main objective.

1. What is the potential of combining maintenance and project activities for clustering of plannable possessions?
2. What process is required to improve the clustering of plannable possessions?
3. What are the effects of postponing and advancing TVPs for ProRail, operators and travellers?

The first question focusses on the potential combinations of maintenance and project activities and what the constraints are that arise with that combinations. Certain combinations cannot be made due to several circumstances. Project activity evaluation and train free period evaluation are determined in this question. How these evaluations should be used is the basis for the second question, developed a process to improve the clustering.

The third question focus on the effects of postponing and advancing TVPs. Costs are considered for the ProRail asset side as advancing means that the assets end-of-life is not reached and additional maintenance is required when a TVP is postponed. Benefits on the other side are for travellers who are not faced with additional hinder.

## 1.4 Methodology

Several steps are required to reach the goal of this research. First a literature research is executed to gain insight in maintenance planning and maintenance activity clustering and compare the current ProRail practice with theory.

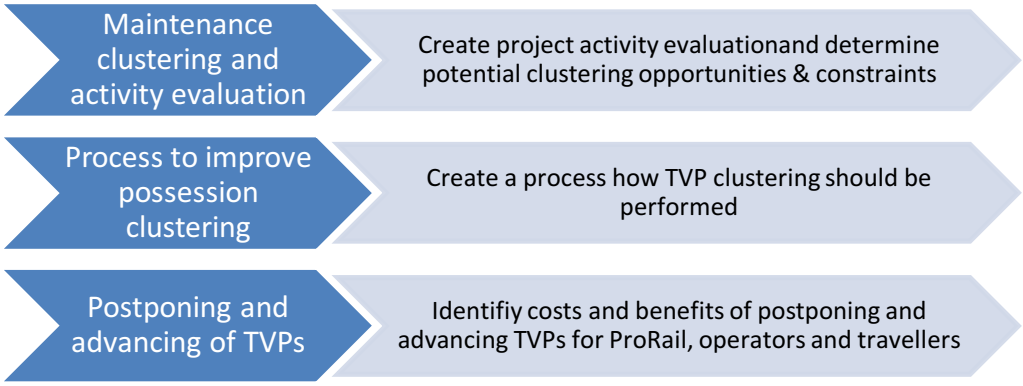



Figure 4: Process in answering questions

### *TVPs clustering and activity evaluation*

Potential combinations of maintenance and construction activities are assessed using a basis on which activities are performed. These activities are gathered from the Operations office. Many activities are performed and a limited amount of time is available so a low-detail list of performed activities is created. These activities are on a low detailed level, for example superstructure renewal and catenary works and give a general insight in the ability to cluster. Very detailed is not possible due to complexity of the network, short intense lines with several interactions and a complicated environment. To determine the ability to combine an early list is made and is assessed using an expert judgement. During this process, several constraints and conditions arise for combining activities and will be used to answer the second sub-question.

For the creation of a project activity evaluation, a set of assumptions is defined. The first assumption is labour availability would not be an issue. The second assumption is that each maintenance activity is individually optimized and no losses are registered during execution. Data is used for 2017 timetable and if necessary data from earlier years is available to be added to the research.

The different activities are assessed using five criteria:

- Logistics
- Interference during execution
- Movement of project
- Required space
- Importance to primary function

These criteria are selected through several discussions with key influencers within ProRail who determine the long-term strategy on project execution. Logistics focus on the availability of adjacent track(s) for other maintenance vehicles to be able to pass to a certain work site. Interference during execution criteria assesses the possibility of activities being performed nearby the currently assessing activity. Movement of project is about the movement of activities; remain at same location throughout a TVP or slowly moving. Required space determines the impact on spatiality of a certain activity; certain activities require larger areas than other. Importance to primary function is to consider the importance of a certain activity in the role of the entire system.

A weighted-scoring method is used to assess the activities. Each activity is ranked based on each criterion with a value between one and five and a higher score is positive for clustering. Assessing the combinations of activities, the total scores of each activity are summarized and this will give a final score between activities.

### *Process and tool to improve clustering of possessions*

From the above questions, several recommendations are made and with a consideration of the applicability in the organisation. How these recommendations are implemented is assessed in the second question and a process is generated to improve the clustering of maintenance activities into less possessions. An Excel tool is created to ease the use of the evaluations for planners. The tool can provide support for planners to give feedback to project managers on cluster ability of certain activities.

### *Case study*

A case study is performed to illustrate the developed methodology in practice and is used to make a comparison between the ProRail plan and the plan created using the new methodology.

The case study is the triangle Utrecht – Leiden – Rotterdam, shown in blue in Figure 5. Gouda was redesigned a couple of years ago but has been postponed several times due to scope changes and problems with financing. Several life-extending measures were taken and now already took up almost same amount of time renewal would have cost. Also, the yard is part of a major corridor and has a lot of traffic going to governmental city, The Hague, and to major hub, Utrecht. Also, it is a railway yard with connections to other railway lines or share tracks with lines to destinations like Rotterdam.

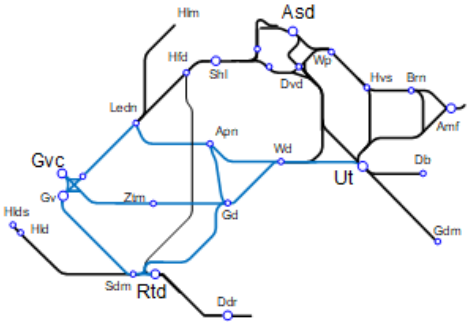



Figure 5: Location of Leiden – Rotterdam – Utrecht triangle in the network

Figure 6, on the next page, gives an in-depth look on the case-study wherein the corridor parts are visible between the given nodes. It allows a quick way to see all possessions requested at a certain location and is therefore very useful. Nodes are named in blue and the thickness of black lines show the number of tracks at that location, ranging from one track to more than four.

### *Postponing and advancing train free periods*

Postponing and advancing train free periods has costs and benefits for ProRail, operators and travellers. A table is made wherein benefits for travellers are given and costs for advancement and based on that table a decision could be made whether postponing or advancing is, from that perspective, profitable.

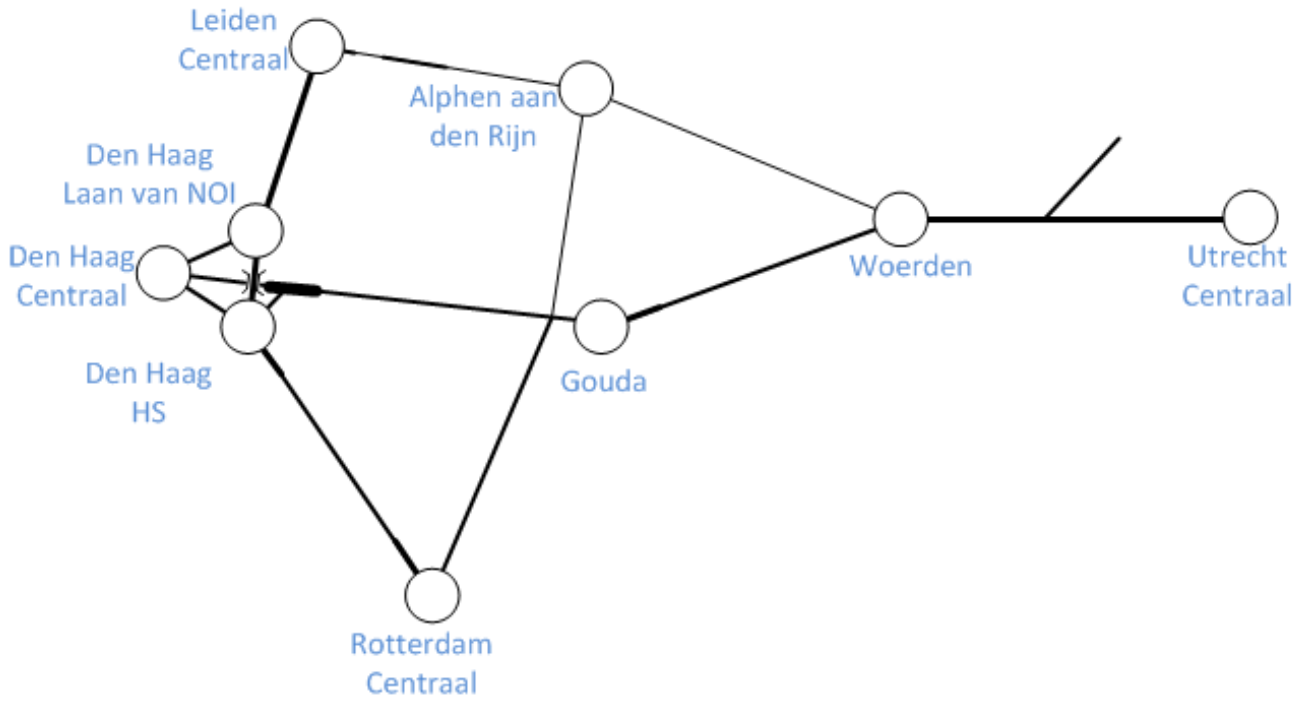



Figure 6: In-depth look on case-study area

## 1.5 Report structure

First, an elaboration on scientific knowledge regarding possession planning and maintenance grouping is given in the next chapter. Current ProRail practice is investigated in chapter 3 to get eyes on possession planning and to identify barriers and opportunities to improve. In this stage, the difference between theory and practice arises and what ProRail is missing to improve their possession planning. Next the design of clustering methodology is given in chapter 4 wherein project activities are assessed on their possibility to cluster. First an individual assessment on project activities is given which identifies the individual characteristics of each project activity based on five criteria. Then a second assessment is made wherein a train free period evaluation is developed and as last a new process required for the methodology is given described. Chapter 4 answers the first and second research questions.

Furthermore, the developed tooling with implementation of the evaluations is shown in section four. Finally, a case study is executed and given in section five to show the proposed methodology and is executed on real 2017 data. Section six answers the third research question regarding postponing and advancing of possessions. Conclusion, discussion and recommendations are the chapters seven, eight and nine wherein a retrospect is given on the research and what could have been improved.

# 2 Conceptual background

## 2.1 Asset deterioration

Asset management is based on deterioration of infrastructure as the asset degrades slowly. All assets deteriorate at different rates and the criteria for renewal differs resulting in separately scheduled renewal (Burrow et al., 2009). Combining maintenance projects could result in earlier than required renewal but in total expenses be beneficial due to the requirement of only one possession on a section. It is however not possible to combine all types of maintenance activities together, work on the overhead contact wire or work on signalling it may not be possible to combine these activities. Other benefit of combining maintenance activities is cost reduction as it may result in lower interruption costs, labour costs and equipment cost.

Optimizing transport infrastructure maintenance has a long history in literature, ever since start of railways, but mostly focusses on sequencing maintenance tasks (Gaudry et al., 2016). Maintenance is defined as the combination of all technical and associated administrative actions to retain a system or item in a state where it can fulfil its desired function (Dekker, 1996). The methodology Highway Development and Management (Worldbank, 2001) distinguishes four different types of road maintenance, similar to the rail maintenance industry, named routine works, periodic works, special works and development. Routine works are yearly or half-yearly recurring activities such as maintenance on a switch or inspection of the overhead contact wire. Periodic works is defined as work that is executed with an interval of several years and can be translated to the rail sector as track renewal. Special works comprehends maintenance that cannot be planned such as removing snow and repair of overhead contact wire occurred by a storm. Development is the expansion of existing infrastructure, in the rail sector best described as adding extra tracks or a tunnel to minimise level crossings.

## 2.2 Maintenance categories

Rail infrastructure maintenance is divided into two different categories, process and renewal. Process maintenance focusses on the daily operation of assets to maintain their main function while renewal focusses on the end-of-life and replacement of ageing infrastructure. To maintain infrastructure a possession is required and is not available anytime. Regular daily maintenance is scheduled in short maintenance windows which comprehends all infrastructure divided in structured sections available for several hours in a night and repeats every two to four weeks. Renewal maintenance however is often planned in periods with lower amounts of travellers, mostly weekends, to minimize hinder. In addition to these two categories is development of infrastructure as the increasing demand for transportation requires additional infrastructure. Development of additional infrastructure is also mostly executed during weekends as it provides a more efficient way of working and results in fewer costs and depending on the type of work the period could be extended to for example nine days or more. Current trend is to combine a lot of periods into a single large period as it offers less hinder and is also easier to offer alternative transport.

Renewal maintenance is executed to replace infrastructure that reached its end-of-life and requires renewal to keep delivering a certain performance level of the infrastructure. Figure 7 shows how ordinary and renewal maintenance relate to each other and what their function is. Ordinary keeps infrastructure at a certain level while renewal brings the infrastructure at a whole new level. Renewal maintenance can be executed in different periods, short periods with a high frequency or long periods with a low frequency. Both have their pros and cons on financial, technical and availability sides. Short periods with high frequency result in high costs as expensive machinery cannot be used as efficient as possible and the crew is paid for eight hours while they might work for only six hours. Blitz maintenance is the general term for maintenance possessions mostly lasting four to twelve days and resulting in execution of major works but also in longer periods of nuisance for travellers.

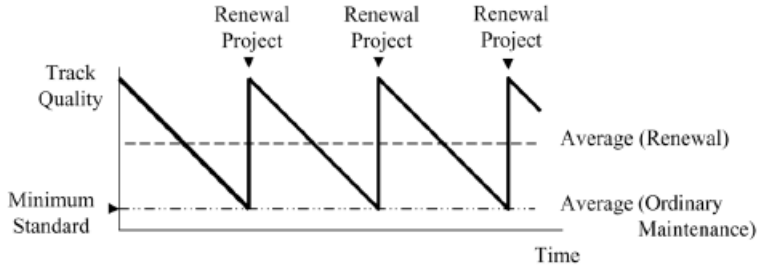



Figure 7: Relationship between renewal, ordinary maintenance and track quality (Grimes et al., 2006)

## 2.3 Possession planning and costs

Every non-train activity requiring a safe and secure work location must obtain a possession (RailNetEurope, 2006). This is also the case on the Dutch rail network and will be elaborated more in other later sections in this chapter. On a European scale agreements are made when certain steps in the allocation process need to be taken, every second Monday of April capacity request require to be delivered to the infrastructure manager. Major possessions for rail freight corridors must be published 24 months in advance of timetable change. This is important for freight as most transport crosses borders and a proper coordination is required to keep the freight moving.

The maintenance of railways must always be executed in possessions, time-windows wherein no train traffic is possible on the section where work is performed. A negative side of that is possessions lead to higher costs, up to 40 to 100%, depending on the required protection and size of the possession. Generally the duration of a possession determines the cost and longer lasting possessions result in higher productivity as mobilization costs are lower (Franklin + Andrews, 2003).

## 2.4 Scheduling problem

Figure 8 elaborates the planning problem of maintenance activities related to the maintenance window size. In this case, the task is considered to take two hours and preparation is required outside and inside the tracks. Preparation both take 30 minutes and outside is only required at the start of a possession. If the possession is 1.5 hours long two periods are required and two times the preparation is required, a total time of four hours for a task of only two hours. If the maintenance window is 2.5 hours, the task could be completed completely and the entire shift takes three hours. If, however a window of 5.5 hours is taken it is possible to add another task of two hours and reduce the required time per task to 2.75 hours. The Dutch situation was unique on the European continent as they introduced early 2000's a repetitive possession schedule where every piece of track was available for maintenance every four weeks (Fokkert et al., 2007) and an improved version of this schedule was presented (den Hertog et al., 2005). Incidental possessions however are still programmed through the year and consume a lot of capacity at weekends and holidays and reached its maximum.

These possessions occur at a certain part of the network and could differ in size and time per type and amount of work to be executed. Combination of these periods should generally result in less occupation of maintenance periods and higher availability for train operations. This is called the Preventive Maintenance Scheduling Problem (PMSP) (Budai et al., 2006) and an optimum is sought in scheduling maintenance activities to reduce possession cost. Possession cost concise mostly of possession duration and is the time required to do maintenance on the track. Several researches have been conducted on solving this problem but mainly focussed on single maintenance executions such as ballast tamping or rail grinding.

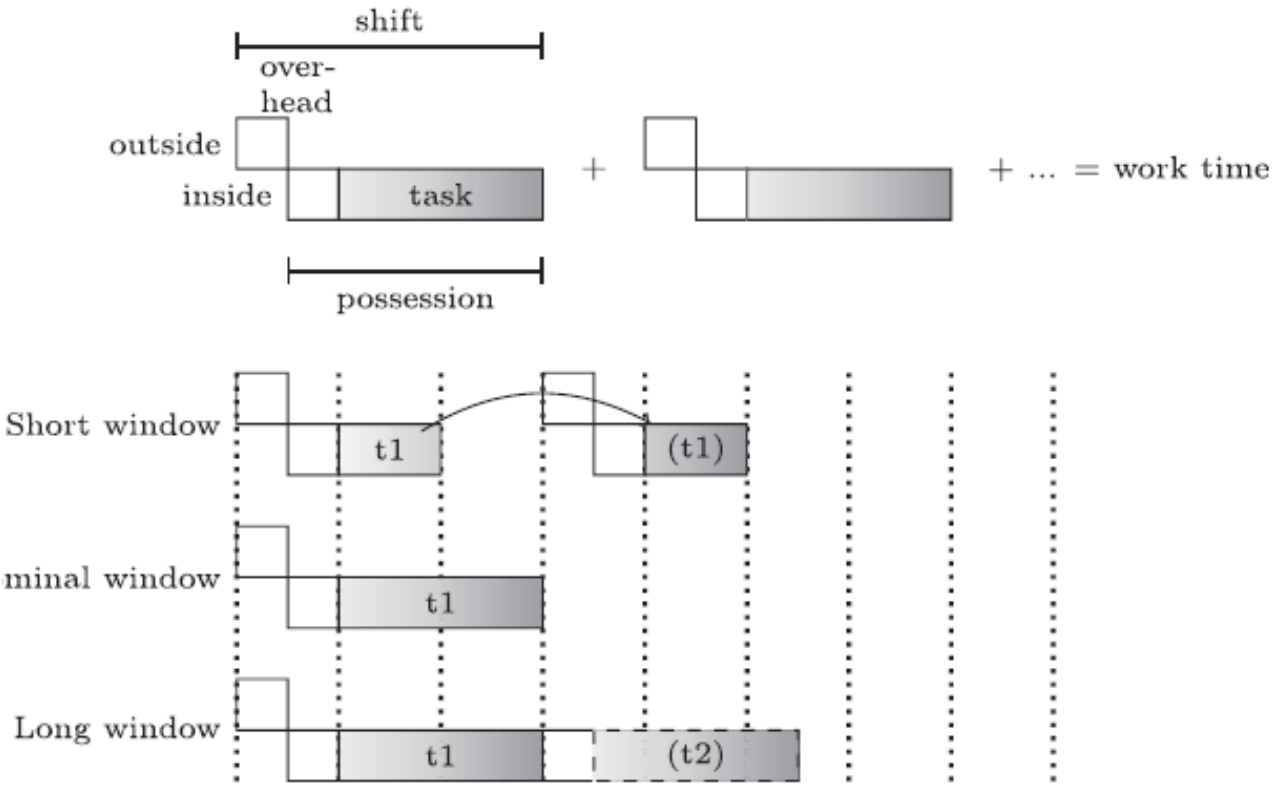



Figure 8: Dimensioning possession windows (Lidén et al., 2016)

## 2.5 Maintenance blitzes

Maintenance *Blitzes* were introduced in the late 90's of the previous century with the first Blitz executed in the United States by BNSF (Vantuono, 1999). Maintenance Blitzes are long periods, mostly between four and twelve days, wherein several maintenance activities are executed. These periods are economically efficient because labour and equipment is used in the most efficient way as every hour at the site is working hour. Week night however are less efficient where only four hours are used effectively (Burns et al., 2005). Such blitzes offer a good opportunity to cluster maintenance as these blitzes require large possessions and not on every location work is performed. Such locations offer opportunities to perform maintenance which would require another possession when not executed in this available capacity. Performing these activities could however influence the logistic side of the already scheduled works so preparation of blitzes requires more attention.

The 'Blitz' methodology allows maximizing productivity for working groups and minimizing inconvenience for the travellers (Grimes et al., 2006). These blitzes however result in large possessions and have a significant impact on the availability of certain parts of the network. The high density of traffic in the Netherlands has its benefits high frequent train paths are offered but also require extensive maintenance. It is however necessary to facilitate certain train paths across the country, especially for cargo, to allow them to still be transported across the country. This will be highlighted in the next section with the elaboration of the Corridorbook.

The theory mentioned above shows the main problem elaborated in the introduction, the trade-off between maintenance capacity and traffic capacity. The problem on clustering multiple maintenance windows in one possession is not issued in the railway sector but has been in various other sectors. Do Van et al. (2013) for example created an algorithm for grouping maintenance activities with a multi-component system and a positive economic dependence. Grouping maintenance is considered to be beneficial to an optimal maintenance policy in an multi-component system (Van Horenbeek et al., 2013). A multi-component maintenance policy may however determine certain activities may be performed earlier or later than

described in the age-based policy. Such multi-component maintenance policy is applicable on the railway infrastructure as it also consists of many components. ProRail uses age-based policy for the renewal of their infrastructure so it is expected based on the data provided in Van Horenbeek et al. (2013) a reduction could be realized when grouping is applied. Application of such a model was done on rail grinding and results were savings of 10% on costs (Gustavsson et al., 2014).

