2018

Design solutions to increase frequency on the rail corridor Den Haag CS – Rotterdam Lombardijen

Timo Dijkstra – 4279727

BSc Thesis – Transport & Planning

Preface

In the past 10 weeks I've worked on the keystone of my Bachelor of Science in Civil Engineering: My Bachelor Thesis. In this thesis, I've processed all knowledge I've gathered during my bachelor and in conversations within NS and ProRail.

I would like to take this moment to thank Wouter Schakel and Yufei Yuan from the TU Delft for mentoring me from the department of Transport and Planning.

I would also like to thank Rob Richelle for his role as mentor and client from NS. He has given me the opportunity to have a closer look inside the organization NS and he has given me the opportunity to gather a lot of knowledge about his organization.

I would like to thank his colleagues from NO Asset Strategy – Team Infra for sharing their knowledge and experience as well as including me in several ongoing projects.

Finally, I would like to thank my parents for their support.

I would like to wish the reader pleasure while reading.

Timo Dijkstra

21-10-2018

Abstract

Research shows that in the future more and more travellers use the Dutch public transport (Eldering, 2018). To accommodate this expected increase of use of the Dutch public transport, the Dutch government initiated a study called 'Toekomstbeeld Openbaar Vervoer 2040'.

This study delivered three different scenarios, which differ from each other in demand for public transport and therefore also supply in the form of frequency differs. The most important requirement for this research is that all three scenarios must be viable. These scenarios are designed for all railway corridors in the Netherlands. The corridor Den Haag CS – Dordrecht is one of these corridors for which three scenarios are designed and has yet to be investigated. At this moment it is still unclear of the current and planned infrastructure provides enough capacity to perform these scenarios. The goal of this research is to investigate whether each scenario can be performed on this corridor. If it might be the case this is not possible, then this research has to provide solutions to make the scenarios performable.

To achieve this goal, initially an analysis of the current infrastructure and the infrastructure known to be realized in the near future, is made. Subsequently three time tables according to the three scenarios are constructed. The schedules are then laid upon the infrastructure. If the train schedules prove not to fit on the infrastructure, adjustments to this infrastructure or train schedule are designed which make the train schedule fit. Because for each scenario the frequency of trains running increases, the solutions are designed such that they are interchangeable and can be stacked. This makes it easy to integrally solve for each scenario, thus making the train schedules fit on the infrastructure.

The results of the research are as follows:

- In the first scenario, roughly one and a half times as many trains run on the corridor, relative to the current frequency. This can still fit on the infrastructure with slowing down only two InterCitys per hour with 1.5 minute.
- In the second scenario, the frequency of the Sprinters is increased by three hundred percent and the frequency of the InterCitys is doubled. This makes a doubling of the tracks between Delft Zuid and Schiedam necessary. Also a fly-over between Den Haag Laan van NOI and Den Haag HS and two fly-overs next to the existing ones at Rotterdam CS are necessary.
- In the third scenario, the Sprinters are swapped out for a metro. The metro needs dedicated infrastructure and therefore two out of the four tracks on the corridor have to be converted to light rail infrastructure. Also, in this scenario the doubling of tracks is necessary, as well as a fly-over between Delft Zuid and Schiedam, two fly-overs at Rotterdam CS on top of the current two, and a large switch cross under the metro tracks at the entry of Rotterdam CS.

These design solutions are all feasible and with this infrastructure, NS has the opportunity to increase public transport supply. Furthermore, the design solutions are designed such the infrastructure can grow with the scenario chosen to accommodate. The solutions have also the benefit it has rest capacity and the practical possibility to further increase frequency and in addition let InterCity Direct from Den Haag CS run on the corridor to Breda and further in a later stadium as well, although this is not a design requirement. If the wish arises to run InterCitys from Gouda to Breda and further, the design solutions differ and can be found in chapter 5. However, the expectation is this there is less demand for this link compared to the InterCitys from Den Haag and is therefore not recommended.

I would like to wish the reader pleasure reading and would like to hear comments on this research.

Content

1. Introduction

In this introduction, some background information about the project the research is part of is presented. It starts with the context and history around the improvement of the railway infrastructure projects in the Netherlands. Also in this introduction, one can find research properties as stakeholders involved in this project, the problem definition, complementary research questions and a technical framework. This technical framework consists out of terminology used throughout this research. Finally a reading guide is presented.

1.1 Context of the project

The Dutch railway network is the most heavily used train network of Europe. Each day, on only 7146 km railway, 1.1 million trips by train to work or school are made. (Over Prorail, in cijfers., 2018). This number increases every year (Eldering, 2018). To cope with this increasing number of travellers, train frequency has to be increased. To do this, Programma Hoogfrequent Spoor (PHS) is initiated by the Dutch railways (NS, public transport company), ProRail (railway administrator), the Ministry of Infrastructure and Watermanagement and freight train operators (Heuvel, 2008). This program aims to increase the frequency of trains on the most heavily used railway corridors. It consists of a set of measures which includes expanding tracks, improving signalling, electrical and ICT systems. After PHS, a new program called 'Toekomstbeeld Openbaar Vervoer 2040' has been initiated as a follow-up. This program has been introduced in 2016 and is based on the idea that demand for public transport will further increase. Therefore, this program dictates that heavy-rail trains can run in a higher frequency. With this increase of frequency, there is a capacity problem predicted, because this increase would likely to require changes in the infrastructure. The program has delivered three different scenarios. All of the scenarios predict a different rise in demand and therefore need a different train frequency. Which scenario is best suitable for actual demand in the future will be decided by the Ministry of Infrastructure and Watermanagement.

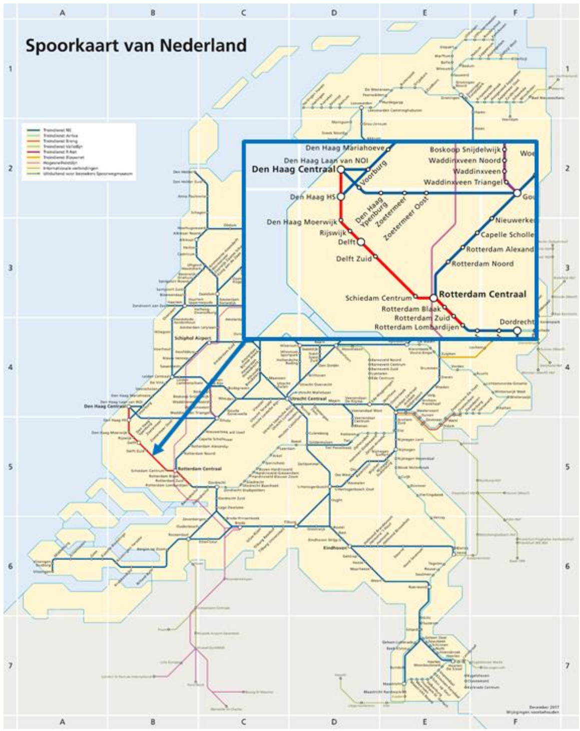


Figure 1: Railway map of the Netherlands (Boon, 2018)

NS is a public transport company, but works close with the railway administrator ProRail. The department infrastructural asset management from NS forms the link between product development at NS and the construction of infrastructure at ProRail. As such, the department designs infrastructural solutions for corridors. A corridor which hasn't be dealt with but may need to be redesigned to meet the demand dictated by the scenarios from the program is the corridor Den Haag CS – Dordrecht. This corridor is marked on the map in Figure 1. A more detailed map will be presented later in the thesis at the paragraph 3.1. The focus of this research is to investigate whether this corridor has to actually be redesigned and how, or not.

Already some improvements to the corridor are made since the beginning of PHS. The station of Delft is placed in a tunnel. This was necessary because of the noise pollution created by the viaduct traversing through Delft. With the tunnel, it is possible to increase the number of trains running from

Rijswijk to Schiedam Centrum. The railway line Rotterdam Central Station – Hoek van Holland Haven has been handed over to the RET. This created two free tracks between Rotterdam CS and Schiedam Centrum, which now can be used to run trains from Delft to Rotterdam. These changes will be visible in the infrastructural analysis.

1.2 Stakeholders

In railway projects usually a lot of stakeholders are involved. In this paragraph, a global elaboration on these parties is presented. First, the heavy rail parties, then the landowners and finally the role of other transportation companies and travellers is explained. The stakeholders are also presented in a power-interest grid. This grid is shown in Figure 2.

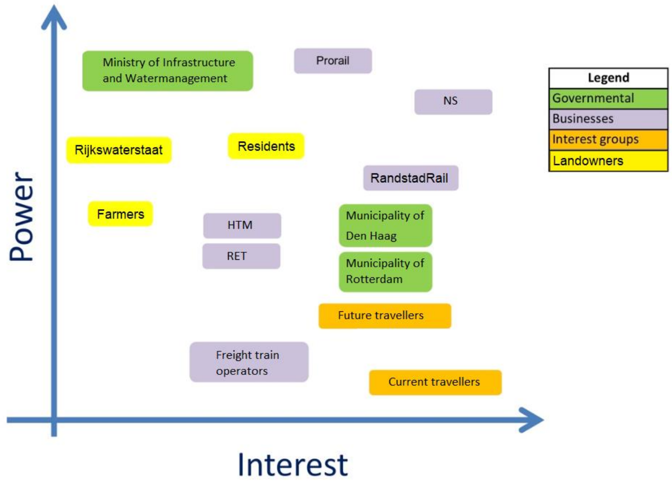


Figure 2: Power-interest grid

1.2.1 Heavy rail parties

In this case, NS is the most involved party in this project. NS is the company who provides public transport on the most of the railways in the Netherlands. This is called the Hoofd Rail Net (HRN) (wetten.overheid.nl, 2004). NS, and in particular the department of NS, NSR NO Asset strategy – Team Infra, is the client. As the railway administrator, ProRail is also a party to keep close. Without ProRail onboard, nothing will ever be set in motion. This is because ProRail is the party which manages the railway infrastructure in the Netherlands. These two are very important and large railway companies. The NO Asset strategy department forms a link between what NS needs, for example a desired railway capacity for their desired frequency, and what ProRail constructs. Therefore, the product has to fulfil NS' demand of increasing capacity. In that way they can serve the travellers. The travellers will be addressed later. Finally, the Ministry of Infrastructure and Watermanagement is an important stakeholder, as it controls the public funds for infrastructure projects.

1.2.2 Landowners

Both the municipalities of Den Haag and Rotterdam are stakeholders due to the possible construction works are within their areas of governance. Because of the same reason, landowners such as farmers, residents or Rijkswaterstaat are also stakeholders. Possible construction works or temporary roads might occupy a piece of their land. If such stakeholders cannot be satisfied, the project will slow down and might come to a (temporarily) stop.

1.2.3 User group

The municipal transport companies HTM, RET and their joint operation Randstadrail have some influence on the project because their infrastructure might have to be (re)moved partially. Also the travellers of NS, HTM, RET, and Randstadrail, as well as freight train operators and their clients have to be informed every step of the way. Their travel can be slightly disturbed during construction works or goods have to be delivered at other times or by other transport means. New users of the corridor are an important target group as this group legitimates the improved schedule.

1.3 Problem definition

To meet the transport demand on this particular corridor, two restrictions preventing the increase of train frequency have to be solved.

1. The corridor Den Haag CS – Dordrecht is used by freight trains, sprinter trains, intercity trains and international trains. Each type of train has a different cruising and average speed. With all these different trains operating on the same railway, the infrastructure capacity cannot be used in the most optimal way. This occurs when faster trains like the international trains and intercity trains have to slow down for the slower freight trains or sprinter trains due to their difference in average speed. This reduces transport capacity when NS still wants their faster trains to run at their design cruising speed.
2. Trains have to cross different directions at the same level. This means trains have to wait to let the other train pass the crossing before they can cross that track section. The wait delays the train itself and trains behind it down, resulting in a further decrease of efficient use of the infrastructure.

1.4 Research focus

The research project comes with a limited time frame. To make sure this timeframe will be met and a thorough researched product can be delivered, the focus of the research has to be clear from the beginning. Otherwise, one might find themselves widening their research too much and not able to finish the project. What inside and outside the scope of this research falls, is stated below.

1.4.1 In scope

In the current situation there are several merging traffic flows between Den Haag Central Station and Rotterdam Lombardijen. The biggest infrastructural challenge will be situated around and between these cities, because there are not enough fly-over or dive-under crossing solutions present at this time. Therefore, this section of the corridor falls inside the scope. When designing the time table, characteristics of rolling stock available now and in the close future are used.

1.4.2 Out of scope

Out of the scope falls the region south of Rotterdam, between Rotterdam Lombardijen and Dordrecht. This is the case because several fly-over and dive-under passages have already been constructed there, to keep different types of trains apart. Moreover, high speed international trains and low speed freight trains get their own separate lines from Rotterdam Lombardijen onwards. Technical innovations which might be implemented at the time of the realization of the project, such as the increase of the current (3kV), the ATB adjustment 'kort volgen' (which allows shorter follow-up times) and the implementation of ERTMS (a new and possibly better safety system) are current are outside the scope too. This is because not a lot of the characteristics of these systems are known at this time. As will be discussed at paragraph 2.2, a timetable will be modelled. For this timetable, connections with trains running on different corridors or transfers within the corridor itself. This will not be a problem because an increasing amount of trains will run on this corridor. This results in lower transfer times and therefore probably result in better transfer options than current options. Finally, this research does not give an answer to the question what scenario is the best scenario because this is not asked for.

1.5 Research questions and goals

Within this research focus, a solution has to be designed to bring the train frequency and railway corridor capacity together. This solution will be designed by answering the research question. To answer this question, several sub research questions with complementing sub goals have to be answered. In this paragraph, the step-by-step route to achieve the final goal and answer the main research question is presented.

