RandstadRail Performance Review

January 2016

HTM

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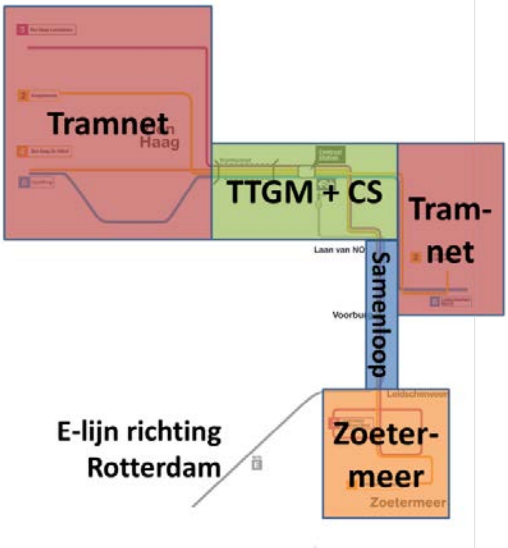


Bron: HTM (bewerkt door Mott MacDonald)

In 2006 zijn de voormalige Zoetermeerlijn en Hofpleinlijn omgebouwd tot lightraillijnen. Deze worden door HTM en RET geëxploiteerd onder de naam RandstadRail. RandstadRail verbindt het tramnetwerk van Den Haag met de metro van Rotterdam en het centrum van Zoetermeer, deels via een gedeelde infrastructuur voor trams en metro's ('de samenloop'). De RandstadRail biedt zes keer per uur een directe verbinding van de metro van Rotterdam met Den Haag CS (lijn E). Daarnaast rijden tramlijnen 3 en 4 gezamenlijk in de spits 18 keer per uur per richting van Zoetermeer via de samenloop naar het tramnet van Den Haag.

RandstadRail is een uniek netwerk van tram en metro dat in relatief korte tijd is uitgegroeid tot een succesvol systeem. De reizigersaantallen zijn hoger dan verwacht bij aanleg en de reizigers waarderen het geleverde product. Echter, de reiziger ervaart ook dat er regelmatig storingen optreden, waarbij soms urenlang geen trams en metro's rijden. Daarnaast kost het in de huidige operatie moeite om 24 voertuigen per uur per richting te rijden op de samenloop, terwijl de vervoersvraag hoger is en het systeem is ontworpen voor 30 voertuigen per uur per richting.

Vraag en aanpak

HTM heeft Mott MacDonald gevraagd om een onafhankelijke review op hoofdlijnen uit te voeren van de prestaties van RandstadRail, onder andere met betrekking tot infrastructuur, voertuigen en operatie. Hiervoor heeft Mott MacDonald meer dan dertig interviews met betrokken partijen gehouden, beschikbare documenten bestudeerd en data geanalyseerd. Daarnaast is met behulp van een operationeel model bepaald wat de maximale capaciteit van RandstadRail is en is met behulp van scenario's onderzocht hoe de dienstregeling kan worden geoptimaliseerd en hoe verhoging van de capaciteit kan worden gerealiseerd.

Scope

De scope van dit onderzoek zijn de HTM RandstadRaillijnen 3 en 4. Waar deze lijnen beïnvloed worden door HTM-lijnen 2 en 6 en RET-lijn E zijn deze ook in beschouwing meegenomen. De studie richt zich op de huidige prestaties van de RandstadRail, gedurende het jaar 2015.

Huidige prestaties RandstadRail

Klantwaardering

RandstadRail biedt een frequente verbinding tussen de steden Rotterdam, Den Haag en Zoetermeer. De reizigers waarderen deze verbinding, dat blijkt ook uit de 7,4 die RandstadRail gemiddeld scoort in de 'OV Klantenbarometer'. Uit interviews met stakeholders, zoals gemeenten en reizigersorganisatie Rover, blijkt ook een hoge waardering voor het product RandstadRail.

Uit de interviews en de klantenbarometer blijkt dat communicatie en reisinformatie, met name in geval van verstoringen, van onvoldoende kwaliteit is. Het wordt daarom aanbevolen om op korte termijn de omroep in voertuigen en op haltes beter te benutten om reizigers bij verstoringen beter te informeren.

Punctualiteit

De punctualiteit (gedefinieerd als minder dan 2 minuten vertraging) is bepaald voor de periode van januari tot april 2015 voor de belangrijkste haltes. Afhankelijk van de lijn en richting, ligt deze tussen 63 en 88 %. Dit is een lage waarde, waarmee niet voldaan wordt aan het programma van eisen van de RandstadRail. Gezien de hoge frequentie waarin wordt gereden, betekent het dat voertuigen elkaar vaak vertragen. Verbetering hierin is mogelijk door het optimaliseren van de gezamenlijke dienstregeling van HTM en RET en het invoeren van wachthaltes voor het ingaan van de samenloop en de Tramtunnel Grote Marktstraat (TTGM).

Betrouwbaarheid

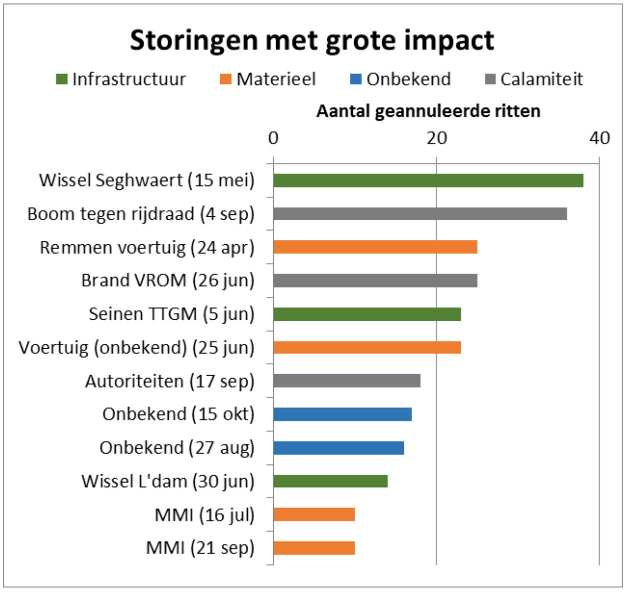
De RandstadRail kent een hoog aantal storingen. Analyse van storingsgegevens laat zien dat er meerdere oorzaken zijn voor de verstoringen (zie Figuren S.1 en S.2). De meeste rituitval wordt veroorzaakt door voertuigstoringen, gevolgd door storingen in de infrastructuur en calamiteiten. Wanneer wordt gekeken naar de verstoringen met de grootste impact, blijkt dat deze in de drie categorieën in gelijke mate voorkomen (zie onderstaande grafieken). Verdeling van de storingen naar locatie laat ook geen significante verschillen zien tussen het Lightrail net, het Tramnet en de Tramtunnel Grote Markstraat inclusief Den Haag CS. Hieruit volgt de conclusie dat er geen eenduidige oorzaak is voor het hoge aantal verstoringen.

Uit de analyse van de storingsgegevens blijkt dat de bronoorzaak van het probleem vaak onbekend is (dit komt onder andere terug in de grote categorieën 'onbekend' en 'overig' in Figuur S2). Het is bijvoorbeeld vaak niet bekend welke component van het wissel daadwerkelijk de oorzaak is van de storing. Er vinden vaak correctieve maatregelen plaats, zoals het direct resetten bij een storing. Hiermee wordt de werkelijke oorzaak niet achterhaald en verholpen, waardoor de kans groot is dat dezelfde storing op een later moment opnieuw plaatsvindt. Door de oorzaken van problemen te achterhalen en structureel op te lossen wordt een grote reductie van storingen verwacht. Dit begint met het uitvoeren van betrouwbaarheidsanalyses, als onderdeel van een overstap naar een preventief en voorspellend onderhoudsregime.

Op basis van de beschikbare storingsgegevens is gekeken naar mogelijke oplossingen van storingen. Bij de voertuigen van HTM lijkt de grootste aandacht uit te moeten gaan naar de remmen en deuren. In de infrastructuur lijkt verbetering mogelijk door frequenter onderhoud van wissels en modificatie van de wisselaanstuurkast.

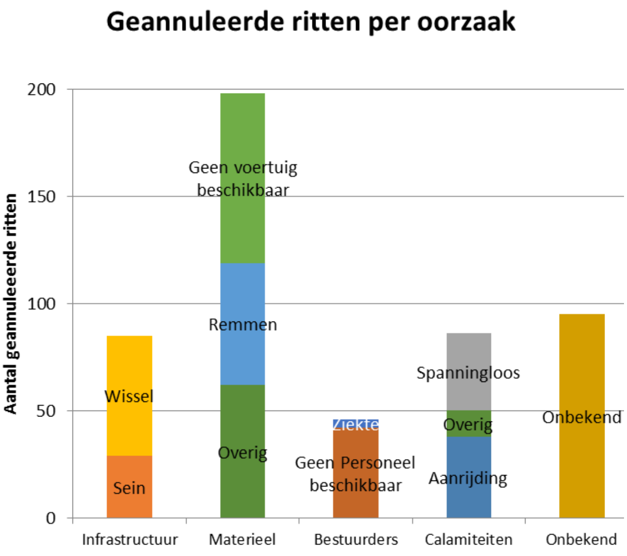
Het samenlooptracé is een technisch complex systeem, met meerdere types voertuigen, twee vervoerders en verschillende beveiligingssystemen. Dit heeft tot gevolg dat in de safety case strenge eisen zijn gesteld aan de infrastructuur en dat de infrastructuur twee verschillende wielprofielen moet faciliteren. De hogere complexiteit betekent echter ook een grotere kans op storingen. Het wordt daarom geadviseerd om te onderzoeken of aanpassing van de normen in de safety case mogelijk is, zodat het systeem versimpeld kan worden, waarmee de storingskans vermindert.

Figuur S.1: Storingen met grootste impact



Bron: Incidentregister Taskforce, lijnen 3 en 4, April t/m Oktober 2015 (bewerkt door Mott MacDonald)

Figuur S.2: Aantal geannuleerde ritten per oorzaak



Bron: Incidentregister Taskforce, lijnen 3 en 4, April t/m Oktober 2015 (bewerkt door Mott MacDonald)

Naast het voorkomen van storingen, kan ook gezorgd worden voor betere afhandeling van storingen en vermindering van de impact hiervan. Uit het onderzoek is gebleken dat de impact van storingen wordt vergroot doordat er geen alternatieve reismogelijkheden zijn, communicatie bij verstoringen gebrekkig is, de tijd tot herstel van het defect lang is en bijsturing niet altijd optimaal verloopt. Het aanbieden van alternatieve reismogelijkheden is lastig, omdat er geen alternatief traject is voor de samenloop. Het verkleinen van de impact van verstoringen kan wel op de punten van communicatie, bijsturing en hersteltijd. Het wordt daarom aanbevolen om te zorgen voor een betere positionering van het operationeel controle centrum als coördinator bij verstoringen en om de organisatie zo in te richten dat de hersteltijd bij verstoringen, met name bij verstoringen op de samenloop of rondom Den Haag CS, wordt verkort.

Mogelijkheden voor capaciteitsverhoging

Om de capaciteit van de RandstadRail, in het bijzonder de samenloop en de Tramtunnel Grote Marktstraat, te bepalen is een operationeel model ontwikkeld waarin de dienstregeling, de infrastructuur en de voertuigen zijn gemodelleerd. Op basis van simulaties van de huidige dienstregeling bleek dat verbetering van de bestaande dienstregeling mogelijk is, o.a. door betere afstemming met RET en het invoeren van wachthaltes voor het begin van de TTGM en de samenloop.

Om de capaciteit te vergroten kan frequenter of met gekoppelde voertuigen worden gereden. Extra capaciteit door gekoppeld rijden is enkel nog mogelijk op lijn 3. Met simulaties in het operationeel model is aangetoond dat een frequentieverhoging naar 30 keer per uur per richting op de samenloop, conform de ontwerpspecificatie, mogelijk is in onverstoorde situatie, mits de dienstregeling is geoptimaliseerd en de wachthaltes zijn geïntroduceerd. Echter, gezien het aantal verstoringen wordt een structurele frequentie-verhoging op dit moment niet geadviseerd vanwege de langere hersteltijden bij verstoringen. Daarnaast zal, voor het kunnen rijden van hogere frequenties, de tractie- en energievoorziening op de samenloop aangepast moeten worden en dient het onderhoudsregime aangepast te worden op hogere frequenties.

Tevens is gekeken naar een verdere verhoging van de frequentie naar 36 voertuigen per uur per richting. Een dergelijke frequentieverhoging vraagt een nieuw beveiligingssysteem en tegelijkertijd kunnen halteren van trams met hoge en lage instap op de samenloop. Hiervoor is verder onderzoek nodig naar de benodigde wijzigingen in de infrastructuur, de voertuigen, de operatie, het onderhoudsregime en de bijbehorende safety case.

De meeste ruimte voor frequentieverhoging ontstaat door het ontvlechten van de E-lijn naar een parallel traject waardoor er geen samenloop meer is tussen HTM-tram en RET-metro. Dit heeft als bijkomende voordelen dat een alternatieve reismogelijkheid ontstaat in geval van verstoringen en dat de complexiteit van de systemen op de huidige samenloop verlaagd kan worden. Dit is echter een zeer ingrijpende maatregel in de zin van kosten, ontwerp, inpassing en tijd. Een minder ingrijpend alternatief is het aansluiten van het Lightrailnet uit Zoetermeer op lijn 19, zodat lijn 3 en/of 4 via lijn 19 en lijn 2 naar Den Haag CS kunnen rijden. Deze optie biedt een alternatieve reismogelijkheid voor reizigers bij verstoringen op de samenloop en biedt ruimte voor capaciteitsverhoging. Echter, het rijden via lijn 19 heeft langere reistijden voor de reizigers vanuit Zoetermeer tot gevolg. Tevens zorgt dit alternatief niet voor ontvlechting van de HTM-tram en RET-metro.

Samenvatting maatregelen

Tabel S1: Samenvatting maatregelen

Maatregel	Effect	Kosten
Storingen voorkomen: ▪ Voertuigen: preventief onderhoud verhogen, bronoorzaak van storingen verhelpen ▪ Infrastructuur: frequenter onderhouden wissels en seinen, bronoorzaak van storingen verhelpen, systeem evt. versimpelen door modificatie wissels	Hogere beschikbaarheid en betrouwbaarheid	Zeer beperkt (< €1 miljoen), eventuele voertuigmodificaties of versimpelingen van systeem vergen investering
Optimaliseren huidige dienstregeling en wachthaltes voor ingaan samenloop en TTGM; in samenwerking tussen HTM en RET	Hogere punctualiteit en hogere robuustheid	Minimaal

Maatregel	Effect	Kosten
Frequentieverhoging naar 30 voertuigen per uur per richting; vereist: optimalisatie dienstregeling, wachthaltes, voldoende herstel bij verstoringen en verhoging capaciteit tractie- en energievoorziening	Capaciteitsverhoging	Beperkt (< €5 miljoen); exclusief aanschaf extra voertuigen
Frequentieverhoging naar 36 voertuigen per uur per richting; vereist optimalisatie dienstregeling, nieuwe beveiligingsfilosofie, tegelijk halteren van HTM en RET-voertuigen, voldoende herstel bij verstoringen en verhoging capaciteit tractie- en energievoorziening	Capaciteitsverhoging	Hoog (€ 20-50 miljoen); exclusief aanschaf extra voertuigen
Parallel traject voor de E-lijn: ▪ Geheel parallel traject E-lijn ▪ Aansluiten lijn 3 en 4 vanuit Zoetermeer op lijn 19	Capaciteitsverhoging en alternatieve reismogelijkheid. ▪ Voor geheel parallel traject hogere betrouwbaarheid door versimpeling systeem ▪ Voor Zoetermeer aansluiten op lijn 19: langere reistijd	Geheel parallel traject: Zeer hoog (> €200 miljoen) Zoetermeer aansluiten op lijn 19: Hoog (€25-30 miljoen)

Bron: Mott MacDonald

List of abbreviations

Acronym	Definition
AC	Alternating Current
AMS	Asset Management System
CCTV	Closed-circuit Television
DC	Direct Current
DEWEMO	Interface between interlocking and switch motor
EBS	Exploitatie Beheer Systeem
EMI	Electromagnetic Interference
FDU	Fault Display Unit
ITCS	Train Control
KPI	Key Performance Indicator
LZB	Linienzugbeinflussung (cab signalling)
MDBF	Mean Distance Between Failures
MDBSF	Mean Distance Between Service affecting Failures
min	Minutes
MRDH	Metropoolregio Rotterdam Den Haag
NFF	No Fault Found
PA	Personal Announcement
PID	Passenger Information Display
PORR	Projectorganisatie RandstadRail
ppm	Planned preventative maintenance
tph	Trams/trains per hour
tphpd	Trams/trains per hour per direction
TTGM	Tramtunnel Grote Marktstraat
VICOS	Signalling information system
UIC	Union internationale des chemins de fer – Internationale Spoorwegunie

1 Introduction

This is the final report for the RandstadRail Performance Review, which was carried out by Mott MacDonald on request of HTM. It provides a high level overview of the system performance of the Randstadrail.

This chapter describes in short the background of the study, followed by the research questions. In section 1.3 the methodology of work is described and in section 1.4 the scope and limitations. The chapter ends with a reading guide of the report.

1.1 Background

RandstadRail is a relatively new light rail network within the Southern Randstad of the Netherlands, connecting The Hague, Zoetermeer and Rotterdam. It uses a mix of metro and tram to provide a high quality service to the passengers. It is jointly operated by HTM and RET jointly and is regarded as a success in terms of ridership, but is considered to underperform in terms of operations, customer experience and public opinion.

The product RandstadRail is complex with many dependencies and interfaces. It has many stakeholders, two operators (HTM and RET), complex technical subsystems and complex processes internal and external to HTM. Parties and agreements are not optimally aligned and have a limited focus on the passengers' interests.

HTM has requested Mott MacDonald to perform a high level review of the RandstadRail system to understand what elements contribute to the poor performance of the system and to provide suggestions for improvements.

1.2 Research questions

The main research questions are:
1. What is the current performance of RandstadRail and how can the performance be improved (chapter 3 and 4)?
2. What is the maximum capacity of the RandstadRail and how can the current capacity be increased (chapter 5)?

1.3 Methodology of work

The review comprises a two stage approach. The first stage aimed at answering the first research question, by creating a high level overview of the system's performance and possible issues related to the reliability or engineering of e.g. rolling stock, infrastructure or operations.

The second stage focused on more detailed aspects which influence the performance of the RandstadRail, with the aim of identifying opportunities for improvement and optimisation. Furthermore, possibilities to increase capacity are elaborated with the help of an operational model. In the following sections, a further elaboration of the methodology of the two stages is given.

1.3.1 Stage 1: high level overview of performance

In order to develop a high level overview of the performance of the RandstadRail system, information on the system and its performance has been collected by performing interviews, observing the functioning of the system and analysis of available documents, information and data. To support this, Mott MacDonald has drawn upon their experience of other light rail systems to provide a comparison of the level of performance of RandstadRail.

Interviews have been carried out with:

- senior staff from HTM, including management, operational and maintenance staff;
- the task force team of HTM (which has been set up by HTM internally to deal with performance issues);
- maintenance contractors VolkerRail and Siemens;
- staff from RET and MRDH;
- policy makers from Zoetermeer, Leidschendam-Voorburg and the Hague; and
- the passengers' representative organisation Rover.

Information has been collected regarding the system performance by:

- observing and riding the system in operation at both peak/off-peak times;
- visiting the depots; and
- analysing data on disturbances, operations, etc.

A full list of interviews can be found in Appendix A. The received documentation is listed in Appendix B.

Based on the preliminary findings from the interviews and the system analysis an initial draft overview has been provided for discussion and agreement with HTM in the form of several presentations and the Stage 1 Report[1].