## 2.6 Maintenance grouping

While there is a gap literature regarding clustering of TVPs maintenance there is research conducted on maintenance grouping. Maintenance grouping focus on grouping of specific maintenance actions but grouping of maintenance windows together is less studied. Only consecutive periods are considered. (Do et al., 2015) studied an example wherein availability is an important factor for maintenance grouping, fitting perfectly in the ProRail situation. Slight difference is the given fixed duration in the possession planning situation where duration is given by project managers.

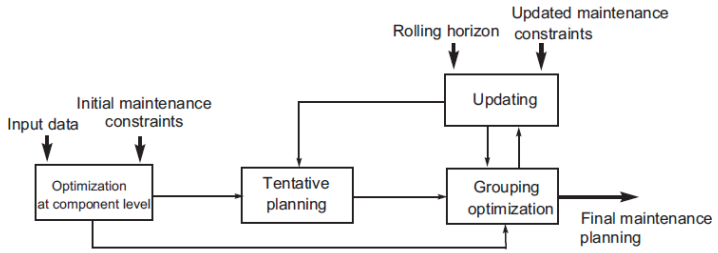



Figure 9: Maintenance grouping approach (Do et al., 2015)

A different approach is therefore required as the goal is to cluster as much work in a limited timeframe wherein projects may not hinder each other as well. Figure 1 shows the maintenance grouping approach and this approach is used in this research. The first step *Optimization at component level* is to determine a maintenance cycle for each component. Step two is to create a *Tentative planning* wherein all components are considered and are at least once planned in a fixed planning horizon. Third step is grouping optimization wherein an optimum is sought to reduce cost and improve availability. Fourth step is to update the planning due to change of maintenance constraints or end of planning horizon. The third step, grouping optimization, is the part developed in this research regarding the clustering of TVPs.

Several researches have been executed regarding the grouping of maintenance activities. To measure the ability to cluster several criteria are identified in researches, for example by (Peng et al., 2014), (Wildeman et al., 1997) and (Reddy et al., 2007). (Peng et al., 2014; Wildeman et al., 1997) used a space criteria to determine differentiation between activities.

## 2.7 Conclusion

A lot of information exists on possession scheduling and planning but not for blitzes or long-lasting possessions. Existing literature mainly focusses on maintenance planning for daily maintenance, not for combining TVPs in weekends or longer periods such as nine days. Gap in literature exists regarding the clustering of maintenance windows lasting longer than five to eight hours. Rail maintenance clustering literature also focusses on the nights that get smaller every year and how the infrastructure manager should decide which maintenance is more important than another. Existing literature on simultaneous track possessions and train operations focusses on small possession slots, shorter than four hours, as for example (Forsgren et al., 2013) and (Albrecht et al., 2013). Next section elaborates on the ProRail practice in possession planning.

# 3 ProRail practice

This chapter describes the current ProRail practice regarding clustering of TVPs and possession planning.

## 3.1 Project formation

ProRail performs a lot of activities on the rail network grouped into maintenance or constructions projects. Maintenance is divided into ordinary and renewal maintenance and construction projects into construction of rail assets and construction of non-rail assets. This research focus on all activities except the ordinary maintenance. ProRail identifies renewal maintenance as maintain function, construction of rail assets as change of function and construction of non-rail assets as local projects. Each project requires a TVP and these three project types, maintain function, change of function and local projects, are approached differently.

ProRail Department Asset Management is responsible for safety of railways and deterioration of infrastructure is the basis for maintenance. Maintaining function is primarily focussed on maintaining the function of infrastructure to ensure reliability, safety and availability and does not change the system. Maintain function focusses on the renewal of assets as is described later. Change of function, as the name says, focusses on infrastructure changes that will change the function such as switches able to handle higher speeds, extra tracks or other projects. Change of function means the construction of new assets or removal of existing assets that will not return and a change in the system. These activities are managed by department Transport & Timetable and are based on projects that will have an impact on the timetable, mostly by extending capacity to create space for extra trains. The third line are the local projects often initiated by local governments, provinces and municipalities and based on small projects such as removing level crossings by construction of a tunnel and responsible for the intake is the Projects department.

Maintaining function is initiated approximately two years before execution when department Asset Management identifies which infrastructure reaches its end of life. The work is gathered, structured and TVPs are created to divide the work in weekends or longer nights. The change of function however is initiated four years before execution and this process is taking place with stake- and shareholders and is initiated by department Projects. Large projects have significant impact on the region so an intensive process takes place with local transport companies, local governments and other parties. Dates are programmed during the process and the friction comes two years before execution as Asset Management identified its own requirements for maintenance and these two hinder. No coordination exists between these two departments regarding the combination of work and projects.

## 3.2 Possession planning

The planning process of possessions is a large and complex process wherein several parties and interests are involved. Appendix A is an elaboration on that process and shows the several parties involved. Work is gathered by a plan coordinator for maintain function, a plan coordinator consults system experts who prescribe which asset requires renewal. These renewals are based on theoretical end-of-life expectancy and practical quality of an asset and these two factors determine if an asset is renewed in a certain year. All these renewals are put together and the plan coordinator creates a workable project optimized on nuisance and costs. This optimization is made with a life cycle tool but only optimizes on selected assets, for example five switches, but does not consider a broader aspect on more assets or other projects. These projects are transferred to department projects to gain a project team with a project manager, rail systems engineer (RSE), project coordinator and a controller. In this stage, a list of activities becomes a project. Based on the projects' activities a RSE will create a functional extraction drawing (FOT) wherein the required tracks for performing activities are visualized.

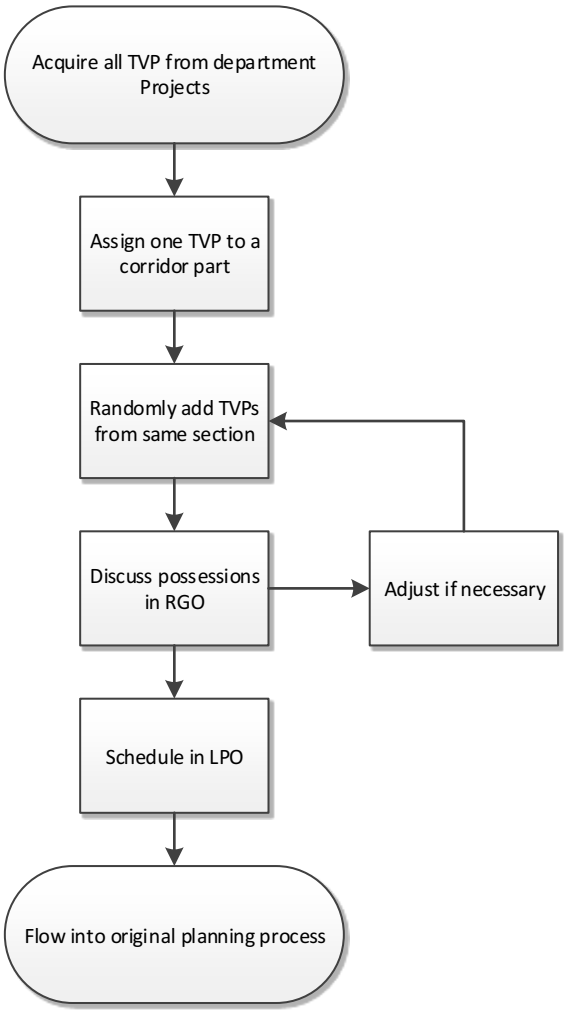



Figure 10: Current TVP planning process

The process for change of function or local projects is roughly the same but has a different starting point. Change of function is mostly initiated by an operator who likes to increase frequency or robustness of train services and requires changes in lay-out of tracks, local projects are initiated by local governments to remove a level crossing. An intake is performed by the Operations Office and a certain outcome could be tracks need to be doubled between location A and location B. In this stage, a project team is assigned to this work and an engineering firm is contracted to design and plan construction of modification. The engineering firm will also create the required FOTs to be able to construct the modification in tracks.

These FOTs are sent to the possession planners where all FOTs are gathered and a planning is made in consultation with operators. Appendix B describes the planning process for 2017, which is every year the same based on EU law. First a rough planning is created for all TVPs with extreme hinder, nearly 14 months ahead of commissioning. These large possessions have large impact on train services and require execution during holidays, when less travellers use the rail system. All other TVPs are scheduled around these large ones. This 'U-Planning' is discussed with operators, project managers and the operations office to assess the feasibility on alternative bus services, national coherence and critical capacity of contractors.

A general process is available for TVPs and is described below and shown on the lift in Figure 10. Two different meetings are executed, Regional User Consultations (RGO) and National Platform Consultation (LPO) to get to a final planning. LPO and RGO are chaired by department Traffic & Timetable as it is their formal responsibility as independent party in allocation of capacity. During RGO the shape of a project FOT is discussed, number of tracks and switches taken away from operation is discussed, considering the performed activities. When all FOTs are assessed the planners will generate a concept planning for all TVPs based on national feasibility, considering events which require sections to be open. The next sections will further highlight the national feasibility problem and effects of the corridor book. The concept planning is consulted with operators in LPO wherein a final decision is made if the planning is feasible, based on the given constraints in the Corridorbook.

## 3.3 Possession categories

The Corridorbook plays a significant role in the ability to schedule possessions and what the restrictions are. Every possession has a defined nuisance category based on the duration and design. Blitzes would be defined as 'U' while a weekend possession is likely to be categorized as an 'R'. These categories have the focus of this research. Table 1 gives an overview of the categories defined by the department Transport & Timetable.

Programming of possessions is executed with a set of guidelines summarized in the Corridorbook (Corridorboek). The guidelines tell the possession planner which tracks should be available when another part of the network is unavailable due to maintenance work. The network is divided into corridors

| Nuisance category | Requirements |
|---|---|
| U | Possession >52hr |
| R | Possession >4 hr & < 52hr |
| A | Possession <4 hr |
| V | Possession without nuisance |

Table 1: Possession nuisance categories from ProRail Corridorbook

and these corridors generally follow the train lines, for example Groningen – Rotterdam is a direct operator line and a corridor. In the Corridorbook a separation is made between passenger transportation, international passenger transportation, freight transportation and events as they require different availability of tracks. International transportation must be available and thus only one border crossing can be blocked at one to keep international passenger transportation and freight transportation on track possible. Also, the NS (Dutch Railways) has three maintenance locations and for example only one location can be obstructed at a time and not two weeks in a row.

Currently large blitzes are planned as early as possible within ProRail as they need to be programmed in periods with fewer travellers. These periods are vacation breaks and around holidays when less travellers use the system and thus resulting in less hinder. ProRail currently plans slight over 50 U-possessions (blitzes) each year. Blitzes often have a large impact on the availability of infrastructure and make large parts of the network unavailable. Due do duration of blitzes and the set of rules from the Corridorbook other possessions are limited during periods of fewer travellers. Before these blitzes weekends or weeknights are planned to perform preliminary works to allow proper and on-time execution of the works. These blitzes are both used for large renewal maintenance and for construction of new assets where large periods are required due to technical limitations in construction.

## 3.4 Cluster factor

A method to quickly determine if a corridor part is clustered enough is to calculate the cluster factor. The cluster factor tells information on the number of requested TVPs on a corridor part compared with the realized number of possessions on a corridor part. When two requested TVPs are clustered into one possession a cluster factor of 2.0 is realized. Through this way a view is obtained how planners perform on clustering and a check is possible on low clustered corridors if a better solution is possible. Formula to calculate cluster factor is $F_c = \frac{\sum i}{\sum s}$.

i = # requested TVPs

s = # planned possessions

Thus, the total number of requested TVPs divided by the total number of scheduled possessions. This method is also applied to assess the performance of the methodology. For example, nationally in 2017 project managers requested 669 R & U TVPs and were planned in 413 scheduled possessions, resulting in a cluster factor of 1.49. Goal of Infra Availability is to increase cluster factor from ~1.49 in 2017 to at least 2.00 in 2018.

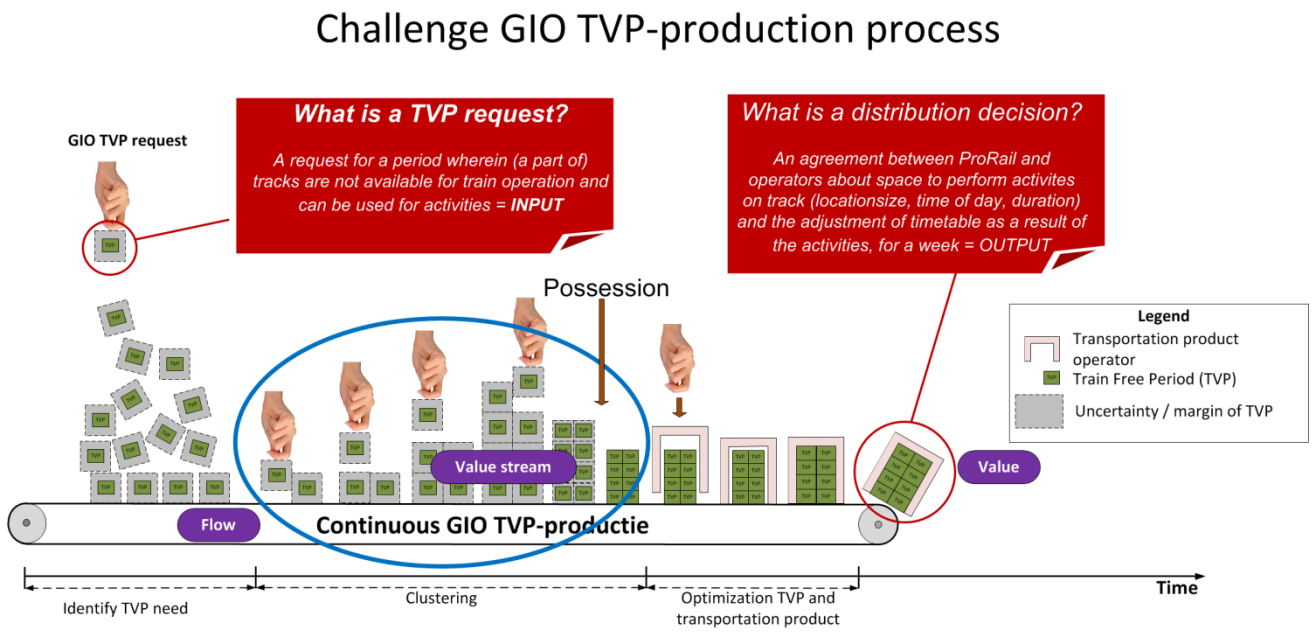
## 3.5 Desired TVP production process

Figure 11 shows the TVP production process as proposed and desired by the Lean management initiative. It is a group of people dedicated to reduce 'waste' within the organization, which is an ideal state and not current practice. This production process is a small elaboration within the process identified and shown in Appendix A. From TVP request to distribution decision continuously value is added along the stream. In that process clustering does not play an important role, clustering is put down as piling of TVPs where a transportation product can be made on. This piling of possessions is crucial in reducing hinder and adding value but has not gained the attention it requires. No process exists how clustering should be performed, when it should be performed and what starting principles should be considered. Several information sheets come with a TVP request but for this research most important is the FOT. The FOT is a drawing wherein the requested tracks are shown and the duration tracks are required.

When clustering is performed the group of TVPs becomes a possession which can be scheduled. Next sentence is not a definition but an explanation; a possession is therefore a combination of requested tracks with a duration which is fixed by the TVP with the longest requested period. It could occur a possession could have different periods wherein different tracks are possessed in different time slots due to clustering. It would be waste if all the requested tracks are possessed for the duration of longest TVP while this would not be necessary.

The in blue circled part of Figure 11 is the part in the process where this research is focussing on, piling and streamlining of clustering. This image is intended to show the ideal possession planning process and this research will focus on a part of it. Appendix B shows the same process but has milestones for the 2017 timetable and is more detailed on the discussion with operators' part.

Figure 11: TVP process as designed by Lean




This section is a small summary on the difference between possessions and projects. A project requires a project team who have a list of tasks, for example renew four switches on Utrecht. To perform a project a TVP is required on the tracks and this mostly results in trains not being able to pass. Multiple TVPs clustered together are a possession. This TVP is requested using a functional extraction drawing (FOT) wherein is described which tracks are required for a project and what the duration of extraction is.

## 3.6 BTD-planner tool

BTD-Planner is a piece of software currently developed by ProRail which will replace the current planning tools. This piece of software will be able to recognize track pieces and can therefore be used to perform clustering while the automated Excel-tool was not able to perform that action. This is a major improvement compared to the Excel tool. The BTD-planner tool will perform an analysis on available TVPs and provide a solution to that problem. In other words, a complete and valid possession planning. The tool identifies by itself the factors influencing the ability and cluster and can determine by itself if a combination can be made. In Table 8 information is provided on requirements for BTD-planner to let BTD-Planner itself create a clustering proposition. This proposition is examined by a planning specialist and if approved used to make a schedule for all possessions. The criteria from Table 4 need to be specified for the BTD-Planner software to create a situation where BTD-planner can determine which TVP can be clustered with another TVP.

Currently the BTD-Planner facilitates several options such as TVP duration, possible moment of execution and hinder class but additional fields are required for clustering. Therefore, a small assessment is performed wherein missing fields are discovered and noted in this report to be added to BTD-Planner. Clustering requires extensive data and knowledge on projects and currently information is not transparent and standardized as it should be. Several different names are used for the same project activity and this does not help and improve an assessment on available data. Therefore, a standardized list of performed projects must be filled to let the software recognize projects. The project activity list used in this report should be sufficient but might be extended in the future if necessary.

## 3.7 Conclusion

ProRail uses current state of infrastructure to determine when to replace assets. Maintenance is then separated between ordinary maintenance and renewal maintenance. Additionally, projects are executed to improve the system such as increasing number of tracks. Currently ProRail' possession planning process is not structured and this could be improved by a more structuring approach with evaluation. ProRail is developing a new possession process and clustering is one of the essential parts of that. How that part should be designed is not clear and this will be developed in the next section.

# 4 Clustering methodology

ProRail currently has no process for clustering TVPs and no technical support. Clustering is, however, mentioned as something that is used in the possession planning process but clear guidance is missing. In this chapter, the clustering methodology and process is given. A methodology is developed wherein two steps are important, project activity evaluation and train free period evaluation and a new process is developed. Project activity evaluation focus on the individual project activities and they are scored using five criteria and score one to five. Furthermore, a train free period evaluation is created wherein TVPs are assessed between each other using three factors influencing the ability to cluster. A new process is given wherein the evaluations are implemented within the current possession planning process. The Excel tool is developed and shown and preconditions for TVP clustering in BTD-Planner are given.

ProRail accepts every project with sufficient funding and will execute it, no matter the consequences. This methodology results in huge piles of work and ditto possessions and plannability of possessions becomes very difficult and a lot of hinder is created. Several factors influence the plannability of possessions and one of these factors is clustering. Performing clustering is possible on several levels and in this case clustering on project level is chosen. This level is chosen as it is the information possession planners work with to create a possession planning. It is assumed projects require the given duration and space when requested. The level of activity detail is determined on project level meaning on level crossing renewal, ballast & track renewal or project P76. P76 is part of a nationwide project for accessibility of public transport and is responsible for adequate platform level boarding. This level is deep enough to create differentiation between the several hundreds of projects and is also broad enough to not get too many types of activities.

Clustering of such projects requires insight in planning of projects and activities taking place in projects. A list of project activities is generated based on projects executed in 2017 as a balanced review on types of work is given. Ministry of Infrastructure & Environment is consulted for long lasting programs such as P76 and MJPG (Multiannual Program Noise Remediation) that have no primary function for the rail system but benefit the rail environment. Clustering of TVPs requires insight in the performed activities in projects to make a comparison in the ability to cluster. Renewal of tracks cannot be combined with catenary works on the same location for example.