1.5.1 Research questions and final goal

The final goal is to create the possibility of running a train schedule with an increased frequency than nowadays. This can be done by adjusting the railway track by construction fly-overs or more railway tracks, or by tweaking the train time table such that within current regulations a good service can be provided. This will be done for three different frequency scenarios. These will be explained further in subsection 3.2.1. This leads to the following research question:

"Given the desired increased frequency scenarios on the corridor Den Haag CS – Rotterdam Lombardijen, are construction works a must or is it feasible to adjust the time table and what are these changes to the infrastructure or time table?"

This research with the answer to this question and the assumptions, methodology, motives and modelling will be handed over to ProRail. ProRail will then decide if ProRail is willing to make the adjustments.

1.5.2 Sub research questions

In order to answer the research question described above, a step-by-step route must be followed, which leads to the following sub questions:

1. What does the infrastructure known to be implemented till 2025 look like?
2. What are the scenarios of NS and how fit these scenarios in a time table?
3. What are the bottlenecks of the railway infrastructure when the time tables as designed in the previous question are carried out?
4. How can these bottlenecks be solved?
5. How will the infrastructure look like when these bottlenecks are solved for each scenario and what scenario is the most beneficial solution?

1.5.3 Sub goals

When answering these sub research questions, the following sub goals will be achieved. This will lead to achieving the final goal.

This can be done by achieving the following sub goals.

1. Analysis of the railway infrastructure to be realized till 2025 from Den Haag CS, Delft Zuid, Schiedam Centrum, Rotterdam Central Station and Rotterdam Lombardijen.
2. Future traffic demand on the corridor Den Haag CS – Dordrecht must be analysed. A timetable for the future traffic flow has to be designed.
3. Identification of the bottlenecks on the infrastructure.
4. Bottlenecks will then be removed by implementing building blocks or adjustments in the time table.
5. Multiple variants for the corridor Den Haag CS to Rotterdam develop to subject these variants to a cost-benefit analysis to distinguish the most economical solution.

The methodology to answer the sub research questions and achieve the sub goals and final goal is explained in chapter 2.

1.6 Technical framework

In this paragraph, first railway infrastructure terminology is introduced. Then the terminology used at the scheduling process is explained. This terminology is used throughout the research.

1.6.1 Railway infrastructure terminology

In the Netherlands, the railway infrastructure has been built around the following structure: **Block sections** are stretches of railway where one train is allowed in. These block sections are demarcated with **signals**. In the Netherlands, these are currently static. This means a train rides through block sections, instead of a block section forming around a train and moving with the train. Together, these block sections form a **railway section**. Between every **node** or **station**, there is a railway section. Because there are more block sections in one railway section, railway sections can handle more than one train at a time. This has been illustrated in Figure 3 below.

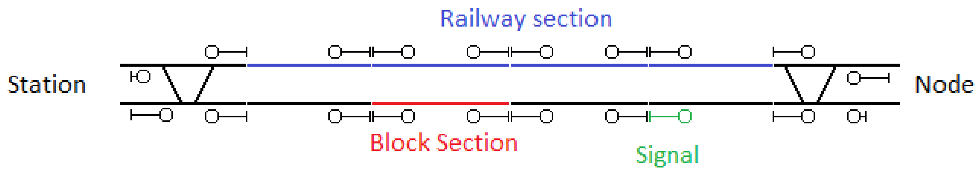


Figure 3: Illustration of block sections between stations and/or nodes.

When railway sections are put together, they form a **railway line** or **railway branch**. These railway branches run through the whole country and can overlap with other railway branches. All the railway branches together form the railway system of a country. A **corridor** is a part of the railway system, between nodes or stations defined by the user of the term, where several sections of different railway branches meet each other. Thus a railway corridor can contain several branches, but does not necessarily have to contain the whole branch.

A straight rail is the back bone of the railway network. However, when entering a station or a node, switches are needed. There are a lot of different switches with different names and different characteristics. The important types for this research are shown in Figure 4.

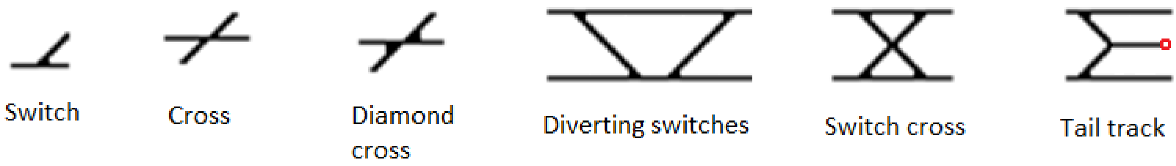


Figure 4: Different types of switches and crossings

The **switch** is the most basic type of split or merge rail infrastructure tool. A **cross** provides the opportunity to cross tracks, so for example from bottom-left to upper-right. A **diamond cross** is an more complicated cross: Trains can also switch directions. For example, a train can go from bottom-left to upper-right and bottom right. **Diverting switches** are used to get one train to the other track, normally used for the opposite direction. A **switch cross** is the same as the diverting switches but compressed. This means the switch cross uses less space and is therefore most of the time used at stations. Also frequently used in stations are **tail tracks**. These tracks are used to turn a train. So when a train arrives at the final destination, it first runs empty to a tail track just after the platform instead of turning at the platform. Turing at the platform costs at least 6 minutes, while running empty and turning away from the main line costs only two. This way ongoing trains can stop at the platform faster after the train which should turn.

1.6.2 Planning terminology

When scheduling, a train gets a path subjected for a specific moment in time. This path is a roadmap how to get from A to B in time moment C to D. When every train which can come across one point in the schedule has been given a path, a **BUP** (Basis Uur Patroon / Basic Hour Pattern) is created. This pattern will then be extended for the whole day. A night has a different BUP due to a lot less trains, more paths for construction and freight trains and therefore is less interesting for this research. When visualizing this BUP in a diagram with the specific points on the one axis and the time on the other, a **TWD** (Tijd Weg Diagram / Time Distance Diagram) has been created. In such a TWD, it is easier to see where paths overlap and therefore are impossible (because two trains cannot use the same infrastructure on the same time). A TWD for a station is called a **BSO** (Basis Spoor Opstelling / Station Layout Arrangement). Here, trains are divided over the different platform tracks.

When constructing a time table, robustness is a very important aspect. It is measured in the number of critical follow-ups divided by the frequency of trains. When the first train of a critical follow-up is delayed, the next train will delay as well because there is no buffer time.

1.7 Reading Guide

In chapter 2 the approach used in this research has been explained. In chapter 3, both the infrastructure and traffic flow analyses have been performed. At chapter 4, the model described at the methodology is used to identify the problems coming with the desired increase of frequency. In chapter 5 solutions are presented to solve the problems from chapter 4. Chapter 6 will be used for discussion and one can find the conclusion in chapter 7. Finally, in chapter 8 recommendations are done.

2. Methodology

The goal and sub goals described in the previous chapter are to be achieved as explained in this chapter. First the method for the analysis of the rail infrastructure and future traffic flow is explained. Subsequently, the way the timetable is modelled will be explained. Given these points, a simulation has been ran. Next, the method on the designing process to cope with potential collision points can be found. Lastly, how the scoring of different designing variants will take place is showed.

2.1 Infrastructure and future traffic flow analysis

To start with, an analysis of the railway infrastructure is made. Large, up to scale, drawings have been requested from ProRail, the railway administrator. These drawings come in small bits of block sections. The detailed drawings received from ProRail are then connected to each other. This way, a clear overview is identified. Then all the infrastructure changes as planned at this moment are added to the drawings. That way, the best infrastructural starting point is achieved. Next, a schematic is made. This has been done because the schematic is more useful to get a quick overview of a section or node where the exact position or number of a signal or switch is not needed. With this schematic, the first part of the data is ready to be put in the simulation.

When the infrastructure drawings are finished, the next part of the system needs to be prepared to analyse the system: Future traffic flow. This future traffic flow consist of three different scenarios set by NS and the Ministry. Those scenarios each contain a set of trains NS must run at the corridor every hour. Every scenario originated from the set of trains in a peak hour. Thus, in each scenario, no overhead capacity has to be present. Some train series in the scenarios have their origin or destination in Rotterdam CS. The designer then has the freedom to connect train series together. This can be useful to have less trains starting and ending in Rotterdam CS, which takes a lot of time at a platform track. This can lead to variants within the scenarios.

2.2 Time table construction

For each scenario variant, a time table will be constructed. This can be constructed with a program like Railsys[1], which is used at the TU Delft. A very thorough programme, with all the current infrastructure already in place. But the infrastructure planned for the next seven years are not present at the moment. In the time span of this research, it is impossible to implement this because of the detailed level of infrastructure Railsys asks for. Therefore, an Excel-based plotting tool used by NSR NO Asset Strategy – Team Infra is built out during this research. That way, the tool can plot a TWD and a BSO with the input data train type, track number, travel time and distance. The tool will now give a visual output of the corridor (TWD) as shown in Figure 5.

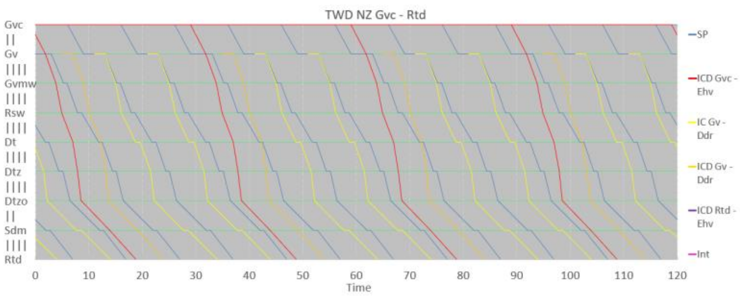


Figure 5: Example of a time - distance diagram (TWD) for the corridor Den Haag CS – Rotterdam CS

[1] Also Donna or Dons could be a possibility to use. These programs are used by the Dutch rail companies and work similar to Railsys. However, due to the fact these programs are like a black box, the programs are not suitable to use in this scientific research. The input data for the plotting tool however is validated with Dons.

On the left of the diagram, labels with station or junction names are situated with the number of tracks connecting the stations or junctions with each other. To make it easier to distinguish different trains on the visual output colours for the different train types will be used. When constructing the TWD, an effort is made to avoid the construction of passing tracks. These efforts are elaborated about at the building block section.

The tool also provides the possibility to construct a station layout arrangement (BSO). An example of a BSO is shown in Figure 6.

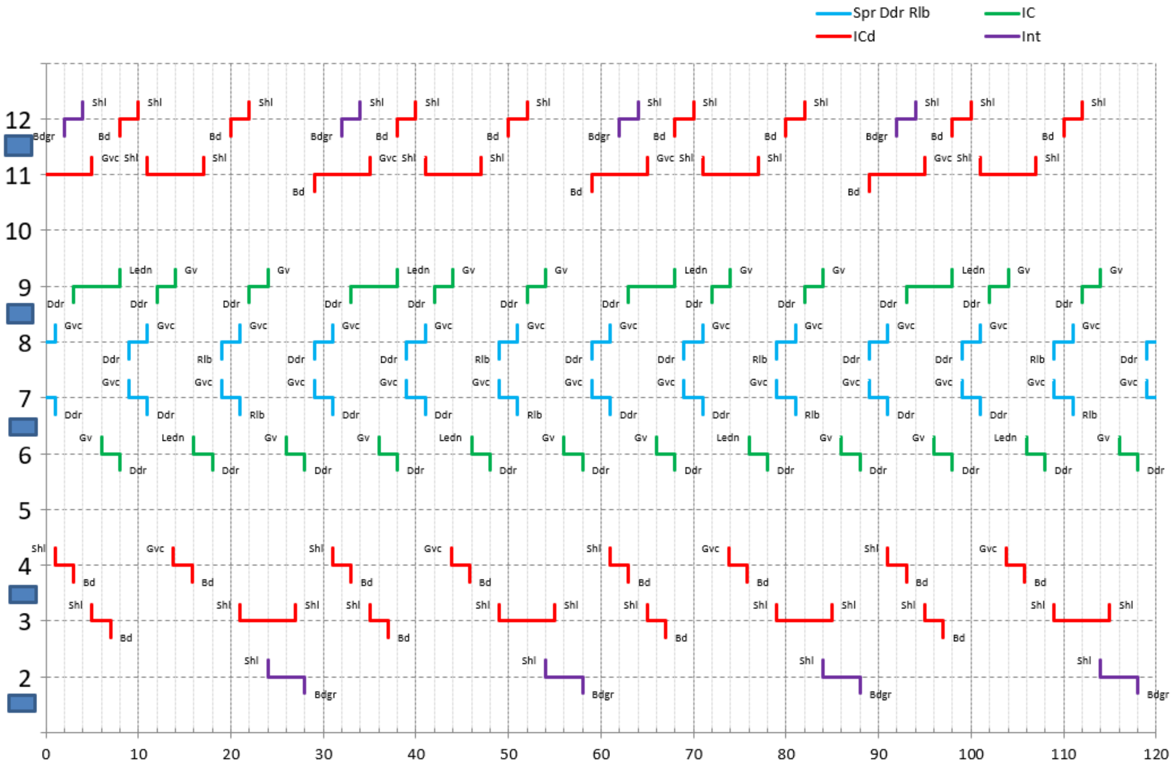


Figure 6: Example of a station layout arrangement Rotterdam Central Station

The platforms are presented at the left of the station layout arrangement (BSO). On the bottom axis, time is displayed. A train is depicted as a lightning bolt. The left side illustrates the starting station of the train and incoming direction, the right side of the bolt illustrates the destination and direction of departure. So when a train turns back, the lightning bolt changes into an u or n (can be seen at tracks 3 and 11).

To construct the train schedule for a scenario variant, the main bottleneck of that scenario has to be identified. If a station is the main bottleneck, the first step is to construct a BSO for this station. If a railway section on the open line is the main bottleneck, constructing a TWD is the starting point for constructing the schedule. When the first modelling step is completed and either a BSO or TWD is constructed, the adjacent railway sections (TWD) or stations (BSO) are modelled.