1.3.2 Stage 2: recommendations for improvement

In the second stage, a more detailed analysis of available data has been performed, in order to try to identify causes for underperforming of (parts of) the system. Based on this analysis, recommendations for improvement of the system performance are given.

In order to define the maximum capacity of the RandstadRail and analyse possibilities to increase the current capacity, an operational model has been developed. By performing simulations in this model, variations in timetables, increase of frequencies, changes in operations and adjustments of infrastructure were tested. This provides recommendations for possible increase in passenger capacity.

[1] RandstadRail performance review, stage 1, Mott MacDonald, July 2015, rev. A.

1.4 Scope

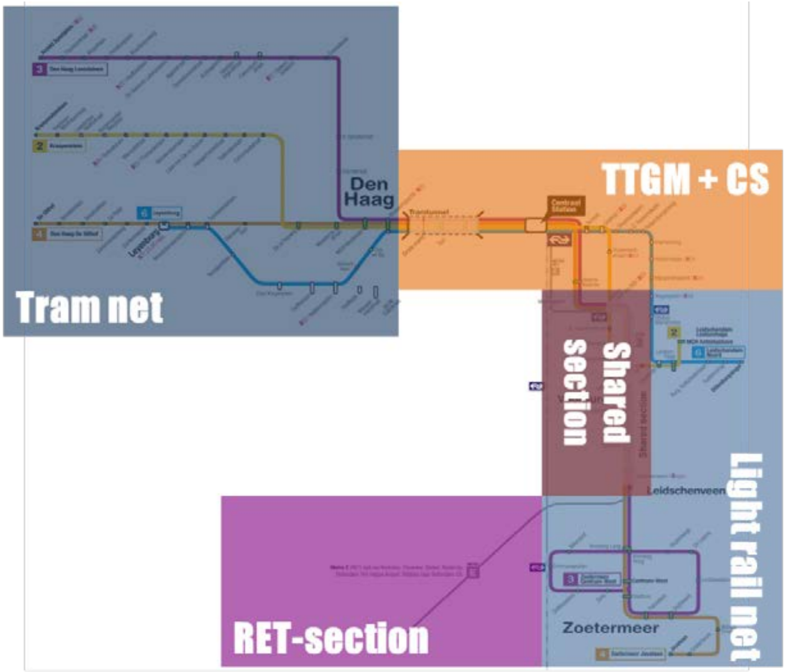
The scope of the review is the RandstadRail system, with its infrastructure, rolling stock, operation, organisation and asset management. In geographical terms (see also Figure 1.1), the scope consists of the shared section ('samenloop'), the stop at Den Haag CS and the Light rail net. Only where they influence the performance of RandstadRail, also the RET-section and the Tram net area ('Tramnet' or 'Binnengebied') are considered. Other areas and possible extensions of the network are out of scope of this review.

The emphasis has been on the performance of the service of line 3 and 4. To this extend, the E-line has been considered for the part that is running on the shared section and lines 2 and 6 are considered for the part that is running in the Tramtunnel Grote Marktstraat (TTGM). Other tram and bus services are not considered as long as the service is not influencing the HTM tram lines 3 and 4.

The review focusses on the performance of the RandstadRail system during approximately the year 2015. The exact period of time considered differs based on available data.

The primary focus has been on the operational performance and the primary causes that adversely affect this. Ancillary areas such as driver behaviour, incident management or incident recovery receive limited coverage in this report as this is covered partly by the Taskforce RandstadRail and is mentioned as less of an issue in the interviews.

Figure 1.1: Sections of RandstadRail



Source: HTM (adapted by Mott MacDonald)

1.5 Reading guide

This report consists of six chapters. Chapter 2 gives a high level overview of the design of RandstadRail and its history. In Chapter 3 and 4 focus is on the current operation. First, chapter 3 provides an analysis of current performance of RandstadRail, measured in passenger satisfaction, punctuality and reliability. Subsequently chapter 4 details the analysis of performance for each of the different parts (rolling stock, infrastructure, asset management and operations). It also suggests possible improvements to the current system performance. Chapter 5 focusses on a possible increase in capacity of the RandstadRail. In all chapters, conclusions and recommendations for that part of the review are stated. The report ends with an overview of the most important conclusions and recommendations (chapter 6).

2 Design and history

In this chapter, key facts on the RandstadRail design are given in the first paragraph. In the second paragraph, some inside is given in the history of the RandstadRail.

2.1 Overview of operations and design

RandstadRail consists of four tram lines (lines 2, 3, 4 and 19), a metro line (line E) and a bus service (line 170) connecting the cities of The Hague, Rotterdam and Zoetermeer. RandstadRail is operated by HTM (tram lines) and RET (metro line and bus service). The main focus of this report is on the two tram lines between The Hague and Zoetermeer, lines 3 and 4.

RandstadRail is considered HTM's premier product and is also one of the most successful lines in terms of ridership. Lines 3, 4 and E carry over 100,000 riders per day of which 70% is carried by HTM and 30% by RET. During a passenger count in April 2013 it was estimated that, at rush hour between 7am and 9am, on average 4,500 passengers are taking line 3 and 4, and 2,000 passengers take the E-line.

2.1.1 Infrastructure

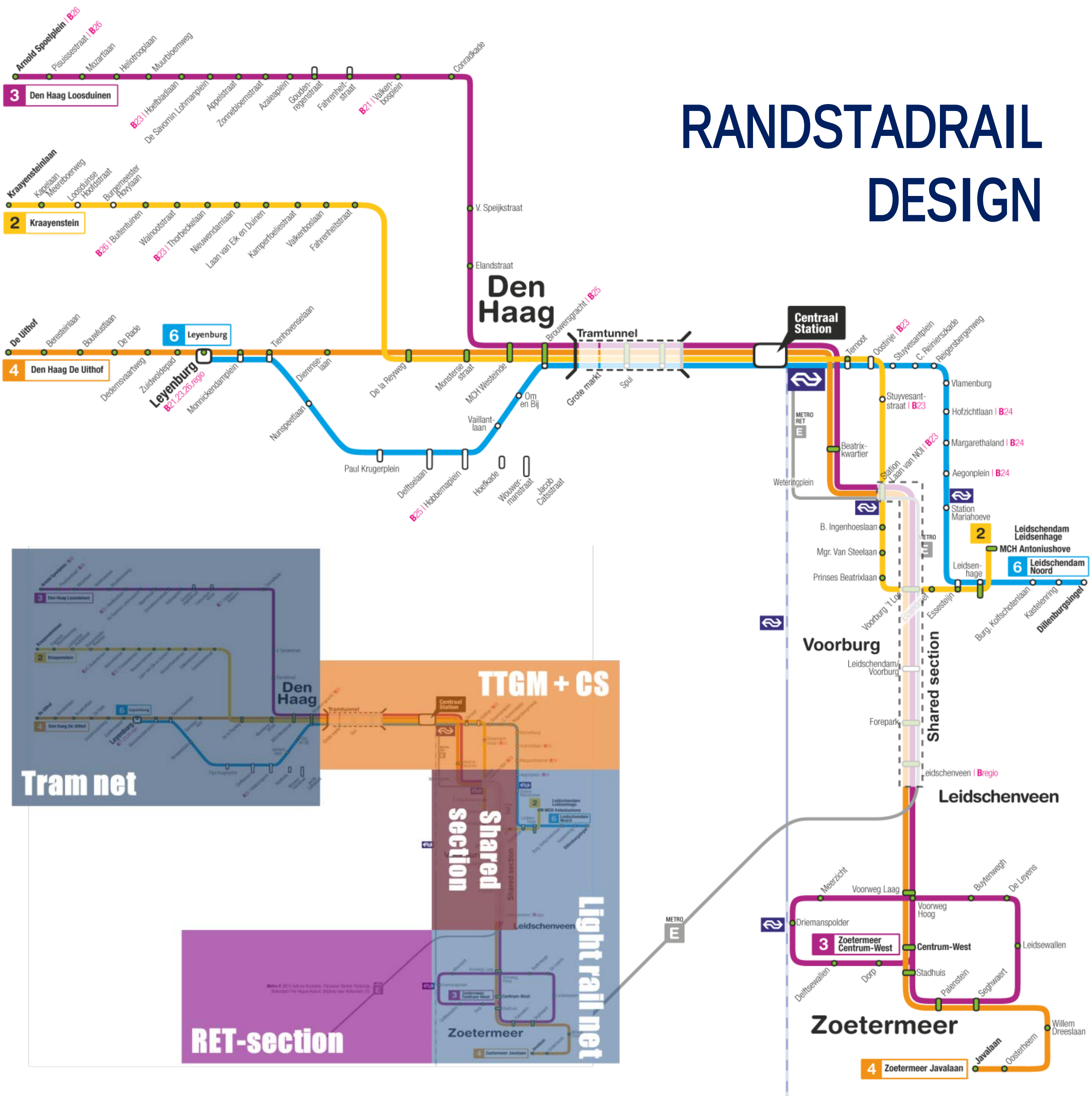
RandstadRail lines 3 and 4 run from the west of The Hague to Zoetermeer and pass both through the Tramtunnel Grote Markstraat (TTGM) and, at elevated level, through The Hague Central Station. The TTGM and the tracks at the Central Station are shared with tram lines 2 and 6. From station Laan van NOI to station Voorburg the line is shared with the RET E-line.

The infrastructure is divided in three sections: the Tram net area (in the city of The Hague), the Central Tunnel section including Den Haag CS and the Light Rail area, including the 'shared section'. The shared section is the infrastructure which are shared between the trams of HTM and the metro of the E-line of RET (see also Figure 2.1).

An extension of the RandstadRail is planned at Javalaan for the project Bleizo. Plans are developed for an extra tail track at Pijnacker and the redesign of the crossing near Beatrixkwartier, where the shared section commences.

The Tram net and Central Tunnel section are maintained by the in-house contractor of HTM. The outer area is maintained by VolkerRail with the switch machines and switch-pull rods under contract of Siemens, which has in turn subcontracted part of the maintenance to VolkerRail. RET is maintaining its own section of infrastructure, between Pijnacker and Rotterdam (RET-section in Figure 2.1).

Figure 2.1: Line layout of lines 2, 3, 4, 6 and E

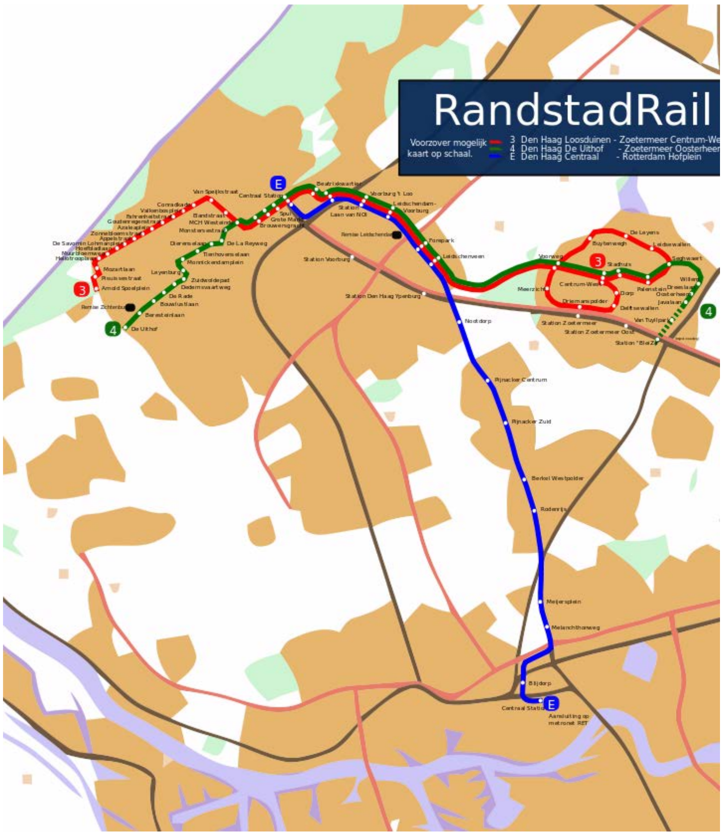


Source: HTM (adapted by Mott MacDonald)

Some relevant elements of the system:

- In the Tram net area, lines 3 and 4 have on street running tracks and are running on line of sight;
- The Tramtunnel Grote Marktstraat and the stop at the Central Station, which are shared with lines 2 and 6, have its own signalling system from BBR Verkehrstechnik;
- The shared section runs from just before Laan van NOI until Leidschenveen. This shared section:
  - has both high floor and low floor platforms to accommodate for the different HTM and RET vehicles; and
  - has a ZUB-signalling system, designed by Siemens.
- The shared section and the Light rail area in Zoetermeer have a voltage of 750V as compared to 600V for the Tram net of the HTM. This requires the RegioCITADIS vehicles to be compatible for dual voltage.
- The E-line has its own stop at Central Station; this stop is being renewed at the moment; and

Figure 2.2: RandstadRail network



Source: RandstadRail

2.1.2 Rolling stock

Figure 2.3: RegioCITADIS

HTM is operating the RandstadRail lines with 72 RegioCITADIS trams, each consisting of three cars, supplied by Alstom. They were delivered in two series: the first series (vehicle 4001-4054) in 2007 and the second series (vehicle 4055 to 4072) in 2011. The second series is equipped with wheel-flange lubrication. Trams 4001 – 4025 and 4055 – 4072 have automatic couplers on the tram to allow for driving in coupled mode with other RegioCITADIS trams. All are low floor bidirectional vehicles and run at a maximum speed of 80 km/h.

The HTM has on-board ticket validators (OV-Chipkaart) and ticket vending machines. The RegioCITADIS each has a capacity of 216 passengers of which 72 are seated. There are three stabling yards where the HTM RegioCITADIS vehicles are stabled: Zichtenburg, Leidschenveen and Javalaan.

Figure 2.4: Bombardier Flexity

RET is operating the RandstadRail line E with 27 Flexity Swift metros from Bombardier, each consisting of two cars. These vehicles are all high floor bidirectional vehicles and have a maximum speed of 100 km/h. Ticket validation takes place at the platform. The Flexity Swift metro each has a capacity of 270 passengers per vehicle of which 104 are seated.

2.1.3 Operations

In normal operation lines 3, 4 and E each run 6 times an hour in each direction. E-Line always operates in coupled vehicle mode. During some periods, also line 4 has been running in coupled mode, and since the start of timetable 2016 (December 2015), line 4 runs coupled. Line 3 runs single, and the stops in the centre and the used rolling stock currently do not facilitate driving in coupled mode.

In addition to the regular lines 3 and 4 both have a short version (3K and 4K) which runs during peak hours. Line 4K operates between the stops Javalaan and Monstersestraat and is thus passing the Tramtunnel Grote Markstraat (TTGM) and the shared section. Line 3K operates between the stops De Savornin Lohmanplein and Centraal Station. It passes the TTGM, but not the shared section. Together with lines 2, 6 and E, it results in a frequency of 24 trams per hour per direction through the shared section and 36 trams per hour per direction through the Tramtunnel Grote Marktstraat, as can be seen in Table 2.1.

Table 2.1: Origin and destination of lines 2, 3, 4, 6 and E.

Line	Origin	Destination	Frequency during peak hours (per hour, per direction)	Approx. duration (min)
3	Den Haag Loosduinen	Zoetermeer Centrum-West	6	66
4	Den Haag De Uithof	Zoetermeer Javalaan	6	54
E	Rotterdam Slinge	Den Haag Centraal Station	6	46
3K	Den Haag De Savornin Lohmanplein	Den Haag Centraal Station	6	19
4K	Den Haag Monstersestraat	Zoetermeer Javalaan	6	37
2	Kraayenstein	Leidschendam Leidsenhage	6	44
6	Leyenburg	Leidschendam Noord	6	35

Source: HTM timetable

The Tram net area, Tramtunnel Grote Marktstraat, shared section and Zoetermeer area are controlled by HTM. The RET section from Pijnacker to Rotterdam is controlled by RET. Communication with both types of vehicles is possible by both control centres.

2.2 History and design requirements

Before RandstadRail lines 3 and 4 commenced operation a major part of the infrastructure was in use as heavy rail line between Zoetermeer and the Hague (‘Zoetermeer Stadslijn’) and between Scheveningen and Rotterdam (‘Hofpleinlijn’). The former heavy rail lines were transformed into a light rail network and connected to the tram network of The Hague and the metro network of Rotterdam. The works were carried out in the summer of 2006 and took just over three months.

Already in 1988, the first ideas of a light rail network in the area of The Hague and Rotterdam under the name of RandstadRail were launched. The goal of the project was to connect the light rail networks of The Hague and Rotterdam, in order to facilitate commuters in the area. In the years between 1988 and 2000, various scenarios for a RandstadRail network were studied. In 2000 an agreement was reached between the local governments and the Minister of Transport, Public Works and Water Management and in 2002, the Minister took the formal decision to go ahead with the RandstadRail project.

A project organisation, ‘Projectorganisatie RandstadRail’ (PORR) was commissioned to manage the design and construction of RandstradRail. The PORR operated under the responsibility of the municipality of The Hague. The design and construction was carried out by BAM and Siemens. During the period of design and construction, various difficulties concerning the infrastructure and alignment between rolling stock and infrastructure arose. For example, it appeared that the ‘Zoetermeerlijn’ was in a bad condition, so more work was needed to be carried out to prepare for operations.

HTM and RET were made responsible for the operation and procurement of rolling stock. HTM procured their rolling stock for lines 3 and 4 by Alstom. RET decided to use vehicles from Bombardier, as on the Rotterdam metro.

The design specification of RandstadRail in 2006 included the following requirements for the shared section:

- Punctuality:
  - In 99% of the cases a vehicle leaves maximum 1 minute late from the starting point;
  - In 99% of the cases a vehicle arrives maximum 4 minutes late at a stop;
  - In 95% of the cases a vehicles arrives maximum 2 minutes late at a stop;
  - No vehicle leaves a stop too early;
- Frequency: 30 vehicles per hour per direction with minimum unhindered headways of 90 seconds on the shared section;
- Line speed: 80 km/h;
- Up to 42,000 passengers per day on lines 3 and 4; and
- Up to 17,000 passengers per day on the E-line to/from Rotterdam.

In 2006 operations of RandstadRail started. However, the start was problematic due to multiple derailments on the shared section, where vehicles from HTM and RET run together. As a result, operations were halted until October 2007. The switches were identified as one of the causes of the derailments. The switches were revised to better fit the two different wheel profiles of the HTM and RET vehicles. In October 2007 operations restarted again for lines 3, 4 and E. Later several expansions were added to the system.

In the research of the TU Delft[2] and the Onderzoeksraad voor de Veiligheid (OVV)[3] it was identified that the alignment between rolling stock and infrastructure in the design and construction was insufficient. Next to this, safety cases were not yet complete at the start of the operations.

In 2009 several studies were conducted on the capacity of the RandstadRail system. A frequency of 24 vehicles per hour per direction on the shared section was the maximum achievable, whilst a frequency of 30 vehicles per hour per direction was designed. Based on studies conducted by Movares and Siemens[4], several improvements to the signalling system were made. A few signals were relocated and all signals were fitted with a ZUB-circuit. This ZUB-circuit enables the vehicle to pick up the colour of the signal before it reaches the signal.

Although the switches on the shared section were revised before continuing operations in 2007, they showed a high level of disturbances. Based on a study of BoschSpoor[5], in the autumn of 2013 renewal of the switches and the switch machines and pull rods was carried out by Siemens. Next to this, a new contract was awarded to Siemens to make one company responsible for the switches and interlocking. However, up to today RandstadRail still encounters a high number of disturbances.