## 4.1 Project activity evaluation

The used hierarchy is based on the three lines within ProRail; Maintain function (FH), Change of function (FW) and Local projects (OW). This is important to make a clear distinction between technical required projects, projects to improve the rail system and projects with less influence on the main goal of ProRail, delivering train paths. Maintain function is technical end-of-life of assets and requires renewal in a predetermined year based on actual asset condition, postponing could require life-extending measures which require cost and possessions. Change of function mostly extends infrastructure to facilitate extra train paths for operators and has importance to stakeholders such as Ministry of Infrastructure & Environment, largest financer of projects, and operators. Operators can also have small changes and to execute these changes a small budget is available within ProRail to change infrastructure if a project is smaller than €5 million. Local projects are mostly financed by local governments or from large programs of the Ministry of Infrastructure & Environment, for example P76, to increase quality of life around tracks or improve accessibility for disabled travellers.

| Maintain function | Abb. | Change of function | Abb. | Local projects | Abb. |
|---|---|---|---|---|---|
| Super structure renewal | SSR | Construct super structure | CSS | MJPO | MPO |
| Catenary renewal | CAT | Construct catenary | CCT | P76 | P76 |
| Signalling renewal | SIG | Construct signalling | CSG | LVO | LVO |
| Engineering constructions preservation | ECP | Construct engineering constructions | CES | MJPG | MPG |
| Engineering constructions renewal | ECR | Construct power supply non-catenary | CPS | Local projects | LPJ |
| Power supply non-catenary renewal | PSN | Construct stations | STW | | |
| Station renewal | STH | Program small FW | PSF | | |
| Telecom renewal | TEL | | | | |

Table 2: List of group of activities on or near tracks

Verification of this list was performed through an assessment with advisors of department Projects. Table 3 is a comprehensive overview of the different projects assessed in this research with a description of the performed activities. Each project activity description is built-up using the same methodology, first a brief explanation of the concept, second are some examples of activities, third some information about maintenance intervals of activities and fourth details on effects on TVPs.

| Project activity | Activity description |
|---|---|
| Super structure renewal | Superstructure renewal is a comprehensive term for every activity required to renew the superstructure, ballast renewal, track renewal, sleeper renewal or one of these combined. Also, included in this set is level-crossing renewal. These assets have different expected renewal intervals but track & sleeper have nearly similar renewal intervals, 42 and 45 years, so it is likely these will be combined. Expected ballast renewal differs from 27 to 34 years depending on soil it lays on. Renewal is performed with large machinery and requires supply and discharge for this machine and tracks are required to be free of obstacles. The machinery itself will only block one track at a time but will most likely obstruct another track as well. |
| Catenary renewal | Catenary renewal represents supporting structure and overhead contact wire with affiliated objects. The supporting structure has an expected renewal interval between 40 and 60 years, depending on type of system. Overhead contact wire has a more differentiated renewal pattern between 10 and 35 years depending on location and supporting system. It is not likely these activities are clustered and an overhead contact wire renewal will only block one track while a complete supporting structure will block the entire track. |
| Signalling renewal | Signalling renewal comprehend different activities such as renewal of signals, cables or parts of the interlocking system. Renewal interval of relays is between 20 and 25 years, cables have a life-cycle of 40 years and interlocking has no clear life-cycle values. Signalling cables are mostly also renewed during track renewal so only remaining part is renewal on off-side assets. During testing if renewal activities were properly executed no vehicle is allowed on tracks as problems may not surface then. In that case signalling renewal obstructs the entire track on and no other activity may take place. |
| Engineering constructions preservation | Engineering constructions preservation is for the maintenance of engineering constructions, fly-overs, bridges or culverts. Bridges require painting to prevent corrosion and require other maintenance activities. Preservation of engineering constructions will result in blockage of tracks crossing constructions and is performed approximately every five to fifteen years. The blockage differs per bridge and sometimes a single-track possession is required and sometimes a double track possession is required. Bridges are objects on itself and require most of the time other renewal trails than normal railway track. Preservation is separated of constructions renewal as it will have different kind of impact and occurs less often. |
| Engineering construction renewal | Renewal of engineering constructions is completely about every construction reaching end-of-life and require replacement. Bridges or fly-overs are examples of constructions having a life-cycle expectancy around 100 years and some minor bridges have been replaced but no major constructions have been renewed in recent history, mostly due to reconstruction after second world War. Engineering constructions require longer lasting possessions as an entire engineering construction needs to be replaced. Renewals completely block a line and will most of the time dictate length of a possession. |
| Power supply non-catenary renewal | Non-catenary power supply are the substations located near tracks which are the connection between catenary and national grid. Renewal interval of non-catenary assets is once every 80 years. Due to their nature of not being situated close to tracks maintenance will not hinder other activities or even train traffic. |

| | |
|---|---|
| Station renewal | Station renewal is mainly about reconstruction of station due to end-of-life of assets. Stations are specified separately because clustering on stations is easier as not all tracks at a station are not required at all time for the maintenance. Stations requires possessions for renewal of building or other objects and for painting of the roof. However, most stations can take one platform out of service and still can perform the timetable on the remaining platforms. Painting of roofs has an interval of at-least 15 years, depending on the material used for coating of steel. |
| Telecom renewal | Telecom cables are situated near train tracks but are positioned far enough and do occasionally not require a possession to be maintained. |
| Construct superstructure | Construction of superstructure occurs when new track is added in cases of doubling or quadrupling. In this case ballast, tracks and sleepers are considered and in special cases level-crossings as they are in normal situations not constructed anymore. In contrast to renewal laying of ballast, sleepers and tracks cannot be performed simultaneously but must be performed sequentially. Construction is mostly performed next to operational tracks and therefore not obstruct, only when new tracks need to be connected with existing tracks. |
| Construct catenary | Catenary construction contains all related assets with catenary on track, such as support structures, overhead contact wires and fasteners. This work is performed sequentially due to technical dependency between different assets. Construction of catenary results in complete obstruction when a line is already in operation and results in significant hinder. When constructed on new tracks same effects appear as on superstructure construction, only hinder when new tracks are connected with existing tracks. |
| Construct signalling | Signalling construction often results in large hinder as near end of possessions all software requires testing. During testing no vehicles are allowed on tracks and this ensures a complicated clustering with other projects. New signalling systems can be installed without hinder on complete new tracks, same as with catenary and superstructure construction. If, however new signalling system on existing tracks need to be installed this will lead to inevitable hinder and obstructions. |
| Construction engineering constructions | Construction of engineering constructions are mostly large projects where a new engineering constructions is created such as a fly-over or dive-under. Such projects largely influence their surroundings and require significant amount of space during construction or can be constructed elsewhere and transported to worksite wherein a period it can be inserted. Hinder is thus depending on work methodology. |
| Construct power supply non-catenary | Power supply non-catenary construction is situated adjacent to the tracks and will mostly result in no hinder for operators, only when the connection is made with the existing network. |
| Construct stations | Construction of stations mostly occurs when extra infrastructure is created or current station becomes too small for number of passengers. Lay-out of tracks is changed, platforms could be added and a new hall is created. New stations are followed by large hinder for operators and travellers. Opportunities exist to cluster projects on adjacent lines wherefore platforms at a station are already obstructed. |
| Program small FW | The program small FW is for current bottlenecks that require quick action and as limitation these projects are limited to a €5 million investment. Such small projects can be clustered with other activities as they are minor interventions. |
| MJPO | MJPO is a large project to remove barriers in nature for animals and plants to restore their habitat. To realize this several culverts and wildlife crossings are constructed but this requires a possession on a specific location but an acquired possession might be larger. This offers opportunities to cluster work on both sides of the worksite. |
| P76 | P76 focusses on stations and could be examined as station maintenance as it is likely the same design of possessions is required. Some stations offer enough platforms to still can execute the normal timetable while other stations are completely blocked with adjacent lines also inside the possession. Possession only |

| | |
|---|---|
| | at the station is better for the train product while obstruction of an adjacent line might improve clustering and less total hinder for an operator. |
| LVO | LVO is a program to increase safety on level crossings. Level crossings are single objects in the infrastructure and in line with MJPO the adjacent line can be used to perform additional maintenance. |
| MJPG | MJPG is a national program to reduce noise nuisance along railroad tracks and a major part of this work is constructing sound barriers. Such barriers are constructed with an obstruction on both tracks so no work train of other activity can pass. |
| Local projects | Local projects are mostly initiated by local governments such as provinces or municipalities to remove a level-crossing or create a fly-over for a dedicated bus lane. |

Table 3: Activity explanation

Project managers deliver a FOT but it is not clear wherein a FOT work is performed. It is therefore necessary to determine the impact a project activity has on clustering and what the possibility to cluster with other activities is. Project activities are evaluated on logistics, interference during execution, movement of project, required space and importance to primary function. Values between 1 and 5 are used to determine the influence on ability to cluster and 1 meaning bad and 5 good. Value 1 means bad availability for logistics and 5 good availability, bad is described as both tracks blocked and good as zero tracks blocked for other maintenance vehicles. Interference during execution means one activity might hinder another activity, a 1 means full hinder and value 5 means no hinder.

Movement of a project determines the rolling operations of execution as a moving activity might hinder another activity later in the TVP. Required space is important to know as activities requiring more kilometres have larger impact on opportunities for other activities to be performed than others. A higher score in this case means less kilometres of track is occupied for execution. Importance to primary function is used to determine differences between activities in relation to the function of the railway system, some are more important for functioning of the system than others.

Table 4 gives the criteria where the projects are scored on with their scores and characteristics. No assumptions are made regarding type of track section as the activities are assessed on their individual characteristics.

| Score | Logistics of maintenance vehicles | Interference during execution | Movement of project | Space occupation | Importance to primary function |
|---|---|---|---|---|---|
| 1 | Complete obstruction of tracks | No other activity possible during performing activity | Prolonged work performed on same location | 3 kilometres >x | No importance to primary function |
| 3 | Partly obstruction of tracks, ≥50% of tracks available | Other activity possible but not on same location (≥1km) | Activity slowly moving across TVP (i.e. catenary renewal) | 1 kilometre<x < 2 kilometre | May improve system reliability but no vital part |
| 5 | No obstruction of rail tracks | No limitations in performing other work | Work performed off-side track | 50 metre<x | Trains cannot run without performed activity |

Table 4: Criteria project activity evaluation

To determine the potential of each project activity an assessment is required on the five above mentioned criteria. This assessment is the project activity evaluation.

For every activity, a total score is determined based on the earlier mentioned criteria and scores. The scores two and four are for interpretation when the score one, three or five is too hard and a mean is required. For example, super structure renewal in general completely blocks both tracks but may occasionally provide space for passage of vehicles. Such opportunities are not specified in scoring activities but may potentially have positive effects in the clustering of activities. First every activity is assessed individually for every criterion and a total score per activity is determined, Table 5 gives an overview of the results and shows which activities have high potential to be clustered with other activities. Power supply non-catenary for example scores very high due to the off-track nature of activities and thus generating no hinder for other activities. Also, the importance is high as unavailability results in no possibility to ride trains. Engineering constructions renewal scores the lowest as Logistics is difficult because all tracks are obstructed and no vehicles can pass but the complete obstruction also provides enough space to perform other activities and score therefore better. Renewal of engineering constructions focusses on one location only and allows other work on nearby locations.

Total score is required when an assessment is performed between projects. Total score is made by summarizing the individual scores per criteria. When clustering between different projects is assessed, this score provides information on the individual cluster ability of a project activity. A lower score means it is less likely that certain projects can be clustered with another project.

| | | Logistics of maintenance vehicles | Interference during execution | Movement of project | Space occupation | Importance to primary function | Total |
|---|---|---|---|---|---|---|---|
| FH | SSR | 2 | 3 | 3 | 1 | 5 | 14 |
| | CAT | 3 | 3 | 3 | 3 | 5 | 17 |
| | SIG | 2 | 2 | 2 | 3 | 5 | 14 |
| | ECP | 3 | 3 | 1 | 2 | 5 | 14 |
| | ECR | 1 | 2 | 1 | 2 | 5 | 11 |
| | PSN | 5 | 5 | 5 | 5 | 5 | 25 |
| | STH | 4 | 5 | 2 | 5 | 4 | 20 |
| | TEL | 5 | 5 | 5 | 5 | 3 | 23 |
| FW | CSS | 2 | 3 | 2 | 3 | 3 | 13 |
| | CCT | 3 | 3 | 2 | 3 | 3 | 14 |
| | CSG | 2 | 2 | 2 | 3 | 3 | 12 |
| | CES | 1 | 3 | 1 | 4 | 3 | 12 |
| | CPS | 5 | 5 | 5 | 5 | 3 | 23 |
| | STW | 3 | 4 | 4 | 3 | 3 | 17 |
| | PSF | 3 | 3 | 2 | 4 | 2 | 14 |
| OW | MPO | 1 | 3 | 2 | 5 | 1 | 12 |
| | P76 | 4 | 4 | 2 | 3 | 2 | 15 |
| | LVO | 1 | 3 | 1 | 5 | 2 | 12 |
| | MPG | 3 | 3 | 2 | 4 | 1 | 13 |
| | LPJ | 3 | 3 | 2 | 5 | 1 | 14 |

Table 5: Results assessment project activities

As an example, superstructure renewal (SSR) is chosen to explain the scoring systematic. SSR scores a 2 on logistics of maintenance vehicles as it will only block one track and will be able to pass a vehicle of another project performed elsewhere in the possession. Interference during execution is scored 3 because it remains possible to perform work without interrupting super structure renewal but not too close nearby. SSR moves when performing but slowly, receiving therefore a score 3 on movement of project. It is likely a project can commence when SSR has left the location and moved on. SSR space occupation however is large, especially when a train is used which replaces ballast, sleeper and rails. It is therefore necessary to take a worst-case scenario into account wherein it will take significant space. Importance to primary function is for super structure renewal especially important as it concerns the safe rideability of track.

## 4.2 Train free period evaluation

With the project activity evaluation in the previous section this section elaborates on the evaluation of multiple TVPs in relation to each other.

Creating an evaluation wherein abilities to cluster are measured is one thing but application is required to fully use the benefits. In this section, an evaluation is created to implement the assessment made for each project activity. This evaluation uses the generated information per activity and gives the possibility to assess several TVPs combined. The values tell some general information on which activity has good clustering opportunities but does not tell how this is works in relation with other TVPs. In practice, some other factors have influence as well on clustering of TVPs. Three factors are added to get a better insight on clustering of activities and are equal influencing each of the activities. These three criteria are 'Number of tracks', 'Duration of project' and 'Location'. These factors are independent from the criteria specified in the project scoring matrix as the factors are for the train free period evaluation .

| Number of tracks | Factor | Duration of TVP (Hours) | Factor | Location | Factor |
|---|---|---|---|---|---|
| Single | 0.75 | x<28 | 0.75 | Overlap | 0.75 |
| Double | 1.00 | 28>x<52 | 1.00 | Partly overlap | 1.00 |
| More than two | 1.25 | x>52 | 1.25 | No overlap | 1.25 |

Table 6: Factors train free period evaluation

The number of tracks in a TVP has an influence on the ability to cluster, a single-track section in the rail network is harder to cluster on than on a section with multiple tracks. On a multiple track line, it is more likely a project can pass while this is impossible on a single track. Therefore, a double-track section is selected as a normal situation, which is also mostly the case in a possession and receives a factor 1.00. A single-track section receives a factor of 0.75 to compensate for not allowing any vehicle to be able to pass. With more than two tracks available in a possession allowing passage of vehicles easier than a double-track and thus receives a factor 1.25. This factor is important as more available tracks in a possession result in opportunities to pass projects and therefore increase clustering.

The duration of a TVP also influences clustering of projects as more time allows more clustering freedom when clustering shorter lasting TVPs. In this light, a longer TVP will lead to a better score than a shorter TVP duration. Project duration is measured for the TVP with the longest duration. If for example a 76 hour TVP is clustered with 24 hours, duration is 'x>52'. Usual project duration for class R and U are between 28 and 52 hours, receiving a factor of 1. Longer than 52 hours receives a bonus of 1.25 being more able to offer a proper clustering of activities while also being able to mitigate cost rises. If longest project is shorter than 28 hours it is mostly not beneficial for clustering projects due to short available time and planning difficulties are nearly never present. In some incidental cases clustering of such short lasting TVPs is possible but this is uncommon.

Locations of activities plays a large role in ability to cluster and is therefore also a criterion. This criterion focusses on the real requested withdrawal of tracks and requires a comparison between two TVPs of projects. On a TVP drawing the required tracks for that activity are highlighted and thus any easy comparison is possible between two drawings which activity requires which tracks. If overlap of a TVP with another TVP occurs a lower factor, 0.75, is designated to that clustering opportunity as it might be more difficult to cluster these TVPs. If a partial overlap occurs it will be easier to cluster than a full overlap and receives a factor 1.00. No overlap is positive for clustering of activities and receives therefore a factor of 1.25.

To create a final score of clustering some steps are required to get to this score. First, the user must select activities that could be clustered based on the information of a specific track section, duration of activity and extraction drawings. Then a calculation is made, given below, to calculate the final score ($S_c$). Dividing sum of TVP scores ($S_p$) by the total maximum theoretical score ($\frac{\sum S_p}{\sum n*25}$) is to scale the scores back to value between zero and one. The values from the project activity evaluation are used in the $S_p$ value.

$$S_c = \frac{\sum S_p}{\sum n * 25} * T * D * G$$

**Parameters:**
$S_c = Final\ score$
$S_p = TVP\ score$
$n = set\ of\ TVP$
$T = Number\ of\ tracks\ factor$
$D = Duration\ of\ TVP\ factor$
$G = Location$ factor

| Final score | Text message |
|---|---|
| >0.75 | Easy clustering |
| >0.6 | Requires attention |
| >0.45 | Difficult to cluster |
| <0.45 | Do not cluster |

Table 7: Outcome generation

When the number of tracks factor, duration of TVP and location is added the lowest outcome could be 0.19 and highest outcome 1.95. The score parameter is the outcome of the formula, TVP parameter is the score of a certain activity. N is the number of TVPs considered in that calculation. T, D and G represent the three different factors from Table 6.

Depending on the outcome of $S_c$ a certain text is generated to let the responder know what the outcome is of clustering certain activities. The user gets four different kinds of messages:

- Easy clustering
- Requires attention
- Difficult to cluster
- Do not cluster

The thresholds of each outcome are defined by trial and error; clustering is performed on a set of data and different thresholds are applied. The trial and error is performed on TVPs programmed by ProRail and these are used as outcomes that should presented by the model. Current clustered TVPs are recreated in the model and their outcome values determine the threshold. This with a check on TVPs that should not come out with the same thresholds. Outcomes of this testing are validated to identify if this result is possible and through that methodology the thresholds are defined. These thresholds however are quite clear but it is difficult to say 'Yes' or 'No' to the question, "Can I cluster these two TVPs?" First, the possession planner does not know all ins and outs of a certain TVP, not mentioning dozens of TVPs. Intensive knowledge has been acquired through years of experience but still no 'one size fits all' solution can be given. Also, several factors require attention where the possession planner does not have influence on, for example enough skilled personnel to perform a project.

Easy clustering means it is most likely these TVPs can be clustered into one possession. Consultation with project managers is required but with high certainty it can be said these TVPs can be clustered. Do not cluster is also quite clear; it is very difficult to cluster these TVPs into one possession and will result in major disturbance for one or more projects. Advice is to better plan these TVPs apart from each other. Two remaining messages, requires attention and difficult to cluster, are both requiring further interpretation. Clustering of TVPs might result in change of execution methodology of projects and thus require additional attention of project managers. The level of attention differs per clustering, minor changes in supply of equipment and materials to reschedule of project execution. The gradation added is based on the outcome of discussion with colleagues and checked at expert planners. Figure 12 gives an idea how the drawings of two different activities looks like and how this influences the evaluations. The upper image shows the work is likely concentrated around the large rail yard while the lower image shows activities likely take place near Den Haag Centraal, according to the requested tracks. The upper image is the basis for comparison as duration is the longest and other TVPs are compared with this TVP. Also, the ability to ride trains was already blocked in the upper image so no extra nuisance is created for travellers.

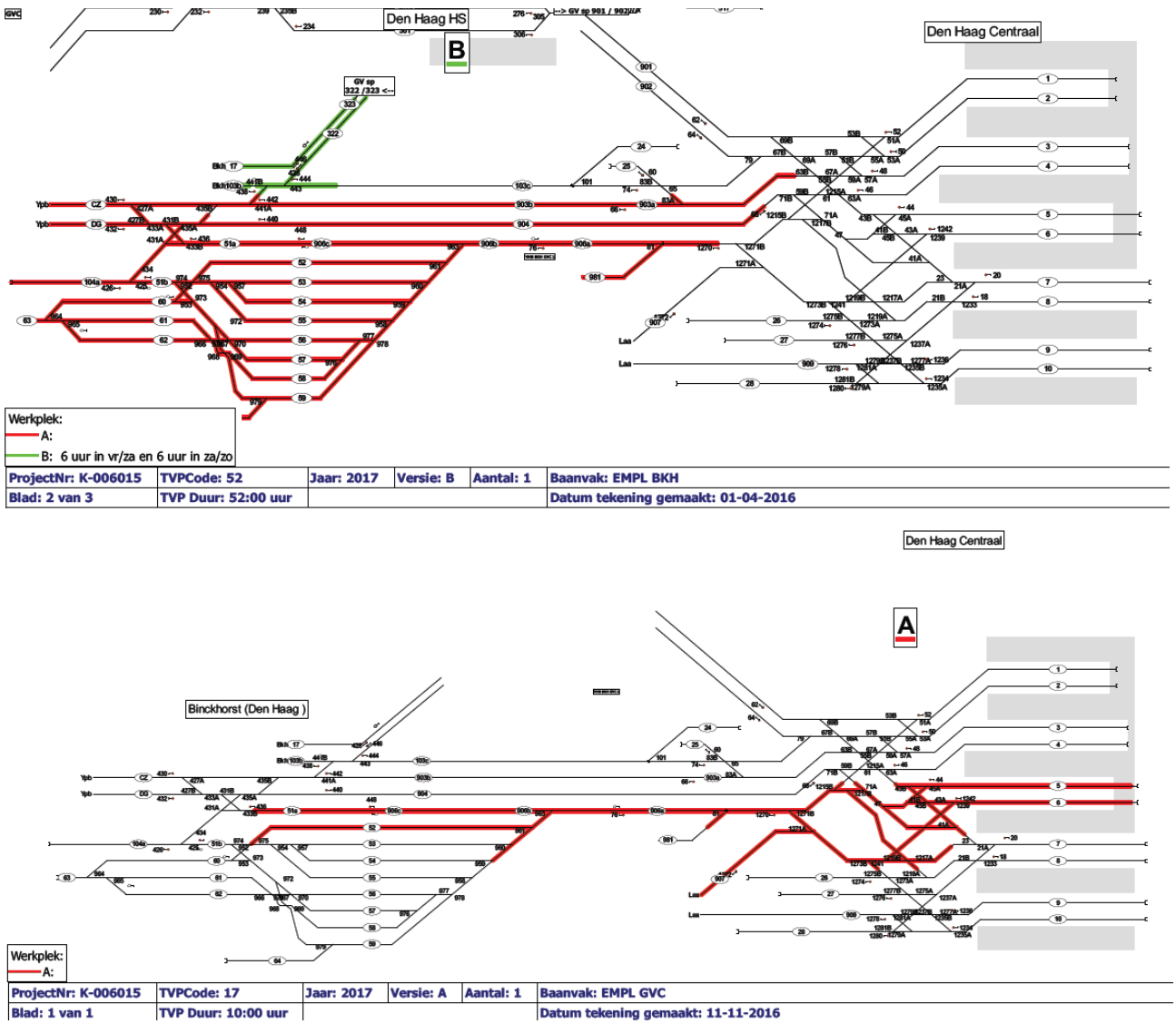



Figure 12: TVP-clustering near Den Haag

Software can perform an assessment on clustering of activities and there a standardized set of information is required. Humans can assess individual TVPs by hand and interpret information written in different words or spelling errors. Therefore, a predefined set of parameters is required where project managers or rail system engineers can describe their project. Such parameters are about duration, location and type of work. Drawings as shown in Figure 12 provide as input for software to assess geography issues such as overlapping. Also, geocode information is incorporated in these drawings so a comparison is possible on amount of work on adjacent geocodes.