2.3 Simulation

During the construction process of a TWD, the first simulation steps are already made. This is inherent to the process because the infrastructure is the main bottleneck and therefore boundary condition when constructing a TWD. When constructing a BSO, the trains calling at the station are the main bottleneck and the infrastructure connecting the platforms to the open line can be adjusted to accommodate the traffic flow.

When constructing the TWD and trains with the same direction intersect, a passing track is needed on the open line. When one line is flat when an intersection takes place, it means that the train represented by the flat line is at a station. Then the passing track needs to be implemented only at the station. When the construction of the BSO is finished, the BSO is linked to the TWD. The infrastructure schematic displays if the necessary sufficient physical connection is already present. If the necessary connection is not present, a solution has to be designed. An example of an insufficient physical connection is a level crossing. If such a crossing is present, the follow-up time between trains is increased compared to running on the open line. Details about this and all other plan norms are further elaborated in paragraph 4.1.

2.4 Design process

The simulation for each design variant shows several areas which need an infrastructural solution. These infrastructural solutions will be designed as building blocks and therefore can be seen individually. Every design variant needs a couple of blocks and sometimes the same blocks. By designing the solutions as stackable and interchangeable blocks, one can switch in scenario or scenario variant and easily see what building blocks are needed extra or what building blocks have to be swapped out of the design.

These areas on the corridor can be found on the open line or where the open line connects to a station. When connecting the open line with a station, a lot of solutions are possible. In order to control the cost of the solutions, the existing infrastructure is used as much as possible.

When all the building blocks are designed, an overview of these building blocks will be presented in a table. The first two columns contains the different building blocks, the second two represent the scenarios where the building block is needed or conflicts with. From these columns, the design solutions follow.

2.5 Review process

The different solutions to the scenario variants are also presented in table 5. The best design solution per scenario follows from scoring the design variants on the following criteria:

- Level of service. This is explained as the average waiting time and average travel time from the current Sprinter stations, the IC stations where not all IC trains stop and the IC stations where all trains stop.
- Construction cost. Construction cost is measured in millions of euros.
- Construction hindrance. Construction hindrance is expressed in months the track is out of service.
- Flexibility of lines. Flexibility in lines is expressed in what railway lines are still possible, however not operated in the scenario.
- Robustness. Robustness is measured in the number of critical follow-ups divided by the frequency of trains.

Then a conclusion can be drawn.

3. Analysis of infrastructure and traffic flow

In this chapter, first the infrastructure is analyzed, followed by the traffic flow of the three scenarios.

3.1 Analysis of infrastructure

The analysis is split in three sections of the corridor. This has been done to increase visual readability. The first section starts at Den Haag CS ends in Schiedam Centrum. The second section starts in Schiedam and ends in Rotterdam Blaak and the third section starts in Rotterdam Blaak and goes to Rotterdam Lombardijen. Acronyms used in the figures are explained in appendix A. This is all shown in Figure 7.

Figure 7: The corridor Den Haag CS - Rotterdam Lombardijen divided in three sectors

3.1.1 Corridor Sector 1

The sections runs from Den Haag CS to Schiedam. Compared to the current infrastructure, at Den Haag CS one switch will be added to make sure trains can leave and arrive at the same time in Den Haag CS. From Den Haag to Rijswijk, nothing will be changed. However, the four tracks ending now at Rijswijk will be extended 600 meters past Delft Zuid. At Schiedam Centrum, switches will be removed and new will be installed. This allow trains to enter and drive through the station with 80 km/h. Because the station is situated in an arc, the speed allowed in this station is lower than the limit on the straight tracks, which is 130 km/h here. The new switches will be installed 500 metres in front of the station. This leaves enough distance to both accelerate and decelerate form 80 km/h to 0 and back for InterCity and Sprinter trains. Therefore, no capacity is reduced by differences in speed. The green line leads to the metro line 'Hoekselijn', which is also An overview is presented in Figure 8.

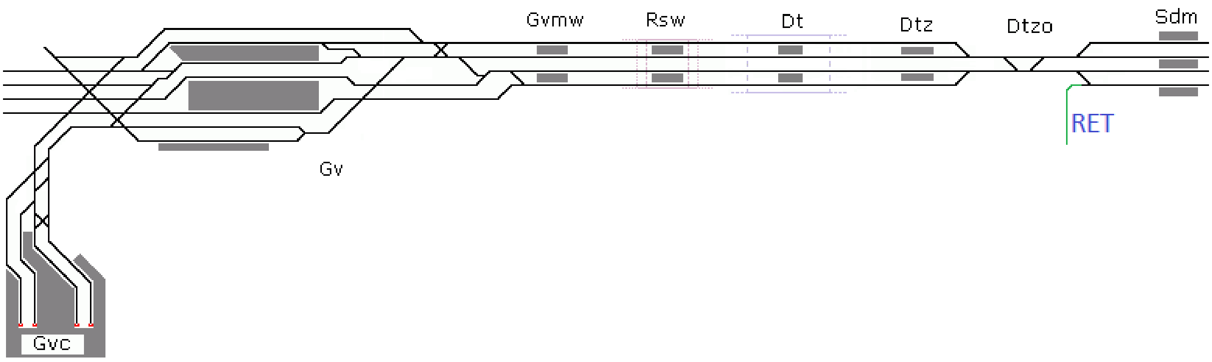


Figure 8: Infrastructure Schematic of Den Haag CS (Gvc) to Schiedam (Sdm)

3.1.2 Corridor Sector 2

Section 2 runs from Schiedam Centrum to Rotterdam Blaak, situated in the Willemsspoortunnel. Many switches are removed in this section and some of them are replaced with switches with a speed limit of 60 km/h instead of 40 km/h. This results in lower travel times and increased capacity. The tracks are constructed such that all the trains to Dordrecht are running through Rotterdam CS at tracks 6, 7, 8 and 9. Trains to the high speed line are handled over tracks 2, 3 and 4 for the south direction and 11 and 12 for the north direction. All this is shown in Figure 9. A detailed drawing of the station Rotterdam CS can be found in appendix B. Seen from left ro right, the Willemsspoortunnel starts directly after Rotterdam CS. Therefore, no space between the tunnel and the station is available to construct a non-level crossing here.

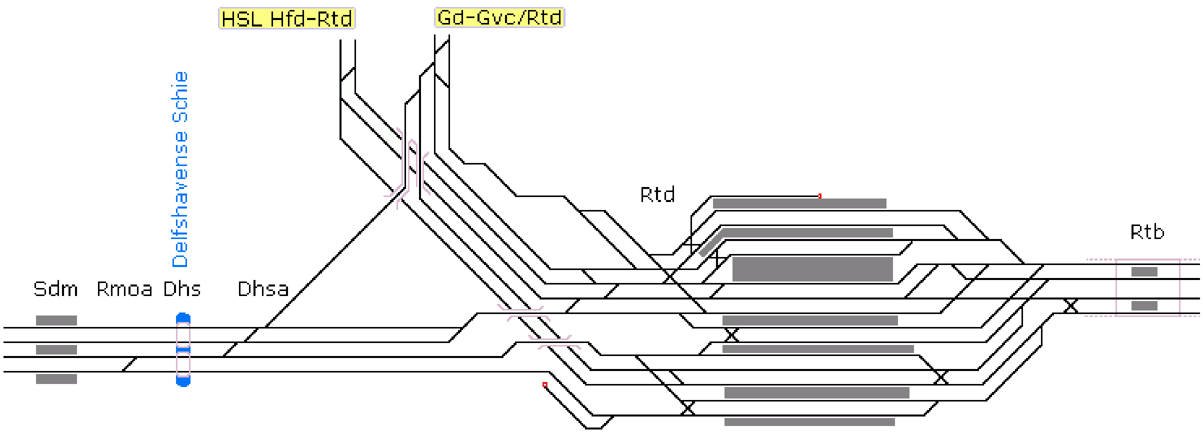


Figure 9: Infrastructure schematic of Schiedam Centrum (Sdm) to Rotterdam Blaak (Rtb)

3.1.3 Corridor Sector 3

Section 3 runs from Rotterdam Blaak in the direction of Dordrecht. Also in this section a lot of switches are removed. This will be done to create a traffic flow more smooth than nowadays. The four green lines ending in nothing are in the direction of a large freight yard. To smoothen the traffic from this yard, a switch cross will be placed between Rotterdam Zuid and Rotterdam Stadion. This means a freight train does not have to ride through the tunnel on the wrong side of the tracks. This cross also provide tube shifting when one of the tunnel tubes is closed due to an accident or maintenance works. Furthermore, the tracks shifting from black to blue is the HSL. The schematic is presented in Figure 10.

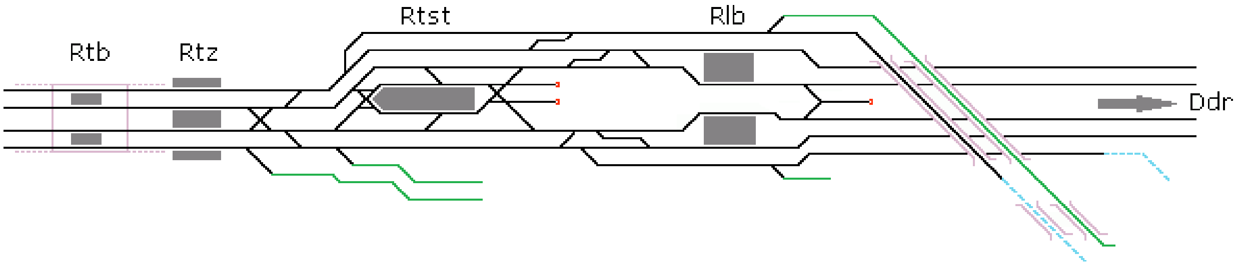


Figure 10: Infrastructure schematic of Rotterdam Blaak (Rtb) to Rotterdam Lombardijen (Rlb)

3.2 Analysis of the Traffic flow

In this paragraph, the traffic flow for each scenario per hour in per direction is shown in tables. For each train type, boundary conditions norms are stated. All the directions exists vice versa and those are not stated to avoid misunderstandings.

3.2.1 Future train routes and frequency

In the next three tables, the 3 scenarios used for modelling are stated. Below every table, explanatory notes are presented.

Table 1: Train routes and frequency in scenario 1

Scenario 1 Train type	Amount of trains	Station of origin	Station of destination	Stops
InterCity Direct	8	Schiphol	Rotterdam CS	None
InterCity Direct	4	Rotterdam CS	Breda	None
InterCity Direct	2	Den Haag CS	Breda	Den Haag HS
InterCity Direct	2	Den Haag HS	Rotterdam CS	None
International	2	Schiphol	Breda border	Rotterdam CS
InterCity	4	Den Haag HS	Rotterdam CS	Delft, Schiedam
InterCity	6	Rotterdam CS	Dordrecht	Rotterdam Blaak
Sprinter	2	Den Haag CS	Rotterdam Lombardijen	Every station
Sprinter	4	Den Haag CS	Dordrecht	Every Station

Trains will run at a 150% frequency compared to the current frequency on the railway line between Den Haag, Rotterdam and Dordrecht and at a 200% frequency at the HSL.

Table 2: Train routes and frequency in scenario 2

Scenario 2 Train type	Amount of trains	Station of origin	Station of destination	Stops
InterCity Direct	8	Schiphol	Rotterdam CS	None
InterCity Direct	6	Rotterdam CS	Breda	None
InterCity Direct	0	Den Haag CS	Breda	Den Haag HS
InterCity Direct	4	Den Haag HS	Rotterdam CS	None
International	2	Schiphol	Breda border	Rotterdam CS
InterCity	4	Den Haag HS	Rotterdam CS	Delft, Schiedam
InterCity	4	Rotterdam CS	Dordrecht	Rotterdam Blaak
Sprinter	6	Den Haag CS	Rotterdam Lombardijen	Every station
Sprinter	6	Den Haag CS	Dordrecht	Every Station

Sprinter trains will run at a 300% frequency and Intercity trains at a 200% compared to the current frequency on the railway line between Den Haag, Rotterdam and Dordrecht and at a 200% frequency at the HSL.

Table 3: Train routes and frequency in scenario 3 (table continues on the next page)

Scenario 3 Train type	Amount of trains	Station of origin	Station of destination	Stops
InterCity Direct	8	Schiphol	Rotterdam CS	None
InterCity Direct	6	Rotterdam CS	Breda	None
InterCity Direct	0	Den Haag CS	Breda	Den Haag HS

Scenario 3 cont. Train type	Amount of trains	Station of origin	Station of destination	Stops
InterCity Direct	8	Den Haag HS	Rotterdam CS	None
International	2	Schiphol	Breda border	Rotterdam CS
InterCity	0	Den Haag HS	Rotterdam CS	Delft, Schiedam
InterCity	2	Rotterdam CS	Dordrecht	None
Metro	12	Den Haag CS	Rotterdam Lombardijen	Every station
Metro	8	Den Haag CS	Dordrecht	Every station

Instead of a Sprinter, a metro line is constructed in this scenario. Because of the difference in characteristics, a comparison in frequency is incorrect. Because of this metro, InterCitys will also not stop at the regular InterCity stops at the corridor Den Haag, Rotterdam and Dordrecht. Their frequency however is increased to 200% compared to the current frequency. On the HSL, a 200% frequency will be run.

3.2.2 Future demand freight trains

Freight trains are not taken in to account for a peak hour as the scenarios prescribe. This is because freight trains have different characteristics compared to passenger trains, especially in the tunnel south of Rotterdam CS (Willemsspoortunnel). This means that in front and at the rear of a freight train, a lot of time and safety margins are set. This does not fit in the PHS program and therefore also not in the 'Toekomstbeeld Openbaar Vervoer 2040' program. These freight trains will be routed as incidents or outside peak hours.

4. Time table construction

The approach to construct a time table is as follows: First, the plan norms are stated. These are used to distinguish a starting point. Using this, three time tables will be constructed. Every time table corresponds with the complementary scenario.