[2] 'Het RandstadRail-project: Lightrail, Zware Opgave', Ernst ten Heuvelhof et al., TU Delft, 26 February 2008, ISBN 9789056381929

[3] 'Ontsporingen bij RandstadRail', R.H.C. Rumping et al., Onderzoeksraad voor de Veiligheid, November 2008, M2006RV1129-04

[4] Attachment to letter 'Performance verbetering RandstadRail perceel 1', R. van den Bert, HTM, 9 July 2009, /09-51897909

[5] 'Wisselproblematiek in het buitengebied van het Haagse deel van de RandstadRail', ir. Roel van den Bosch, 7 May 2013, BS080/02

3 Performance

This chapter presents the performance of RandstadRail on a high level. The performance is measured in stakeholder satisfaction (paragraph 3.1), punctuality (paragraph 3.2) and reliability (paragraph 3.3).

3.1 Stakeholder analysis

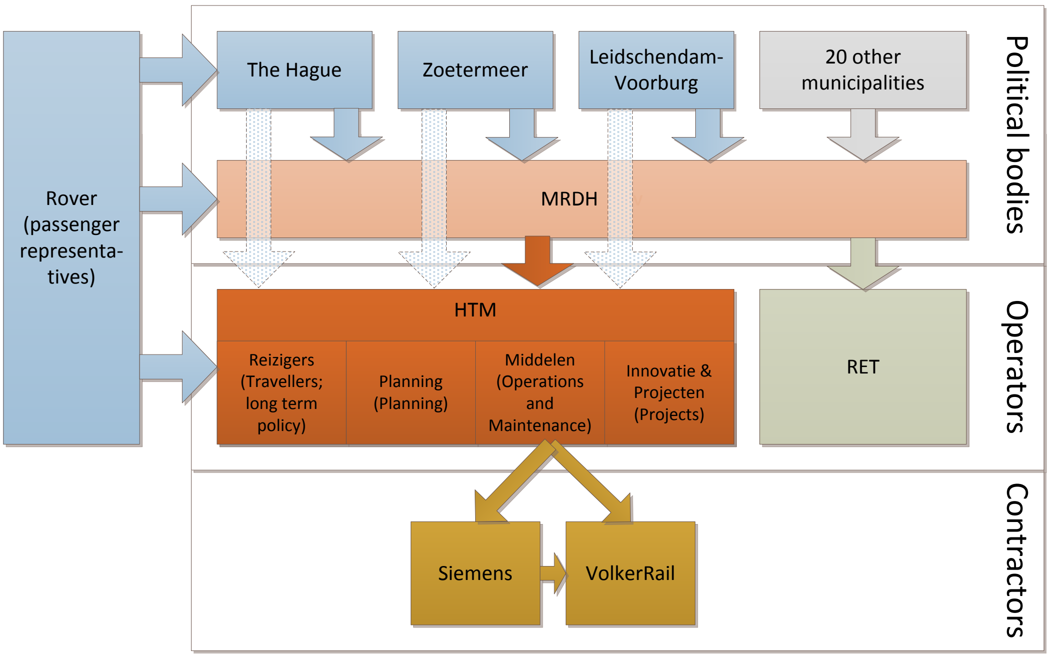
Interviews were carried out with the following groups of internal and external stakeholders to gain an overall view of the expectations, issues and other perspectives on RandstadRail:

- HTM: Planning, Operations and Control, Asset management and 'Reizigers' (responsible for long term planning and concession);
- MRDH (concessionaire to HTM for both infrastructure and operations);
- RET: Operational Control Centre;
- Historical perspective: Project manager Signalling (2002-2007), Project manager RandstadRail to improve service (2008-2009), RET technical director (2008-2011);
- Municipalities: Senior policy makers of The Hague, Zoetermeer and Leidschendam-Voorburg;
- Contractors: Siemens and VolkerRail;
- Passengers' representative organisation: Rover.

The complete list of interviews can be found in Appendix A.

The list below provides key points of interpretations and views held by the different stakeholders. Due to the number of interviews, not all can be or have been independently verified. However, it provides a indication of where to focus and what elements are performing better or worse within the RandstadRail-system. In Figure 3.1 a stakeholder map with their respective relationships is provided.

Figure 3.1: Stakeholder relationships



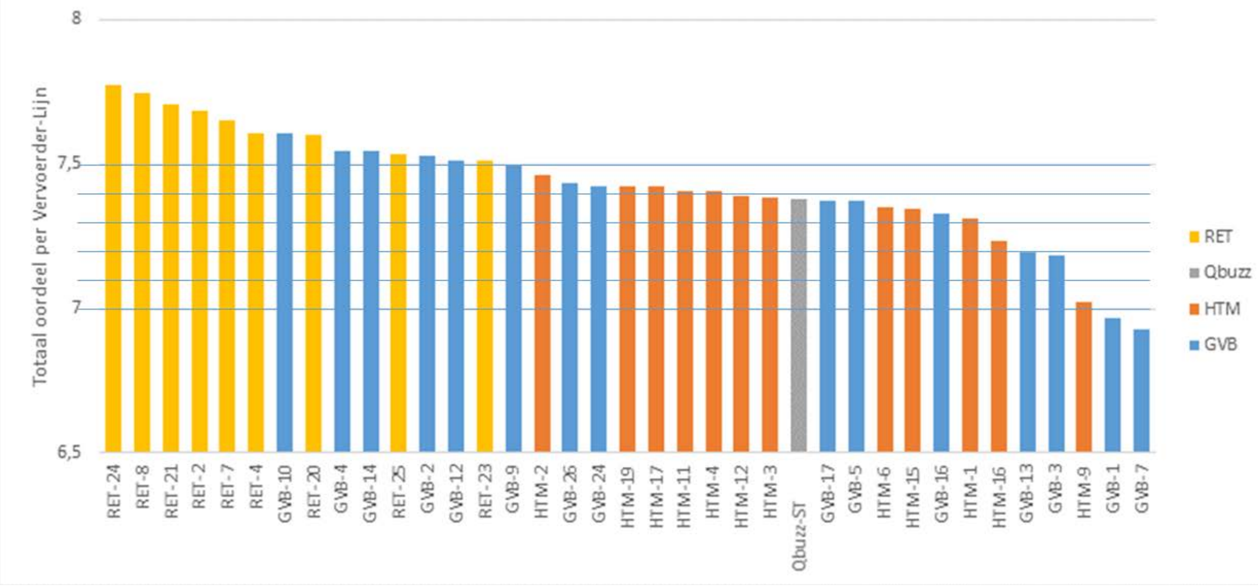
Source: Mott MacDonald

3.1.1 Key points from external stakeholders

Key points highlighted by external stakeholders' (passengers, municipalities) points of view:

- The general opinion of stakeholders is positive regarding RandstadRail in terms of service and frequency. They understand that the service cannot be failure-free and accept limited numbers of disturbances. It is also perceived that drivers are friendly;
- Communication and travel information, in particular during disruptions, is considered poor and needs to improve significantly. This was considered the highest priority for the municipality of Zoetermeer, but is mentioned by all municipalities as the key issue to resolve. This becomes most apparent in the marking HTM receives from passengers on the annual 'OV Klantenbarometer'. HTM scores a 7.4 (out of 10) on RandstadRail in general – similar to other tram and metro systems in the Netherlands. However, on travel information in case of disruption, HTM scores only a mark of 5.1 (out of 10) which is lower than average. It is recommended in the short term to make better use of the announcement system in vehicles and at stops to better inform passengers in case of disturbances.

Figure 3.2: Satisfaction of all tram lines in the Netherlands, based on the OV-Klantenbarometer



Source: OV Klantenbarometer 2014

- Reliability of service is mentioned as an issue – '90% of trips are on time however with 10% there is a problem'. Most problematic in this case is also the limited travel information provided to passengers on the cause and duration of the disruption.
- The recent communication from HTM to municipalities and stakeholders regarding the reliability/performance data was appreciated, but with the cautionary note – 'if correct'. This information has been provided recently as part of the Taskforce RandstadRail and stakeholders would like to receive this information on a regular basis. It would not be considered too difficult to build on this by regularly reporting performance and holding frequent meetings with the interested parties.
- The HTM Twitter site is considered good. However, disruption information at the stops is not always consistent. It is noted a new software tool – Infoactueel – is being implemented.

3.1.2 Key points from internal HTM points of view

Below an overview of key points from the interviews with employees of HTM is given.

- A lack of communication between departments and working in silos is considered a significant problem, as opposed to working in an integrated manner and keeping the passenger's interest as the top priority.
- Punctuality has improved owing to the changed focus following the appointment of the new managing director but also owing to improved cooperation between Assets (Infrastructure and Vehicles) and Drivers.
- The organisation is quite reactive and focussing on solving problems, with limited focus on the lessons learnt from these problems.
- There is not one single asset owner of the tram fleet at HTM. One manager is responsible for the availability of the fleet while another is responsible for the reliability of the fleet. It is understood this has changed recently, however it is unclear to Mott MacDonald what the intentions of this change are.
- Switches are considered the biggest problem in terms of reliability, even after the renewal of several switches by Siemens.
- The fall back scenarios at the shared section are limited in case of a disturbance. Only one tail track exists and some sections are a few kilometres long, creating a big impact on the operations in the case of single track running.
- The organisation of providing travel information is complex with the ownership of the information being with HTM, whilst, the Passenger Information Displays (PIDs, in Dutch 'DRIS') are owned and maintained by MRDH.
- The driver shift system ('slippende bemanning') is perceived as efficient for required number of drivers but not so beneficial for passengers in case of disruptions as due to little slack in the drivers diagrams longer recovery times occur after a disruption.

3.1.3 Key points from meetings with RET and MRDH

The list below gives key points from the interview with RET and MRDH. RET is the operator of the Rotterdam section of the RandstadRail and MRDH is the transportation authority for the conurbation of The Hague and Rotterdam and concessionaire to HTM and RET.

- Concerns were expressed over the quality of RandstadRail, the public image of HTM is experienced as poor whereas of RET it is viewed as good. There are differences identified between HTM and RET in terms of organisation, approach and former management. It was acknowledged that the relationship between HTM and RET is complex with regards to operational control.
- HTM, RET and MRDH would like to increase service frequencies on RandstadRail to accommodate more passengers, but the current infrastructure is limited. The following (conflicting) elements are mentioned:
  - A conflict exists where lines 3 and 4 converge with RET line E: this is a bottleneck. There is no 'flex/spare capacity' in the system.
  - The system currently runs at 24 vehicles per hour per direction. In current operations, it does nog appear possible to increase operating capacity to the design capacity of 30 vehicles per direction per hour in the shared section.

- The signalling system on the shared section is 10 years old and does not allow for an increase of capacity. Section lengths within the shared section are considered long and therefore represent a constraint.
- Stations are designed for double car operation. However, shared stopping of HTM and RET is not allowed due to safety regulations and the signalling system.
- Currently there is a project in the design stage to introduce a tail track near Pijnacker which should, accommodate a higher frequency between Rotterdam and Pijnacker. Extension of the increased frequency to The Hague is not considered to be possible in the short term, given the capacity of the shared section.

- MRDH is designing KPIs for the system but does not have a measure for rolling stock reliability monitoring (e.g. MDBSF). It is noted that MRDH is focussing more on the infrastructure KPIs.
- There are many occasions when the road traffic in the city is causing delays in the tram services. This is not always due to HTM. The municipality of The Hague could potentially better design and optimise the road layouts and traffic support operations in this respect.

3.1.4 Key points from meetings with contractors Siemens and VolkerRail

3.1.4.1 Contractual point of view

In the interviews, VolkerRail and Siemens both indicate that they would like to work on the basis of a more predictive maintenance regime. The manner in which the contracts have been arranged is not optimal due to budget constraints and the fact that the contracts are input-oriented. The contracts are managed on a unit price based approach e.g. by number of tracks to be renewed, number of inspections to be carried out, etc. The HTM respond to VolkerRail with regards to identification of work arising is ‘to see if it can be done within existing VolkerRail budget’. Only very limited budgets were made available in the past years to carry out the required (preventive) maintenance.

The VolkerRail contract is for maintenance only. They are required to obtain approval from HTM for any repairs arising, although some common minor repairs can be carried out without approval, if budget is available from the yearly budget. HTM may ask VolkerRail to reduce maintenance in one area and increase maintenance in another to stay within budget.

VolkerRail has the following KPI’s, which are, according to the contract, reported on a monthly basis:
- Number of works planned on time, target value 100%;
- Number of works performed on time, target value 100% performed within 7 working days of planned date;
- Number of reopened work orders, target value 0;
- Number of exceedances of response time, target value 0;
- Number of exceedances of time to come to a temporary or definite solution, target value for both 0.

The KPIs of VolkerRail focus on the timing of solutions, not on the quality of the maintenance.

Siemens is responsible for the maintenance of point machines of the switches and not the whole switch assembly. Siemens has subcontracted VolkerRail for their part of the switch. However, due to this double contract, Siemens is not (yet) responsible for the complete functioning of the switch.

Siemens has a function restore time of 3 hours, but to rectify an in service fault usually no more than 15 minutes is allowed (usually in-between services) for access to the asset. Therefore little time remains to investigate and establish the root cause of failures.

The main KPI for Siemens is the technical and functional availability, not reliability, which is shared with HTM in Siemens' monthly reports and in the face-to-face monthly meetings with HTM to discuss performance. Next to this, most of the failures occurring to the switches or signalling system are, according to Siemens, exogenous to their system. A large number of reported failures are due to miscommunication and mismanagement.

The allocation of responsibilities between VolkerRail and Siemens is complex and does not define a clear scope. This becomes most apparent in a switch failure, whereas it is not always clear what causes the element to fail. This results for instance in all three parties (VolkerRail, Siemens and HTM) visiting the switch in case of an incident.

3.1.4.2 Organization

VolkerRail considers HTM to be reactive and has asked HTM what VolkerRail should focus their maintenance activities on. The response has been to apply the same level of maintenance to a low usage switch as to a high usage one. VolkerRail has suggested applying preventative maintenance which includes focussing on finding the root cause of failures and solving these. However, HTM has given preference to attending failures as quickly as possible with a prompt arrival on site and reset of the failure without identifying or addressing the root cause. This is also visible in the KPIs from HTM to VolkerRail, see paragraph 3.1.4.1

VolkerRail is willing to participate in improving reliability and has made various unsolicited proposals to HTM to improve performance of the system. Recently, a proposal to start a reliability programme on the switches has been implemented ('K2-programma'), see paragraph 4.2.3.

3.2 Punctuality

HTM does not, at least on a management level, regularly report on punctuality. Consequently, punctuality numbers were not available to Mott MacDonald while carrying out this performance review.

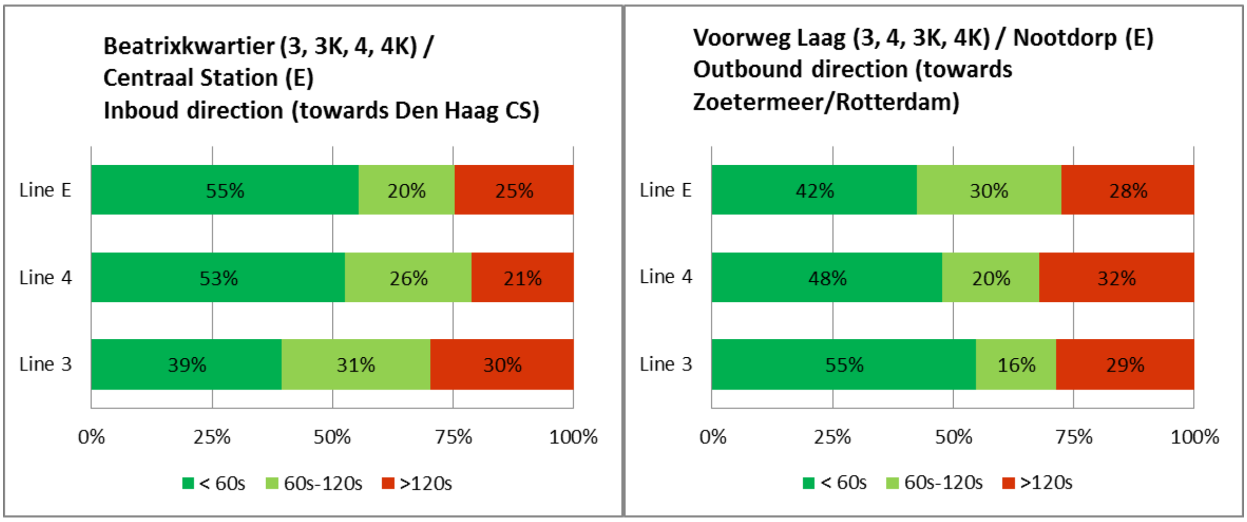
To gain an understanding of the performance of RandstadRail in terms of punctuality, Mott MacDonald has calculated punctuality data using ITCS-data (timetable statistics) of 26 January 2015 to 31 March 2015 for lines 3(K) and 4(K) and 05 January 2015 to 01 April 2015 for line E. The ITCS data is compared to the timetable as valid during that period. Based on this comparison, punctuality is calculated for vehicles departing one minute later than planned and two minutes later than planned (1-minute and 2-minute punctuality). In Table 3.1 below, an overview of punctuality at the main stops in focus is given.

Table 3.1: Punctuality at main stops

Station	Line 3		Line 4		Line E	
	1-minute	2-minute	1-minute	2-minute	1-minute	2-minute
Inbound (towards Den Haag CS)						
Voorweg Laag	44%	84%	61%	88%	34%	63%
Leidschenveen	39%	78%	56%	83%	38%	65%
Beatrixkwartier/Den Haag CS	39%	70%	53%	79%	55%	75%
Brouwersgracht	43%	73%	56%	77%	n/a	n/a
Outbound (towards Rotterdam/Zoetermeer)						
MHC Westeinde	59%	82%	55%	82%	n/a	n/a
Brouwersgracht	58%	81%	51%	79%	n/a	n/a
Beatrixkwartier/Den Haag CS	60%	79%	52%	74%	72%	88%
Laan van NOI	56%	78%	56%	73%	47%	78%
Voorweg Laag	55%	71%	48%	68%	42%	72%

Source: ICTS data (adapted by Rambøl and Mott MacDonald)

Figure 3.3: Punctuality at Beatrixkwartier (line 3&4) / Den Haag CS(line E) (inbound) and Voorweg Laag (line 3&4) /Nootdorp (line E) (outbound)



Source: ICTS data (adapted by Rambøl and Mott MacDonald)

In Figure 3.3 the punctuality is visualised in a graph, in this example for Beatrixkwartier for the inbound direction (towards Den Haag CS) and Voorweg Laag for the outbound direction (towards Zoetermeer/Rotterdam). These are the 'ends' of the shared section, thus showing the performance of the shared section. As can be seen in the graphs, approximetely half of the vehicles departes at least one minute late at the end of the shared section, and approximetely a quarter departes more than two minutes late.