## 4.3 Planning process with clustering evaluation

The clustering methodology requires a new process wherein the new developed evaluations are embedded within the complete possession planning process. This section focusses on creating a new process wherein the evaluations get their place and can be used at the right moment. Also, it is highlighted where a change in current processes is required. These changes have a high impact on current work methodology but are required to improve clustering and remain being able to create a viable planning in the future.

### *Possession planning changes*

The methodology needs to be implemented within the current planning process given in Appendix B. More specifically, during the 'Preliminary phase service year'. Currently clustering is already performed by possession specialists but this is on a loose basis and not with standardized methodology. A standardized methodology is used when clustering is applied and a structured process which shows why certain choices were made. Importance of transparency increases as operators require ProRail to be more open about choices made during planning process. Possession planning changes from a reactive planning to an active planning where the proposed planning is verified and adapted if necessary. It becomes more necessary to perform more work before the evaluations are used. Taking the evaluations into account a new process is developed which can be embedded within current BTD (Buitendienststelling)-processes.

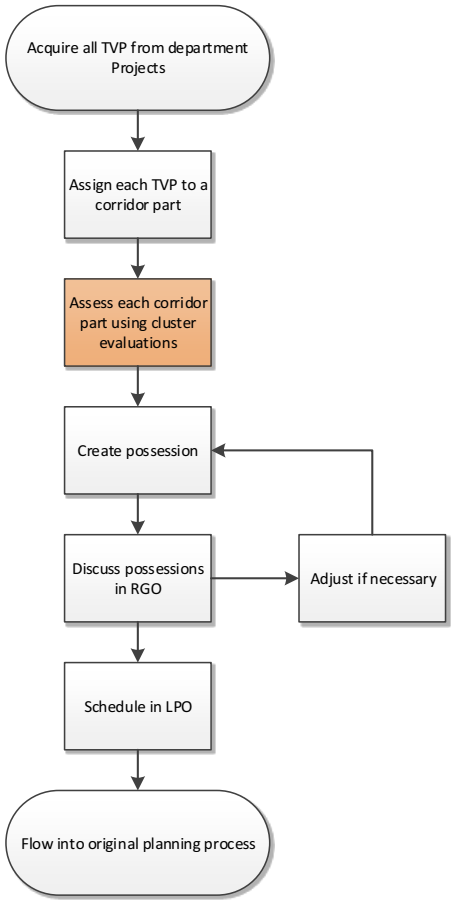



Figure 13: New clustering process

On the left is Figure 13 and this image shows the new clustering process. Largest differences with the old process is the structure how the TVPs are clustered and usage of the evaluations to support the clustering choices. Clustering is now based on data instead of random adding and individual knowledge and skill of possession planners. The altered process is started when all TVPs are gathered by the department possession planning. This is as current usual practice and should not be changed. Then the new process will start and first step is to assign each TVP to a corridor part or a certain rail yard. TVPs compromising multiple corridor parts should be assigned to a certain yard. Then each corridor part or yard is assessed using the methodology and possessions are created for each corridor part and rail yard.

Using the evaluations TVPs are clustered and possessions arise which can be scheduled. Assessing each corridor should be performed using the following steps:

1. Define for each TVP the project activity
2. Sort TVPs from longest to shortest duration
3. Select TVP with longest duration
4. Set the factors for train free period evaluation
5. Select second longest TVP and add to evaluation
6. Evaluate the TVPs
7. If advice is 'Easy clustering' or 'require attention' group the current set, add next longest TVP to evaluation and go to step 6
8. Else, remove last added TVP and continue with next longest and go to step six
9. Restart evaluation from step 3 until no TVPs left
10. End evaluation

First of all, each TVP should be assigned to a project activity to identify what type of work is performed. This is the first evaluation. Secondly, each TVP should be sorted from longest to shortest duration. Duration is fixed so there should be at least one possessions as long as the longest one. Thirdly the longest TVP is selected because information is required for step four, set factors for the train free period evaluation. Then, second longest TVP is added to the evaluation and is evaluated. Dependent on the advice given from the TVP evaluation additional TVPs are added or the evaluation ends. If the advice is 'easy clustering' or 'require attention' TVPs are added until the advice becomes different. When the advice changes the last added TVP is removed and the next remaining TVP is evaluated with the already evaluated TVPs. When this done all removed TVPs are reassessed until all TVPs are evaluated and grouped. When all TVPs are assessed, the evaluation will end. Appendix C shows the flowchart belonging to the described process above and is incorporated in the highlighted box of Figure 13.

The TVP groups are from now on possessions which are ready to be scheduled onto the network. The possessions are discussed with operators in the RGO. There the design of a possession can be discussed

regarding certain switches or tracks can be removed from the possession. This in contrast to current RGO wherein individual TVPs are assessed. When a possession is rejected assessment of entire corridor part should be repeated with different starting principles or adjusted TVP information. When possessions are accepted, scheduling can commence wherein every possession is programmed, concept planning is discussed with operators in LPO and planning is accepted or rejected.

This is contrary to current process wherein TVPs are planned, on a loose basis other TVPs are added and then for good or worse a planning is created. Also, in current practice each TVP is submitted and individually assessed with operators what each FOT should look like. New practice should be operators should only be faced with possessions, it is only interesting for them where trains can be operated and where not. And if there is an obstruction, what are my diversion routes and are these free? Therefore, it also necessary for operators, especially passenger, when they will use replacement busses or will operate a train service. This can be considered when clustering and certain options can be shown to operators with different hinder characteristics. This will result in a more transparent process for operators regarding possession planning and a more structured process for ProRail BTD when clustering can be implemented and how this should be used. Operators will also have more insight into the level of nuisance they are facing for the coming year as this is visible during RGO. Current RGO set-up does not tell information on number of possessions on a corridor part as it is not known which TVPs are clustered into a certain number of possessions.

When the BTD-planner has TVP clustering implemented the process of clustering will change. Currently clustering in BTD-Planner is determined as every mandated user can make a proposal on which TVP can be clustered. This proposal can then be accepted or rejected by the stakeholders. During this process, the outcome could still be no clustering is performed if no stakeholder's acts, this is however not the ProRail mission wherein hinder is as low as possible. The BTD-Planner clustering model proposed will create clustering possibilities for every corridor part, even if not necessary for planning of possessions. Because TVP clustering is performed autonomously the only thing required is on one moment when all TVPs are added the clustering stops.

Then the proposed clustering of TVPs can be discussed with operators and project managers, as is the same in current process. The only extra step necessary is one moment in time when all possessions are gathered the button is pressed and BTD-Planner stops clustering of TVPs. The software will automatically stop when all TVPs are clustered in the best way but some moment in time a freeze is required to allow possessions to be assessed and discussed.

#### *Department project changes*

To make clustering a success department Projects is also required to make commitment to changes. Their project realization depends on planning of all requested TVPs and it is for them therefore also important clustering of TVPs improves. First, it is important projects uses standardized categories for type of work performed, this will improve ability to cluster and in reliability of clustering options. Implementation can start with the list used in this research, shown in Table 2, and could be extended later when the list is too short.

Further a more detailed FOT drawing is required to get clustering to a higher level. Differentiation between work location and safety location is important to improve clustering and achieve a higher availability as safety location can be shared with other projects. This requires department Projects to make a step where in an earlier phase more detailed information is required. Current FOT drawings are simple sketches where work might be performed and are set up broad as it is not known where work will be performed. A step is required to go from these undetailed sketches to a detailed drawing where a separation is between work and safety locations. Impact is envisaged not only at ProRail itself but also at engineering firms who require more detailed engineering plans. There should always be consultation with one or more project managers required to be able to verify if certain projects can be clustered or not. Due to these uncertainties, it is always necessary the result is verified by a project manager.

It is therefore important to have department Projects on board when these changes are made and their support is good. It is however also in their interest clustering improves as capacity is scarce on Dutch rail network and projects need to be performed.

## 4.4 Excel tool evaluation

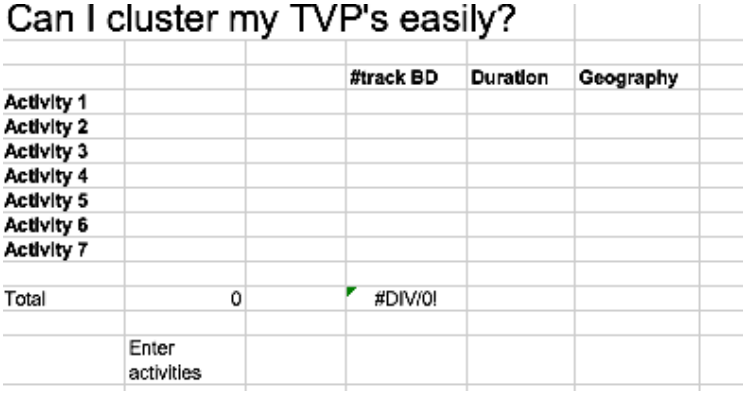
Currently planning of TVPs is performed by hand using achieved knowledge throughout the years. This methodology resulted in proper planning's for past years but has now reached its limit and support is required to progress to a new level of programming. Manual determination of several alternative planning's is a time-consuming task and requires significant personnel which are not available. Also, pressure is growing due to the increasing number of possessions and operators are forcing ProRail to increase infrastructure availability.

Support of software should improve programming of TVPs and offer more analysis on creating a better planning. A software program can make several hundreds of assessments while a person can make much less assessments. An algorithm should therefore be developed wherein an optimal solution is sought in TVP planning. Basis of algorithm are the clustering evaluations elaborated before as this performs the first step which will determine TVPs to be clustered or not.

Such an approach has several benefits. One of them is transparency which will improve due to standardized working and information being equally useable by everyone. Also, due to consistency between projects a better understanding for stakeholders can be reached why certain choices are made. Second benefit is possession planners can plan with a chunk of TVPs, a single possession, instead of single TVPs, increasing an optimized planning.

The developed evaluations in the previous sections are used to create a tool which will support ProRail in their clustering decision making and makes the evaluations easier. Excel provides basic programming possibilities for the developer and is also easy to use for the end-users. Every TVP requires manual assessment by the user. The tool is used according to the evaluations and users must fill in the data themselves completely. A column with seven rows is available wherein planners can fill in the type of work. Three cells are available wherein a dropdown menu is given in each cell to perform the train free period evaluation. Figure 14 shows an image of the tool which is developed and shows the key components. The '#DIV/0!' notification is because no activities are entered and therefore no calculation is possible, in used situation it will display the calculated score $S_c$. On the 'Enter activities' cell the advice is displayed, currently no advice is given as no activities are entered. Figure 16 on page 54 shows the filled in tool.

Figure 14: Design Excel Tool




Based on that information the tool provides an advice which the planner can use to inform project managers these TVPs require clustering. All information is required to be put in manually by the possession planners and analysis of outcome is also performed manually. The tool is used to assess real data in the case-study and the results are elaborated in section 5.

After the development of the manual Excel tool an automated Excel tool is developed. Objective of this tool is automating the clustering process. Automation however results in not being able to use the geography factor as Excel cannot read drawings. Solution to this is creating a matrix wherein every TVP is offset to another TVP and mark which overlap with each other and which do not. The creation of such a matrix is very time consuming and is therefore not recommendable. Development is therefore halted and no further steps are taken for development.

A clear definition on corridor parts must be available to let BTD-Planner determine which TVP is on which location and create lists of TVPs on corridor parts. Current definition of a corridor part is 'One or more (subsequent) track sections on a (traveller) corridor' (ProRail, 2016a). This is a detailed enough description for capacity allocation but not sufficient for TVP clustering as this must be on a track level. Therefore, each track must be assigned to a corridor part so it can be identified and assigned to a corridor part. Follow-up

of this methodology is (node) stations are not defined but float between corridor parts and are always subject of discussion. Therefore, nodes need to be added to corridor parts wherein a logic consistency between adjacent corridor part and node is required, for example via inserting tracks at a node used in a corridor on a corridor part. Additional information is required on when a TVP should be planned and if there are mutual exclusion between TVP requests from same project. In some cases, TVP A must be performed ahead of TVP B and it is necessary to take that into account.

## 4.5 Integrating the clustering methodology in BTD-Planner

BTD-Planner is currently in development and is expected to perform clustering in the future. To perform clustering BTD-Planner should have information on every TVP and with this data the software can determine which TVPs can be clustered. This section describes the preconditions BTD-Planner requires to be able to perform clustering. Information about duration of TVPs is already available, as is information on location of TVPs. However, this information is not detailed enough as it is just a red line on a track showing which space is required and no info on difference between work location, de-energized section and safety requirements. Difference between work location, de-energized location and safety location is required to know as work location cannot be shared but de-energized location and safety location can be shared between TVPs. This requires two steps, a more detailed drawing coming from Rail Systems Engineers and recognition of BTD-Planner between the three different types of shells.

Currently information is provided on when a TVP could be performed, for example 'Q2-Q4', and such information is not specific enough. Therefore, two fields are required, a possible moment of execution and a preferred moment of execution. Project managers should provide information on possible execution periods wherein a TVP may be performed and a preferred period. TVPs always have preferred periods within a possible moment of execution and this should be considered.

| Requirement | Must be created | Available | Explanation |
|---|---|---|---|
| TVP Duration | No | Yes | TVP duration is necessary when clustering of TVPs and planning on the network is performed |
| Hinder class | No | Yes | Hinder class is required to prioritize between different TVPs, U TVPs are more important to schedule than A TVPs. |
| Safety location | No | Yes | Safety is very important for ProRail and a safe working location must be provided, therefore current FOT can be used to get a general idea on a TVP. |
| Work location | Yes | No | Determination is based on fact work location cannot be combined but safety & de-energized location can. |
| De-energized location | Yes | No | See above |
| Possible moment of execution | No | Yes | It is necessary to know when a TVP can be scheduled to have the freedom to optimize the planning |
| Preferred moment of execution | No | Yes | Project Managers could have a preferred moment when a TVP could be planned and this can be considered in different planning settings. |
| Analysis on overlapping work locations | Yes | No | An assessment on working locations is required to let the software determine if working locations overlap. Currently such analysis is not available but BTD-planner is able to recognize individual track sections and switches. |
| Definition of corridor part | Yes | No | Currently corridor parts are defined between *Timetable points* but to let BTD-Planner cluster it is necessary to be more detailed. Therefore, a step is required wherein corridor parts are defined on track-level so the software can create possessions. |
| Type of work | Yes | No | Standardized type of work improves traceability and transparency towards planners and stakeholders who work with possessions. Can be derived from current Project tools as SAP or Primavera or a drop-down menu can be used for manual input. |
| Logistics of other TVPs | Yes | No | Checkbox for project managers to let know if it possible for other maintenance vehicles required for other work to pass, e.g. tracks in TVP available for other vehicles to pass. |

| | | | |
|---|---|---|---|
| Dependencies between TVPs | No | Yes | In some cases, it could occur TVP A must be performed before TVP B. A field is required wherein this information can be provided. |
| Clustering algorithm | Yes | No | An algorithm is required wherein an assessment is performed and all projects are clustered and presented in possessions. This algorithm requires more explanation and is therefore discussed further on in this section. |
| Logistics of maintenance vehicles | Yes | No | Checkbox for project manager wherein information can be entered if train movements are required during execution. |

Table 8: List of requirements BTD-Planner for clustering

Quality of data is important and currently the quality is not good enough for possession planning to create a proper planning. The above-mentioned criteria provide a more detailed level of information of TVPs and related products. Therefore, a shift is required not only at possession planning but also at department projects to deliver more detailed information on TVPs.

Information on type of work can be submitted by a Project Manager or Rail Systems Engineer or extracted from current databases as SAP or Primavera. Each has its own benefits with submission and extraction from SAP or Primavera resulting in a new connection between different software packages but ensures proper information. A discussion which source is better or easier than another does not influence clustering but a choice is required, one must be chosen.

Part of automation is also to let go the scoring of work as it is an arbitrary value which is multi interpretable and should therefore be replaced by a stricter system. This system should perform the analysis directly wherefore now a broad evaluation is used. The first criteria *Logistics of maintenance vehicles* is replaced with an in-app analysis on difference between work and safety location. If the safety location is larger than the work location than a vehicle of another TVP can pass. This results in a clear yes or no answer instead of an approximation used in the evaluation. *Interference during execution* can be addressed using a checkbox wherein a choice is given between 'Other work allowed' or 'No other work allowed', resulting in yes or no answer. It should however be made clear this exclusion is not meant for Project Managers to eliminate any other work to be performed nearby whilst this is still possible. *Movement of project* and *Space occupation* are replaced when a more detailed FOT drawing is used as it will have a more detailed view on work locations. Necessity for those criteria was raised due to the inaccuracy of current FOTs wherein it was not clear where exactly work is performed. Last criteria *Importance to primary function* can be replaced by an in-app analysis on type of work which will determine what the background is certain TVPs. Assessment is required on which TVP is more important than another. This is necessary to make a choice between work that must be performed and work that can be postponed. Postponing is a last resort but it might occur a choice is required between different TVPs.

Determination of most optimal clustering is a difficult question as the answer depends on the basic principle you choose. Total duration of scheduled possessions, hinder, traveller hinder, least complete obstructions and less clustering as possible for department Projects are some of the principles you can choose from to optimize clustering. Every stakeholder has their own interest in this and a starting point needs to be chosen. During this research, total duration was the main incentive to measure optimal clustering but least complete obstructions could be a good second knowing the effects of a complete obstruction regarding the corridor book. BTD-planner should therefore have the option to calculate and evaluate the different principles.

## 4.6 Conclusion

A new methodology is developed for clustering of TVPs. A project activity evaluation is developed wherein 20 common project activities are mentioned and assessed based on five criteria. A train free period evaluation is created to assess the TVPs towards each other based on factors that influence the ability to cluster. Furthermore, a new process is developed how and when the evaluations should be used. The developed tool is developed in Excel and is therefore easy to use. It has both the project activity evaluation and train free period evaluation embedded and a front screen is used for input and output. ProRail is developing BTD-Planner to replace their current possession planning software and ProRail would like to have

clustering implemented within that. Therefore, requirements are defined which are required for clustering implementation.

# 5 Case study

The developed methodology is assessed in a case study wherein the proposed methodology is applied on real data. The selected case-study area between Leiden – Rotterdam – Utrecht triangle is a comprehensive area with significant train traffic and an area requiring intensive maintenance. 2017 has 77 R and U TVPs requested to be performed and an optimal planning is required to satisfy operators and to be able to perform all projects. These projects request 77 TVPs containing 4188 hours of work and require adequate programming with optimal clustering. Selection of TVPs is performed based on geocode within the case-study area. A complete list of all TVPs is given in Appendix D.

Each corridor part is individually assessed as optimization should be performed at a corridor part level as scheduling of possessions is executed on a corridor part level. Possessions on corridor parts can then be combined with possessions on adjacent corridor parts to finally generate a feasible possession planning. TVPs are assessed as they are requested meaning it is assumed the duration of a TVP is correct and no change is possible in TVP duration. Each corridor part is assessed and results are shown in tables wherein each new heading means a new possession is created with the TVPs shown below the heading. For example, Alphen aan den Rijn – Gouda has one possession while Gouda has two, separated by the heading.