4.1 Plan norms

When constructing a time table, a lot of boundary conditions and rules are set up for various of reasons. This can be a technical limitation or a safety margin. In this paragraph, the most important plan norms are explained.

4.1.1 Infrastructural norms

ProRail has legally issued three different scenarios for norms regarding the time between two trains (ProRail, Netverklaring, 2018). All of them will be used and can be found in appendix C. V stands for departure, A for arrival, D for pass and K for short stop. That means a stop in less than one minute. These four characters are used to describe what trains do. For example, V-A means the first train departures and the second train arrives. The norm then states the minimal time which has to exist between these two trains or actions. Generally, the K-K norm is only theoretical achievable. Therefore, 4 instead of 3 minutes is used in this research. Moreover, some adjustments for specific geographical situations are made. For Den Haag HS and Den Haag CS, the norms V-A, K-K and the K-A are adjusted. In the cases of Den Haag HS and CS the norms are only 4 minutes instead of 6. (ProRail, Robertolijst, 2018).

4.1.2 Rolling stock specific norms

The norm for the time to reverse the direction of a train is 6 minutes. The minimum time a Sprinter stops at a station is 45 seconds and for an InterCity, this is 57 seconds. However, a stop at Rotterdam CS always takes 2 minutes because of the amount of travellers getting in and out of the train (NS, 2017). The time trains ride from the one to the other station or node is calculated with the acceleration-speed-distance-time relation and checked with planning software from NS. This software provides the run time with an added tolerance percentage of 8%, which is the norm.

4.2 Time Table construction

When constructing a time table, first the system bottlenecks or boundary limitations have to be identified. Then, the main limitation has to be distinguished. This will be the starting point for the time table construction and can either be a TWD or a BSO (For an explanation on these acronyms, see paragraph 1.6). Subsequently, from the TWD or BSO the trains will be plotted over the whole corridor. When this won't fit exactly, a solution has to be designed. These building blocks can vary from bending out the run times for these railway sections to constructing more infrastructure.

4.2.1 System bottlenecks

System bottlenecks can be identified by investigating the system. Every merging, crossing or unravelling point will be a system bottleneck. This can be found on the open line, in this case between Delft Zuid Aansluiting – Schiedam Centrum. The number of tracks there decreases from 4 to 2, and then increases to 4 again. These points can also be found at stations. The station Rotterdam CS is such a point, because of the HSL (merging) and tunnel next to the station (crossing). Also Den Haag HS with the crossing of trains from Leiden CS and to Den Haag CS is a station where crossing takes place. This is also true for Den Haag CS. This is because the trains have to cross their own paths when reversing direction.

4.2.2 Boundary conditions

The different scenarios have their own boundary conditions. In the scenario with 12 Sprinters their tracks form a blockade which cannot be filled with more trains or crossed by trains due to the extremely high frequency already present on those tracks. In the scenario with the metro, due to the different characteristics of the metro infrastructure, trains cannot use the metro tracks anymore. In every scenario, the arrival and departure times of International trains in the direction Breda and arrival time in the direction Schiphol are also fixed. These times are coordinated internationally and are very difficult to adjust. This hasn't been done for over two decades and therefore these times are considered fixed. (van Dijk, 2018)

4.3 Simulating

During the construction of a TWD, a simulation step is already implicitly executed as mentioned in paragraph 2.3. However, when a BSO is constructed, a simulation step will be performed as well. Each proposed BSO will be accompanied by explanatory notes on the possibility of running the proposed BSO and if this is not possible, what building blocks are needed to make it viable. An overview of these building blocks are presented in paragraph 5.1.

4.4 Time table construction and simulation for the first scenario

From the infrastructure and the traffic flow analysis of scenario 1, it is likely the main bottleneck is the crossing between the tracks from Den Haag CS to Den Haag HS. Therefore, the construction of the time table for scenario 1 starts by constructing a BSO for both stations. Because the stations are extricably linked to each other, cannot be investigated separately without accepting trains have to wait for a long time at a station or between the stations.

4.4.1 Station layout arrangement Den Haag HS and Den Haag CS

Figure 11 shows the BSO designed for Den Haag CS. Den Haag CS has 4 platform tracks for the departing direction of Rotterdam, as shown in subsection 3.1.1.

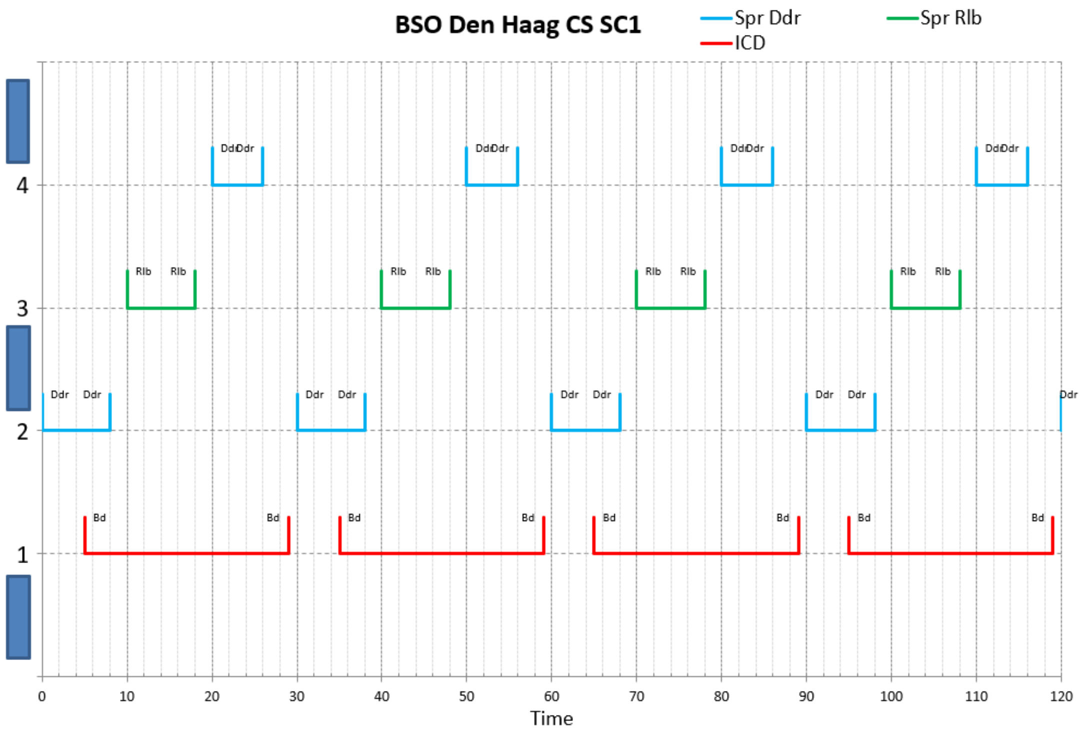


Figure 11: BSO Den Haag CS Scenario 1

Noticeable are the short turning times for the Sprinters (blue and green lines), especially the Sprinter from platform 4. This Sprinter has to wait at the next station to form a 10-minutes-structure again. The reason for this will become clear when examining Figure 12. Also, the Sprinters could fit on only 2 tracks, but then the norm of crossing in the opposite direction from V-A will complicate the BSO. When using 3 tracks for the Sprinter trains, less crossings are made every hour, which leaves more freedom which is needed at Den Haag HS. Again, this will become clear when viewing Figure 12. The InterCity Direct (ICD) has a relatively long turnaround time. Actually, it is on the limit of the norm of opposite crossing. The reason can be seen in Figure 12 below. Den Haag HS has 5 platform tracks and 2 tracks without a platform; tracks 2 and 7.

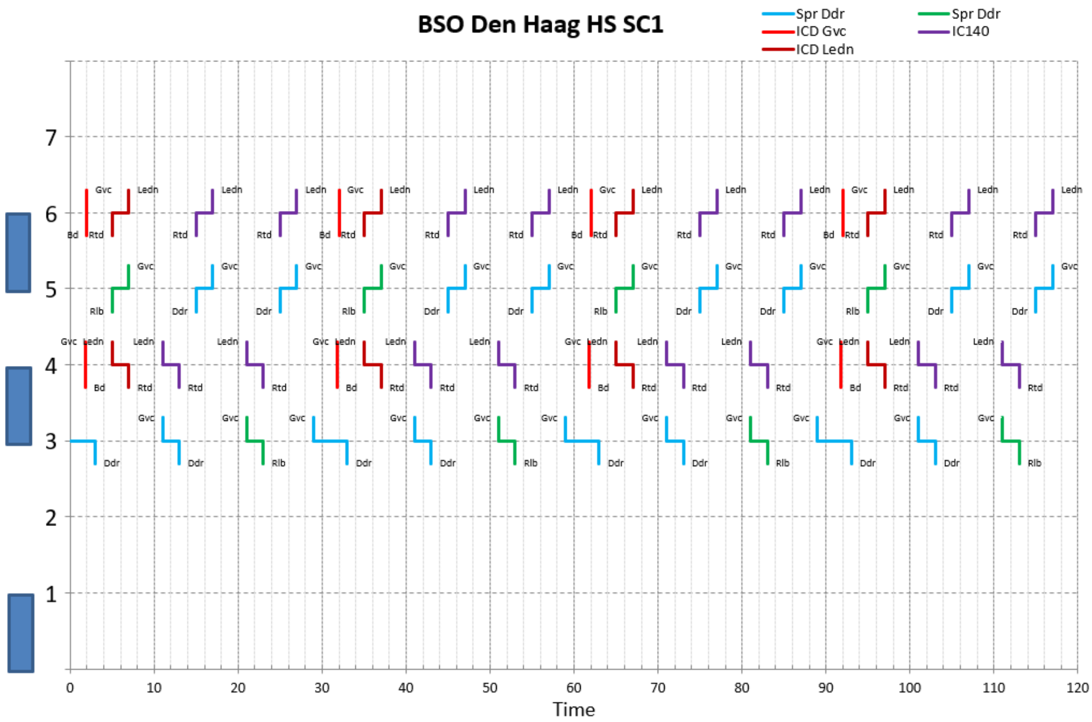


Figure 12: BSO Den Haag HS Scenario 1

The InterCity Direct from Den Haag CS could not leave earlier because it would come too close to the InterCity with more stops (IC140) down the line. This is verified in the TWD shown in Figure 13 and Figure 14. The IC140 and ICD from Leiden have to cross the Sprinters to Den Haag CS. To solve this problem, the Sprinters in the direction from south to north are also implemented in the BSO. The norms states Sprinters can leave one minute after the arrival of the InterCitys but the next InterCity can then arrive 4 minutes later. The Sprinter which has to wait at Den Haag HS, mentioned in the BSO of Den Haag CS, is clearly visible here. Now it is clear to see that the Sprinter with this extra waiting time will now fit in the 10-minute-structure again.

Platform 1 and track 2 are not used at the moment. Track 2 does not has a platform and therefore only the ICD from Den Haag CS can theoretically use this track. However, it complicates the TWD and is not needed in the BSO. Therefore, track 2 is not used. Platform 1 can theoretically be used for Sprinters. This however means cross-platform transfers are no longer possible. Because platform 1 is not actually needed, this option is not chosen because it decreases the service level for travellers.

4.4.2 Coupling north to south

When continuing on the base of the two BSOs from subsection 4.3.1, the TWD from Figure 13 follows.

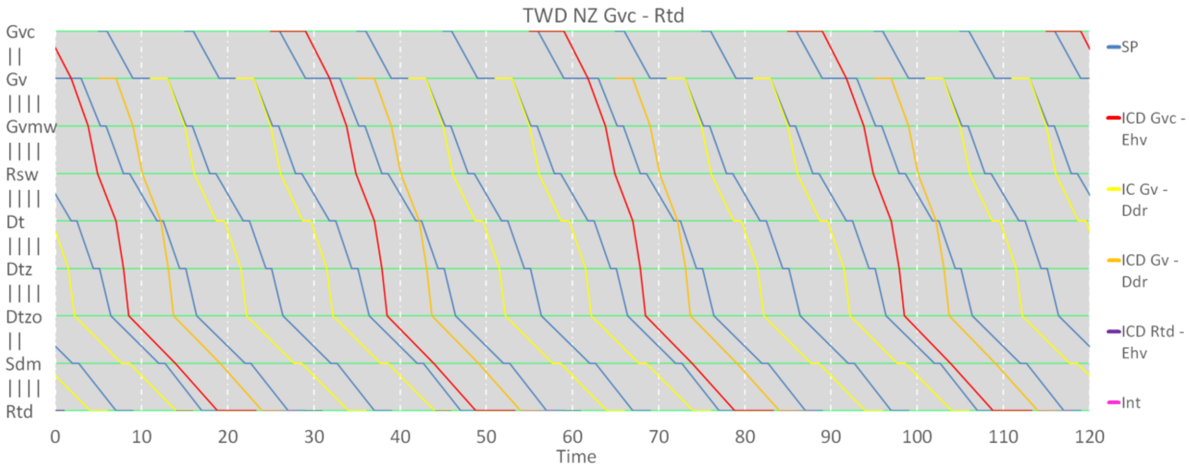


Figure 13: TWD North-South Den Haag CS to Rotterdam CS

The BSOs can be interpret from the first two stations. From there, it is clear to see the Sprinters need a separate track from both the IC140s as the ICDs. A collision point arises at Delft Zuid Aansluiting. The ICD from Den Haag CS comes too close to the Sprinter. The rest of the trains merge perfectly at Delft Zuid Aansluiting. At Schiedam they can but not necessarily have to separate again. When entering Rotterdam CS, only two tracks are used again. This way, the entry of Rotterdam CS will not have to be adjusted. The infrastructure layout will remain the same as shown in subsection 3.1.3.

With the trains for Den Haag HS already planned, a TWD for the direction south to north follows. This results in limitations for the BSO of Rotterdam CS, but this fact cannot be bypassed. The TWD is shown in Figure 14.