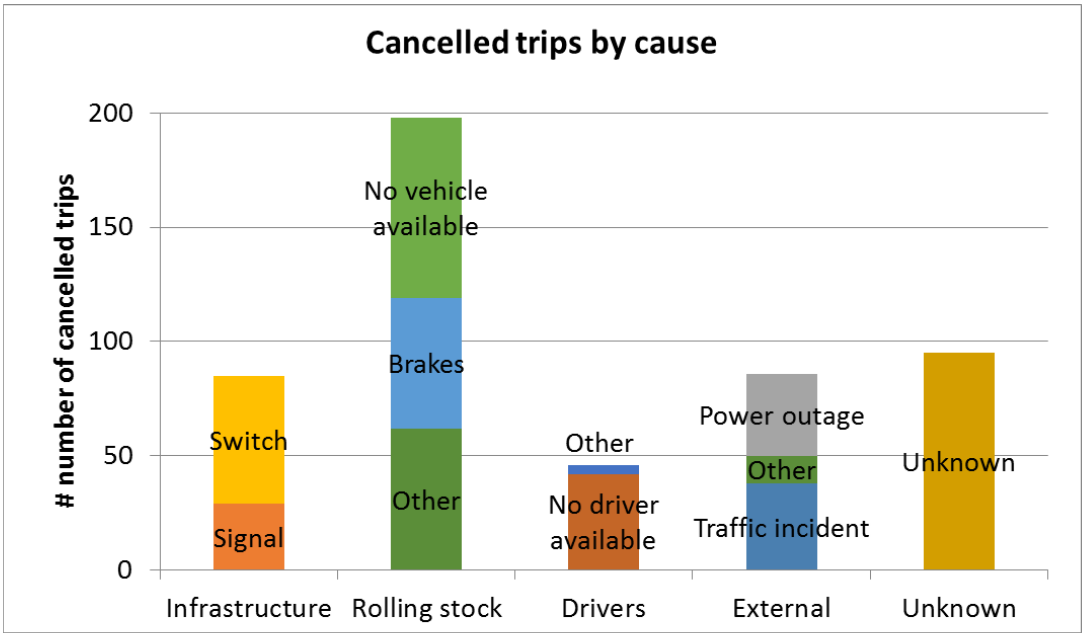
In general for all stations in the shared section, the 1-minute punctuality is around 40 to 50%, as can be seen in the table. This means that, on average, more than half of the vehicles departes more than one minute late at every stop. The 2-minute punctuality differs between 63 and 88%. At a frequency of 24 vehicles per hour per direction, approximately every 2.5 minute a vehicle arrives. If the previous vehicle is more than two minutes late, it is almost certain the following vehicle will be hindered by the previous one. In line with what is expected, the delays are increasing reaching the end of the line. The exception being line E which receives additional time to recover in the forelast stop. Although there are no KPI target values, the punctuality of the RandstadRail is considered too low and does not meet the design nor the consession requirements.

3.3 Reliability

Mott MacDonald carried out a high level review of disturbances by using the 'incidentregister' collected by Taskforce HTM since April 2015 up to end of October 2015. On a daily basis the number of services withdrawn and details providing the cause of the failure is reported. This data is used to identify the areas that affect service most.

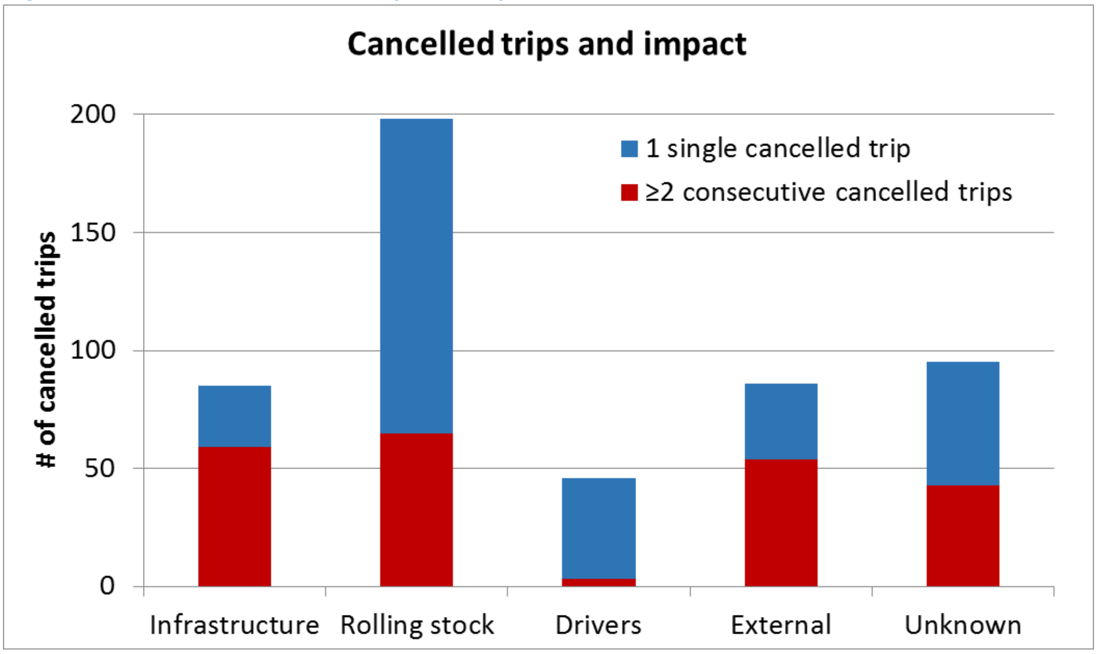
Based on the data, the graphs in Figure 3.4 and Figure 3.5 have been made, both representing main causes of cancelled trips (infrastructure, rolling stock, drivers, external factors and unknown). In Figure 3.4, the cancelled trips are categorised by their cause. In Figure 3.5, further analysis has been carried out regarding the impact of the failure, namely whether there is only one trip cancelled, or two or more trips cancelled consecutively.

Figure 3.4: Number of cancelled trips by cause



Source: Incidentregister Taskforce (adapted by Mott MacDonald)

Figure 3.5: Number of cancelled trips and impact

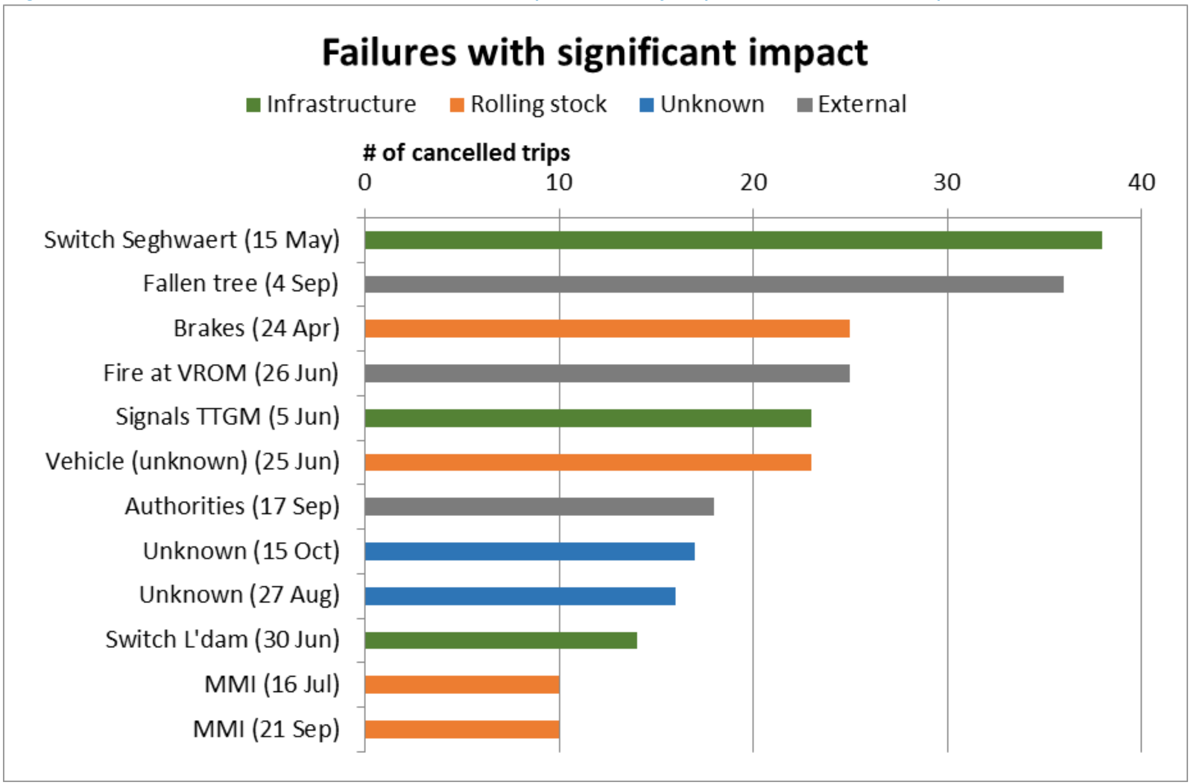


Source: Incidentregister Taskforce (adapted by Mott MacDonald)

From the above figures it is clear that rolling stock is the most significant cause of cancelled services. However, failures of rolling stock have in approximately 70% of cases not had a significant impact on passengers as it results mainly in a single cancelled trip thereby adversely affecting a smaller number of passengers and no 'knock on' effect compared to multiple trips for e.g. infrastructure failures. In most cases the cause is unavailability of a vehicle in the morning. The same accounts for drivers, where most cancelled trips are due to a driver not being available in the morning. Infrastructure failures are due to mainly switch or signal failures. These failures have a significant impact on service as in 70% of these failures result in multiple trips being cancelled.

In Figure 3.6, the data is ordered after the failures with most impact, measured as the amount of consecutive cancelled trips. In the period April to October there were twelve failures with significant impact of which three were infrastructure related, four were rolling stock related and three were due to other causes. The cause of two incidents was unknown at the time of recording.

Figure 3.6: Failures with at least 10 cancelled trips, sorted by impact. Lines 3 and 4, April 2015-October 2015

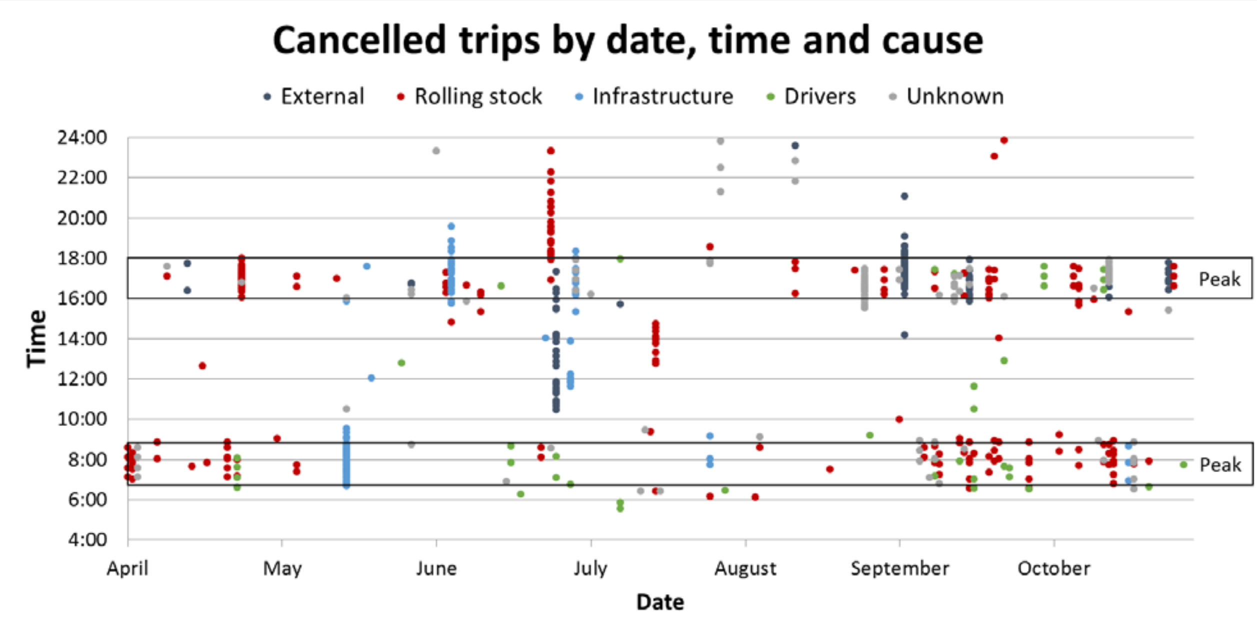


Source: Incidentregister Taskforce (adapted by Mott MacDonald)

There is a common view that switches, or more general infrastructure, are the major cause of disruption. This is probably due to the fact that a disruption caused by any switch failure is significant and will certainly be apparent owing to the effect it has on the system i.e. severe disruption, and therefore memorable to all involved. However, as is demonstrated above, rolling stock, external incidents and signal failures are causing approximately the same number of significant disruption to regular service and should also be addressed.

In Figure 3.7 it is shown when and why a trip was cancelled. In 67% of the cases a trip was cancelled during peak hours (7 – 9AM and 4 – 6PM). It also highlights that, in case of disruption, time required to restore services after an incident was significant, up to six hours. The average time to restore service is 2 hours and 21 minutes for an infrastructure A-failure, based on data from January to October 2015 received from the Taskforce.

Figure 3.7: Cancelled trips by date, time and cause, April-October 2015, lines 3 and 4. Each dot is a single cancelled trip.



Source: Incidentregister Taskforce (adapted by Mott MacDonald)

The graph also highlights the number of single trips being cancelled. In nearly three out of five working days (57%) a single trip is cancelled and one out of five working days (17%) two or more consecutive trips were cancelled. A single cancelled trip is not causing any significant delays to the passenger other than those on the affected vehicle, however, multiple cancelled consecutive trips are causing significant delays to the passenger and should be avoided. There is no correlation identified between the number of cancelled trips and the line number (line 3 or 4).

This analysis was only possible due to collection of cancelled trips and their cause by the Taskforce since April 2015. This is a very positive development and should be continued and expanded in the future to include punctuality data and other key performance indicators to include reliability. However, the data shows a lot of causes as ‘unknown’ or ‘other’. This means that it is unknown how a failure is caused and therefore how it should be prevented next time. Therefore, collection and quality of data should be improved (see section 4.3.3).

3.4 Summary of performance

The above paragraphs describe the performance of the RandstadRail in terms of passenger satisfaction, punctuality and reliability. This paragraph gives a summary of this conclusisons and recommendations. In the next chapter the causes of these performance is detailed out.

The general opinion is positive about RandstadRail in terms of service and frequency. Policymakers and passengers' representatives understand the service cannot be failure-free and accept limited numbers of disturbances. It is also perceived that drivers are friendly, but driving standards can be addressed. However, communication and travel information, in particular during disruptions, is considered poor and needs to improve significantly. This is apparent in the mark of 5.1 (out of 10) for travel information in the 'OV Klantenbarometer'. It is recommended in the short term to make better use of the announcement system in vehicles and at stops to better inform passengers in case of disturbances.

Concerns were expressed over the public image of HTM, which is viewed as poor whereas of that of RET is viewed as good. There are differences identified between HTM and RET in terms of organisation and approach. It was acknowledged that the relationship between HTM and RET is complex with regards to operational control.

The punctuality on a 2-minute basis varies between 63 and 88 %, depending on line and stop. This is considered a too low value and does not meet the design nor concession requirements. Considering the high service frequencies, it means vehicles are often delaying each other. Improvement is possible by optimisation of the joint timetable of HTM and RET and by applying regulation at the entrance of the shared section and the Tramtunnel Grote Markstraat (TTGM). Further improvement can be gained if less failures occur; see the next section.

Analysis of available data shows that there are multiple causes for disturbances. Rolling stock failures accounts for the highest number of cancelled trips, followed by failures in infrastructure and external factors. When considering the failures with the highest impact, all three categories account for a comparable number and are therefore equally important in reducing the number of failures occurring. This analysis has only been made possible due to collection of cancelled trips and their cause since April 2015. This is a very positive development and should be continued and expanded in the future. However, the data shows a lot of causes as 'unknown' or 'other'. It is recommended to expand and improve data collection, data analysis and based on this, define of root causes of failures, to resolve the failure permanently and therefore reduce the number of cancelled trips.

4 System analysis

In the previous chapter, a description of the performance of RandstadRail is given in terms of reliability, punctuality, and stakeholder satisfaction. This chapter gives a description of the system of RandstadRail, and how this influences the performance. Together with this, recommendations for improvement are given. The chapter is split in four topics:

- rolling stock (paragraph 4.1);
- infrastructure (paragraph 4.2);
- asset management (paragraph 4.3); and
- operations (paragraph 4.4).

The chapter ends with a summary of conclusions and recommendations (paragraph 4.5) and an overview of all recommendations (paragraph 4.6).

4.1 Rolling stock

HTM operates RandstadRail with 72 Alstom RegioCITADIS vehicles, of which at least 62 vehicles are in service. These vehicles do not only run on RandstadRail; they are also used on line 19 and formerly on line 2.

This paragraph first describes the performance of the rolling stock (4.1.1), followed by an analysis of possible causes of failures (4.1.2) and some points on the cooperation with manufacturers of the rolling stock (4.1.3).

4.1.1 Performance

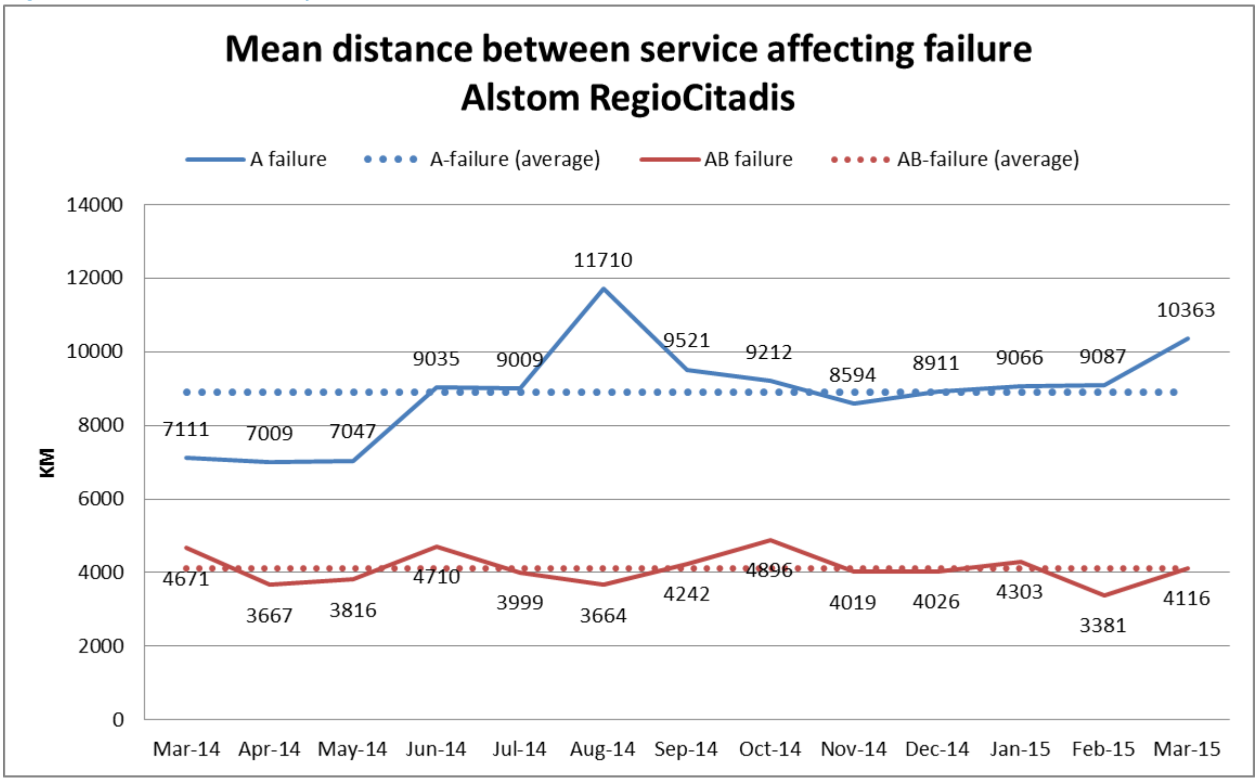
Based on the received data from Rimses for the period of March 2014 to March 2015 only a high level analysis could be carried out to produce a value for the 'Mean Distance Between Service affecting Failures' (MDBSF). This has been done for the Alstom RegioCITADIS vehicle. HTM uses three categories for failures:

- A-failures: a vehicles has to be taken out of service immediately;
- B-failures: a vehicle can continue service, but should be replaced when possible; and
- C-failures: all other failures, which are not service affecting.