### *Alphen aan den Rijn - Gouda*

An analysis is performed on the case-study area using the methodology elaborated in the previous section. Data of 2017 is used as these 77 TVPs provide a realistic amount but is also manually manageable to be performed. The used approach is to first plan the longest TVPs, in this case 556 hours on Gouda – Alphen aan den Rijn. Four other TVPs exist on that line, one taking 76 hours and three lasting 52 hours. These TVPs are currently planned in three slots wherein one 52 hours and one 76 hours TVP is integrated within the 556 hours TVP and form one possession. Due to sequentiality not all TVPs can be clustered within this large 556 hours and it is therefore necessary to plan a 52 hours TVP first, same as in realized planning. Also, a last 52 hours TVP is required to perform last activities. Therefore, only the 556, 76 and 52 hour TVPs can be clustered into one 556-hour lasting possession and is put into the tool.

Table 9 shows the information input into the methodology and the outcome of the methodology, this methodology is also used on the other corridor part. The 556-hour project is assessed as Change of function station because a new station is constructed and the two other projects as super structure renewal as certain parts are renewed, see the image in Table 9. As track factor a single track TVP is checked, duration is longer than 52 hours and no geographical overlap is found when FOTs are assessed. Sum of the single scores is 45, 17 for STW and 14 for each SSR. Using the formula presented in previous section a score of 0.70 is the result. The advice will then be 'Requires attention' as it is likely these three projects can be combined but a manual additional determination is required. This means it is possible to cluster these TVPs but discussion with project managers is required. This is also performed for 2017 and same result is realized. The clustering tool therefore did not realize any extra possession duration reduction but also showed current methodology was properly performed. Cluster factor did not decrease or increase and will remain at 1.5 (6/4). Cluster factor did not improve as same possession scheme is acquired as is realized for 2017. Total duration also remained the same at 660 hours.

| Section | Corridor part | PA | TVP description | Duration |
|---|---|---|---|---|
| Alphen - Boskoop | Alphen - Gouda | STW | Various project activities construction phase 2 (stop and underpass Waddinxveen Triangel) | 556:00 |
| Alphen - Boskoop | Alphen - Gouda | SSR | Various project activities. • construction phase 1 | 76:00 |
| Alphen - Boskoop | Alphen - Gouda | SSR | Various project activities. • construction phase 1 | 52:00 |

Can I cluster my TVP's easily?

| | | | #track BD | Duration | Geography |
|---|---|---|---|---|---|
| Activity 1 | STW | | Single | x≥52 | No overlap |
| Activity 2 | SSR | | | | |
| Activity 3 | SSR | | | | |
| Activity 4 | | | | | |
| Activity 5 | | | | | |
| Activity 6 | | | | | |
| Activity 7 | | | | | |
| Total | 45 | | 0,703125 | | |
| | Requires attention | | | | |

Table 9: Results evaluation Gouda – Alphen aan den Rijn

### *Rotterdam – The Hague*

Next corridor part being assessed is Rotterdam – The Hague where longest TVP duration is 168 hours, twice. One between Rotterdam and Schiedam and one between Den Haag and Delft at station Moerwijk. Two other TVPs lasting 52 hours and two TVPs lasting 28 hours are also requested for 2017. Currently aside of one 52 hour projects all TVPs are clustered into one 168-hour possession. For this case, no dependency between TVPs is found and it is free to cluster and plan throughout the year.

These six projects, shown in Table 10, give input for the tool where three projects perform maintain function station, twice super structure renewal and one engineering construction preservation. This input gave the result *Easy clustering* meaning that current planning practice resulted in a sub-optimal planning module. The 52 hour TVP currently scheduled apart could have been implemented within the 168-hour possession and total hinder could have been reduce from 220 hours to 168, a reduction of nearly 24% in duration. This result offers two opportunities, other TVPs can be performed on Rotterdam – The Hague section or TVPs can be planned on other section now possible to be planned on as it is not obstructed by a possession on Rotterdam – The Hague.

| Section | Corridor part | PA | TVP description | Duration |
|---|---|---|---|---|
| Rotterdam C - Schiedam | Den Haag C – Rotterdam C | SSR | Replacement two 1:9 switches, a cross and twice 1.5 km complete track renewal. | 168:00 |
| Den Haag HS - Delft | Den Haag C – Rotterdam C | STW | Station Moerwijk | 168:00 |
| Den Haag HS - Delft | Den Haag C – Rotterdam C | | Maintenance works tunnel Rijswijk | 52:00 |
| Den Haag HS - Delft | Den Haag C – Rotterdam C | SSR | Renew sleepers, fastenings and ballast around switches 465 and 467 | 52:00 |
| Yard Schiedam | Den Haag C – Rotterdam C | STW | Measures flooding elevator shaft and passengers tunnel platform 1, 2 and 3 | 28:00 |
| Yard Schiedam | Den Haag C – Rotterdam C | STW | Measures flooding elevator shaft and passengers tunnel platform 2 and 3 | 28:00 |

Table 10: Results evaluation Rotterdam - The Hague

### *Gouda*

Next in list is Gouda – Rotterdam with longest TVP of 100 hours and 12 other TVPs, whereof ten are 52 hours, one 76 hours and one 12 hours. Some TVPs however are situated on Gouda but for some reason only got Gouda – Rotterdam as corridor part. It is therefore necessary to divide TVPs which are situated on Gouda – Rotterdam and TVPs are situated on Gouda and affect other corridor parts to Den Haag or Woerden. In addition, several TVPs located at Gouda are assigned to several corridor parts and therefore such filtering is

not effective. Therefore, an approach is used wherein Gouda is clustered as much as possible and adjacent track sections should be clustered as much as possible to existing Gouda TVPs.

In total 11 TVPs are requested on Gouda with a total duration of 566 hours. Longest duration is 100-hour superstructure renewal and work is performed on between and on Gouda and Gouda Goverwelle. The 100 hour TVP can be combined with two 52 hour TVPs on Gouwebrug, benefits in duration are achieved as safety measures only need to be taken once and the four hours can be overcome. Another catenary TVP is added which is a small project lasting 12 hours. This results in advice *Easy clustering* and is therefore recommendable to cluster these four TVPs into one possessions lasting 100 hours. Second longest TVP is superstructure renewal for 76 hours. Two catenary TVPs (52 hours and 14 hours) are added to this TVP and advice is also *Easy clustering* in this possession. Now three 52-hour superstructure renewal TVPs remain and a 52-hour catenary work TVP. During assessment, it was found that the superstructure renewal could not be combined with each other but the remaining catenary work can. Therefore, one 52-hour possession can be reduced and total hours go from 384 to 332 hours.

| Section | Corridor part | PA | TVP description | Duration |
|---|---|---|---|---|
| Yard Gouda | Gouda - Rotterdam | SSR | Complete renewal activities | 100:00 |
| Yard Gouda | Gouda – Den Haag | CAT | Renew conductor system Gouwe brug northern tracks (HW-HV and RB-RA) | 52:00 |
| Yard Gouda | Gouda – Den Haag | CAT | Renew conductor system Gouwe brug northern tracks (HW-HV and RB-RA) | 52:00 |
| Yard Gouda | Alphen - Gouda | CAT | Renewal of contact wire, circuit breakers and support structure | 12:00 |

| Section | Corridor part | PA | TVP description | Duration |
|---|---|---|---|---|
| Yard Gouda | Gouda | SSR | Complete renewal activities | 76:00 |
| Yard Gouda | Gouda - Woerden | CAT | Renew beam, pole connection | 52:00 |
| Yard Gouda | Gouda | CAT | Renewal of contact wire, circuit breakers and support structure | 14:00 |

Table 11: Results evaluation Gouda

Figure 15 shows in upper image where in which possession work is performed and in lower image the FOT with the requested infrastructure. Clearly visible are the different colours in upper image which represent work performed in each possession. Lack of coherence in one possession, work is performed criss-cross over the railyard and from hinder perspective this could have been increased significantly. Also, more work performed on a less stretched location improves clustering because overlap is less likely to occur between different TVPs. The red coloured lines represent the TVP which lasts 100 hours and the green section represent the TVP lasting 76 hours.

During an in-depth look in what activities is performed it was found work was not optimized at all and many activities were performed criss-cross over the railyard. The red lines in the lower image represent the possessed tracks in the FOT for each super structure renewal at Gouda in 2017. Visible is on every possession the entire yard is possessed whilst this could have been prevented if earlier a clear scope was which asset is renewed in what TVP.

Possible solution is to group work more on one location and possibly result in a possession where train operation is still possible. This shows current FOT sketches, which are used to create a planning wherein many difficulties occur due to lack of optimization, require a significant improvement in detail and when this step is made a better planning can be realized.

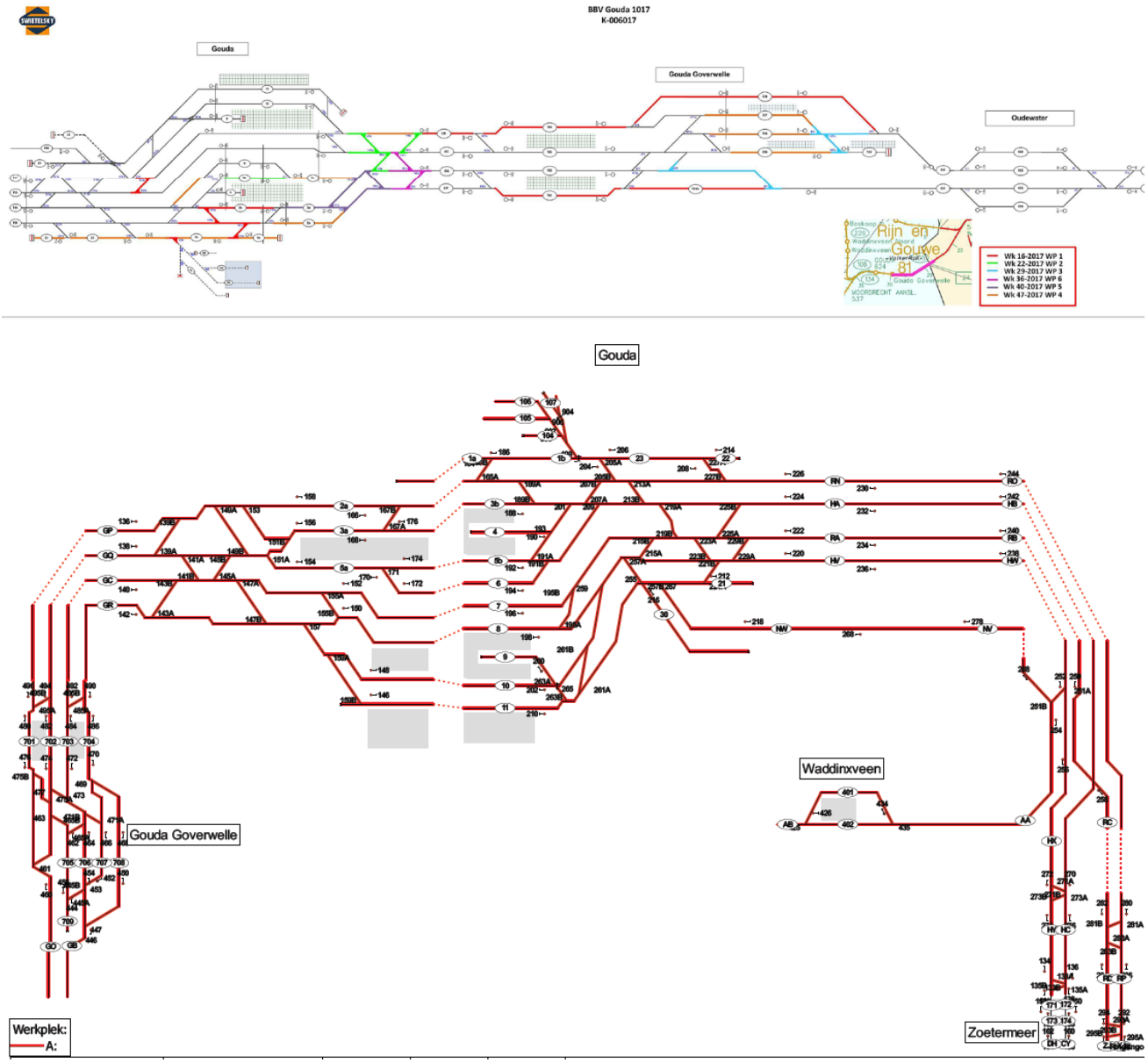



Figure 15: Work locations and FOT project Gouda 2017

The in total at least required five possessions could not be reduced with the presented methodology. It is therefore not possible to get a better result than current planning. It is however possible with in previous mentioned solutions to create a more optimized FOT with less tracks withdrawn from operation for trains.

### *Gouda – Den Haag*

Next in line is The Hague – Gouda line with largest TVP lasting 76 hours. Four 52 hour TVPs, one 28 hour, one 24 hour and three even smaller TVPs. Limiting TVP for this corridor part is the construction of a new station Bleizo near Zoetermeer. Four TVPs are requested for construction and these cannot be combined in any way and therefore create at least four complete obstructions of the line. It is therefore important to cluster as much work into these four possessions as possible. The realized 2017 planning shows five different weekends are planned. These weekends can be perfectly planned alongside the Gouda TVPs as a TVP at Gouda results in no intercity traffic between Gouda and The Hague and dependent on project location on no local trains between The Hague and Gouda.

First the 76 hour TVP is set for input in the tool due to its duration and then a 52 hour TVP is added. This TVP is for construction of the new station Bleizo and can therefore not be clustered with another station construction at Bleizo. It is however possible to cluster with other super structure renewal and two catenary projects. These TVPs have a short duration and do not overlap with the large projects. Advice of clustering on these TVPs is *Easy clustering* and recommendable to schedule in this way. Six TVPs remain and three of them are work at Bleizo and three are catenary works, therefore these TVPs are clustered into three possessions each lasting 52 hours and got a proper result out of the tool. Total reduction is from 294 to 204 hours in duration, reduction of 31%.

| Section | Corridor part | PA | TVP description | Duration |
|---|---|---|---|---|
| Yard Den Haag C | Gouda – Den Haag C | SSR | Renewal switch complex, fastenings and mesh and shielding windows | 76:00 |
| Moordrecht - Zoetermeer | Gouda – Den Haag C | STC | Construction transferium Bleizo phase 1 | 52:00 |
| Yard Den Haag C | Gouda – Den Haag C | SSR | Renewal of track, fastenings and mesh and shielding windows | 24:00 |
| Yard Binckhorst | Gouda – Den Haag C | CAT | Renewal of contact wire, circuit breakers and support structure | 16:00 |
| Yard Binckhorst | Gouda – Den Haag C | CAT | Renewal of contact wire, circuit breakers and support structure | 16:00 |

Table 12: Results evaluation Gouda - The Hague

### *Utrecht – Woerden*

Next corridor part is Utrecht – Woerden wherein TVPs at Utrecht station, Utrecht – Woerden section and station Woerden are assessed. This is done because a possession on Utrecht towards Woerden immediately results in less traffic to and from Woerden. It is therefore best to cluster these locations together to minimize hinder and less obstructions on that corridor part. Six TVPs are requested on Utrecht – Woerden axis with longest TVP lasting 76 hours and two 52 hour TVPs. Three other TVPs vary between 23 and 15 hours.

The 76 hour TVP at Utrecht is clustered with a TVP between Utrecht and Woerden where cables need to be relayed for construction of a new bridge. These TVPs slightly overlap and therefore the factor overlap is filled in with 'Partly overlapping', duration is longer than 52 hours and track is double. Large parts are four tracks but only two tracks are present at the bridge and are decisive. As third TVP a renewal of switch heating systems is added near Woerden. This project is situated on Woerden and does not conflict in any way with the projects on Utrecht and Woerden – Utrecht. Outcome of the tool, given in Table 13, shows *Easy clustering* and it is therefore recommended to be implemented. Second set of TVPs is also added into the tool and is given as result *Requires attention*. Factors are set as double; duration is between 28 and 52 hours for longest TVP and FOTs are partly overlapping. Because the two CAT TVPs are lasting 15 and 23 hours it is however likely these TVPs can be clustered as 14 hours of spare time is available for logistics and other coordination. Clustering of these activities resulted in a major reduction of duration as these were all planned apart. From total 234 hours to 128, nearly 50% reduction.

| Section | Corridor part | PA | TVP description | Duration |
|---|---|---|---|---|
| Utrecht | Utrecht | CES | Grubbing cable sleeves after step 5K | 76:00 |
| Vleuten - Utrecht | Woerden - Utrecht | SSR | Divert cables, pipelines and various adjustments catenary | 52:00 |
| Woerden | Woerden - Utrecht | SSR | Renewal of point heating installation to electric | 16:00 |

| Section | Corridor part | PA | TVP description | Duration |
|---|---|---|---|---|
| Vleuten - Utrecht | Woerden - Utrecht | SSR | Divert cables, pipelines and various adjustments catenary | 52:00 |
| Utrecht | Yard Utrecht | CAT | Extra work catenary construction step 5F | 23:00 |
| Utrecht | Yard Utrecht | CAT | Extra work catenary construction step 5F | 15:00 |

Table 13: Results evaluation Utrecht - Woerden

### *Woerden – Alphen aan den Rijn*

Next track section to be discussed is Woerden – Alphen aan den Rijn where two 52 hour TVPs are requested, twice stabilisation of substructure and these cannot be combined. It is therefore not possible to reduce any duration or number of possessions on this track section, only option is to combine this with other possessions nearby such as on Alphen aan den Rijn or Woerden.

### *Alphen aan den Rijn – Leiden*

Alphen aan den Rijn – Leiden is a separate corridor part from Woerden – Alphen aan den Rijn and has four TVPs requested. One 52 hours wherein a level-crossing is removed and a tunnel is created and three lasting 28 hours wherein twice platform roofs are painted and in one TVP catenary parts are renewed. First the construction of the tunnel is added into the tool, and then the two painting TVPs. This results in *Requires attention* as duration is between 28 and 52 hours, section is single track and no overlap between the projects is present.

Combining two painting TVPs results in slight overtime, 28 + 28 is 56, but this is compensated because only once start-up time is required. Total duration from 2017 compared to results of this tool dropped from 136 to 80 hours.

| Section | Corridor part | PA | TVP description | Duration |
|---|---|---|---|---|
| Zoeterwoude - Leiden | Alphen - Leiden | CES | - Insertion foundation<br>- Insertion substructure<br>- Excavation under substructure | 52:00 |
| Zoeterwoude - Leiden | Alphen - Leiden | STH | Painting of platform roof track 1 | 28:00 |
| Yard Leiden | Alphen - Leiden | STH | Painting of platform roof track 2 | 28:00 |

Table 14: Results evaluation Alphen - Leiden

Possessions on Alphen aan den Rijn – Leiden relate to Possessions on Alphen aan den Rijn and two TVPs are requested at Alphen aan den Rijn, one lasting 76 hours and one lasting 52 hours. A complete obstruction of Alphen aan den Rijn results in a possibility to combine this with work on Alphen aan den Rijn – Leiden. Such opportunities should be exercised to reduce additional hinder and increase efficiency. For the last remaining TVP, catenary renewal, a combination can be sought with the other Alphen aan den Rijn possession but this project also partly obstructs tracks towards The Hague. It is not possible to combine this with the other projects as the overtime would increase too much and execution in available time becomes an issue. This remaining project results in hinder towards Alphen aan den Rijn, The Hague, Schiphol and Haarlem and is therefore and is therefore difficult to determine which corridor part to be clustered with. However, complete obstruction is towards Alphen aan den Rijn only

### *Leiden – The Hague*

Leiden is connected to The Hague via four tracks where two tracks are designated for the Central Station and two for Hollands Spoor. Two outer tracks are used for trains to and from The Hague Central Station and two inner tracks to and from Hollands Spoor. This creates opportunities for clustering of work but is dependent on train operation schedules which tracks can be obstructed and still be able to perform a certain timetable.

For 2017 18 TVPs are requested on this section and varies between super structure renewal to adjusting height of tracks to allow a level access to trains through P76 program. Most TVPs do not completely obstruct all four tracks and a discussion is required which solution suits best for both parties, complete obstruction or partly obstruction. Twelve TVPs last 52 hours, five TVPs 16 hours and one lasts 12 hours. Complete obstruction to increase clustering is the preferred methodology and therefore a maximum is sought wherein complete obstruction is achieved and maximum number of TVPs is added into one possession. The renewal TVPs on station De Vink cannot be clustered together and are therefore limiting clustering opportunities to at least four possessions.

First a large super structure renewal TVP is taken which already obstructs three tracks and then more work is added. Around station De Vink different projects are working throughout the year, super structure renewal and P76. They cannot share same track but one can work in track 1 and 2 while other project performs work on track 3 and 4. With that in mind super structure renewal on track 2 and 3 is added and P76 on track 1 and track 4. Additionally, the roof of Leiden Centraal requires painting as maintenance and therefore tracks adjacent to roof need to be taken out of operation. Therefore, a complete island platform is possessed and taken out of operation. With an additional TVP added, tracks will overlap and advice would not be as positive as it currently is, *Easy clustering*.