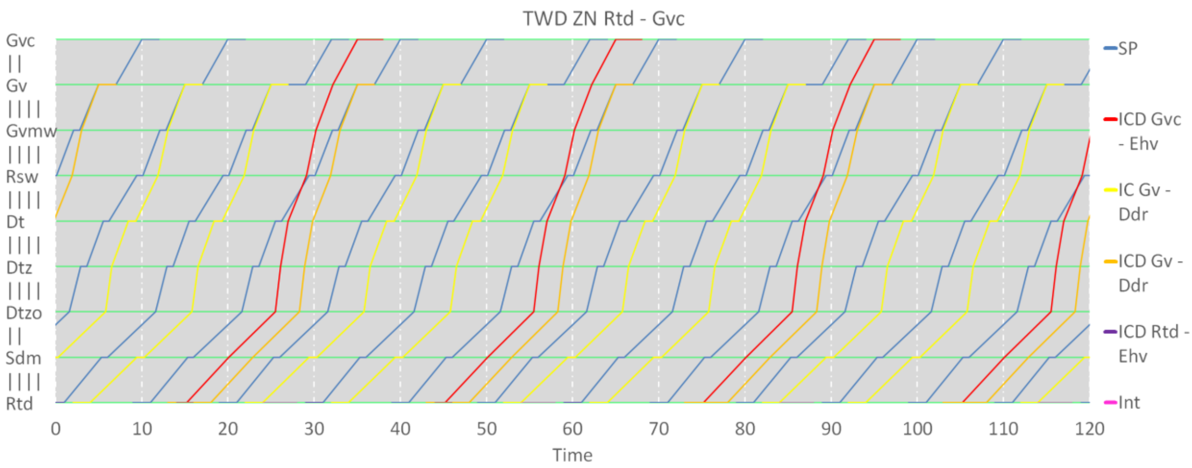


Figure 14: TWD South-North Rotterdam CS to Den Haag CS

The TWD fits on the infrastructure everywhere and gives a symmetric pattern. This is favourable to a non-symmetrical pattern due to its logic and therefore appeals to travellers. The only exception forms the Sprinter which needs to stop longer at Den Haag HS, as stated and explained in the previous subsection.

4.4.3 Station layout arrangement Rotterdam Central Station

These TWDs leads partially to the following BSO for Rotterdam CS. The trains from the High Speed Line form the other input. This BSO is shown below in Figure 15: BSO Rotterdam CS Scenario 1.

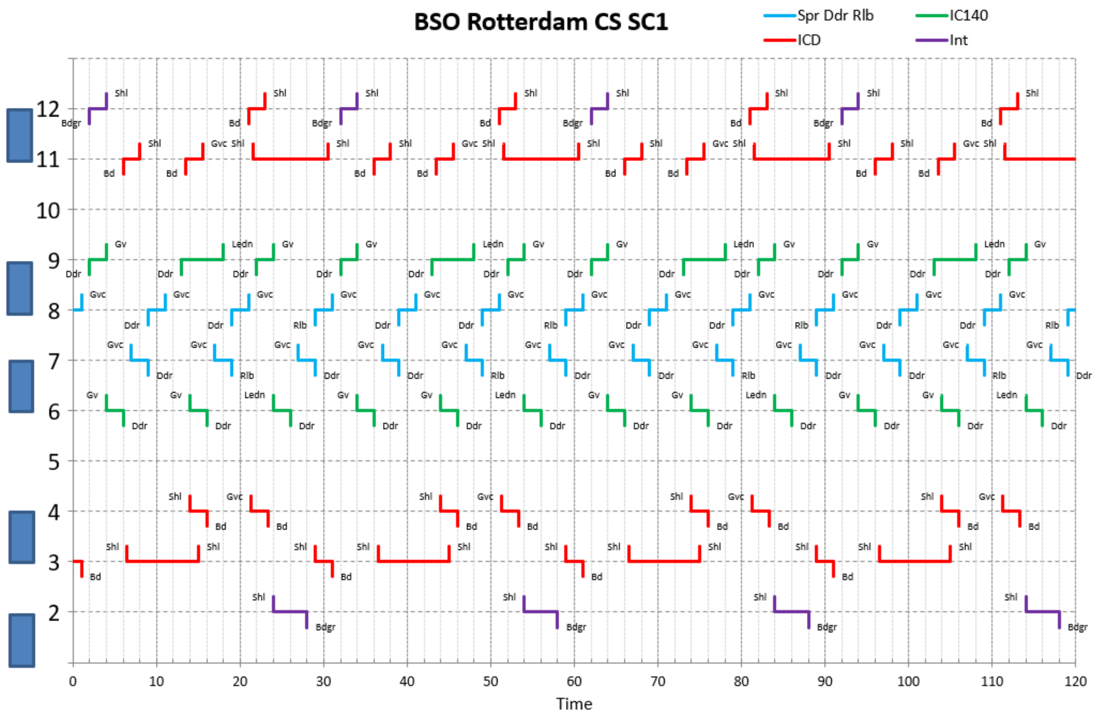


Figure 15: BSO Rotterdam CS Scenario 1

The TWDs provide in the trains from tracks 6, 7, 8 and 9 and the trains from Den Haag CS to Breda v.v. Around these trains which are considered fixed, the trains from the HSL are planned. The purple international trains are also fixed as explained in subsection 4.2.1. Around these trains, 8 trains per hour from Schiphol arrive and 4 of them need to reverse at Rotterdam CS. It is theoretically possible to turn the IC140s and let the trains from Schiphol continue to Dordrecht. However, this is more difficult to plan regarding to rolling stock types. This scenario even leaves the possibility to run direct InterCitys from Gouda via platform 4 to Breda and vice versa via platform 13 or 14. These platforms are already currently in use for trains from Rotterdam CS to Gouda and further.

When constructing TWDs for the south of Rotterdam, the routing is as follows: The Sprinter and IC140 trains to Rotterdam Lombardijen and Dordrecht use the inner tunnel tube of the Willemsspoortunnel between Rotterdam CS and Rotterdam Zuid. The outer tube is used by the international trains and trains to Breda. At Rotterdam Lombardijen HSL Aansluiting (Rlb HSL), the tracks expand to 6 and so the Sprinter and IC140 trains will thus be separated from each other. The figures which subscribe this conclusion can be found in appendix D.

4.5 Time table construction and simulation for the second scenario

When analysing the future train routes and frequencies for scenario 2, a large increase of Sprinters can be seen. The time table designed for the previous scenario was pushing the limits on the norms. In this scenario, there can be concluded Sprinter trains and InterCitys cannot cross each other at a level crossing anymore. It is assumed that a non-level crossing will be there. Because there are many possibilities for a location, type and task to accommodate, the solution corresponds to building blocks 3 and 5. Also the 2 tracks between Delft Zuid Aansluiting and Schiedam Centrum cannot accommodate this amount of traffic. Tracks have to be doubled here, this corresponds with building block 1. Therefore, the main bottleneck is Rotterdam Central Station.

4.5.1 Station layout arrangement Rotterdam Central Station 2a

As mentioned in subsection 4.2.2, the starting point when constructing the BSO for Rotterdam CS is the consequence of the fixed arrival and departure times of the international trains. The Sprinter trains will run through the station and the inner tube at the Willemsspoortunnel. No InterCity trains can merge in this section due to the heavy traffic load at this section. This means the InterCitys will take the outer tubes in this scenario. This can result in a BSO for Rotterdam CS as shown in Figure 16.

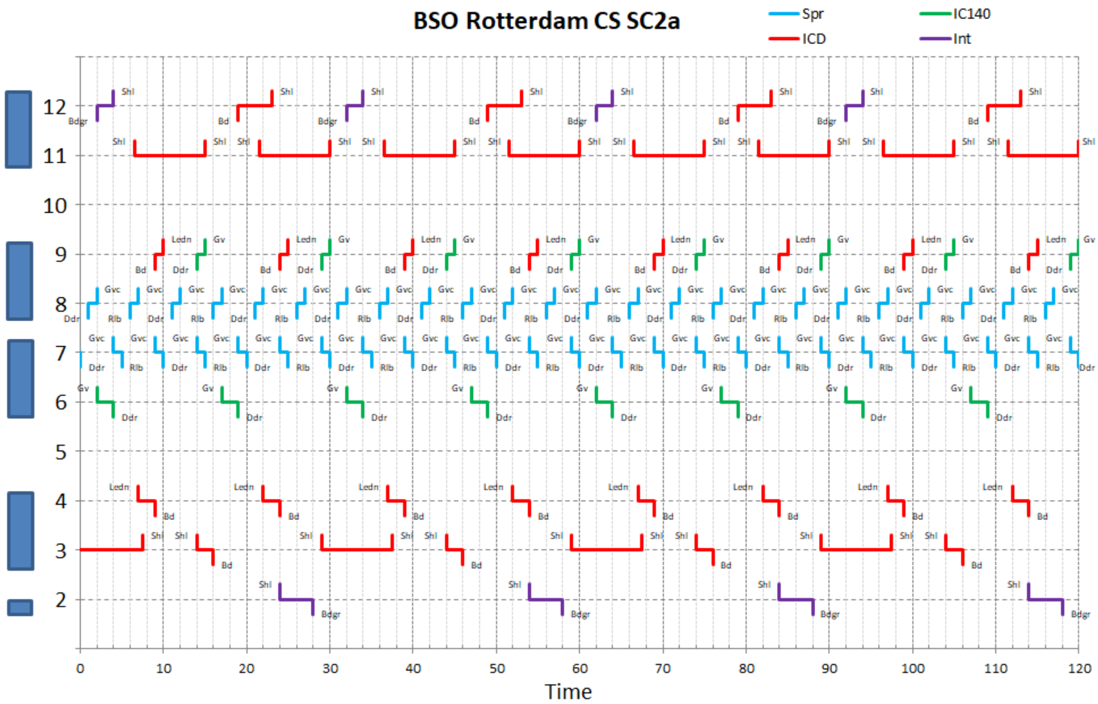


Figure 16: BSO Rotterdam CS Scenario 2a

With these departure and arrival times of all trains, all norms but one are met. In this particular case where the norm isn't met, the trains which come after the IC to Dordrecht and v.v. are too close behind each other. This time is 6 seconds. These seconds will be accommodated in the tolerance of 8%. In both directions, no problems occur. The figures which subscribe this conclusion can be found in appendix E.

4.5.2 Alternative station layout arrangement Rotterdam CS

As mentioned in the previous section, the boundary conditions can lead to the above BSO. However, a different variant can be designed. In Figure 16, all the reversing trains come from Schiphol. Another possibility is to reverse both trains from Leiden and Schiphol. In this case, from and to both Leiden and Schiphol direct trains are offered. However, this alternative requires the building block 6 instead of 3 and 5. The BSO corresponding to this alternative is shown in Figure 17. In the chapter 5, the difference in cost, level of service, robustness etc between these alternatives can be seen. In appendix F, the TWDs for scenario 2b are shown. Here, in both directions, no problems occur.

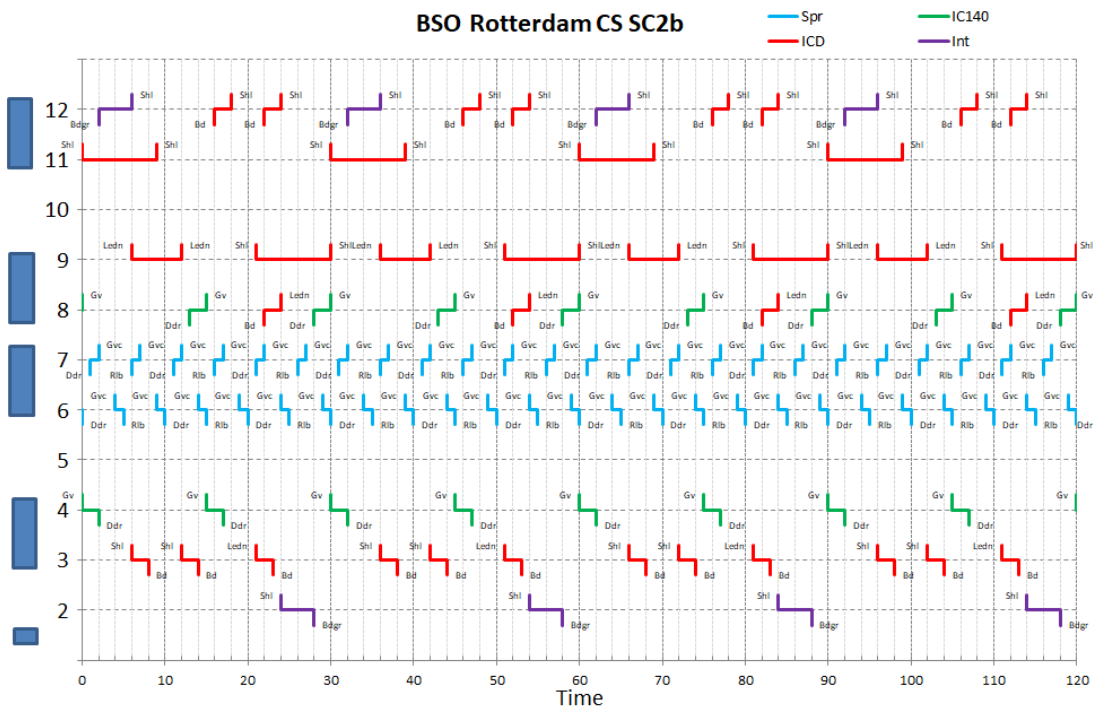


Figure 17: BSO Rotterdam CS Scenario 2b

4.6 Time table construction and simulation for the third scenario

In this scenario separate metro infrastructure is constructed. To cope with this, two starting points can be chosen. Either the Sprinter tracks from scenario 1 and 2a are converted to metro infrastructure or the Sprinter tracks from scenario 2b are modified to metro infrastructure. Also, from the infrastructure analysis is known there is no possibility to construct flyovers between Rotterdam CS and the Willemsspoortunnel. After this tunnel, almost straight away the freight trains separate and this cannot be solved with an flyover due to the lack of space after the tunnel. The service type of the tunnel tubes therefore remains the same in each scenario variant. This means that in both cases, the BSO of Rotterdam CS is the bottleneck because the railway lines have to weave and cross to use the correct tubes of the Willemsspoortunnel and 6 of the 8 trains from Den Haag HS have to reverse at Rotterdam CS. By requirement this can only take place at Rotterdam CS and therefore BSOs for Den Haag or a TWD does not offer new insights and are therefore not presented in this paragraph. In all BSOs the trains from the HSL are scheduled on the same time, due to the fixed international trains and the optimized structure of ICD built around these international trains. The ICD from Leiden has been replaced by the ICD from Schiphol south of Rotterdam CS. From the 8 trains from Den Haag HS, which no do not stop at Delft, Schiedam and Rotterdam Blaak, only 2 run to Dordrecht. The other 6 have to reverse in Rotterdam CS. Where the IC140 trains reverse and which platform tracks the metro uses will differ in the BSOs.