The two graphs in Figure 4.1 illustrate the development of the MDBSF in the period of March 2014 to March 2015. The blue graph indicates the MDBSF for category A-failures, indicating the mean distance between two A-failures. On average, the MDBSF for category A-failures over the given period is approximately 9,000 km. The red line indicates the MDBSF if A-failures and B-failures are both considered to be service affecting. This gives an approximate value of 4,000 km for the MDBSF. Therefore, on average each vehicle has a category A- or B-failure per 4,000 km of service. Given the average number of kilometres of an HTM per vehicle per year of 80,000 km, each vehicle has almost nine A-failures per year, and almost every two weeks an A- or B-failure.

The results highlight the significant number of failures occurring within the rolling stock. A MDBSF of approximately 9,000 km is considered to be a very low value, compared to trams on other light rail systems. In general, the MDBSF of a modern tram fleet should be in excess of 21,000 km and for a reliable vehicle it is common to achieve a value of over 30,000 km between two failures. For example at Manchester Metrolink the tram is achieving targets in excess of 48,000 km. RET achieves approximately 40,000 km on their tram and metro services. However, it should be noted that any comparison or benchmarking with other fleets must be treated with some caution. There may be differences in the categorisation of what constitutes a service affecting failure, e.g. one system categorises a failure causing a delay of five minutes as service affecting, while another categorises only a vehicle withdrawn form service as service affecting. However, by only considering A failures as service affecting for HTM, it is expected that other systems will not have a three or four times higher MDBSF by only considering different failures.

Figure 4.1: MDBSF for only A-failures and for a combination of A and B failures



Source: Rimses from depot (adapted by Mott MacDonald)

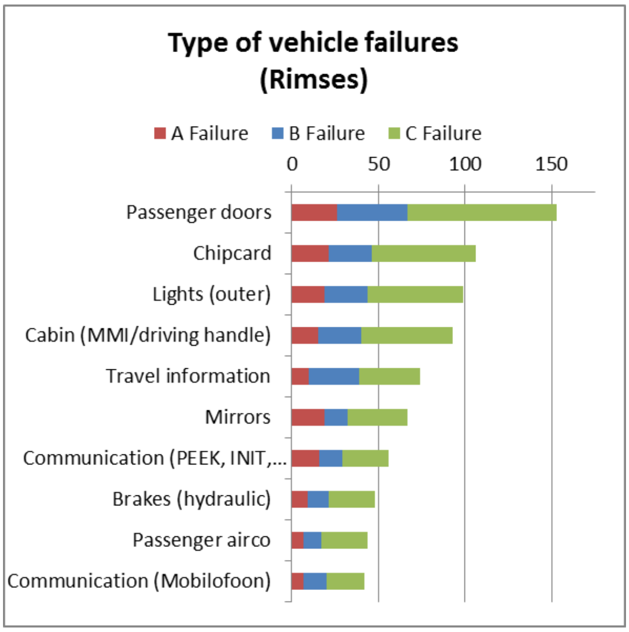
4.1.2 Failures

Approximately 50 vehicles are withdrawn from service each month based on the notification of a failure. In many cases there is a no fault found (NFF). It is understood that nearly 70% of all tram repairs are corrective and only 30% of the repairs is dedicated to preventative maintenance. Establishing a link between a disruption and its root cause is not easy as there is no structured recording and analysis of failures. The various data sources – Clientele, Maximo (formerly Rimses) and a separate spreadsheet –

are not helping in measuring the performance or conducting root cause analysis, let alone identifying improvement opportunities.

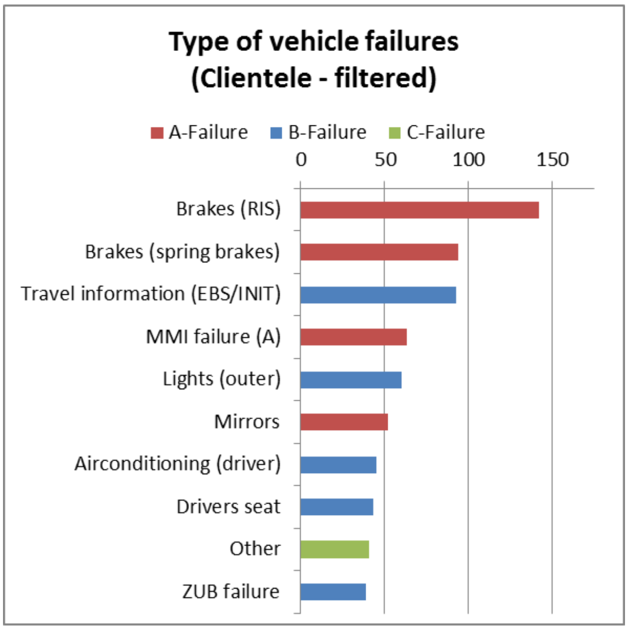
Utilising the available data from August 2014 to January 2015 a high level analysis was carried out to identify the faults that contribute most to service affecting failures, see Figure 4.2 and Figure 4.3. In this analysis, data from Rimses (Figure 4.2) and Clientele (Figure 4.3) is compared. The two data sources show very different top failures. This indicates unreliable data collection and differences in data input and storage between the two systems. Since root cause analysis is key factor in performing a predicative maintenance regime, it is recommended to improve data collection and data analysis, see also paragraph 4.3.

Figure 4.2: Number of vehicle failures in Aug 2014 to Jan 2015, based on Rimses; A+B-failures are service affecting, while C-failures are not service affecting.



Source: Rimses (adapted by Mott MacDonald)

Figure 4.3: Number of vehicle failures in Aug 2014 to Jan 2015, based on Clientele; A and B failures are service affecting, while C-failures are not service affecting.



Source: Clientele – filtered by HTM (adapted by Mott MacDonald)

When analysing the available data from Rimses, it can be seen that the cause 'Chipcard' scores high in terms of numbers of failures. It should be excluded from the failures of rolling stock, provided that the power supply and fixation of the Chipcard equipment to the vehicle is not the issue, as the Chipcard machine and software is outside the remit of the rolling stock team. Including it in the analysis would give a false impression of the vehicle's reliability. However, consideration should be given to whether it is in the passenger's interest that a tram is withdrawn from service when a ticket validator fails.

As can be seen in the graph in Figure 4.2, passenger doors, lights and the systems in the cabin are areas which give potential improvement opportunities and should be subjected to more detailed investigation.

Based on the available data on passenger doors, it seems that these failures are in many cases related to the door setup and their associated parameters.

Considering the Clientele failure database, the brakes are most significant and understandably disruptive to service. Currently modifications are being carried out to the flange lubrication system, brake safety switch and brake overhaul as part of a general overhaul of the bogies. It is important to monitor this implementation to ensure if the vehicle's reliability has improved as a result of this refurbishment.

In many cases the root cause of a failure is not identified. The system is reset and registered as 'in order' or 'no fault found'. This works as a short term solution, but will not improve the reliability of the vehicle in the long term as the root cause is not identified and therefore the cause of the failure is not solved. A trivial example of this is inflating a car tyre on a daily basis, which may be an effective short term solution, but in the long term identifying and repairing the leak is essential. Identifying the root cause of nearly all failures and identifying measures to prevent failures from occurring, will improve the reliability of the rolling stock, therefore resulting in less failures, and shift the workload to a more preventative and less corrective maintenance regime. This is described in more detail in section 4.3.

It is noted that the rolling stock asset management is short on resources to capture data and carry out data analysis. Ideally one person should have the ownership of this task for consistency with the aim of investigating and establishing the root causes of failures each week as staff and information will be available. The result should be presented each four week period. Over time trends and improvement opportunities can then be identified.

The perception is that not all drivers are of the same competence level for fault finding, which is strongly supported by the high level of failures registered as no fault found (NFF). Additional failure information is often available on the drivers Fault Display Unit (FDU), but is not recorded. Display of this fault code to the driver could be relayed to a control centre to accurately document the fault and inform technicians. It would also enable the control room to provide more support regarding rectification to the driver or allow the driver to follow a predetermined routine, for example by following instructions on a card to reset the tram. This may require a modification in the software by Alstom to make the information visible on the FDU.

There are some organisational issues, for example who is the fleet manager/engineer and therefore responsible for the availability and reliability of the trams? Who is maintaining the assets? Not one conclusive answer has been or can be given. It is noted that recently the department of infrastructure and rolling stock are separated. It is suggested that in the new organisational setup one asset manager is responsible for the availability and reliability of the trams.

4.1.3 Cooperation with rolling stock manufacturers

4.1.3.1 Alstom RegioCITADIS

The Alstom RegioCITADIS vehicles are now out of warranty and any modification to the vehicles would have to be funded by HTM. Despite the identification of improvements Alstom have remained unresponsive demonstrating poor after sales service, e.g.:

- HTM has been waiting one year for a response to a request for minor changes to a software parameter to extend shutdown time from 30 to 45 minutes.
- A modification is required from Alstom to allow the display of full failure information to driver i.e. fault codes, which can be relayed to control and hence the Asset Management System to aid rectification and provide better information to drivers regarding rectification.

Given the above response it does seem that, without any significant payment, Alstom is not willing to be of any assistance in the analysis of problems or development of solutions, nor willing to participate in a working group to address reliability issues. However, this should not prevent from Alstom being approached and given the opportunity to assist. Assuming Alstom will not be willing to do so, HTM must be prepared and be equipped to carry this out independently.

When introducing the Alstom RegioCITADIS in service, there was no process put in place with Alstom to focus on the reliability monitoring of the vehicles to ensure reliability growth. This lack of monitoring may be one of the reasons why these vehicles are underperforming. With the warranty period ended, any improvements to the RegioCITADIS vehicles are likely to require an investment.

4.1.3.2 Siemens Avenio

Although outside of the scope of this assignment, it is considered of great importance to learn from the Alstom RegioCITADIS experience and to agree on and put in place a process with Siemens to focus on the reliability monitoring and growth of the new Avenio trams whilst within the warranty period. It is in HTM's interest that they do not pay for changes during the warranty period and it is in the manufacturer's (Siemens) interest they meet the contractual reliability targets. In the process with Siemens the following should be noted:

- Early successes /improvements are the quick wins – 'the low hanging fruit', software, etc. – and this will deliver some benefits as evidenced by the early reduction in failures as vehicles are introduced.
- It is important that modifications can be implemented without any adverse effect on warranty or with limited risk.
- Not all modifications will be designed to deliver reliability improvements e.g. some are aimed at protecting warranty by addressing for example issues such as corrosion and chafing of cables.

4.2 Infrastructure

The infrastructure analysis is focussed on the overall performance of the RandstadRail lines, which is also influenced by the Beatrixkwartier, Tramtunnel Grote Markstraat (TTGM) and the Tram net in the inner city. The shared section is considered in detail. The first paragraph addresses the performance of the infrastructure in general. The second paragraph gives special attention to switches and signalling, followed by a description of a reliability improvement program in section 4.2.3.

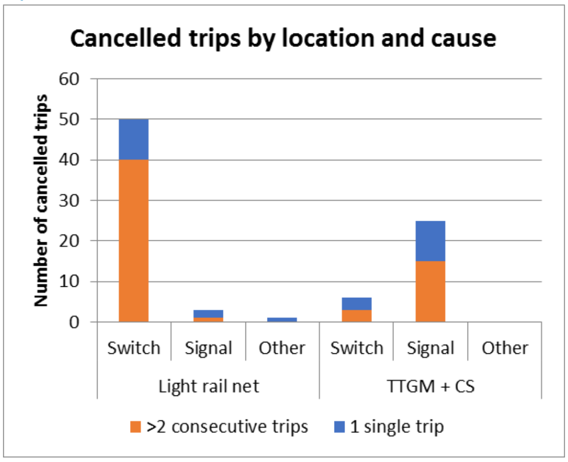
4.2.1 Performance

Utilising Maximo data (August 2014 to January 2015) and the 'incidentregister' of the Taskforce (containing data from April 2015 to October 2015) a high level analysis of infrastructure failures which have been reported into the various HTM systems was undertaken.

The charts in Figure 4.4 and Figure 4.5 below illustrate the infrastructure failures affecting line 3 and 4 on the Tram net, the Light Rail area (shared section and Zoetermeer section) and the TTGM, including Beatrixkwartier. The causes are split between signals, switches and other infrastructure. Figure 4.4 shows the number of cancelled trips, based on the 'incidentenregister'. Figure 4.5 shows the number of incidents, based on Maximo, where priority 1 and 2 are classified as service affecting. The data sources report failures in a different unit, namely 'number of cancelled trips' and 'number of incidents', which makes comparison and good analysis difficult.

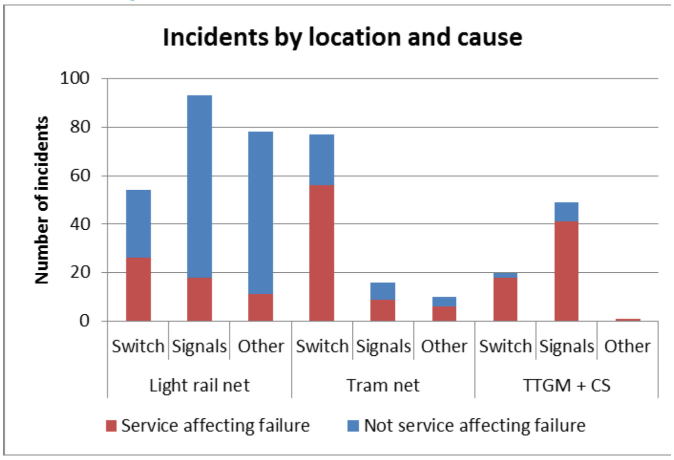
In Figure 4.6 the failures are categorized by repair and in Figure 4.7 by asset. This data is only available for the Light Rail area (shared section and Zoetermeer section) in the period of April to October 2015, as it is only collected in the 'incidentenregister' of the Taskforce and not by default in Maximo. In these graphs, service affecting is classified if the priority 1 is 2 is given; classification with priority 4 or 5 is not service affecting.

Figure 4.4: Number of cancelled trips, lines 3 and 4, April to October 2015



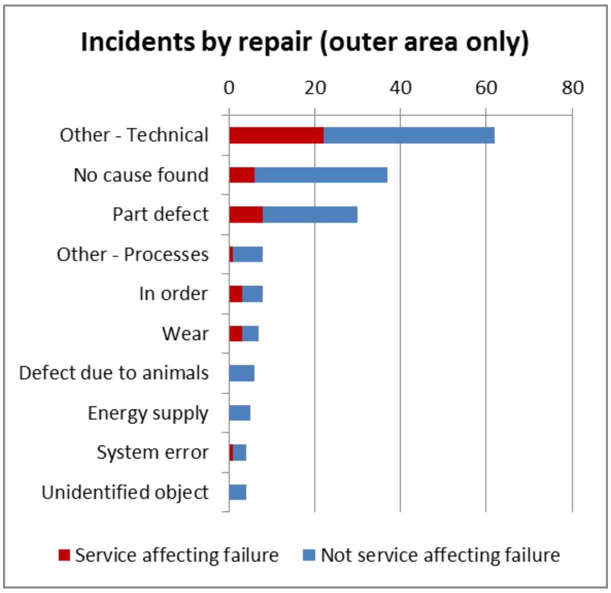
Source: Incidentregister Taskforce (adapted by Mott MacDonald)

Figure 4.5: Number of incidents by location and cause, lines 3 and 4, Aug 2014 to Jan 2015



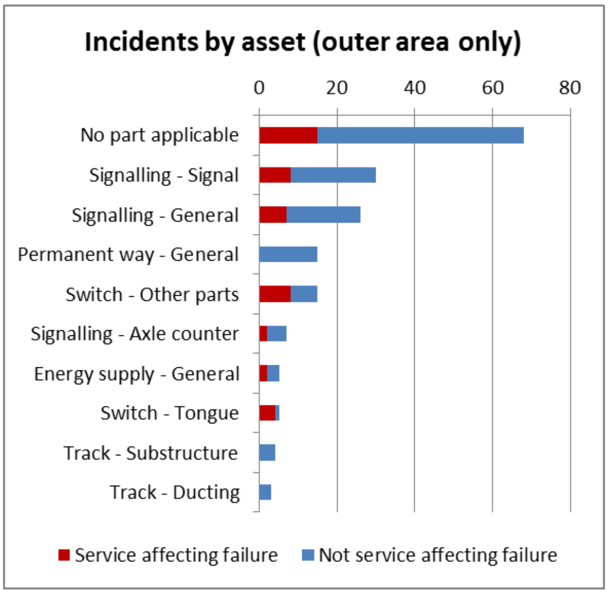
Source: Maximo (adapted by Mott MacDonald)

Figure 4.6: Infrastructure failures categorised by repair (Light Rail area only, Aug 2014 to Jan 2015)



Source: Maximo (adapted by Mott MacDonald)

Figure 4.7: Infrastructure failures categorised by asset (Light Rail area only, Aug 2014 to Jan 2015)

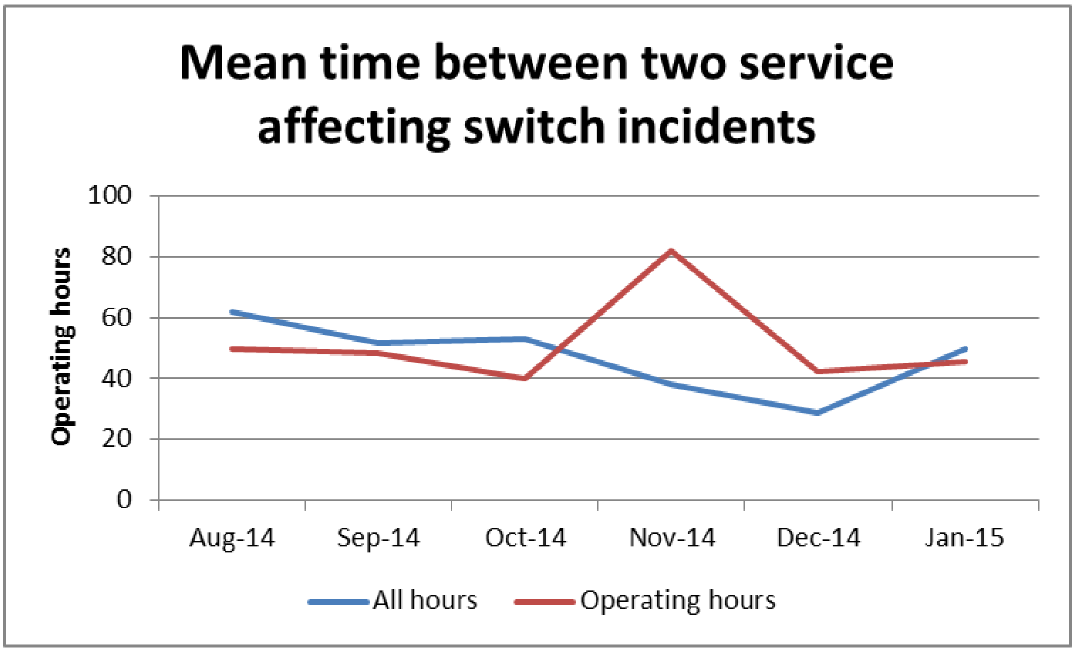


Source: Maximo (adapted by Mott MacDonald)

As can be seen in the figures, for a high proportion of infrastructure failures the cause is not found or not registered. For example, in Figure 4.6 the second group is ‘No cause found’ and in Figure 4.7 by far the largest number is classified as ‘No part applicable’, which means the defect could not be allocated to a specified asset. Further investigation is required for these failures, including more detailed and accurate data collection and data analysis. Further it would be of interest and significance if the data were enhanced to show the total delay/duration of the failure rather than the number of failures and cancelled trips.

In the absence of KPIs, such as mean time between failures, infrastructure performance is illustrated over the six month period by the number of failures per month distinguishing between switches and signals (Figure 4.4 and Figure 4.5). An improvement to be more accurate would be to provide a KPI by dividing the number of operational hours in a four week period by the number of failures (accepting not all months are the same duration) to provide a mean time between failures. For instance, if the data is corrected for the number of operating hours per month, it appears that in November 2014 there was a peak in the number of operating hours between two service affecting incidents, while this is not visible in the data considering all hour; see Figure 4.8.