Second possession is assessed in the same way, complete obstruction of all tracks and add as many TVPs as possible to create a most optimized schedule. So again, start with super structure renewal, P76 on an outer track and painting of station roofs.

| Section | Corridor part | PA | TVP description | Duration |
|---|---|---|---|---|
| Yard Leiden | Den Haag - Leiden | STH | Painting of platform roof track 9 | 52:00 |
| Yard Moerwijk | Den Haag - Leiden | SSR | Renewal of switches and fastenings and reconstruction of switch heating | 52:00 |
| Leiden - Moerwijk | Den Haag - Leiden | SSR | Station de Vink, tracks 2 en 3. | 52:00 |
| Leiden - Moerwijk | Den Haag - Leiden | P76 | Station de Vink, raise track 1. | 16:00 |
| Leiden - Moerwijk | Den Haag - Leiden | P76 | Station de Vink, raise track 4. | 16:00 |
| Yard Leiden | Den Haag - Leiden | STW | Painting of platform roof track 8 | 52:00 |
| Section | Corridor part | PA | TVP description | Duration |
| Leiden - Moerwijk | Den Haag - Leiden | SSR | Station de Vink, tracks 2 en 3. | 52:00 |
| Yard Leiden | Den Haag - Leiden | STW | Painting of platform roof track 5 | 52:00 |
| Yard Leiden | Den Haag - Leiden | STW | Painting of platform roof track 4 | 52:00 |
| Yard Moerwijk | Den Haag - Leiden | SSR | Renewal of switches and fastenings and reconstruction of switch heating | 52:00 |
| Leiden - Moerwijk | Den Haag - Leiden | P76 | Station de Vink, raise track 1. | 16:00 |

Table 15: Results evaluation Den Haag - Leiden

Third possession is also filled with work, super structure renewal near Den Haag Laan van NOI and De Vink, P76 around De Vink and catenary adjustments near Den Haag Moerwijk. Result is *Easy clustering* and can be implemented easily. Fourth possession consists out of rest work between Den Haag Laan van NOI and Den Haag HS and a final super structure renewal project on De Vink.

| Section | Corridor part | PA | TVP description | Duration |
|---|---|---|---|---|
| Leiden - Moerwijk | Den Haag - Leiden | SSR | Station de Vink track 1 | 52:00 |
| Yard Laan van NOI | Den Haag - Leiden | SSR | Renewal of sleepers, fastenings and ballast. Renewal switch 215A/B and regulate catenary | 52:00 |
| Leiden - Moerwijk | Den Haag - Leiden | P76 | Station de Vink, raise tracks 2 and 3. | 16:00 |
| Leiden - Moerwijk | Den Haag - Leiden | P76 | Station de Vink, raise tracks 2 and 3. | 16:00 |
| Yard Moerwijk | Den Haag - Leiden | CAT | Renewal of contact wire, circuit breakers and support structure | 12:00 |
| Section | Corridor part | PA | TVP description | Duration |
| Leiden - Moerwijk | Den Haag - Leiden | SSR | Station de Vink, track 4 | 52:00 |

| | | | |
|---|---|---|---|
| Yard Laan van NOI | Den Haag - Leiden | SSR | Renewal of sleepers, fastenings and ballast. Renewal switch 213 and regulate catenary | 52:00 |

Table 16: Results evaluation Den Haag – Leiden

Realized planning for 2017 resulted in 512 hours of possession scheduling, with the used methodology this is reduced to 208 hours, a 60% reduction. This reduction however requires some further explanation. Most TVPs are scheduled individually and only one complete obstruction is planned whilst in the tool three complete obstructions are used. From point of clustering this gives the best result but an operator could prefer current practice with several weekends less traffic.

### *Gouda – Rotterdam*

On Gouda – Rotterdam 10 TVPs are requested and most of them are related to reconstruction of a station and catenary works on Rotterdam. Renewal of Alexander station is restrictive for clustering TVPs as these four TVPs cannot be clustered and are required to remain separated. Also, there is a TVP requested for catenary work and this one cannot be combined with the works on Alexander as it is expected this work conflicts with work at the station. Therefore, a minimum of five weekends is required. Five other TVPs remain, whereof four are also 52 hours and one is 12 hours in duration. These TVPs can all be assigned one by one to one already existing TVPs as they do not overlap, duration is equal or shorter and number of tracks is sufficient. Table 17 shows the result involved in clustering on Rotterdam – Gouda. All other combinations score better than this and for every possession a positive advice *Easy clustering* is given.

| Section | Corridor part | PA | TVP description | Duration |
|---|---|---|---|---|
| Rotterdam – Westelijke splitsing | Gouda - Rotterdam | STH | Station Rotterdam Alexander | 52:00 |
| Yard Rotterdam | Gouda - Rotterdam | CAT | Renewal of contact wire, circuit breakers and support structure | 52:00 |

Table 17: Results evaluation Gouda - Rotterdam

Results of clustering are 104 hours are saved and a reduction from 312 to 260 hours is realized, just over 28%.

### *Results*

The results are quite significant as in some cases reduction of 30% was possible. There are however some notes that require to be considered. Additional optimization is possible to schedule the possessions along with other possessions. For example, adjacent corridor parts to yard Gouda where in total six times a complete obstruction is forced into all directions. Such complete obstructions are opportunities to cluster as much work as possible into these periods, especially when these are periods lengthy, for example 100 hours. Two station renewals between Gouda and Rotterdam could be clustered into one and a reduction to four possessions is possible between Rotterdam and Gouda. Six possessions are scheduled on Gouda itself so a proper service will not be provided but some local service can be operated.

This example sketches the rising difficulties with clustering of TVPs and the influence on the network. Clustering can have significant results on a single-track section but effect can be minimal on a network view as adjacent sections require more possessions.

Table 18 shows the total reduction of duration from 2841 hours to 2144 hours, 697 hours and 25% duration reduction in total. This accounts for 9 weekends less possessions and thus a lot of freed capacity wherein other TVPs could have been performed or normal train operation could have been possible.

| Corridor parts | 2017 realized (hr) | 2017 methodology (hr) | Delta | 2017 realized (n) | 2017 methodology(n) | Delta |
|---|---|---|---|---|---|---|
| Utrecht | 99:00 | 76:00 | 23:00 | 2 | 1 | 1 |
| Woerden | 16:00 | 0:00 | 16:00 | 1 | 0 | 1 |
| Woerden - Utrecht | 104:00 | 52:00 | 52:00 | 2 | 1 | 1 |
| Alphen - Gouda | 660:00 | 660:00 | 0:00 | 3 | 3 | 0 |
| Alphen - Leiden | 136:00 | 80:00 | 56:00 | 4 | 2 | 2 |

| | | | | | |
|---|---|---|---|---|---|
| Alphen - Woerden | 104:00 | 104:00 | 0:00 | 2 | 2 | 0 |
| Gouda | 384:00 | 332:00 | 52:00 | 6 | 5 | 1 |
| Gouda – Den Haag C | 294:00 | 204:00 | 90:00 | 7 | 4 | 3 |
| Gouda - Rotterdam | 416:00 | 260:00 | 156:00 | 8 | 5 | 3 |
| Den Haag HS/C - Leiden | 512:00 | 208:00 | 304:00 | 12 | 4 | 8 |
| Den Haag C - Rotterdam | 220:00 | 168:00 | 52:00 | 2 | 1 | 1 |
| Total | 2945:00 | 2144:00 | 801:00 | 49 | 28 | 21 |
| | | | -27,20% | | | -43% |

Table 18: Overview of clustering results

### *Methodology sensitivity*

To identify the sensitivity of the methodology the same TVP data is used but the assessment is changed. Only two criteria, logistics of maintenance vehicles and interference during execution, are used in the tool as these two criteria were preferred by ProRail. This sensitivity is performed to find out if the results of the tool change when certain criteria are left out. The removed criteria are 'Duration', 'Required space' and 'Importance to primary function'. The sensitivity analyses is performed using the same data as in section 3.3.

For Gouda – Alphen the result did change as the score lowered by 0.04 but the advice 'requires attention' remains the same. Figure 16 shows the result of the tool when only two criteria remain. Additional tests on Den Haag – Rotterdam result in 'Easy clustering' which is the same result as in the original tool. According to this result it is recommended to perform additional investigation and this might only give an indication.

Can I cluster my TVP's easily?

| | | | #track BD | Duration | Geography |
|---|---|---|---|---|---|
| **Activity 1** | STW | | Single | x≥52 | No overlap |
| **Activity 2** | SSR | | | | |
| **Activity 3** | SSR | | | | |
| **Activity 4** | | | | | |
| **Activity 5** | | | | | |
| **Activity 6** | | | | | |
| **Activity 7** | | | | | |
| Total | 17 | | 0,6640625 | | |
| | Requires attention | | | | |

Figure 16: Results tool Gouda – Alphen aan den Rijn

# 6 Postponing and advancing possessions

Planning of possessions is currently assessed on a yearly basis and does not consider possession planning for multiple years. Hundreds of projects are executed each year and each project manager requests its own TVP for their projects and does not consider other projects on the same corridor part. This work methodology causes non-optimized work scheduling as project manager one requires a possession in 2017 for Gouda – Woerden and project manager two requires one in 2018, while no knowledge is on what each other is performing. Increasing knowledge for possession planners on projects in the future could enhance the planning process as more efficient combinations can be made.

A risk of such clustering actions is postponing of activities and possibilities of ignoring end-of-life of an asset. The risk of postponing renewal is mitigated with maintenance performed by the service contractor. This is possible due to new contracts, PGO, initiated by ProRail several years ago wherein the service provider is responsible for the level of performance of an asset. Within the contract, it is defined which asset is to be renewed in a certain year to allow the service provider to achieve a proper bid based on reliability of assets. Depending on the contract postponement or acceleration of renewal is possible but this is different for every contract. A bandwidth is given between acceleration of one year and maximum postponement of two years, but this is different per contract.

The three lines; FH, FW & OW, have a different planning interval in the case of knowledge on execution year. For maintain function a quite clear schedule is known for the coming years, especially if the renewal dates of assets are required to be known for service contracts. A clear prognosis can be made which asset should be renewed in which year and which clustering opportunities can be made.

In 2017, major works are scheduled in Randstad Zuid and in the feasabilitystudy made by ProRail another major pile of work is coming to this region in 2018. The feasabilitystudy is a document wherein the number of TVP's per corridor part is given to identify possible bottlenecks. This pile of work gives a large problem in programming of possessions due to the required availability of sections when other sections are unavailable. Programming on longer term, more than one year, gives the possibility to spread work over a larger amount of time. ProRail knows which asset requires renewal and or maintenance five years ahead so a clear scope is possible for renewal or maintenance. With the knowledge ProRail is required to give contractor information on its renewal schedule a proper planning can be formed and matched with practicability. Renewals can be postponed or accelerated to improve efficiency of programming possessions.

Programming of possessions is performed with the guidelines given in the corridor book. In basis, it is possible to claim a section of a track 52 weekends in a row, resulting in other sections not available for maintenance, an unlikely situation. However, guidelines tell between every possession a section should be free for at least three weeks to minimise nuisance for customers. This already minimises the amount of options to a theoretical 13 possessions per year in a weekend. Further limitations are events where before and after transportation of visitors is required so a possession is undesirable, depending on the size of an event. An event with 500 visitors is easier to facilitate alternative transportation than events with several ten thousand of visitors. Some large 'events' such as accessibility of Schiphol during summer period or near the beach make it difficult to plan

The national coherence also prevents simultaneous programming of several track sections due to availability of reroutes for mostly freight trains. Other limiting detail are the reachability of maintenance facilities for trains, at least two should be available out of total three. Maastricht, Onnen (near Groningen) and Leidschendam (near Den Haag) are the location of the maintenance facilities. Border crossings are also important, three crossings with Germany (Deventer – Bad Bentheim, Utrecht – Emmerich and Utrecht – Eindhoven – Venlo) and two with Belgium (Roosendaal – Essen and Maastricht – Visé). For Germany, at least two crossings should be full available if one is closed and for Belgium one of two crossing should be available. At last, the final consideration is travellers should not be confronted with more travel time than 30 minutes.

The above-mentioned guidelines are however not concrete; it is possible in consultation with operators to deviate from these guidelines. Deviation is mostly applied in case of small events and minimum interval

between possessions as sometimes for the greater good of the network possessions are programmed at a certain moment.

The Dutch network has eleven critical sections which prevents other corridors to be closed for rerouting of trains. These locations are:

| | | |
|---|---|---|
| Rotterdam – Gouda | Amersfoort – Utrecht | Tilburg – Boxtel |
| Gouda – Woerden | Zwolle – Lelystad | Amersfoort – Hilversum |
| Woerden – Utrecht | Lelystad – Almere | Deventer – Wierden |
| Zwolle – Amersfoort | Almere – Weesp | |

If one of these locations is obstructed the other ten must be available for rerouting trains. Two sections of these critical locations are situated in our case study, which has three sections in total. The three sections together however cannot be programmed together due to availability of a reroute and to not increase travel time too much. This limitation makes it difficult to plan all possessions throughout a year.

To realize a multiannual planning throughout the organization changes are required. Largest impact for department Asset Management which will need to realize a proper and solid long-term planning on asset renewal. Then department Projects requires action to deliver products five years ahead of execution, a major step wherein financing, contractors and ProRail are influenced. Planning of certain projects could significantly differ from what was early accepted as normal and it should also be considered projects can be postponed. Stakeholders are then influenced as their project is postponed or advanced, requiring a different mindset. Such change would change entire organization but operators and travellers will benefit due to reducing hinder. Early experience can be gained by performing a trial on a small scale and with a small year span, for example two years.

## 6.1 Advancement or postponement of TVPs

If a multiannual planning is considered advancement or postponement of projects could occur as better clustering could be made. Multiannual planning could result in more clustering opportunities as every year every track section is possessed at least once. When more TVPs are considered a more optimal clustering can be made as more options are available to cluster. To identify the benefits of a multiannual planning advancement and postponement investment and loss is considered. Advancement costs money as the expected end-of-life is not reached and postponement comes with risks on reliability. Only renewal work is considered in postponement or advancement as construction or local projects are more bounded by funding and have more political impact. When TVPs are advanced or postponed clustering opportunities arise and with the given info it is possible to identify cost benefits or deficits.

First advancement is considered and the benefits depend on the track section which is considered and the worth of assets which is replaced. For this case, it is assumed four standard 1:15 switches are renewed, with a value of €250.000 per point in a planned possession lasting 52 hours. Value of a switch is taken from cost engineers and is a reliable value for renewal of such an asset. From a social perspective, it is assumed on a normal weekend 60.000 travellers used that certain section and the value of time for an 'Other' traveller is set at €7 (KIM). It is also assumed travellers will face an extra 30 minutes' travel time due to the possession. The cost of a switch renewal is calculated at €1.000.000,00 and if performed a year in advance 4% of life-cycle cost is wasted, thus resulting in €40.000 cost of earlier replacement.

Benefits on the other side are travellers are not faced with an extra possession and thus no extra travel time is required. These benefits are calculated using the value of time of 'other' travellers from the KIM report, €7 per hour. As 60.000 travellers will have 0.5 hour extra time this would cost 60.000 * €3.50 = €210.000. Total benefits are thus €210.000 - €40.000. Through this methodology some factors are neglected such as maintenance cost. These risks are however laid with the process contractors and are embedded in the bid contractors offer to ProRail.

Through this methodology, a table is made wherein clearly visible is what the benefits are when a possession is clustered in another year depending on number of passengers on a certain corridor part versus value of renewal and life-expectancy of an asset.

To sum up the above the benefits for passengers can be calculated using the next formula:

$Benefits = \#passengers * €3.5$

The calculation for residual asset value is:

$$Residual\ asset\ value = \frac{Replacement\ cost}{Expected\ life - cycle}$$

| # Passengers | Value of time |
|---|---|
| 30.000 | €105.000 |

Table 19: Social travelling costs

| Cost of replacement | Expected life-cycle (yr.) 5 | 10 | 15 | 20 | 25 |
|---|---|---|---|---|---|
| €1.000.000 | €200.000 | €100.000 | €66.667 | €50.000 | €40.000 |

Table 20: Residual asset value

Table 19 and Table 20 show the example costs of a possession and through this way a cost/benefit analysis can be executed to identify the social cost of a possession. To determine cost/benefit the asset value depreciation needs to be subtracted from the value of time. These values depend on value of replacement, expected life-cycle and the number of passengers. If for example cost of replacement is €1.000.000, -, expected life-cycle is 20 years and number of passengers is 30.000. Then the lost value of asset is €50.000 and benefits are €105.000. The total benefits are thus €105.000 - €50.000 = €55.000 and it is from total expense beneficial to advance that renewal.

Postponement of TVPs results in risks for reliability and availability as assets will get more worn. This will result in increasing number of failures of assets and this must be prevented. Two options exist to prevent additional failures, extend daily maintenance or take life-extending measures. Life-extending measures will result in additional possessions as few years ago life-extending measures were taken at Gouda. This resulted in several possessions wherein life-extending measures were taken but also affected train operations. It is therefore wisely to choose other methods than life-extending measures to cope with increasing wear and minimizing failures. Other option is additional daily maintenance to prevent failures. Daily maintenance is contracted on performance basis and therefore the contractor is responsible for the performance of their assets. At the procurement phase ProRails informs bidders which assets will be renewed during their contract period, with a certain bandwidth fluctuating between -1 year to +2 years. Contractors make their bid based on the asset information and with the given bandwidth ProRail has the freedom to schedule renewal work. As assets are used longer than their expected end-of-life no extra costs are made from that side. Contractors for daily maintenance will base their prices on the given bandwidth and thus additional costs are not made if the movement of renewal is within the given bandwidth.

## 6.2 Planning costs and benefits

Aside from costs and benefits from assets and travellers point of view also costs and benefits are contributed from ProRail and operators around possessions. Most benefits are made at other stakeholders than ProRail as hinder is reduced for operators and travellers and ProRail lumbers itself with additional work. More coordination and consultation between TVPs is required and benefits are mostly not directly for ProRail itself and therefore requiring a different view. Only when the performed project is change of function or a local project ProRail will pay for bus costs, and then directly transferred to client.

This analysis uses the same benefits data but looks from a wider perspective on the costs and benefits for operators and projects. What are they required to perform to make clustering a success and what are costs of these actions? Starting principle is a standard weekend possession, 52 hour, on an average corridor part with 30.000 passengers per weekend.

Clustering of TVPs results in less costs as less alterations are required and five types of cost can be identified:

- Planning costs (operator)
- Bus costs (For operators when FH, for ProRail when FW/OW)
- Personnel shift changes (Operator)
- Travel information (Operator)
- Coordination between TVPs (ProRail)

Most costs are made during a possession and not in the planning phase. Planning costs represent all cost made for an alternative plan, where do busses should stop at a station and how many do I need, how can passengers be rerouted best and how many extra trains are required on alternative routes to cope with extra passengers? Bus costs are the costs for replacement bus services and depend on distance busses need to travel and the number of passengers requiring transportation. Operators use a distribution module to determine number of passengers who will use replacement busses and calculate how many busses are required. Bus costs represent most cost made and can go up to over a million euro for possession on a very dense corridor part where replacement busses are fastest alternative and many passengers need to be transported. Personnel is required for customer guidance at intermediate station to answer question and provide routes to busses. Travel information needs to be assessed, where are signs required and how should they look like and the actual placement of it. Last additional cost is the coordination required between TVPs when these are clustered and alignment is required they will not hinder each other in execution.
Benefits of clustering of TVPs:

- Less planning costs (operator)
- Less bus costs (For operators and ProRail)
- Less personnel shift changes
- Less travel information

Benefits are mostly at operators and only in case of bus costs for certain types of TVPs ProRail benefits of possession reduction. In general, the benefits are no work is required to be performed because no possession are scheduled. It is therefore wise to assess the costs and benefits of TVP clustering for the entire rail sector. When only ProRail cost/benefits are assessed, a negative result is likely to occur due to the large costs of replacement busses and when only operators' costs are assessed the result would always be positive.

As the costs of planning, personnel, travel information and coordination between TVPs are difficult to estimate it is assumed these costs are low enough to not have significant impact and could even balance each other. Bus costs are therefore the main driver for additional savings when it comes to possession clustering. The only additional costs are the coordination between TVPs and are total on behalf of ProRail.

## 6.3 Conclusion

Advancement or postponement of TVPs for clustering comes with benefits and disadvantages. Costs and benefits are depended on the track section and number of passengers on that section and the value of replacement. Benefits are only achieved when a possession is reduced and thus hinder is less, otherwise no benefits arise. An example calculation showed benefits are reached soon and therefore advancement of TVPs to reduce a possession is lucrative and quickly achieves hinder reduction.

On the postponement side the benefits are clearer, if the postponement is still within the boundaries for the daily maintenance contractor risks on extra failures is for the contractor. Additional costs are not made as end-of-life of an asset is already reached and therefore no value is discarded.

# 7 Conclusion

The research question is as follows: '*How can ProRail cluster plannable maintenance possessions in order to decrease infrastructure unavailability?'* The solution is a new methodology which will improve clustering of TVPs through a more structured evaluation.

During this research, it is found in basis any TVP can be clustered with another TVP and only very limited projects result in a complete blockage for clustering. However, multiple constraints are found which limit clustering opportunities especially the logistics component limits as materials and machines require delivery to the work location and supply routes cannot be obstructed. TVPs are required to hand in a FOT, a drawing wherein is projected which tracks are required for execution of work, but this drawing only informs about the safety shell and nothing about the exact work location.

Therefore, an evaluation is developed wherein an approximation is made what the work location is of a project within a FOT. This evaluation uses five criteria, logistics of maintenance vehicles, interference during execution, movement of project, space occupation and importance to primary function. The criteria are valued using a scoring system wherein each criterion has certain characteristics which will determine the final score. Each project type is assessed with that assessment and a total score is determined by summation of all individual criteria scores.