4.6.1 Station layout arrangements Rotterdam CS when modifying scenario 1 and 2a

When modifying the BSO of scenario 1 and 2a, the metro call at platforms 7 and 8. This means the InterCitys to and from Dordrecht can run over platform 3, 4, 6 and 9. In variant 3a, reversing takes place at platforms 4, 6 and 9 and continuing trains only call at platforms 4 and 9. This gives a lot of space in the time table which can be used to reschedule in case of delays. The corresponding BSO can be seen in Figure 18 and the corresponding building blocks are 1, 2, 3 and 7.

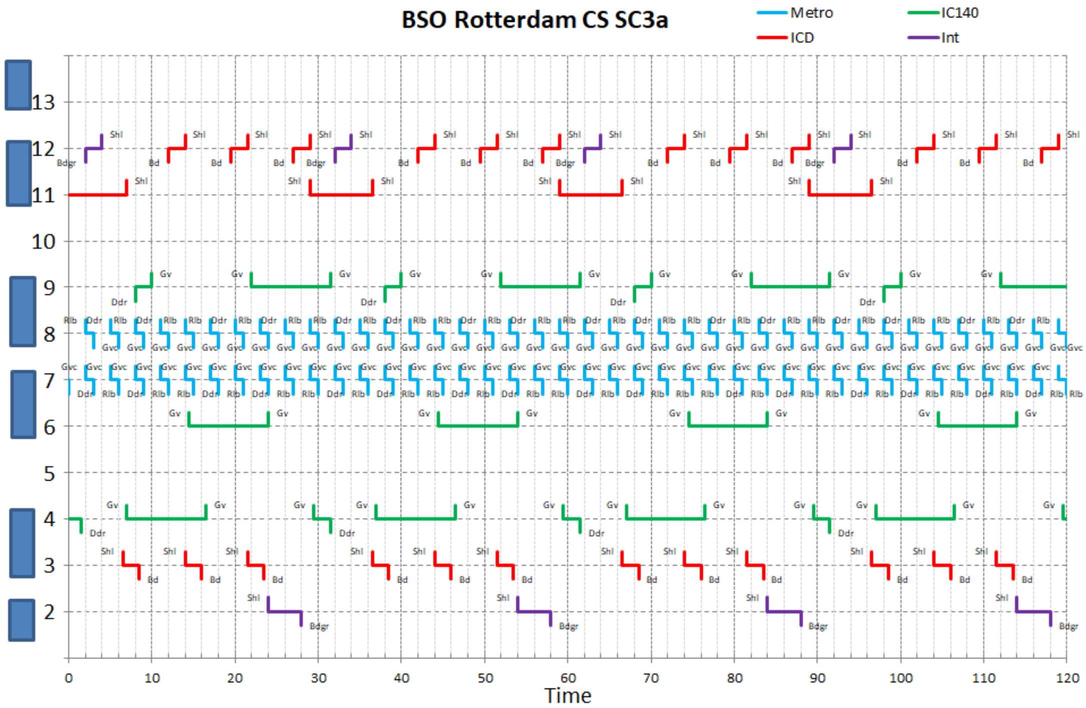


Figure 18: BSO Rotterdam CS Scenario 3a

In variant 3b, reversing takes place only at platforms 6 and 9 and continuing tracks call at platform 3 and 9. This leaves platform 4 free to rescheduling purposes or it can be used for trains from Gouda to Dordrecht or Breda in the future. The corresponding BSO can be seen in Figure 19 and the corresponding building blocks are 1, 2, 3 and 7 as well.

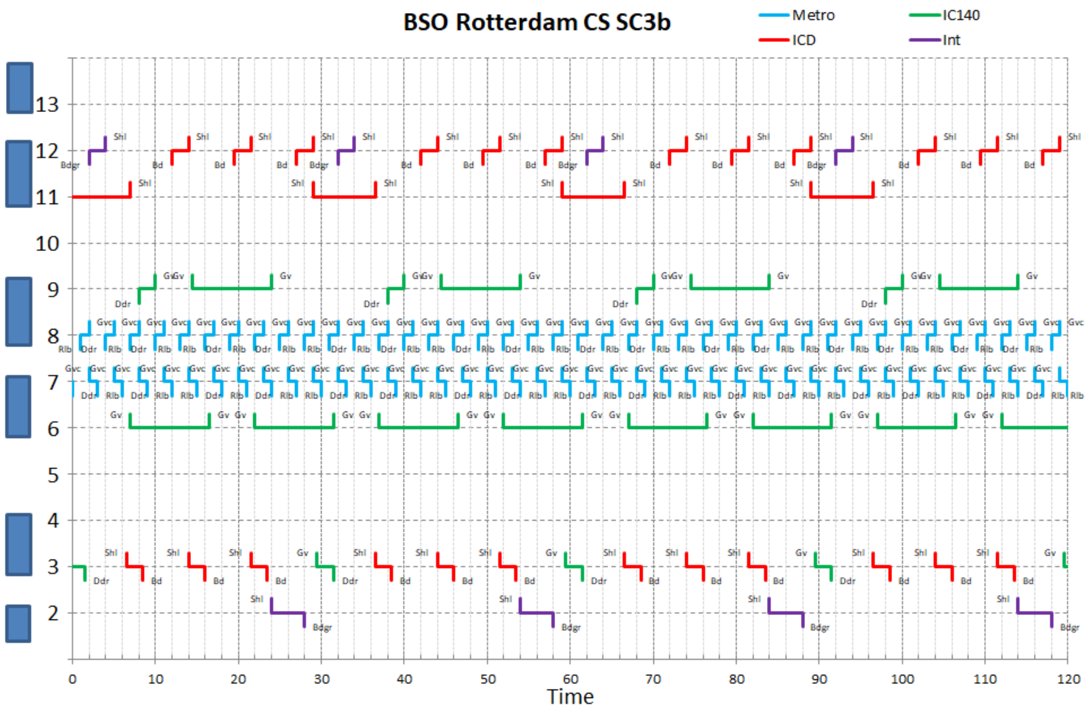


Figure 19: BSO Rotterdam CS Scenario 3b

4.6.2 Station layout arrangements Rotterdam CS when modifying scenario 2b

When modifying the BSO of scenario 2b, the metro calls at platforms 6 and 7. This means the InterCitys to and from Dordrecht can run over platform 3, 4, 8 and 9. Variant 3c uses the same principle used in variant 3a in Figure 18. This means a lot of space in the time table which can be used to reschedule in case of delays. However, the metro calls now at 6 and 7 and tail track 6 is changed to track 8. The corresponding BSO can be seen in Figure 20 and the corresponding building blocks are 1, 2 and 8.

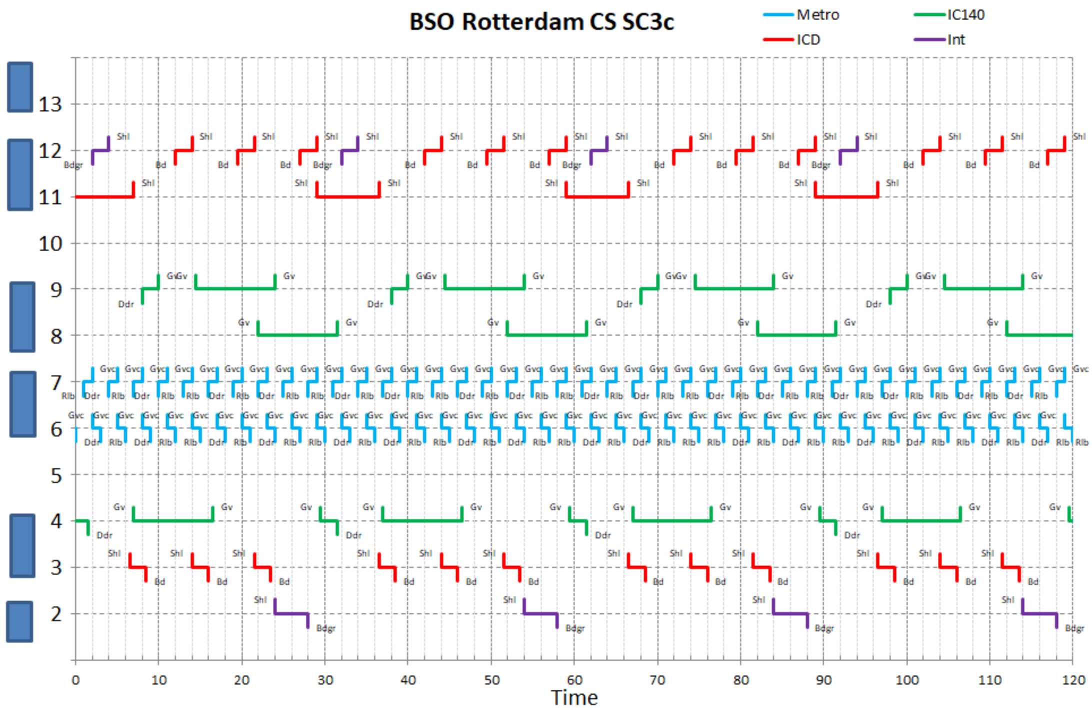


Figure 20: BSO Rotterdam CS Scenario 3c

Variant 3d uses the same principle of the variant 3b when modifying scenario 2b in Figure 19. However, the metro tracks are now at 6 and 7, turning track 6 is changed to track 8 and the IC to Dordrecht now calls at platform 4. The corresponding BSO can be seen in Figure 21 and the corresponding building blocks are 1, 2, 3, 8 and 9.

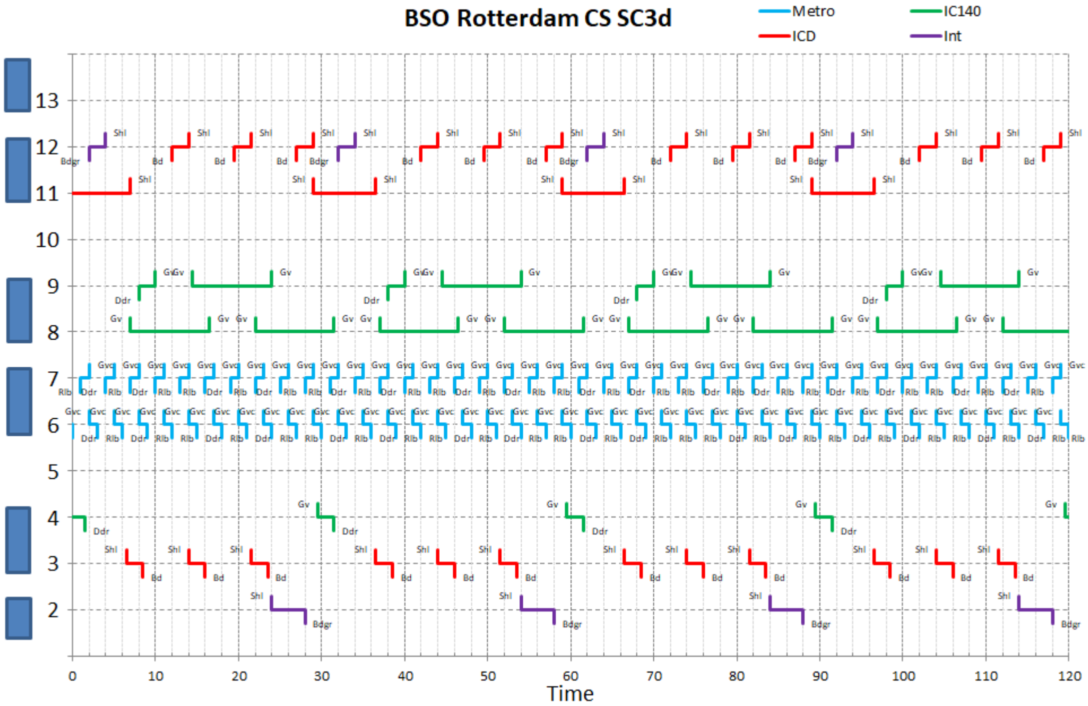


Figure 21: BSO Rotterdam CS Scenario 3d

5. Overview of the building blocks and scenario variants

In paragraphs 4.4, 4.5 and 4.6 time tables are constructed. To make the time tables executable, adjustments to the infrastructure have to be made. These are presented in those paragraphs as building blocks. In this chapter first the building blocks are shown. Second, the scenario variants allowed by these building blocks to be executed, are reviewed.