Figure 4.8: Comparison of mean time between two service affecting switch incidents. Operating hours is corrected for number of operating hours per month, whilst all hours is only corrected for number of days (Aug 2014-Jan 2015)



Source: Maximo (adapted by Mott MacDonald)

This should be the type of information that is ideally compiled and presented monthly to provide an indication of the performance, for the period but also cumulatively over time by which relative performance can be assessed. Greater focus could be provided if the data was further categorised into subsystems and locations and filtered on the amount of delay incurred by the failures rather than the number of failures or cancelled trips. However, as with the rolling stock, having complete data, of better quality and all data contained in one system would make the analysis a far simpler task. Of particular importance is the ability to link the incident and its consequence e.g. lost time or lost kilometres with the root cause such that those issues which cause the most significant disruptions are identified and rectified. It is therefore recommended to develop a vision on data, preferably resulting KPIs which are regularly reported, and, based on this vision, collect and analyse data on a structural basis.

4.2.2 Switches and signalling

A switch failure will by its nature always be disruptive. Therefore, although switch failures perhaps are occurring less frequently than vehicle failures, they have in the perception of HTM, its stakeholders and the public a higher impact. Therefore, preventing switch and signalling failures is of major importance to HTM.

4.2.2.1 Switches

HTM is responsible for 62 switches within RandstadRail. These are operated by 97 Contec and Siemens switch machines. HTM switches are maintained by VolkerRail under a maintenance contract which is input-oriented, rather than performance-oriented. HTM has acquired a number of units (e.g. track patrols) which are used to deliver the planned preventative maintenance (ppm). Inspections are carried out by VolkerRail and they submit the inspection reports to HTM. This is considered less than ideal in supporting HTM's objectives for reliability as maintenance is procured on a per unit basis.

Siemens maintains in cooperation with VolkerRail the Siemens point machines of the switches. VolkerRail is also sub-contracted by Siemens to provide low level maintenance and first line fault response. This can result in delays if the 'wrong' party shows up at a failing switch, or in inefficiency if all three parties – HTM, Siemens and VolkerRail – arrive, which is currently often the case. VolkerRail and Siemens meet once per month to discuss maintenance, but HTM is not involved in these meetings.

Currently there is no measure of switch reliability such as a mean time between failures, switch failures per hour, switch failures per number of operations, etc. In order to monitor performance it is important to establish such measures to identify poorly performing assets and also measure if improvements are having a positive effect on performance. No benchmarks are available so far.

In a similar manner to the rolling stock, there is a need to gather data, and in particular to identify the root cause of the failures. It is important to collect comprehensive information as weather conditions and vehicles passing. For example it is important to identify if a RET or HTM vehicle was present when a failure occurred, and if so, which one, as the problem may have been initiated by the vehicle. Monitoring and analysing failures by location may also yield some interesting trends. More on this subject is described in paragraph 4.3.

There are occasions where the failure of a switch cannot be reproduced to enable identification of the root cause. Besides this, an established root cause does not always replicate the fault during out of service testing. The use of data loggers at key / troublesome locations may support the analysis, in order to be able to find and solve the root cause of switch and signalling failures.

Next to the need of data collection and establishing the root cause of problems, it should be noted that the frequency of inspections of switches is only once or twice a year. This is considered insufficient to address any seasonal variations. Given the high number of switch failures it is suggested to increase the frequency of inspections significantly (possibly every four weeks for each switch) until the number of failures is reduced and then relax to a frequency which makes it possible to adjust for seasonal variability and correct the setup before it fails.

In 2013 some Contec machines were replaced by Siemens machines in an attempt to improve reliability, which to some degree has been successful. However, both machines are still considered unreliable or not sufficiently reliable, even by the asset owner. For the changed switch machines, it is unknown whether the interface between the four wire connection of the Siemens switch and Contec switch machine has been replaced during the replacement of switch machine. Otherwise, replacement of this interface could probably deliver a solution for the unreliability of the switches with changed switch machines.

4.2.2.2 Signalling

Problems have been encountered with the Siemens interlocking which VolkerRail would like to investigate. However, in order to restore the services as fast as possible, HTM requires VolkerRail to reset the system as quickly as possible, without the possibility to collect data on the failure, as indicated in paragraph 3.1.4. Siemens stated that they do not investigate these interlocking problems as this is not in their scope, hence no investigation and fault trend analysis is carried out. It is recommended that this is resolved, in order to collect data on failures, identify and solve them by their root cause and put in place long term measures.

4.2.3 Reliability improvement program

In order to improve the reliability of switches and signalling, a reliability improvement program has been initiated by HTM and VolkerRail, under the name ‘K2 programma’. In this program, some work has been initiated on the analysis of switch related failures. VolkerRail has taken various measurements and obtained data to analyse. As part of this program, the decision was made by HTM to give the engineer 15 minutes extra time to note details of the cause and identify the root cause.

Mott MacDonald supports the initiative of the improvement program and advises to expand this even further to a joint working group of operator, manufacturer and maintainer resources. Such a group would need to cover all relevant areas, including operational response, control, rolling stock and the infrastructure maintainers.

Although the number of switch and signal failures is high with respect to impact on service, the absolute number for thorough analysis is limited. Therefore, it is important to gather as much data as possible from each incident. In case of an incident it is suggested to visit the switch with an electrical and mechanical expert to capture as much information as possible from the failure. Next to this it is recommended to monitor switches and signalling continuously. It is suggested following elements are measured:
- Last vehicle that passed;
- Switch position;
- Status of the DEWEMO (interface between interlocking and switch motor) and its internal LEDs;
- The rail temperature with an intelligent monitoring system, remotely monitored to provide early warning of potential issues for aiding the investigation process and retained for future use as a track maintenance aid; and
- Voltages and currents in and out of the motor drive and detection circuit.

The ‘K2 programma’ until now has for instance tested the influence of dry vs. wet slide chairs and alternative frog setups are considered in identifying the root cause. The results suggest that the difference between lubricating the current chair/roller is negligible and can be discounted as a root cause failure. Alternative moving frog set up methods have been investigated with encouraging results. A notable increase in switch failures is apparent at an air temperature of ≥ 21°C, although the root cause is currently unknown. Based on the interviews with HTM employees and review of available data and documents, Mott MacDonald has identified three possible root causes, which could be further investigated by the enhanced reliability improvement program (see Appendix G for more details):

- Shared drive/detection contacts: determine the expected lifecycle of the switch machine and measure the switch machine in great detail;
- Switch detection settings to less stringent value: review the norm for exceedance of the switch before it reports a failure and see if any relaxation of the norms are feasible and what the impact are; and
- Reinvestigate the impact of a uniform wheel profile for both types of rolling stock with the objective to reduce the complexity of the switch layout by removing the moving frog and parts of the interlocking system.

4.3 Asset management strategy

This paragraph first describes the current organisation of asset management, followed by recommendations for improvement on reporting and data analysis (section 4.3.3) and KPIs (4.3.4).

4.3.1 Asset management organisation

Most infrastructure assets are maintained under a contract with VolkerRail, with the exception of signalling, switch machines and SCADA which is maintained by Siemens and Cegelec. In addition, HTM carries out some elements of the maintenance themselves. Within the VolkerRail contract unit prices are defined for various maintenance activities, as well as inspections and measurements to be undertaken by VolkerRail. Based on these inspections and measurements, in addition to the data of HTM’s measurement tram, VolkerRail proposes maintenance activities. HTM is then responsible for planning and approving these maintenance activities based on the unit costs, maintenance requirements and available budget. This means that maintenance activities may need to be prioritised based on budgets available. This is determined by HTM maintenance engineers who need to authorise all maintenance activities, as well as inspections, undertaken by VolkerRail.

The current unit-based contract with VolkerRail is following a performance-based contract that was used between 2007-2011. Experience with the performance-based contract was not satisfactory for HTM, because they lacked control over the maintenance that was carried out. Experience with the current contract is much better and has also provided a significant reduction in maintenance costs. However, no integral responsibility for the performance of the system is contracted, resulting in not a single party taking full responsibility. It is suggested to reconsider the responsibilities and see in what form and in what manner the system’s performance can be contracted out, in particular the switch-interlocking-signalling interface.

The rolling stock is planned to be maintained on a preventative regime with mileage based exams. However, approximately 70 % of the maintenance activities are corrective. Giving more focus on establishing the root cause of failures, identifying the remedy for these failures and implementing this remedy across the fleet would reduce the corrective element of tram maintenance and allow the department to move to a more predictive maintenance regime, thus increasing the reliability of the fleet.

4.3.2 Maintenance regime

Key to a predictive and preventative maintenance regime that addresses reliability will be the further development of an asset management strategy detailing when, where and why maintenance on which assets is carried out. This analytical approach requires a further professionalisation of the asset management organisation, a change in behaviour and improved working processes. This should be supported by an appropriate asset management system and additional training of staff in using the system as part of their daily work activities. In the asset management system all asset data (e.g. asset specifications, drawings, suppliers and incident management) is stored centrally and is used to plan and manage maintenance and renewal activities. This is specified in detail in the 'Infrastructure asset condition and forecasting assessment' (Mott MacDonald, 2015).

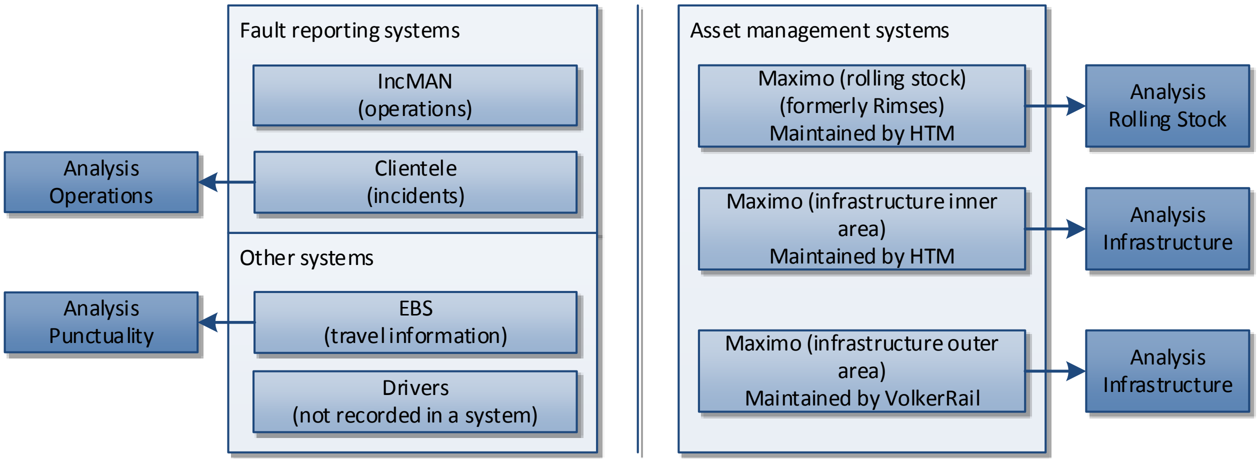
Mott MacDonald has organised a workshop with all relevant departments within HTM to discuss and assist by suggesting a process to conduct reliability and root cause analysis. However, attempts to follow up were not pursued by HTM, and HTM has not yet agreed on the required next steps to conduct such a reliability analysis. It is Mott MacDonald's opinion that this reliability analysis is essential to improve the reliability of the rolling stock and infrastructure.

It is essential to understand the root causes of the failures, including which occur most frequently and which are the most disruptive before putting in place actions to reduce or eliminate their occurrence. This cannot be emphasised enough and will require commitment from all relevant departments, at all levels of the organisation and the establishment of a management working group to monitor, implement and execute the analysis with regular reporting to the technical director. Reliability management should be an ongoing process to manage and optimise the reliability of the asset throughout the life cycle, not a one off fix as the asset changes as it ages and different reliability issues emerge overtime. Maintaining a high level of reliability requires this continued focus. Introducing a process for this is essential for ongoing improvement. This applies equally well to rolling stock and infrastructure.

4.3.3 Reporting and data analysis

It has been difficult to obtain an objective overall view of RandstadRail performance supported by evidence due to data not being recorded and not stored in one database and categorised to allow easy filtering at a high level to identify problem areas. Performance data is currently collected in a number of sources both new and historic (an overview is given in Figure 4.9). Incident management is recorded in IncMAN and Clientele. Work orders for infrastructure are recorded in Maximo. Work orders for rolling stock used to be recorded in Rimses and are now recorded in Maximo; however this Maximo system is not linked to the Maximo system for infrastructure. Finally, operational data on timetables and driving of vehicles is recorded in EBS. However, these systems are not connected, which is essential to enable a good analysis of data and allowing for the identification of the link between incidents, consequences and root causes. If this is not established, the identification of areas to improve is difficult and time consuming and could result in inappropriate solutions.

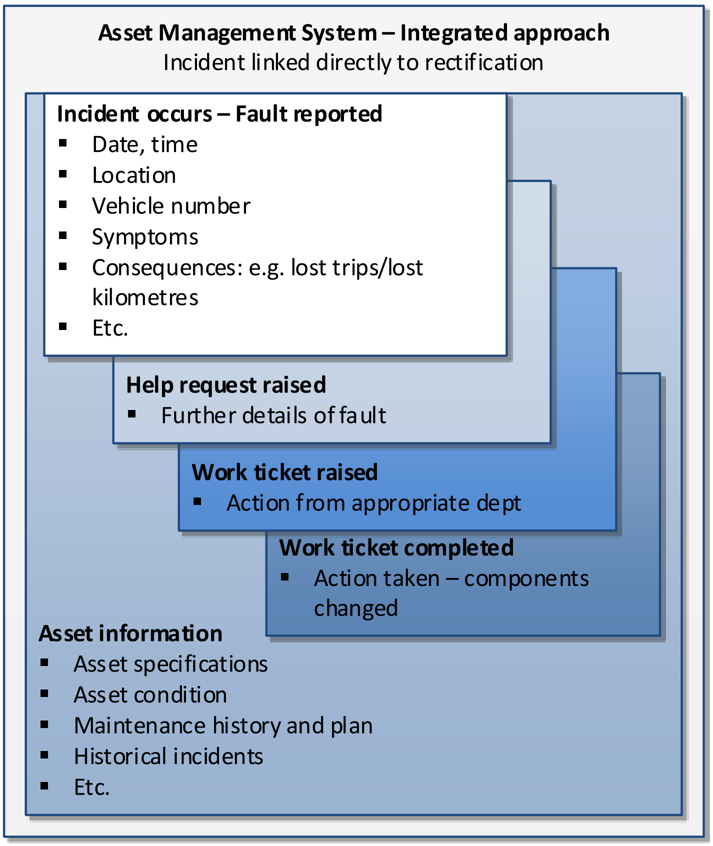
Figure 4.9: Overview of different fault reporting and information systems within HTM .



Source: Mott MacDonald
* IncMAN is currently being phased out and Maximo is introduced in April 2015 for vehicles.

It is recommended to move towards a more integrated asset management system. This could include different dashboards for the different users (it is acknowledged that not every user is interested in and capable of filling in all required fields). Figure 4.10 gives a conceptual example of the design of a more integrated asset management system and suggested categories for high level incident analysis. Most essential is the availability of all asset and incident information, this can be used to establish trends, performance indicators and identify required improvements.

Figure 4.10: Example of integrated asset management system



Source: Mott MacDonald

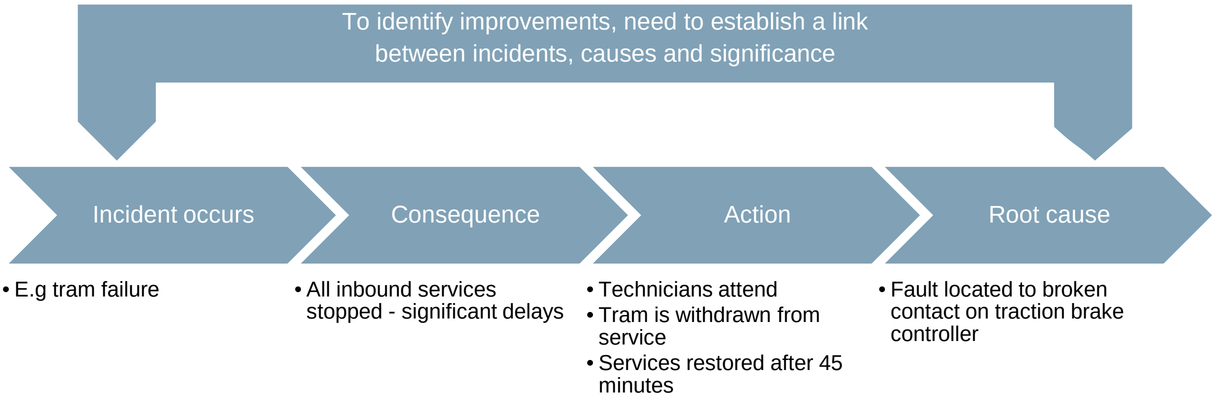
At present no process exists to routinely carry out the performance and reliability analysis. which is exacerbated by the lack of integration of systems. In order to identify the problem areas facing RandstadRail, it is essential to carry out such a high level analysis based on historic information. In the future the same analysis can be carried out to monitor performance on a 4-weekly basis with a weekly analysis of that week's failures. The analysis also identifies links between the root cause and the incident occurring. This will help to identify and resolve any failures occurring repeatedly, hence improve the performance and reliability of the system.

In identifying the root cause it is essential to systematically and routinely collect data, analyse the data and identify opportunities for improvement. Such a process will take time as data from multiple incidents need to be analysed before the root cause is identified. Processes should be established to include:

1. Collect relevant data of incident, location, vehicle number, weather conditions, actions taken, consequences, etc.
2. Analyse service disruptions by category, e.g. trams, operations, signalling, etc.
3. Focus on the major causes and divide into greater detail; consider not only quantities and numbers but also their significance e.g. lost kilometres, trips, the effect on a KPI, lost time.

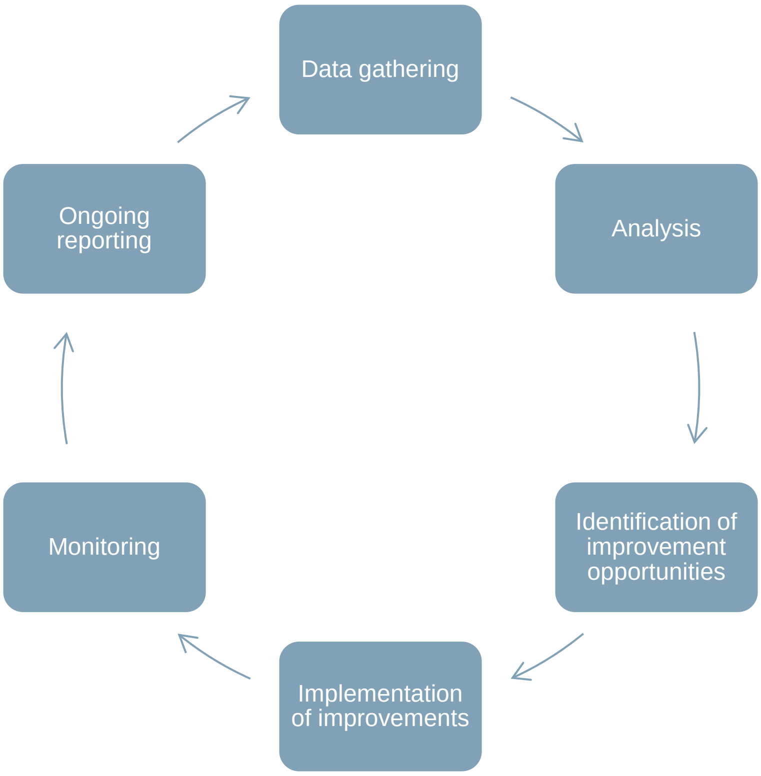
4. Look at data in different ways e.g.
   a. asset failures by location;
   b. vehicle number – are there underperforming or rogue vehicles;
   c. service affecting against non-service affecting failures;
   d. attribution of lost mileage to failure category; and
   e. look at sub systems and identify a top 5 or 10 – focus on these.
5. Investigate and establish the root cause; a fishbone diagram, adding a branch for each cause and placing tally marks, can assist in identifying the root cause (see Figure 4.11). *'the devil is in the detail'*
6. Identify improvement opportunities. The improvement options available are limited to the following:
   a. renew or replace components;
   b. identify modifications to systems and components;
   c. change the maintenance strategy or practices;
   d. improve the training and information provided to staff; and
   e. manage the problem more effectively by putting in place contingency arrangements.
7. Select the best solution on a cost benefit basis i.e. those that give the best value-for-money e.g. reduction in lost kilometres.
8. Implement the solutions and monitor their effectiveness (see Figure 4.12).