To come to a final evaluation wherein the dependencies between TVPs are assessed additional factors are required. These factors are number of tracks in project, duration of a TVP and overlap between projects. These are the factors influencing wherein logistics also takes an important position, number of tracks and duration are both related to logistics. Each factor is represented with three different characteristics wherefrom must be chosen by the user. With the scores of individual TVPs, factors giving influence between TVPs and the project types it is possible to create possessions.

Advancement or postponement of a TVP has several costs and benefits. If a TVP in year x can be advanced to year x-1 benefits and costs will arise. Life-cycle costs increase as full life expectancy is not reached and a deficit is registered. These costs depend on the value of assets and what the expected end-of-life is. Operators and especially travellers however benefit a lot when a part of the network is less obstructed and through this calculation an approximation is made what the benefits or costs are. If a corridor part is dense the social benefits for travellers rises sharp and from that perspective advancement or postponing to reduce a possession is always positive. Benefits are large, especially on busy traveller sections and with a long life-cycle expectancy.

Analysis with use of the methodology on 2017 case-study region showed promising results. Several track sections had already been optimized and no further optimization was possible, also a result good to know. Several track sections had the opportunity to be further optimized, compared with the realized planning for 2017. From 48 scheduled possessions to 27 possessions, nearly 43% reduction in number of possessions. If the duration is considered a reduction is realized from 2945 hours to 2144 hours, a reduction of 801 hours and 27%.

A simple tool in Excel is developed wherein the evaluations are incorporated and. This tool provides an easy-to-use environment and provides the user with an advice on ability to cluster with the given TVPs. ProRail is developing the BTD-Planner as new main system for managing possessions and would like to incorporate clustering. To be able to do that starting principles for TVP clustering are defined. These principles describe what the BTD-Planner should have as basic functions and what information is necessary from other departments within ProRail and how this should be delivered.

A new process is developed to integrate clustering within the current possession planning process. With clustering, more integrated it will become more reliable and provides operators with more information enhancing transparency. This process is especially designed for the manual Excel tool and as possession clustering is performed within BTD-Planner automatically a separate process is not required.

# 8 Discussion

During this research, several points occur where discussion could arise from, in this section several points are discussed and remarks are made where the research and developed methodology, tooling and process limits.

### *Evaluations*

The methodology is successful but is limited on the evaluations side. The evauluation remains to be opportunity based and can therefore not provide a clear advice. This is due to lack of information on exact working location being directly available for assessment within Excel. Information on the safety location is available from FOT drawings but only describes the safety shell and does not provide information wherein this drawing exactly work is performed. As location information is important for clustering this resulted in only being able to create an evaluation wherein location within safety shell is estimated. It is possible to create a conflict matrix for safety shell but with some corridor parts having over 20 TVPs this will result in a major matrix and would also cost a significant amount of time. Implementation of clustering within BTD-planner is therefore better as BTD-planner has direct asset information and as project managers draw FOTs within BTD-planner this information can be directly assessed.

The results of this research, reduction in possession numbers and duration, are like expectations. It was however not expected the reduction would be this high as it was assumed clustering was performed on a larger scale. It can therefore be stated that this research has a larger potential than was expected beforehand. The expected scientific literature available was however limited and did not cover some parts of this research, such as clustering of TVPs. Most research is performed on optimization of individual activities or optimization of work within a short period, such as four hours. This gap of knowledge in literature prevented this research from making a proper comparison with existing literature.

### *Probability usage*

The methodology is a probability assessment to determine wherein a TVP work is performed for that project. This is necessary due to the limited amount of available information of work locations within a FOT which only represents the safety shell. This methodology provides a stable assessment but is limited due to being a probability methodology. It could therefore occur an advice is given which may not be feasible for execution. This problem should be overcome when projects hand in a more detailed FOT wherein a differentiation is added between work shell and safety shell. Until that moment, a probability methodology is required to assess the differences between TVPs.

In current methodology, no difference is made between two TVPs having the same duration, long or short. When two 60 hour TVPs are clustered a factor of 1.25 is multiplied as the duration of longest possessions exaggerates 52 hours. When these TVPs are put into the evaluation the result is ‘Difficult to cluster’, meaning the evaluation already predicts it is not likely these TVPs can be clustered and a manual determination is required. During that determination, a possession planner will see a combination of these two TVPs is feasible or not.

### *TVP spread*

When clustering is performed, capacity is freed from the network and can be used for two things. More TVPs to be executed or train operation and thus less hinder for travellers. In the light of number of TVPs it is not likely soon that much capacity is freed for train operation and only more capacity is made to be able to perform all TVPs.

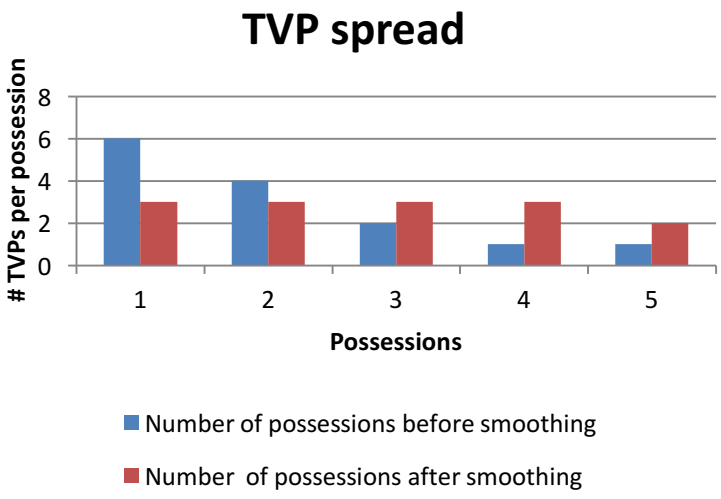



Figure 17: Number of requested TVPs per scheduled possession

In current methodology, the first clustered possession is filled to the max if the score is high enough. This is not directly an issue as these TVPs can be clustered but to ease the coordination between TVPs it could be better to spread out TVPs over other possessions. This should be performed manually as a restrictive criterion 'only four possessions per clustering' would mean opportunities can be missed. Figure 17 describes this principle with in blue the original result of the clustering methodology and in red the manual spread of possessions. Both results are correct and can be performed but six possessions clustered into one will result in requiring more coordination and a more complex logistic component. To ease this process and provide with a less complex logistic component possessions should be spread more.

### *Subcorridors*

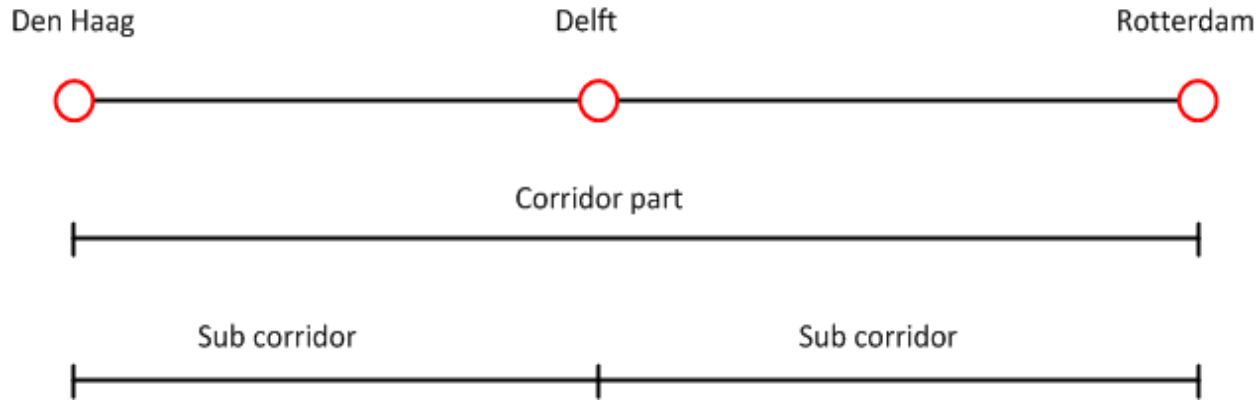



Figure 18: Sub corridor example

Current approach of clustering is on entire corridor parts and means a complete obstruction of that corridor part. In some cases, operators will perform train operation when not the entire corridor part is taken out of service. It would therefore be interesting for ProRail to have insight in when operators would still perform a train service and when they will not. For example, corridor part Den Haag – Rotterdam where Delft lies in between. If two TVPs are requested on Den Haag – Delft and two on Delft – Rotterdam a result of the methodology could be one TVP on Den Haag – Delft should be clustered with one on Delft- Rotterdam and the other two also together. This results in twice complete blockage of Den Haag – Rotterdam and is completely understandable in line with the Corridorbook. For operators, it would however be interesting to cluster the TVPs on the sub corridors to continue train operation. This method is especially for operators as it has no influence on the constraints in the Corridorbook.

### *Workforce*

Clustering of TVPs gives a lot of benefits but also increase workforce required for a certain moment in time where a large peak is necessary. Currently there are certain work areas which lack significant amount of mechanics, such as catenary and signalling mechanics. When too many TVPs are clustered into one weekend the level of required capacity could be greater than amount of available capacity. Knowing this information

would help clustering a lot and could be embedded into the BTD-planner assessment. Currently a brief indication is given how many mechanics are required and when TVPs are scheduled an assessment is performed what capacity is requested and what the expected available capacity is. When that signal comes Project Managers are informed capacity may become scarce and a check must be performed if their requested capacity is available. It should however be considered to implement this knowledge into BTD-planner and automatically determine if the requested capacity is too high or still below available capacity. Additional research is required on availability of mechanics and how this can be scheduled best given the different factors influencing the possession planning.

Optimization on a corridor part is a good result but large benefits are found when multiple corridor parts are combined in one period. Such benefits mostly occur when a corridor part is complemented with a possession on an adjacent rail yard. When a corridor part is obstructed most adjacent yards also require less capacity for trains and possessions can be combined in planning. Other way around, if a yard is complete obstructed adjacent corridor parts can easily be combined because train operation is already obstructed. Such synergy advantages are already used but because optimization is performed on corridor part basis new optimization is possible. A corridor part always has on both sides a yard and therefore has two options to be combined with. These options can be exercised to find the best solution to which yard a corridor part must be connected to reduce hinder or for best train operation.

### *Geographical differences*

The geographical assessment of possessions on the network is correct. However, it does not consider train or passenger intensity on a region. North-East is larger in terms of network length but has fewer train services and is also less flexible in rerouting trains as most sections are double tracks and not have four tracks as is much more the case in the Randstad. In the Randstad, more opportunities exist to take two tracks out of service while being able to perform a reduced train service on the remaining two tracks. The impact of a possession might therefore be higher in areas where rerouting is limited and most sections consist out of double tracks.

The Excel tool faced a limitation on overlap of TVPs and on technical dependency. This influenced results largely and ensured an unreliable result of clustering. It was not possible to take this into account as the provided dataset did not have information on technical dependency. Also, the methodology sensitivity analyses outcome could also say the other three criteria are not relevant for the tooling. The outcome could however change if specific project activities are selected which gain more points from the other three criteria such as engineering construction renewal with signalling. When such combination is made with all criteria the advice is Difficult to cluster while only the two criteria from the sensitivity analyses are selected the advice is Do not cluster. This shows each criterion is relevant for the analyses but the outcome depends on the data inserted and due to no TVP combination of such project activities currently exists was also not tested.

# 9 Recommendations

ProRail should improve possession clustering, that was already clear and in this research solutions are provided to improve clustering. The evaluations and manual Excel tool should be adopted to gain quickest benefits and improve clustering of possession to reduce hinder. Information on asset life-expectancy is widely available within ProRail and average life-expectancy is much longer than for example five years. It should therefore be relatively easy to identify assets which require renewal for the coming five years and with the cost of an asset an analysis can be made which is more cost effective.

### *BTD-Planner*

With the development of BTD-Planner clustering could get another leap into the right direction as multiple determinations can be performed simultaneously. BTD-Planner should therefore be quickly expanded with the prescribed information to improve clustering of TVPs. Also, towards department Projects more awareness is required regarding the problems ProRail is facing on planning possessions. Further standardization is required of information they sent to possession planners as this will help to improve clustering. Standardized information will help improving automated clustering as software can automatically determine specific data specified by Project Managers without manual interruption.

During this research, several interesting side notes were given that do not directly benefit the research questions but can improve the overall planning process. This chapter will go deeper into the side notes and provide information what the problem is, how it can be overcome and what the results are. These points strengthen the results of my research and can further reduce hinder for operators and travellers. These points are acquired during discussions with colleagues and all points are mentioned multiple times but fall outside the scope of this research. Also, time was limited and is therefore recommended to execute further research on these points to further reduce nuisance.

### *Individual project managers per corridor-part*

Planning of TVPs is a complex and difficult process due to involvement of many people with also different interests. Project managers work on a project basis and can have work on multiple corridor parts. This results in multiple project managers having projects on one corridor part, not aware of each other's presence. Conflicts arise due to this methodology and project managers could better be organized on a corridor level. This could result in less hinder due to optimization on a corridor part level, less costs as project optimization is possible and shared benefits on a corridor.

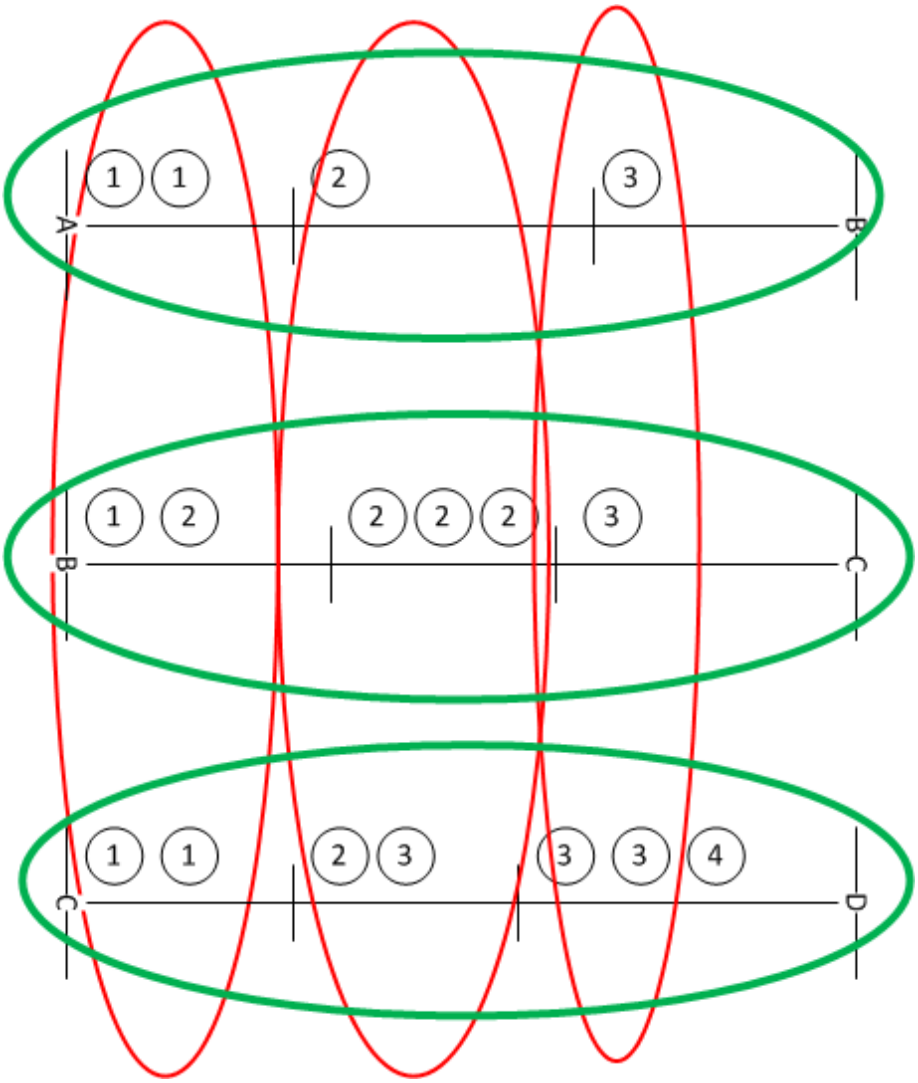



Figure 19: Current project methodology (red) and suggested project methodology (green)

Figure 19 shows what the current methodology is, in red, and what a proposed methodology is, in green. Currently a project manager has TVPs, numbered 1 to 4, and these TVPs can be performed on different corridor parts. Project 2 for example has one TVP on A-B, four on B-C and one on C-D including interference with other TVPs. These TVPs are in current methodology however not aware of each other, no optimized work scheduling as project manager 1 does not want project manager 2 to be near their work. When one project manager is responsible for all work on one corridor part this should be prevented, especially when an incentive is given on minimizing hinder.

### *Hinder reduction*

For Asset Management, hinder reduction is a major issue and this issue is shared with capacity allocation who must deal with operators who find every year much more capacity is used for maintenance or expansion. Main source for hinder is department Projects of ProRail where hundreds of projects are scheduled, tendered and executed each year.

Hinder is however not an issue for department Projects, the Iron Triangle 'Time – Scope – Cost' is the only driver for that department. Projects are tendered and valued using MEAT and within that methodology contractors get a fictive discount based on their sustainability and safety assessments. Within that MEAT an assessment should be performed on reduction of hinder in comparison with the expected amount of hinder. A contractor should get additional fictive discount based on the reduction of hinder they realized compared to an expected baseline. This methodology would require a different tendering strategy as a contractor is required to be earlier in the process than the current methodology. Most maintain function is currently pre-engineered by an engineering firm and a calculation on number of possession and duration is performed. The contractor only is required to perform the prescribed work in the prescribed time and if it is not possible to perform the work extra possessions are scheduled, with additional hinder.

Hinder reduction could be measured by making an assessment on additional costs due to discussion between project managers and cost reduction due to less bus costs and no costs for society due to additional travel time.

### *Power of the contractor*

The power of a contractor however is their knowledge how to renew assets as fast as possible in the cheapest way. To use that power a different tendering strategy is required wherein no prescribed set of works is given but the contractor can engineer the work methodology by themselves, often in collaboration with an engineering firm. Integrated contracts can be used to fulfil this need for hinder driven tendering and require a new market approach from ProRail. Hinder driven tendering results in contractors thinking how a project must be executed to reduce hinder and still get a competitive price. A choice however is required, less hinder for operators and passengers or inefficient possessions and thus more hinder.

Currently possession planning is responsible for the actual programming of delivered TVPs. The operations office does the intake of projects and all projects flow through the operations office to make a first determination on number of possessions. This information is now gathered in the newly formed feasibility study on x-2 years to identify coming issues. The possession planning and operations office are however further separated and a better integration between these two could benefit possession planning.

### *Future research*

For future research, it is recommended additional software is developed. The current Excel solution is fine on itself but has limitations on automation or partly automation of clustering. It is therefore recommended to developed clustering within the BTD-Planner as this software tool should be able to cluster TVPs. It is also recommended to extend the project activity scheme with more activities. Current list is compact due to limited time but also ensures different sub-activities are gathered into one activity whilst they could be separated. A recommendation is to further split-up activities into more sub-activities to further distinguish them.

One of the outcomes of the evaluation is 'require attention' and it is assumed TVPs can be clustered with this result. It should be further researched if this is true. Additional knowledge on clustering is required, more in-depth knowledge on barriers for clustering is required. What truly determines a yes or no in clustering. More research is required on the significance of the factors and the factors, additional factors may be required to further improve clustering.