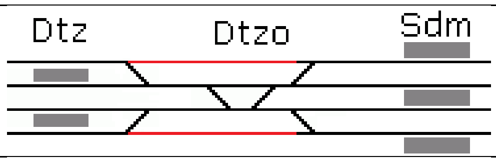
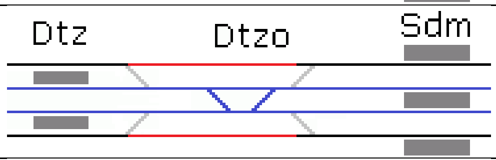
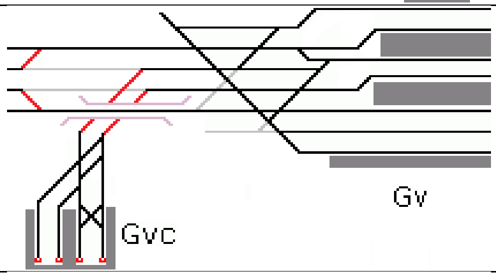
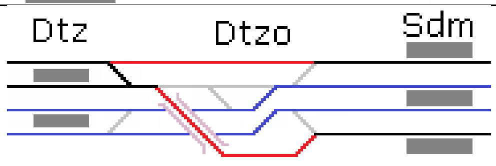
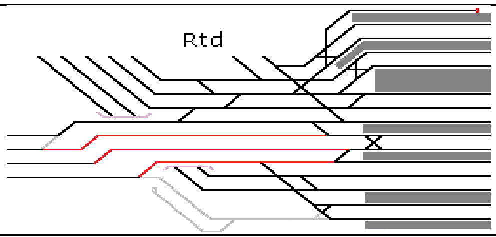
5.1 Building blocks

In the table below an overview of the building blocks is presented. This overview consists of:

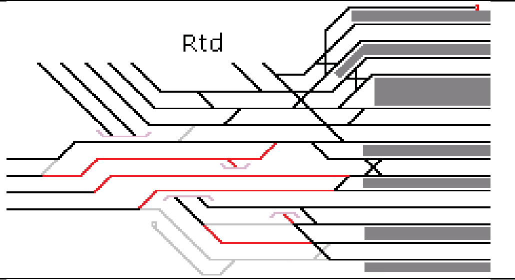
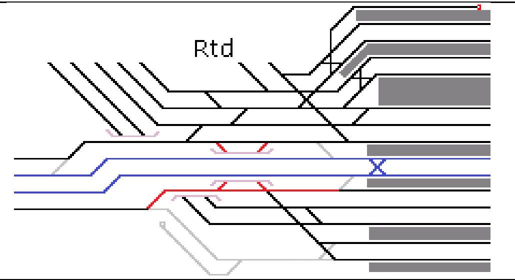
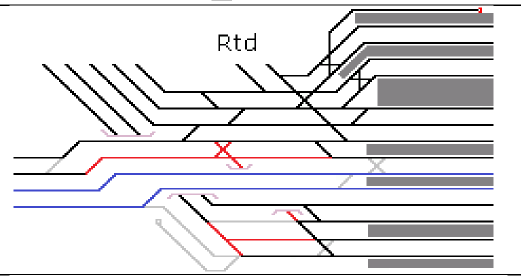
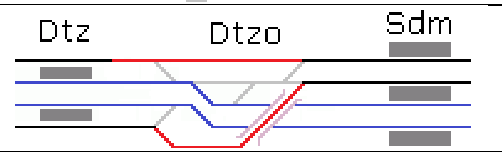
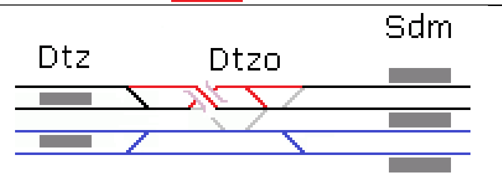
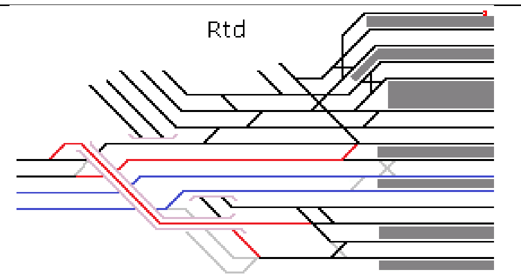
- The building block number
- The design of the building block
- In what scenario the building block is needed
- With what scenario the building block has a conflict
- The cost of the building block multiplied by 1 mln euro

A new railway track is presented in red, metro track in blue. Demolished track is presented in grey.

Table 4: Building block overview

Building block number	Building block	Needed for scenario	Conflict with scenario	Cost (×1 mln euro)
1		2a, 2b, 3a, 3b, 3c, 3d	3a, 3b, 3c, 3d	160
2		3a, 3b, 3c, 3d	2a, 2b	790[2]
3		2a, 3a, 3b,3d	2b, 3c	220
4[3]				160
5		2a	2b, 3a, 3b, 3c, 3d	300

[2] For the whole corridor, not only between Dtz and Sdm.
[3] An option for building block 3. Cheaper, but reduction of line flexibility

6[4]		2b	2a, 3a, 3b, 3c, 3d	450
7		3a, 3b	2a, 2b, 3c, 3d	320
8[5]		3c, 3d	2a, 2b, 3a, 3b	450
9		3d	2a, 2b, 3a, 3b, 3d	180
10		3c	2a, 2b, 3a, 3b, 3d	140
11		3c, 3d	2a, 2b, 3a, 3b	460

[4] It the dive-under from building block 6 is not technically possible, building blocks 10 and 11 are needed

[5] If the dive-under from building block 8 is not technically possible, building blocks 10 and 11 are needed.

5.2 Scenario variants review

In table 5, the different variants are shown. A cross comparison is made, with scenario 1 as bench mark. Scenario 1 is used for this because this scenario does not need any building blocks and can therefore be implemented on the current infrastructure. Remarks about data can be found below the table.

Table 5: Variant review

Scenario	1	2a	2b	3a	3b	3c	3d
Level of Service (in minutes)							
- **Sprinter stations**							
○ **Waiting time**	7,5	2,5	2,5	1,5	1,5	1,5	1,5
○ **Travel time**[6]	24	24	24	27	27	27	27
- **Old IC stations**							
○ **Waiting time**	10	7,5	7,5	1,5	1,5	1,5	1,5
○ **Travel time**	22	21	21	27	27	27	27
- **IC stations**							
○ **Waiting time**	10	3,75	3,75	3,75	3,75	3,75	3,75
○ **Travel time**	22	19,67	19,67	19	19	19	19
Construction cost[7] **(× 1 mln euro)**	0	680	610	1.490	1.490	1.400	1.800
Construction hindrance[8] **(in months)**	0	1-2	1-2	12+	12+	12+	12+
Flexibility of lines[9]	+ Gd	+ Gd	+ Gd	+ Gvc[10]	+ Gvc[10]	-	+ Gd + Gvc[10]
Robustness[11]							
- **Gv**	8	0	0	0	0	0	0
- **Dt-Sdm**	6	0	0	0	0	0	0
- **Amount of trains north**	14	20	20	28	28	28	28
- **Rtd**	6	10	12[12]	4	10	6	10
- **Amount of trains Rtd**	24	30	30	38	38	38	38
- **Rtb**	8	4	0	0	0	0	0
- **Amount of trains south**	20	24	24	30	30	30	30

[6] The travel time of the metro is predicted on the basis of the Hofpleinlijn and the Hoekselijn, two former NS railway lines which are currently used as metro line. Some stops are added on the both the Hofpleinlijn as the Hoekselijn. It is reasonable to expect the same to this corridor.
[7] Based on several (semi-) confidential reports by ProRail and the Ministry of Infrastructure and Watermanagement about similar measurements to make PHS possible on different corridors. Every amount must be multiplied by 1 mln euro
[8] An average of days the track is out of service, based on reference projects. Every construction works which can be done simultaneously, are considered so and construction days are therefore not added but shared.
[9] Gd = Gouda, Gvc = Den Haag CS
[10] This requires a separate station for the metro at Den Haag CS which will lead to an increase in cost of around €70.000.000,- euros. (Haag, 2013)
[11] Critical follow-ups at Gv (crossing at Den Haag HS), Dt-Sdm (2 instead of 4 tracks), Rtd (station Rotterdam CS) and Rtb (Station Rotterdam Blaak). Frequency of the trains on that part of the corridor are also presented to display the impact of the critical follow-ups.
[12] With the alternative building blocks, this number lowers to 10.

6. Discussion

In this research assumptions are made. Some of these assumptions should be checked in further research. This applies to the following assumptions:

- The level of service is simplified by showing only the average waiting time and average travel time. A more thorough way to investigate the level of service offered by a variant is to construct a origin-destination matrix. This matrix shows for how many people the service actually improves. The matrix was however not possible to construct in the time span of this research. Also the travel time for the metro should be modelled exactly instead of an assumption based on the history of converting heavy rail to light rail in the Netherlands. When this conversion took place in recent history, the infrastructure of these railways has been improved too. For example the speed limit on railway sections of the Hofpleinlijn is. Therefore, the assumption might not be accurate. Because the level of service is very important at a cost-benefit analysis for public works, the level of service calculation is very important to improve if the tools to do so are available.
- Adjusting the railway safety systems ATB, ERTMS and applying 3 kV on the catenary system are three aspects which lie outside the scope of this research. However these aspects can have a big impact on the solutions, travel times, follow-up times and plan norms. When more information about implementation dates and technical characteristics are available, the time tables have to be reconstructed.
- The design solutions are based on schematics. It is necessary to make technical drawings check the civil engineering feasibility of the solutions proposed. Engineering software was not available during this research. When technical drawings are made, costs can be predicted more accurate too.

With the assumptions as mentioned above, the results in table 5 are found.

Scenario 1 can be executed without having to construct new infrastructure. However, almost half of the trains have a critical follow-up. This is especially true for the InterCity Direct from Den Haag CS running to Rotterdam CS when merging at Delft Zuid. To make this happen, the train should slow down by 1.5 minutes. All these critical follow-ups make it very difficult to construct a time table for the entire Dutch railway network with this much fixity in only one corridor. An adjustment to the ATB can lower the number of critical follow-ups. The ATB adjustment 'kort volgen' falls out of scope and is therefore not researched. This could increase the validity of the solution for this scenario.

Scenario 2 has an increased level of service for all current and future travelers. The average waiting and travel time for all stations decrease by almost 6 minutes. Both variants show a decrease critical follow-ups on the corridor, even when the frequency is increased. Only in Rotterdam CS, the number of critical follow-ups has increased. Variant 2a has more critical follow-ups compared to variant 2b and is more expensive. Both variants facilitate an ongoing railway link from Gouda, via Rotterdam CS to Breda. Although the InterCity link to Den Haag CS is preferable, because there is more demand for this line, this is made impossible by the 12 NS Sprinters. So variant 2b is recommended.

Scenario 3 offers an increased level of service of 4 minutes compared to scenario 1. The number of critical follow-ups have decreased on the whole corridor, except at Rotterdam CS for variant 3b and 3d. Also the frequency on the corridor is heavily increased. Variant 3d offers the most flexibility in lines, but is the most expensive as well. Variant 3c does not offer any flexibility in lines and is the cheapest variant. Variants 3a and 3b cost the same and have the same line flexibility, however variant 3a has the least critical follow-ups of all variants for scenario 3. So variant 3a is recommended.

7. Conclusion

In this chapter, an answer is presented on the following research question:

> "Given the desired increased frequency scenarios on the corridor Den Haag CS – Rotterdam Lombardijen, are construction works a must or is it feasible to adjust the time table and what are these changes to the infrastructure or time table?"

In scenario 1 construction works are not necessary and only one adjustment to the time table has to take place.

In scenario 2 variant 2b is the best variant because it contains the least fixed points in scenario 2 and is cheaper.

In scenario 3 variant 3a is the most optimal variant because this variant has the least critical follow-ups, the most flexibility in lines and therefore is more valuable than the slightly cheaper variant 3c.

8. Further research recommendation

During this research on the viability of the three scenarios, I’ve started to believe a different, optimized scenario could solve the problem more thorough. In my opinion this optimized scenario combines the Sprinters of scenario 2 with the InterCitys of scenario 3. These InterCitys will have to make 1 or 2 extra stops to increase the level of service for the old InterCity stations.

Reference projects

Passenger corridor Alkmaar – Amsterdam

Passenger corridor Amsterdam – Utrecht – Eindhoven

Passenger corridor Schiphol – Utrecht – Arnhem/Nijmegen

Passenger corridor Breda – Eindhoven

Passenger corridor OV SAAL

Freight corridor Zutphen – Hengelo

Freight corridor Meteren – Boxtel

Bibliography

Frontpage picture, ProRail. *Prorail.nl*. Taken at Rotterdam Central Station. Retrieved from ProRail: https://www.prorail.nl/nieuws/tussenstandje-werkzaamheden-aan-spoor-in-rotterdam

Boon, T. (2018). *nieuws.ns.nl*. Retrieved from Nieuws NS: https://nieuws.ns.nl/nieuwe-spoorkaart-hier-te-downladen/

Eldering, P. (2018, mei 31). Treinen raken tjoskvol. *De Telegraaf*.

Heuvel, G. v. (2008). *Programma Hoogfrequent Spoorvervoer.* Utrecht: Samensporen (NS, Prorail, BRG).

http://www.infrasite.nl/definitions/definition.php?ID_content=943. (n.d.). Retrieved from Infrasite.

LMCA, P. (2007). *Landelijke Martk- en Capaciteitsanalyse Spoor.* Utrecht: ProRail.

Milieu, M. v. (2016). *Programma Hoogfrequent Spoorvervoer voortgangsrapportage nr. 12.* Den Haag.

Milieu, M. v. (2017). *Programma Hoogfrequent Spoorvervoer voortgangsrapportage nr. 13.* Den Haag.

Ministerie Verkeer en Waterstaat. (2008). *Kabinetsambities Spoor, Voortgangsrapportage nr. 1.*

NS. (2017). Keertijden matsoort. NS intern.

OV, P. L. (2007). *Landelijke Martk- en Capaciteitsanalyse Regionaal OV.*

Over Prorail, in cijfers. (2018, September 7). Retrieved from Website van Prorail: https://www.prorail.nl/reizigers/over-prorail/wat-doet-prorail/prorail-in-cijfers

ProRail. (2009). *Goederenboog Deventer.*

ProRail. (2017). *Discussienota financiën PHS.* ProRail.