Figure 4.11: Process of fault identification and linking cause and effect



Source: Mott MacDonald

Figure 4.12: Process of root cause analysis



Source: Mott MacDonald

4.3.4 Key performance indicators

'*What gets measured gets done'*

Throughout the organisation there is an absence of cohesive and meaningful performance indicators and accompanying target values. Nevertheless, it is understood that some are developed as part of the new concession with MRDH. Without performance indicators the organisation is unable to evaluate current performance or judge any improvement or deterioration overtime. Key performance indicators are a key requirement for both Operations and Engineering. However, careful thought should be given to their number, definition, construction, reporting and target values by which the performance of each asset/department can be measured. Furthermore if KPIs are in common with other organisations it will allow benchmarking with other light rail systems.

Some examples of possible KPIs are provided below, which could be reported e.g. each 28 day period:
1. Vehicle availability per day – am peak, pm peak – actual vs target;
2. Vehicle reliability – mean distance between service affecting failures (MDBSF, see also section 4.1.1); note – it will be required to agree on the definition of a service affecting failure to be consistent on which failures qualify;
3. Lost km or lost trips, where lost km is more representative of the overall disruptions;
4. Infrastructure reliability – mean time between service affecting failures (MDBSF, general and asset specific, see also section 4.2.1);
5. Completion of scheduled preventative maintenance, planned vs. actual;
6. Availability of key customer facing equipment e.g. validators, PIDs, CCTV;
7. Punctuality.

4.4 Operations

This paragraph describes the different aspects of operations and their influence on the performance of the system. The following aspects are addressed:
- Frequencies (section 4.4.1);
- Planning (section 4.4.2);
- Control philosophy (section 4.4.3);
- Operations control room (section 4.4.4);
- Passenger communication (section 4.4.5);
- Drivers (section 4.4.6);
- Rolling stock (section 4.4.7); and
- Infrastructure (section 4.4.8).

4.4.1 Frequencies

In Table 4.1 below the frequencies and travel times of line 3(K), 4(K), 2, 6 and E in the current timetable are given.

4.4.1.1 Section: Tramtunnel Grote Markstraat (TTGM)

The service level through the TTGM between Brouwersgracht and Den Haag Centraal Station is 36 vehicles per hour per direction, in the current timetable during peak hours. This is made up of lines 2, 3, 3K, 4, 4K and 6. The average headway in the TTGM is 1 minute 40 seconds. The headway values vary and reflect the distances between signals. However, unlike the shared section, line speed remains consistent, thus it is signal spacing determines headway values.

In order to determine the capacity of RandstadRail and especially the shared section and the Tramtunnel Grote Marktstraat, an operational model has been developed. In this model, the timetable, infrastructure, rolling stock and operations are modelled and evaluated (see chapter 5). With the operational model it is shown that it is possible to run a service frequency of 40 vehicles per hour in the TTGM, in non-delayed operation. With such high frequencies, there is very little room for recovery, so the impact of disturbances is high, which requires good predefined measures for recovery of operations.

4.4.1.2 Shared Section

The frequency at the shared section is in the current timetable 24 trams per hour, made up of lines 3, 4, 4K and E. This gives an average headway of 2.5 minutes. Simulations with the operational model (see chapter 5) show that in non-disturbed operation, it is possible to run at this frequency. However, it is a high frequency, which requires good predefined measures for recovery in case of disturbances. This is even more important because of the shared section being a bottleneck, with no alternative routes.

Table 4.1: Frequencies and travel times in detail

				Travel time (minutes during peak hour)					
Line	Origin	Destination	Frequency (per hour per direction)	Complete line	Vice versa	Tramtunnel Grote Marktstraat	Vice versa	Shared section	Vice versa
3	Arnold Spoelplein	Dorp	3x	66	65	5	5	8	8
	Arnold Spoelplein	Centrum West	3x	69	67	5	5	8	8
3K	De Savornin Lohmanplein	Spui	6x	19	17	4	4	NA	NA
4	Javalaan	De Uithof	6x	54	54	5	6	7	7
4K	Javalaan	Monstersestraat	6x	37	36	5	6	7	7
E	Slinge	Den Haag CS	6x	46	46	NA	NA	7	7
2	Kraayensteinlaan	MCH Antoniushove	6x	44	46	5	5	NA	NA
6	Leyenburg	Dillenburgsingel	6x	37	37	6	5	NA	NA

Source: Timetable HTM.

4.4.2 Timetable

Mott MacDonald has interviewed planners from HTM and RET. This results in the following observations regarding the planning of HTM on the shared section.

Point to point journey times are planned to be either a 75th or 50th percentile depending on the location and time of day. By timing services at a percentile, failure is already being built into the timetable as some services by their nature will be unable to meet these times. This also creates a reliance on the ability of the vehicle to be able to accelerate faster and brake harder to make up lost time which can lead to an increase in maintenance costs and a more uncomfortable ride for passengers. It is noted that a recovery time is allowed at the end of service, creating a 99th percentile planning. This is however in conflict with the required consistent headway on the signalled sections. The current services are timed to the second. This means that there is no flexibility during the trip for when services are delayed, nor does the very specific timing permit for variations in different driving styles.

Analysis and interviews have confirmed that overall journey times have increased over the years, whilst the variation of driving styles between fastest and slowest has decreased due to an updated Driver Assistance System which gives the driver more frequent feedback. It is unclear why the overall journey times have increased in recent years. There could be two reasons for this:

- Increased ridership, requiring therefore longer dwell times at stations, or
- Drivers are driving slower to match the percentile journey times to not arrive early at the next stop, rather than drivers being trained to drive to a particular minimum speed level.

Whilst recovery time has been included at the end of a journey, and therefore allows for the recovery of any delay incurred during that journey and prevents the next journey from starting delayed, the lack of recovery time included in the point-to-point journey times means that on time arrival at key locations can be difficult. This often takes the form of bunching where services close up to each other, wich has been observed at the Brouwersgracht junction for example. This bunching has limited effect on the TTGM and HTM only sections, but a bigger impact on the shared section, due to RET-vehicles from the E-line driving more according to the timetable.

To resolve the bunching and create a more punctual service it is recommended to introduce a time buffer at either end of the shared section and possibly TTGM. At these stations the dwell times are increased on all tram services from HTM to ensure correct spacing. Furthermore some form of countdown clock could be installed at Beatrixkwartier on the end of the platform. The timer on this clock is to be set for the headway requirement on the shared section. The operational model confirmed that regulation at the beginning of the shared section and TTGM improves the punctuality significantly and only increases travel times by a maximum of 30 seconds.

To counter the increase in overall journey times brought on by the increase in dwell times through the city centre section, it is also recommended that the driving to a specific time for the lines 2, 3, 4 and 6 sections from Brouwersgracht to the ends of their respective lines away from Den Haag are abandoned. These sections of line are only to be concerned by the frequency of service, not the headway. As such drivers should be encouraged to drive faster, and should not be required to wait in platforms for a designated period of time.

4.4.3 Operating philosophy

The HTM network has traditionally been a line of sight, self-contained high frequency operation. Frequency was the primary driver in operations, and over large parts of today's tram network it still is. However the tram of HTM interacts with the metro of RET. The performance of the E line has a direct impact on the performance of lines 3 and 4, and indirectly on that of lines 2 and 6. This interaction has been identified as an issue. Based on the interviews, this can be related to the different approaches to operations of HTM and RET. HTM has its tradition of trams, while RET has a more metro oriented approach.

HTM's services on lines 3 and 4 vehicles do not arrive at the shared section junction at their planned times and no active regulation is undertaken by planning or control to space services out in time. This means that services of line 3 and 4 often affect the journey of an E line service and this leads to a source of tension between the two organisations.

To resolve the tension, both organisations will have to control their vehicles on and around the shared section on the same way. Given that the shared section is a signalled track, it is most logical to drive vehicles more 'metro like', as RET does. This will require a change in approach by HTM both in control and in planning. It will need a transition zone to be created in which services change from complete line of sight operation with no regulation to one where they drive to signals and are regulated. This is needed to ensure correct headways and services according to the timetable the moment the vehicles enter the shared section. It is suggested that HTM and RET work more closely together in developing a control philosophy for the shared section, including better coordination on timetables, operations and control.

4.4.4 Operations Control Room

HTM and RET both have their own Operations Control Room, from where they control RandstadRail. Operations on the shared section are controlled from the Operations Control Room of HTM. Drivers from HTM and RET can contact both control rooms. Mott MacDonald visited the control rooms at HTM and RET and discussed issues with the staff present. The discussions and visit resulted in the following observations.

The organisation of HTM control is considered suboptimal. Many manual operations are required to register an incident and report to all responsible. The communications team is situated outside of the control room. In addition, no communication between driver and incident management is possible from the control room – communication to the driver is only possible via the control room operator. The HTM control has limited visibility on EBS (timetable information system) of approaching RET services and also limited information from VICOS (signalling information system). Visibility and availability of this information is needed to aid regulation and decision making. This results in less optimal communication and ineffective response to an incident.

RET Control Room staff is more experienced, better resourced, and better structured to deal with problems. All required resources, operator communications and technical support, are located in the same room and close together. E.g. the communications team sits behind the control room operator's desk, technical resources are close by and have direct visibility of the overview screens. Therefore, they are able to be proactive in providing passenger information without any intervention from the operator. If communication between the operator and the communications team is required it is easily achieved, without recourse to email as they are in close proximity.

It is recommended for the HTM control room to introduce the ability to communicate between a technical coordinator and the driver. The technical coordinator should be experienced with the different failures and can either assist a driver to resolve a failure or to inform the technical response team better. This could help in providing a more adequate response to a failure.

The control room operator is a key role and it was stated that there was a lack of formal training and retesting for operators. This is reinforced by the view that not all HTM control room operatoins staff are of the same competency level or can deal with pressure in the same way. Training, for example simulator training, would improve responses and consistency of response.

In case of an incident, the control staff of HTM does not have (detailed) standardised incident control scenarios. This means that for each incident they have to develop solutions from scratch, which can result in sub-optimal solutions, e.g. a vehicle standing in open fields, more cancelled trips than needed, etc., Therefore, it is suggested to develop in greater detail incident control scenarios on possible failures. This helps in reducing the impact of a failure. To support the incident control scenario, the design of mitigation measures (e.g. turn-back facilities) should be considered. Relocation and adding of e.g. turn-back facilities can keep parts of operations running and reduce the time required to restore operations.

4.4.5 Passenger communication

As stated in paragraph 3.1.1, passengers and municipalities consider travel information, in particular during disruptions, poor. Therefore, it needs to improve significantly, which could be a quick win. The poor quality can be illustrated by the following examples:

- There is a marked difference in communication strategy between RET and HTM. RET makes Personal Announcements (PA) on the platforms and in the vehicles, while HTM drivers generally do not make announcements and platform personal announcements are only made in emergency. Particularly at times of disruption, RET makes good use of personal announcements, thus informing passengers on duration of the disturbance and, if possible, alternative travel options. It is recommended that HTM enhances the use of personal announcements in vehicles and on platforms, in particular during disruptions.
- Passenger communications are not situated in the control room. Therefore, the communications officer cannot see problems the moment they emerge and inform the public in a timely manner.
- There are four interchange points between lines 3 and 4 in Zoetermeer. When, in case of a disruption, passengers are informed in time, they could make use of this flexibility.
- The Passenger Information Displays (PIDs, in Dutch 'DRIS') do not always provide the correct information. Next to this, PIDs show delays of as little as 1 minute. This is not required as it is too detailed, in particular given the high frequencies. It is suggested to start notifying at e.g. delays of three minutes.
- Information on PIDs does not adjust to changed information during disruptions.
- In periods of disruption diversionary routes are not always clear to passengers. For example route 9 becomes 69 when diverted, thus causing confusion.

The organisation of travel information on the shared section is complex. HTM is the owner of the information and the systems and cables etc. leading up to the PIDs. However, the PIDs itself are owned and maintained by MRDH. The PIDs are of five different types, of differing reliability and it is not clear which type is located where. Problems have been experienced in the TTGM and Zoetermeer with one particular PID supplier. Clearly having one authority responsible for the whole system, including the information, is preferable. Next to this, a standardisation to the most reliable PID is recommended. It is noted that it is considered to make HTM responsible for the total travel information system on RandstadRail.

Currently, a new software package (‘InfoActueel’) is being implemented which gathers information from different sources (e.g. cause, location and duration of incident) and can distribute an automated message to different media (e.g. twitter, website and PIDs). Furthermore HTM has done a recent improvement by the introduction of the HTM mobile phone app which provides information on departure times, lines and disruption information along with walking routes to stops. Both are considered by Mott MacDonald a good improvement.

4.4.6 Drivers

During the interviews with HTM staff, it has been stated that drivers are often required to swap from one vehicle to another during their shifts. This happens most often between lines 3 and 4. During normal service operation this can be accommodated quite reasonably and this enables optimal scheduling of drivers over the course of day, including rest and meal brakes. It is understood that the minimal number of drivers required to operate a single service over the course of a day is 3.

However in times of disruption this type of organisational arrangement can lead to performance issues as it can not only import a delay from one line to another, but in the event of severe service disruption drivers become trapped and are not available where they need to be. This can often prevent service recovery and has a significant impact on public perception of the network. It is recommended that measures are taken to prevent drivers from changing vehicles, especially in case of disturbances. This can either be done by preventing changes of line in the total roster, or by introducing a measure that, in case of disturbance announced by the control room, all drivers stay with their vehicle, thus changing to the ‘disturbed driving mode’.

It has been confirmed that not all drivers are trained to drive all types of rolling stock over all lines. This provides a hindrance to service recovery. As such it is recommended that drivers are trained to drive the all types of rolling stock.

A number of observations with regards to driver behaviour were made in at least one of the stakeholder interviews. These may not be typical but could be easily resolved.

- Drivers have a FM-radio in the cabs that is able to play loud music. This can be a distraction and may prevent the driver from hearing alarms and sets unequal rules for passengers and drivers.
- Drivers do not always observe the platform stop marks; this can increase the dwell times at stops and lead to overcrowding on certain sections of the vehicle with passengers not evenly distributed. This is a particular problem for wheel chair users when wheel chair bays don’t line up with doors located nearest to the wheelchair bay. Therefore it is suggested to apply better visible stop marks and train the drivers to use them.
- Drivers’ approach speed to stops is sometimes too high, leading to braking too hard causing people to fall, track brakes can be heard to operate which in turn gives rise to complaints.

- Limited or no announcements are made by drivers during incidents, which is a key recommendation to improve (see section 4.4.5).

Although the number of trips cancelled by unavailable drivers is not significant, it could be further examined if a larger pool of reserve drivers is feasible to reduce the number of cancelled trips. Next to this, it could be studied, based on e.g. incident data, whether spare capacity at key locations can help to recover quicker from a disruption in service.

4.4.7 Rolling stock constraints

Multiple lines interface with lines 3 and 4. Most notably are lines 2 and 6 in the Tramtunnel Grote Marktstraat and RET line E on the shared section. These lines run with four different vehicle types (RegioCITADIS, Flexity Swift, GTL and Avenio). Each of these vehicles has different driving and boarding characteristics, e.g. high floor – low floor, on-board – off-board ticketing, 80 km/h – 100 km/h. This results in different driving and dwell times.

All HTM rolling stock has on-board ticket validators. As observed when travelling, this is one of the main sources of delay, especially at the busier interchange stations. People are clustering round the on-board card readers delaying loading and unloading times. In peak periods or times of sudden demand, when performance is most required, performance will suffer as dwell times are extended and next services have to wait to access platforms. Consideration can also be given to address the marking on platforms of wheelchair boarding areas and door positions to reduce dwell times. Reducing dwell times is required to increase capacity and the ability to recover from any variation in the timetable (‘robustness’).

It is recommended to investigate the relocation of the travel card readers off the HTM vehicles to the platforms, as is the case for RET vehicles and platforms. This increases capacity per vehicle and reduces boarding and alighting times. This improves the robustness of the system, and therefore will also be of help when increasing frequencies to achieve higher passenger capacity.

4.4.8 Infrastructure constraints

The introduction of mixed services of HTM and RET on a shared section has, according to some, been the reason behind worsening levels of performance. It has also been suggested that one of the reasons for poor performance of RET services is the running of HTM services on the shared section outside their booked paths. The operational model confirmed that there is, in the current timetable even without disruptions a significant number of delays is occurring on the shared section on all lines.

Most critical in normal operations in the infrastructure are the following elements:
- The combined low floor and high floor platform can only be used by one vehicle at a time.
- The signalling system enforces long distances between two vehicles, thus using a lot of capacity per vehicle.
- The level junctions at Beatrixkwartier, Ternoot and to a lesser extent Seghwaert results in interference between vehicles driving in opposite direction.

The stabling yard at Leidschendam is used to stable HTM vehicles overnight – RET does not use this location. During the ramp up of service, vehicles entering the shared section can conflict with already running services from RET and HTM services which started at Javalaan. It is suggested that the timetable is adjusted to ensured that all vehicles are already outside of the stabling yard before peak hour and therefore do not interfere with running services. Leaving and entering the stabling yard at Leidschendam should be actively regulated by control in the morning.

It is suggested to consider the infrastructure constraints in designing a new timetable. This timetable should consider in particular the critical junctions and busiest stops, as well as the timings with RET metro and HTM tram services. Verification of a new timetable with the operational model in OpenTrack is recommended.

4.5 Summary of analysis

The above paragraphs describe the different aspects of the system of RandstadRail and their impact on the performance of the system: rolling stock, infrastructure, asset management and operations. In each paragraph, conclusions and recommendations are stated. This paragraph gives a summary of these conclusions and recommendations. A full overview of recommendations is given in paragraph 4.6.

A general conclusion is that it is difficult to obtain an objective overview of RandstadRail performance due to data not being recorded and stored in one database. Different systems and databases are used and these are not linked. Furthermore, there are no agreed performance indicators, so it is impossible to measure performance against a desired level of performance. It is therefore recommended to couple data sources, agree on performance indicators (possibly KPIs) and target values and measure against these on a regular basis.

This lack of data gathering and analysis is also visible in the way recovery of failures is carried out for both rolling stock and infrastructure. In order to restore services as quickly as possible, systems are reset and root causes are not sought and/or registered. This is the easiest solution for the moment, but it increases the possibility of the incident recurring, because the cause has not been found and solved. It is recommended to develop an asset management strategy and based on this shift to an approach in which root causes are determined, data on failures is recorded including the root causes and data is analysed to support preventative maintenance.

For rolling stock it is concluded that the reliability and availability for the HTM vehicles are low. The Mean Time Between Service affecting Failures (MTBSF) is low, with a value of 9,000 km between two A-failures, while other tram systems achieve at least 21,000 km. Failures are often solved on an individual basis, where no root cause analysis is done and no definite solution is sought. It is recommended that an improvement process is established to identify root causes and develop and implement solutions to improve reliability. This will enable a shift from corrective maintenance to preventative maintenance. Based on the analysis of failure data, the reduction of failures could commence with more in-depth analysis of brake and door systems.