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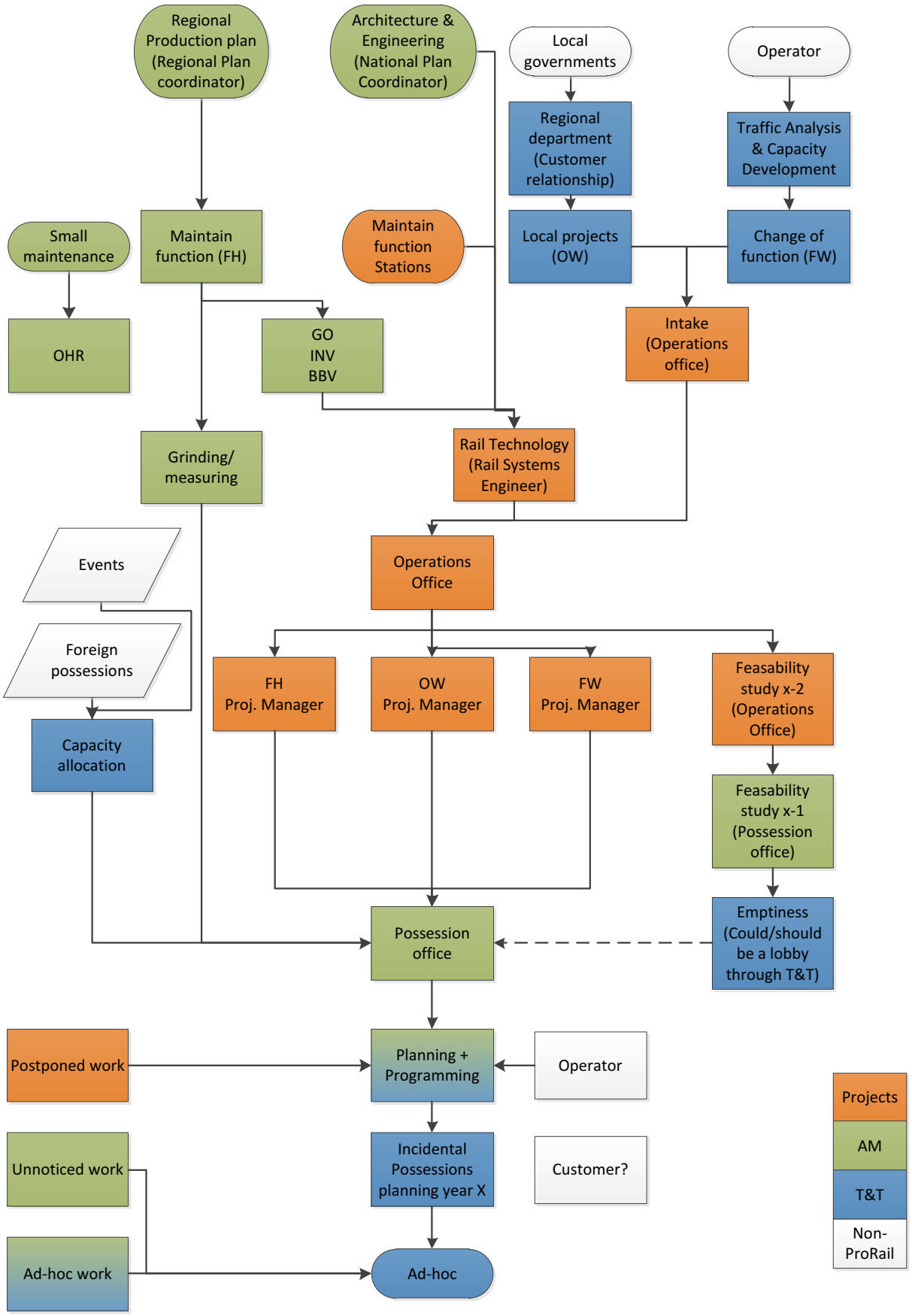
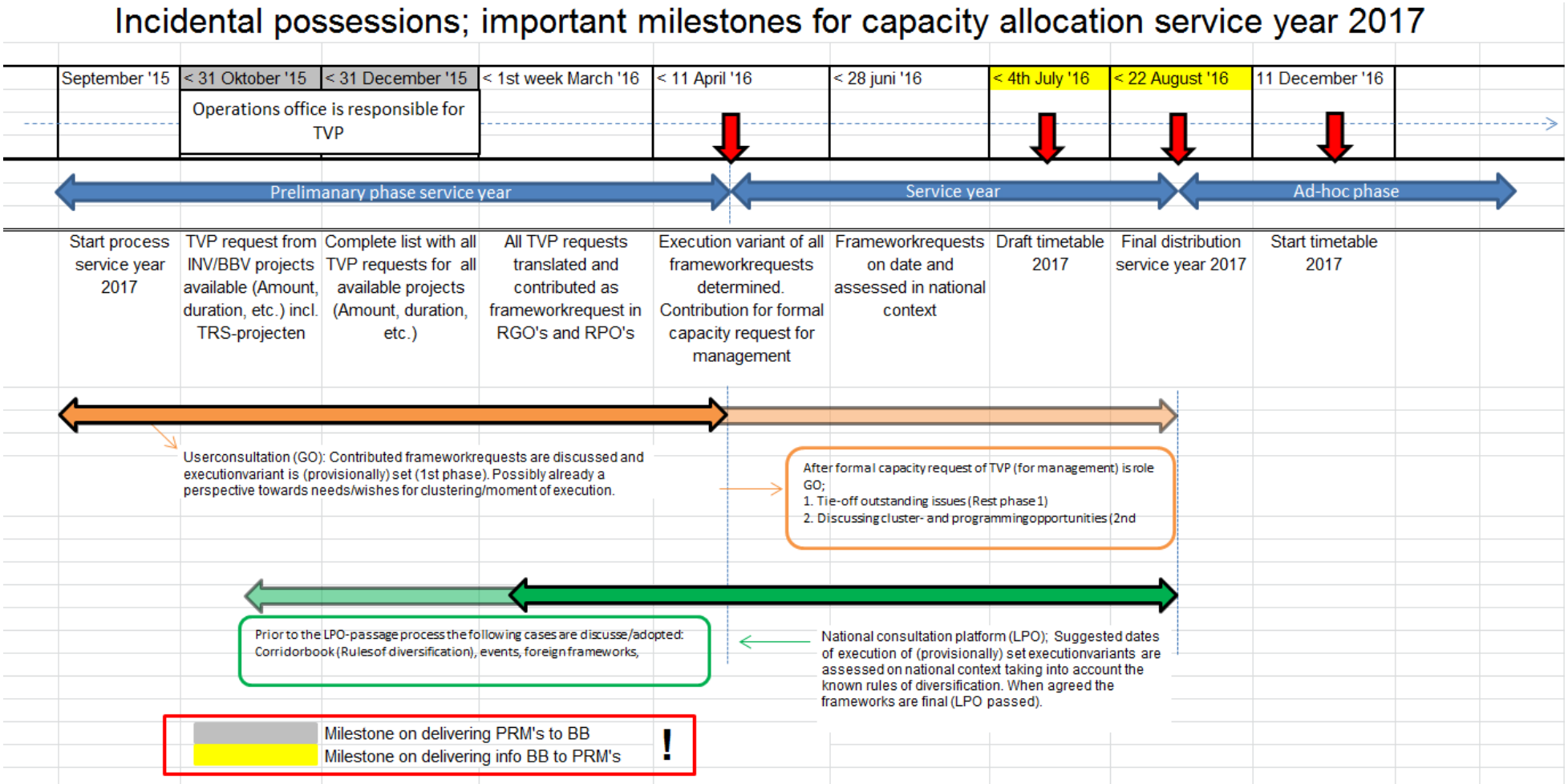
# 11 List of figures

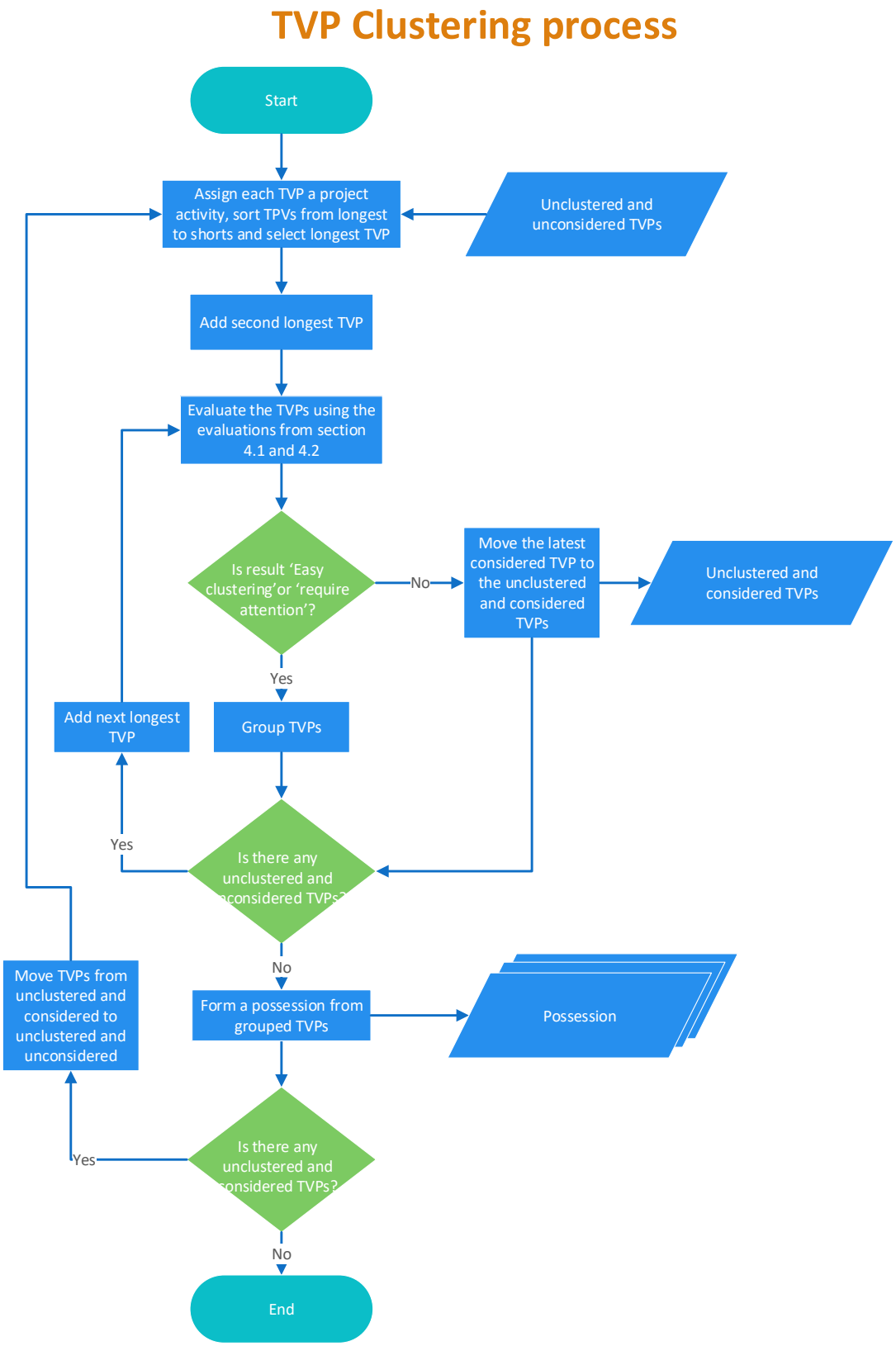
## A. Parties involved in possession generation



**B. Milestone process incidental possessions**



## C. Flowchart possession planning process



## D. Projects list on case study area

| Clustergroup tool | Clustergroep 2017 | Section | Corridor part | Work type | Duration | Project description |
|---|---|---|---|---|---|---|
| 1 | 7 | Yard Gouda | Gouda | SSR | 100:00 | Complete renewal activities |
| 1 | 15 | Yard Gouda | Gouda | CAT | 12:00 | Renewal of contact wire, circuit breakers and support structure |
| 1 | 30 | Yard Gouda | Gouda | CAT | 52:00 | Renew conductor system Gouwe brug northern tracks (HW-HV and RB-RA) |
| 1 | 44 | Yard Gouda | Gouda | CAT | 52:00 | Renew conductor system Gouwe brug northern tracks (HW-HV and RB-RA) |
| 2 | 15 | Yard Gouda | Gouda | SSR | 76:00 | Complete renewal activities |
| 2 | 37 | Yard Gouda | Gouda | CAT | 52:00 | Renew beam, pole connection |
| 2 | 44 | Yard Gouda | Gouda | CAT | 14:00 | Renewal of contact wire, circuit breakers and support structure |
| 3 | 15 | Yard Gouda | Gouda | CAT | 52:00 | Renew beam, pole connection |
| 3 | 21 | Yard Gouda | Gouda | SSR | 52:00 | Complete renewal activities. |
| 4 | 30 | Yard Gouda | Gouda | SSR | 52:00 | Complete renewal activities |
| 5 | 44 | Yard Gouda | Gouda | SSR | 52:00 | Complete renewal activities |
| 6 | 17 | Alphen - Boskoop | Alphen - Gouda | STW | 556:00 | Various project activities construction phase 2 (stop and underpass Waddinxveen Triangel) |
| 6 | 17 | Alphen - Boskoop | Alphen - Gouda | STW | 76:00 | Various project activities. • construction phase 1 |
| 6 | 17 | Alphen - Boskoop | Alphen - Gouda | STW | 52:00 | Various project activities. • construction phase 1 |
| 7 | 13 | Alphen - Boskoop | Alphen - Gouda | CSG | 52:00 | Testing various project activities |
| 8 | 35 | Alphen - Boskoop | Alphen - Gouda | STW | 52:00 | Various project activities construction phase 2 (stop and underpass Waddinxveen Triangel) |
| 9 | 36 | Yard Leiden | Alphen - Leiden | STH | 28:00 | Painting of platform roof track 2 |
| 9 | 2 | Zoeterwoude - Leiden | Alphen - Leiden | CES | 52:00 | Insertion foundation<br>Insertion substructure<br>Excavation under substructure |
| 9 | 18 | Zoeterwoude - Leiden | Alphen - Leiden | STH | 28:00 | Painting of platform roof track 1 |
| 10 | 42 | Yard Leiden | Alphen - Leiden | CAT | 28:00 | Renewal of contact wire, circuit breakers and support structure |
| 11 | 28 | Yard Utrecht | Utrecht | CES | 76:00 | Grubbing cable sleeves after step 5K |
| 11 | 12 | Yard Woerden | Woerden - Utrecht | SSR | 16:00 | Renewal of point heating installation to electric |
| 11 | 6 | Vleuten - Utrecht | Woerden - Utrecht | SSR | 52:00 | Divert cables, pipelines and various adjustments catenary |

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| 12 | 10 | Yard Utrecht | Utrecht | CCT | 23:00 | Extra work catenary construction step 5F |
| 12 | 10 | Yard Utrecht | Utrecht | CCT | 15:00 | Extra work catenary construction step 5F |
| 12 | 41 | Vleuten - Utrecht | Woerden - Utrecht | CES | 52:00 | Divert cables, pipelines and various adjustments catenary |
| 13 | 27 | Yard Schiedam | Den Haag - Rotterdam | STH | 28:00 | Measures flooding elevator shaft and passengers tunnel platform 1, 2 and 3 |
| 13 | 27 | Yard Schiedam | Den Haag - Rotterdam | STH | 28:00 | Measures flooding elevator shaft and passengers tunnel platform 2 and 3 |
| 13 | 27 | Den Haag - Delft | Den Haag - Rotterdam | STH | 168:00 | Station Moerwijk |
| 13 | 27 | Den Haag - Delft | Den Haag - Rotterdam | ECP | 52:00 | Maintenance works tunnel Rijswijk |
| 13 | 34 | Den Haag - Delft | Den Haag - Rotterdam | SSR | 52:00 | Renew sleepers, fastenings and ballast around switches 465 and 467 |
| 13 | 27 | Rotterdam - Driehuis | Den Haag - Rotterdam | SSR | 168:00 | Replacement two 1:9 switches, a cross and twice 1.5 km complete track renewal. |
| 14 | 1 | Yard Woerden | Alphen - Woerden | ECP | 52:00 | Stabilisation substructure fly-over Woerden |
| 15 | 14 | Yard Woerden | Alphen - Woerden | ECP | 52:00 | Stabilisation substructure fly-over Woerden |
| 16 | 8 | Yard Binckhorst | Gouda - Den Haag | CAT | 16:00 | Renewal of contact wire, circuit breakers and support structure |
| 16 | 19 | Yard Binckhorst | Gouda - Den Haag | CAT | 16:00 | Renewal of contact wire, circuit breakers and support structure |
| 16 | 19 | Yard Den Haag C | Gouda - Den Haag | SSR | 76:00 | Renewal switch complex, fastenings and mesh and shielding windows |
| 16 | 19 | Yard Den Haag C | Gouda - Den Haag | SSR | 24:00 | Renewal of track, fastenings and mesh and shielding windows |
| 16 | 8 | Moordrecht - Zoetermeer | Gouda - Den Haag | STW | 52:00 | Construction transferium Bleizo phase 1 |
| 17 | 31 | Yard Binckhorst | Gouda - Den Haag | CAT | 52:00 | Renewal of contact wire, circuit breakers and support structure |
| 17 | 22 | Moordrecht - Zoetermeer | Gouda - Den Haag | STW | 52:00 | Construction transferium Bleizo phase 1 |
| 18 | 43 | Yard Den Haag C | Gouda - Den Haag | CAT | 28:00 | Renewal of contact wire, circuit breakers and support structure |
| 18 | 31 | Moordrecht - Zoetermeer | Gouda - Den Haag | STW | 52:00 | Construction transferium Bleizo |

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| 19 | 40 | Yard Den Haag C | Gouda - Den Haag | CAT | 10:00 | Renewal of contact wire, circuit breakers and support structure |
| 19 | 45 | Moordrecht - Zoetermeer | Gouda - Den Haag | STW | 24:00 | Construction transferium Bleizo |
| 20 | 11 | Yard Rotterdam | Gouda - Rotterdam | CAT | 52:00 | Renewal of contact wire, circuit breakers and support structure |
| 20 | 9 | Rotterdam - Westelijke splitsing | Gouda - Rotterdam | STH | 52:00 | Station Rotterdam Alexander |
| 21 | 9 | Rotterdam - Westelijke splitsing | Gouda - Rotterdam | STH | 52:00 | Station Rotterdam Alexander |
| 21 | 23 | Rotterdam - Westelijke splitsing | Gouda - Rotterdam | CAT | 52:00 | Renew beam, pole connection |
| 22 | 32 | Rotterdam - Westelijke splitsing | Gouda - Rotterdam | STH | 52:00 | Station Rotterdam Alexander |
| 22 | 32 | Rotterdam - Westelijke splitsing | Gouda - Rotterdam | STH | 52:00 | Rotterdam Alexander, redevelopment station |
| 22 | 48 | Rotterdam - Westelijke splitsing | Gouda - Rotterdam | CAT | 52:00 | Renew beam, pole connection |
| 23 | 46 | Rotterdam - Westelijke splitsing | Gouda - Rotterdam | STH | 52:00 | Station Rotterdam Alexander |
| 23 | 46 | Rotterdam - Westelijke splitsing | Gouda - Rotterdam | STH | 52:00 | Rotterdam Alexander, redevelopment station |
| 24 | 38 | Nieuwerkerk | Gouda - Rotterdam | MPG | 52:00 | Construction wall elements for sound barriers |
| 24 | 38 | Yard Rotterdam | Gouda - Rotterdam | CAT | 12:00 | Renewal of contact wire, circuit breakers and support structure |
| 24 | 49 | Rotterdam - Westelijke splitsing | Gouda - Rotterdam | STH | 52:00 | Station Rotterdam Alexander |
| 24 | 49 | Rotterdam - Westelijke splitsing | Gouda - Rotterdam | STH | 52:00 | Rotterdam Alexander, redevelopment station |
| 25 | 16 | Yard Den Haag Moerwijk | Den Haag - Leiden | SSR | 52:00 | Renewal of switches and fastenings and reconstruction of switch heating |
| 25 | 16 | Yard Leiden | Den Haag - Leiden | STH | 52:00 | Painting of platform roof track 9 |
| 25 | 33 | Yard Leiden | Den Haag - Leiden | STH | 52:00 | Painting of platform roof track 8 |
| 25 | 16 | Leiden - Den Haag Moerwijk | Den Haag - Leiden | P76 | 52:00 | Station de Vink, tracks 2 and 3. |
| 25 | 16 | Leiden - Den Haag Moerwijk | Den Haag - Leiden | P76 | 16:00 | Station de Vink, raise track 1. |

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| 25 | 16 | Leiden - Den Haag Moerwijk | Den Haag - Leiden | P76 | 16:00 | Station de Vink, raise track 4. |
| 26 | 39 | Yard Den Haag Moerwijk | Den Haag - Leiden | SSR | 52:00 | Renewal of switches and fastenings and reconstruction of switch heating |
| 26 | 4 | Yard Leiden | Den Haag - Leiden | STH | 52:00 | Painting of platform roof track 5 |
| 26 | 20 | Yard Leiden | Den Haag - Leiden | CAT | 16:00 | Renewal of contact wire, circuit breakers and support structure |
| 26 | 24 | Yard Leiden | Den Haag - Leiden | STH | 52:00 | Painting of platform roof track 4 |
| 26 | 4 | Leiden - Den Haag Moerwijk | Den Haag - Leiden | SSR | 52:00 | Station de Vink, tracks 2 en 3. |
| 26 | 5 | Leiden - Den Haag Moerwijk | Den Haag - Leiden | P76 | 16:00 | Station de Vink, raise track 1. |
| 27 | 25 | Yard Den Haag Moerwijk | Den Haag - Leiden | CAT | 12:00 | Renewal of contact wire, circuit breakers and support structure |
| 27 | 47 | Yard Laan van NOI | Den Haag - Leiden | SSR | 52:00 | Renewal of sleepers, fastenings and ballast. Renewal switch 215A/B and regulate catenary |
| 27 | 3 | Leiden - Den Haag Moerwijk | Den Haag - Leiden | SSR | 52:00 | Station de Vink track 1 |
| 27 | 29 | Leiden - Den Haag Moerwijk | Den Haag - Leiden | P76 | 16:00 | Station de Vink, raise tracks 2 and 3. |
| 27 | 39 | Leiden - Den Haag Moerwijk | Den Haag - Leiden | P76 | 16:00 | Station de Vink, raise tracks 2 and 3. |
| 28 | 26 | Yard Laan van NOI | Den Haag - Leiden | SSR | 52:00 | Renewal of sleepers, fastenings and ballast. Renewal switch 213 and regulate catenary |
| 28 | 20 | Leiden - Den Haag Moerwijk | Den Haag - Leiden | SSR | 52:00 | Station de Vink, track 4 |