ProRail. (2018). *Netverklaring.* Utrecht: ProRail.

ProRail. (2018). *Robertolijst.* Utrecht: ProRail.

van Dijk, G. S. (2018, October 3). (T. Dijkstra, Interviewer)

wetten.overheid.nl. (2004, 12 20). Retrieved from Website van de Overheid: http://wetten.overheid.nl/BWBR0017795/2015-01-01

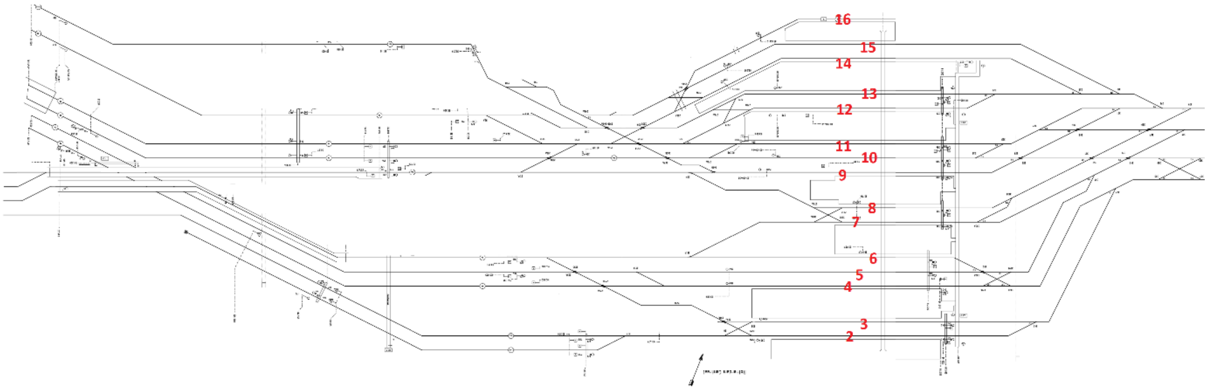
Wilma J. Mansveld, S. v. (2014). *Besluitenlijst PHS.* Den Haag.

Appendix

Appendix A: Station and node acronyms

Shl	Schiphol Airport
Ledn	Leiden Centraal Station
Laa	Den Haag Laan van NOI
Gvc	Den Haag Centraal Station
Gv	Den Haag Hollands Spoor
Gvmw	Den Haag Moerwijk
Rsw	Rijswijk
Dt	Delft
Dtz	Delft Zuid
Dtzo	Delft Zuid aansluiting
Sdm	Schiedam Centrum
Dhsa	Delshavense Schie aansluiting
Rtd	Rotterdam Centraal Station
Rtb	Rotterdam Blaak
Rtz	Rotterdam Zuid
Rtst	Rotterdam Stadion
Rtlb	Rotterdam Lombardijen
HSL	High Speed Line
Bd	Breda (via HSL)
Bdgr	Border at Breda between the Netherlands and Belgium (via HSL)
Ddr	Dordrecht

Appendix B: Detailed drawing of Rotterdam CS



Appendix C: Plan norms

Table 6: Follow-up time (ProRail, Netverklaring, 2018)

Follow-up time		Train 2			
		A	D	K	V
Train 1	Arrival (A)	3	2	3	n/a
	Pass (D)	3	3	3	2
	Short Stop (K)	3	3	**4** (mentioned in paragraph 4.1)	3
	Departure (V)	4 (when using the same platform)	4	3	3

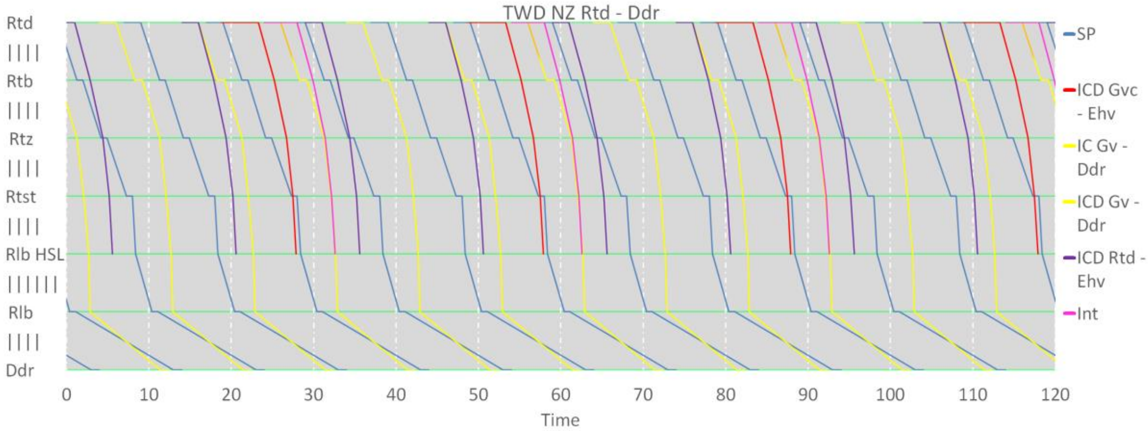
Table 7: Follow-up time when crossing same direction (ProRail, Netverklaring, 2018)

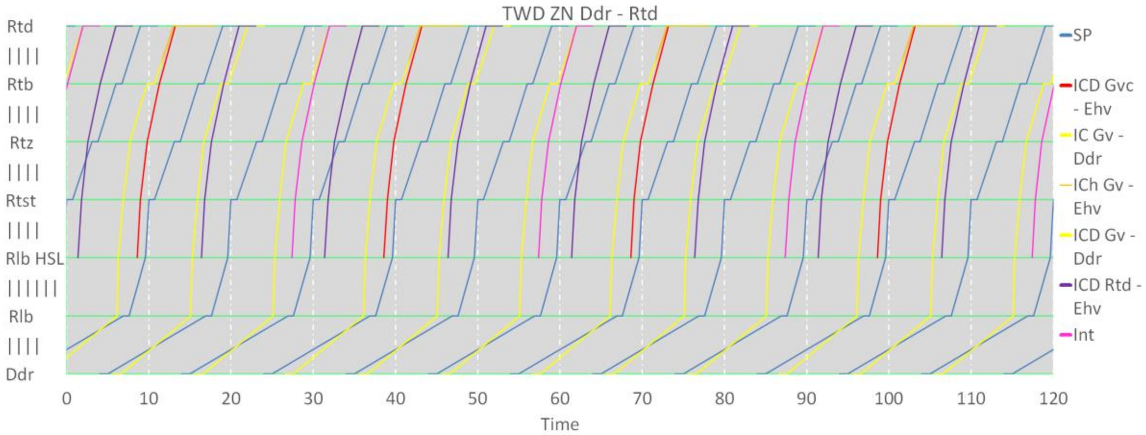
Crossing same direction		Train 2			
		A	D	K	V
Train 1	Arrival (A)	3	2	3	1
	Pass (D)	3	3	3	2
	Short Stop (K)	3	3	3	2
	Departure (V)	4	3	3	2

Table 8: Follow-up time when crossing opposite direction (ProRail, Netverklaring, 2018)

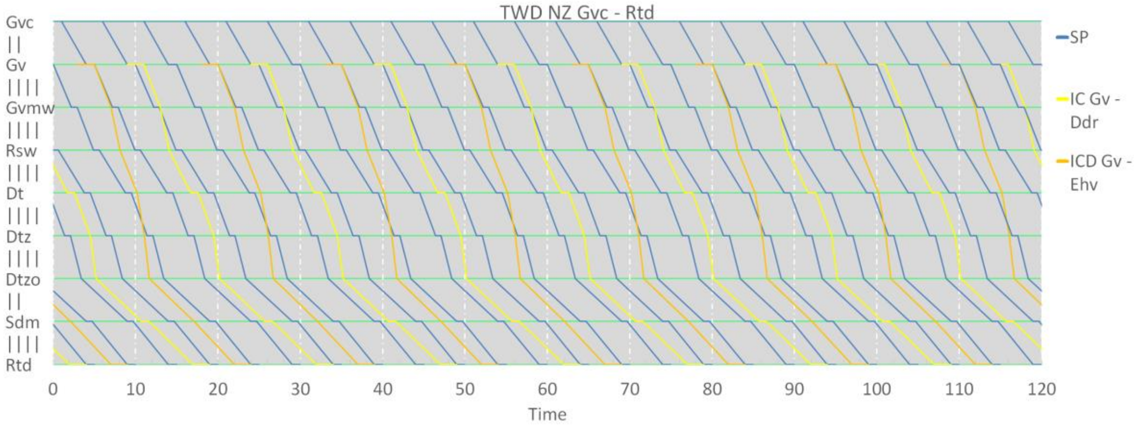
Crossing opposite direction		Train 2			
		A	D	K	V
Train 1	Arrival (A)	3	2	1	1
	Pass (D)	4	3	4	1
	Short Stop (K)	6	5	6	1
	Departure (V)	6	5	6	2

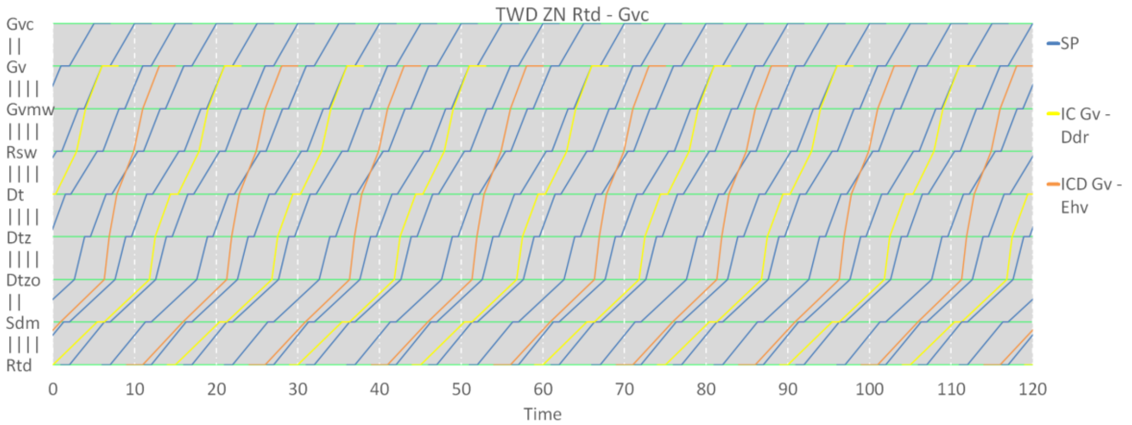
Appendix D: TWDs scenario 1

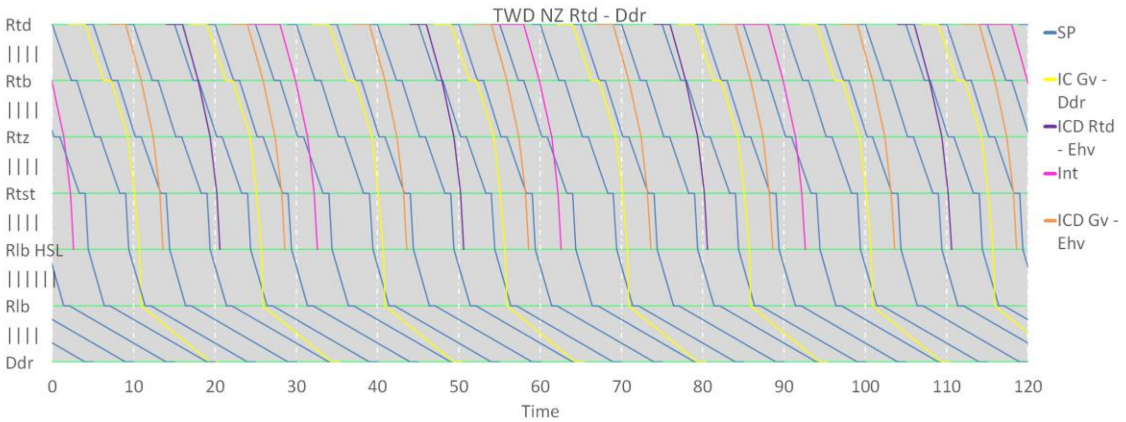


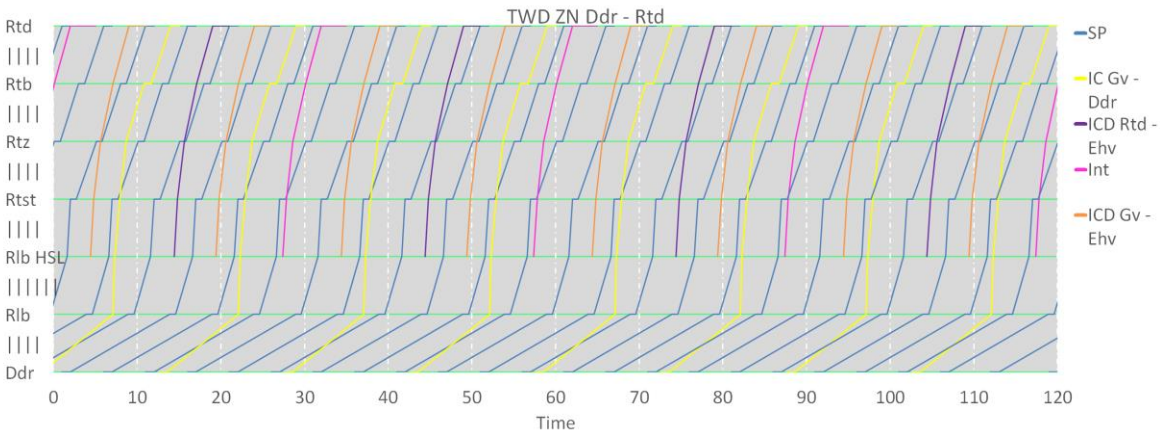


Appendix E: TWDs scenario 2









Appendix F: TWDs scenario 2b