With respect to infrastructure, the RandstadRail and especially the shared section has a complex design, due to the use of two types of vehicles, two operators and various signalling systems. As a result, the safety case puts stringent requirements on the infrastructure in order to facilitate the two different vehicle types of HTM and RET vehicles, with e.g. their different wheel profiles and high and low floor. This has resulted in a complex design of e.g. switches, with a lot of possible failure causes. Improvement seems possible by modification and more frequent maintenance of the switch machines, as is started in the reliability improvement program, which is advised to expand. Furthermore, it is advised to investigate the possibilities to adjust the requirements in the safety case, so the system can be simplified, resulting in reduced probability of failures occurring.

Next to prevention of failures, performance of RandstadRail can be increased by reducing the impact of failures and by improving operations. Key recommendations in this are:

- Improve the organisation of the HTM control room by
  - developing a shared operating philosophy between HTM and RET for the shared section;
  - appointing a technical coordinator to coordinate in resolving technical incidents; and
  - positioning a travel information officer in the control room.
- Improve the quality of travel information, in general and in case of disturbances, amongst others by using Personal Announcements (PA) by drivers in vehicles and on platforms.
- Take measures to prevent drivers from changing vehicles, especially in case of disturbances; either by preventing changes of line in the total roster, or by introducing a measure that, in case of disturbance announced by the control room, all drivers stay with their vehicle, thus changing to the ‘disturbed driving mode’.

4.6 Overview of recommendations

Below, an overview of the recommendations is given. They are organised by recommendations to the different disciplines. For each measure, an indication of impact on performance, time of implementation and costs is given.

Recommendation	Reference	Impact	Timeframe	Costs
Asset management strategy				
Develop an asset management strategy: ▪ determine when, where and why maintenance on which assets is carried out; ▪ implement an appropriate Asset Management System (AMS) and train staff in using the system as part of their daily work activities.	4.3	High	Medium	Medium
Develop a vision on data, preferably resulting in KPIs which are regularly reported: ▪ based on this vision, collect and analyse data on a structural basis ▪ develop key performance indicators (KPIs) for Operations and Engineering; ▪ enhance data from failures to show the total delay/duration of the failure rather than the numbers of failures and cancelled trips; ▪ increase data quality to link incidents and their consequence; ▪ establish measures for switch reliability such as mean time between failures and, based on this, monitor performance of switches; and ▪ develop one database with different dashboards for different users, with all asset and incident information available, to establish trends, performance indicators and identify required improvements.	4.1; 4.2; 4.3	High	Medium	Low (organisational change)
Rolling stock				
Conduct reliability analysis for rolling stock regularly: ▪ with commitment from all relevant departments on all levels of the organisation; ▪ the establishment of a management working group to monitor, implement and execute the analysis with regular reporting to the technical director and commitment from all relevant departments; ▪ improve data gathering on failures of rolling stock; ▪ identify the root cause of failures; ▪ solve the failures at their root cause; and ▪ monitor modifications to rolling stock to see if they improve vehicle reliability.	4.1	High	Medium	Low (organisational change); excluding modifications
Agree on and put in place a process with Siemens for reliability monitoring of the new Avenio trams	4.1.3	Medium	Short	Low
Appoint one asset manager as responsible for availability and reliability of the trams	4.1.2	Low	Short	Low (organisational change)
Display more detailed fault codes on the Man Machine Interface (MMI) to the driver and record these; this will possibly require a software modification in the vehicles	4.1.2	Low	Medium	Medium (dependent on Alstom)
Consider whether it is of the passengers interest that a tram is withdrawn from service when a ticket validator fails	4.1.2	Low	Short	Low

Recommendation	Reference	Impact	Timeframe	Costs
Infrastructure				
Expand the reliability improvement program: ▪ to a joint working group of operator, manufacturer and maintainer resources, which covers all relevant areas, including operational response, control, rolling stock and the infrastructure maintainers; ▪ monitor switches and signalling continuously; ▪ visit a switch failure with an electrical and mechanical expert to capture as much information as possible from the failure; ▪ further investigate possible root causes for switch failures (shared drive/detection contacts, switch detection settings and reinvestigation of the impact of a uniform wheel profile for both types of rolling stock); ▪ use data loggers in switches to support in the root cause analysis for failures ▪ establish processes to systematically and routinely gather data on normal performance and at time of incidents, analyse the data and identify room for improvement	4.2.3	High	Medium	Low (organisational change); excluding modifications
Increase frequency of inspections of switches significantly, amongst others to address any seasonal variations	4.2.2.1	Medium	Short	Low
Reconsider the type of maintenance contract with VolkerRail and Siemens and aim at contracting the systems performance, in particular the switch-interlocking-signalling interface	4.2	Medium	Medium	Unknown
Solve the dispute between VolkerRail, HTM and Siemens on who is to investigate interlocking problems	4.2.2.2	Low	Short	Low
Investigate whether replacement of the interface between the four wire connection of the switch and switch machine helps preventing switches from failing	4.2.2.1	Low	Medium	Medium
The municipality of The Hague could potentially design and optimise the road layouts and traffic support operations better with respect to road traffic in the city causing delays in tram services	3.1.3	Low	Long	Medium
Operations				
Change the HTM control philosophy on the shared section to a more ‘metro like’ style: ▪ including a transition zone in which services change from complete line of sight operation to one where they drive to signals and are regulated; ▪ in cooperation between HTM and RET; ▪ including better coordination on timetables, operations and control; and ▪ develop standardised incident control scenarios, possibly including the design of mitigation measures (e.g. turn-back facilities).	4.4.3; 4.4.4	Medium	Medium	Low
Improve the organisation of the HTM control room: ▪ better train control room operators, e.g. by using a simulator ▪ introduce in the control room the ability to communicate between a technical coordinator and the driver to provide a more adequate response to a failure; and ▪ position a communications officer at the operational control centre.	4.4.4; 4.4.5	Medium	Short	Low
Improve passenger communication and travel information: ▪ make better use of Personal Announcements (PA) in vehicles and on platforms and use these during normal operations and especially at times of disruptions; ▪ position a communications officer at the operational control centre ▪ show delays on Passenger Information Displays (PIDs) not of as little as 1 minute; start e.g. from 3 minute delays; ▪ adjust information on Passenger Information Displays (PIDs) to changed information during disruptions;	4.4.5	Medium	Medium	Low

Recommendation	Reference	Impact	Timeframe	Costs
▪ make one authority responsible for the whole travel information system, including the information; and ▪ standardise to the most reliable Passenger Information Displays (PIDs).				
Optimise the timetable by: ▪ allowing a larger headway before E-line services, compared to that of line 3 and 4, due to the different rolling stock characteristics; ▪ ensuring in the timetable that all vehicles are already outside of the stabling yard before peak hour and therefore not interfering with running services; ▪ introducing a time buffer at either end of the shared section and possibly TTGM to avoid bunching effect and increase punctuality and robustness; ▪ abandon the driving to a specific time for the lines 2, 3, 4 and 6 sections on the Tram net area from Brouwersgracht to the ends of their respective lines to decrease overall journey times; and ▪ verification of the new timetable by simulation in the operational model in OpenTrack.	4.4.2; 4.4.8; 5.5.1	Medium	Short	Low
Undertake investigations into the removal of the travel card readers off the vehicles and onto the platforms to increase capacity per vehicle as well reduce boarding and alighting times.	4.4.7	Low	Medium	Medium
Improve drivers operation: ▪ take measures to prevent drivers from changing vehicles in case of disturbances, for example by introducing a ‘disturbed driving mode’; ▪ train drivers to drive all types of rolling stock to be more flexible, e.g. in case of disruptions; and ▪ study whether it is useful if a larger pool of reserve drivers is feasible to reduce the number of cancelled trips and whether spare capacity of drivers at key location can help to recover quicker from a disruption in service.	4.4.6	Low	Medium	Low
Apply platform stop marks better visible for the driver and the passengers, in order to decrease dwell times and evenly distribute passengers over the vehicles.	4.4.6; 4.4.7	Low	Short	Low
Install some form of countdown clock at the end of the platform at Beatrixkwartier to avoid bunching effects.	4.4.2	Low	Short	Low

5 Increase in capacity

5.1 Introduction

The number of passengers traveling with RandstadRail exceeds expectations and forecasts show a further increase in the coming years. From a mobility perspective, this suggests RandstadRail serves its purpose. At the same time, the larger than expected number of passengers impacts the service. The trams and metros are very crowded during peak hours; in particular the metros of the E-line exceed the occupancy norms of MRDH. Therefore, the question has been raised whether it is possible to increase capacity of lines 3, 4 and E on the shared section.

This chapter describes several solutions to increase capacity (paragraph 5.2), the design of the operational model (paragraph 5.3), the model cases (paragraph 5.4) and the results from the simulations (paragraph 5.5). In the last paragraph, conclusions are drawn about how an increased service frequency could be reached, thus accommodating an increase in passenger capacity.

5.2 Solutions to increase capacity

Increase of passenger capacity can, in general, be achieved in two ways: (1) more passengers per vehicle by either longer or more spacious vehicles, or (2) an increase in service frequency by adding extra infrastructure or by optimising existing infrastructure and operations.

Option one, longer or more spacious vehicles, requires that the platforms at the stops are able to accommodate these longer vehicles or the infrastructure can accommodate the wider or higher (in case of double-decker trams) vehicles. At the moment, line E already runs in coupled mode and since the start of timetable 2016 (December 2015), line 4 runs in coupled mode as well. Line 3 runs single, so to increase capacity on this line it could run with longer vehicles. However, this would mean adjustment of the infrastructure in the Tram net area, where stops accommodate single vehicles only. Furthermore, additional rolling stock will need to be procured. Driving in coupled mode on Line 3 helps to increase the capacity on HTM-lines, but does not increase the capacity of the E-line. It is recommended to consider this option for any medium term solution.

More spacious vehicles, which could be with double decker or wider vehicles, would effectively mean buying and probably designing new vehicles and adjusting infrastructure on the whole network to accommodate these new vehicles, including adjustment to various structures. This is not considered a viable option and is not explored any further.

Option two, increase in service frequency, can either be achieved by adding extra infrastructure or by optimising the current infrastructure and operations. The most significant increase in capacity will be achieved by creating a dedicated infrastructure for line E by separating it from lines 3 and 4. This would enable a very frequent service of RET lines and HTM lines (order of 40 to 60 vehicles per hour per direction on both infrastructure systems together). Besides this, it would reduce the technical complexity of the shared section significantly due to the separation of a metro and tram system (see chapter 4). However, this is a complicated and expensive solution with a very large impact. If the passenger demand is high enough it should be explored and considered as a long term solution. In paragraph 5.7 these conceptual alternatives are explored.

Alternatively, by optimising the current infrastructure and operations it is possible to increase frequencies as well. This is considered the most viable and realistic short to medium term solution to increase capacity of RandstadRail. To determine which optimisations are required an operational model has been developed. This operational model helps to gain insight in the current capacity of RandstadRail and in possibilities to increase service frequencies. The next paragraphs explain in detail the functioning and results of this operational model.

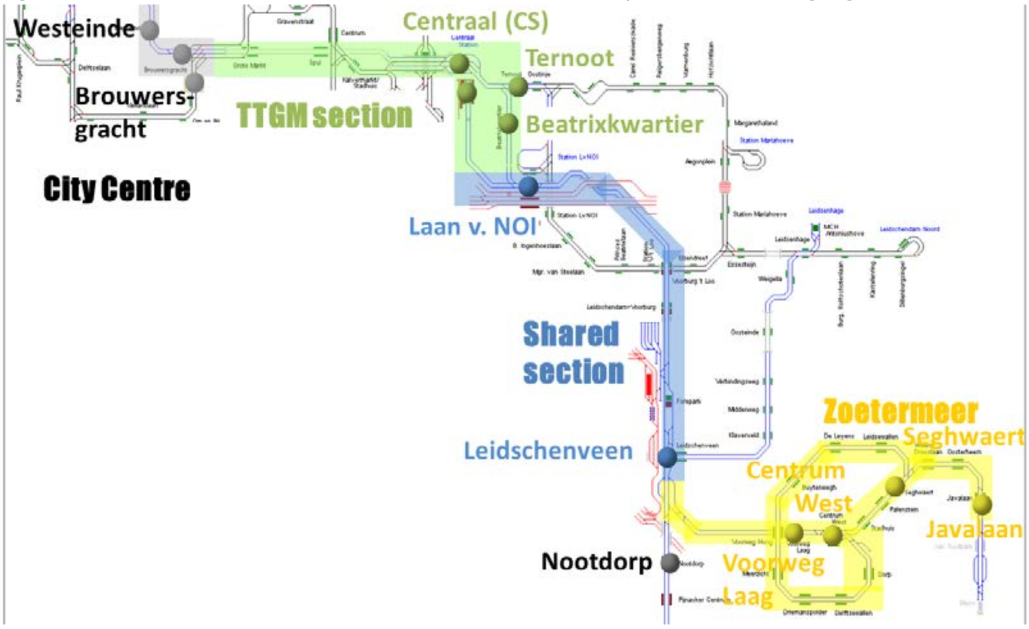
5.3 Operational model: Design

The operational model is an OpenTrack simulation model designed by Ramboll. Inputs to this microscopic rail simulation are the timetables and detailed characteristics of the infrastructure and rolling stock.

- Infrastructure:
  - The shared section, the Tramtunnel Grote Marktstraat, the metro section between Laan van NOI and Den Haag CS and the Zoetermeer section are modelled in detail (up to the position of the axle counter).
  - The remaining infrastructure of lines 3 and 4 (west of Westeinde) are modelled in simplified form (only average travel time and variability).
  - The remaining infrastructure of line 2, 6 and E is not modelled. The vehicles from these lines feed into the model with a delay distribution based on the ITCS-data.
  - The new terminus layout of line E at Den Haag CS is not included in the model (and has no significant impact on operation).
- Rolling stock:
  - All relevant vehicle characteristics (e.g. maximum speed, deceleration characteristics and traction effort curves describing the acceleration characteristics) from the four types of rolling stock running on lines 2, 3, 4, 6 and E are included in the simulation (Alstom RegioCITADIS, Bombardier Flexity Swift, BN GTL8 and Siemens Avenio).
  - The traffic effort curve of GLT8 is extracted from the distance time diagram.
  - The curve resistance is not simulated, as it is not required in light rail modelling.
- Timetables:
  - The model is calibrated using ITCS-data (timetable statistics) from 26 January 2015 to 31 March 2015 for lines 3, 3K, 4 and 4K and 05 January 2015 to 01 April 2015 for line E. For both datasets (ITCS and model run), the 50-percentile is used in the comparison.
  - All input is based on the morning peak, the busiest time of the day in the inbound direction (towards Den Haag CS).
  - The number of services is the same in both directions, based on the number of services in the inbound direction.
- Operations:
  - Vehicles from lines 3 and 4 start their operation on time.
  - There are no disruptions during operation.
  - The influence of road junctions is not considered to be significant.

– Driver's speeding behaviour is based on a stochastic distribution of 95% performance on average.
– Dwell times are derived from the ITCS data provided by HTM and RET.

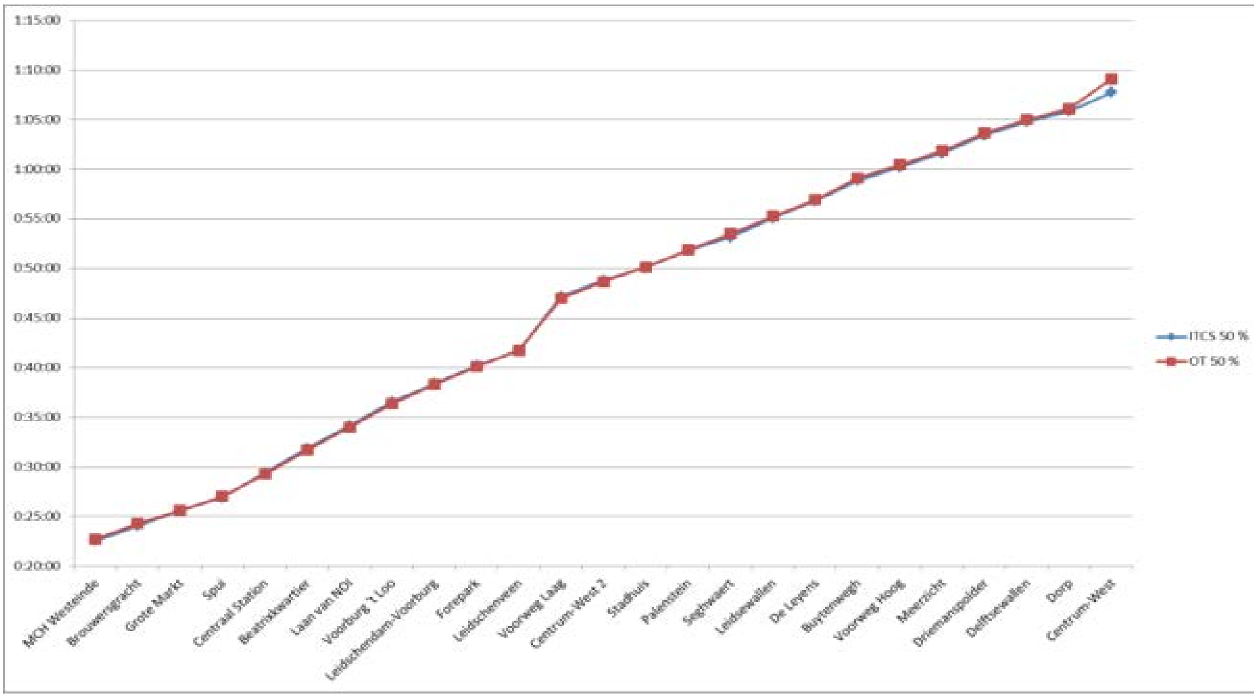
Figure 5.1: Areas of RandstadRail: main sections and stops in focus. All highlighted areas are simulated in detail.



Source: Mott MacDonald

As can be seen in Figure 5.2, the model run times are virtually the same as what is achieved in reality. This means that the model gives a good reflection of reality. It is therefore assumed suitable to be used as a tool to study the effect of changes in infrastructure or different timetables.

Figure 5.2: Example of comparison between ITCS-data and model results line 3, MHC Westeinde – Centrum West; outbound direction. Blue: ITCS-data, red: model results



Source: Ramboll

5.4 Operational model: Timetables and scenario's

To evaluate the capacity of the shared section and TTGM and identify optimisations in the timetable or required changes in infrastructure, various model cases were designed together with HTM and RET. A model case consists of a timetable and a scenario. The timetable is designed with different frequencies on the shared section, e.g. 30 or 32 vehicles per hour per direction. The scenarios are designed infrastructure or operational measures, e.g. a new signalling layout or implementing regulation points.

This paragraph first describes the evaluated timetables, followed by the scenarios with changes in operations and infrastructure. The paragraph ends with an overview table of all model cases.

5.4.1 Timetables

For the timetables, the base case (timetable A) is the current timetable, where lines E, 3, 4 and 4K run, each in a frequency of 6x per hour per direction on the shared section, resulting in a frequency of 24 vehicles per hour per direction on the shared section. The frequencies in the TTGM and in Zoetermeer are 36 and 18 trams per hour per direction respectively. The headway between two vehicles on the same line is 10 minutes for all lines.

In addition to the base timetable (timetable A), the following timetable options with increased frequencies were studied:

- Timetable C (max option): Doubled frequency on the E-line to 12 vehicles per hour per direction and extension of line 3K on the shared secion. This means a headway of 5 minutes for line E and a headway of 10 minutes for lines 3, 3K, 4 and 4K. This results in a frequency of 36 vehicles per hour per direction on the shared section.
- Timetable C*: Doubled frequency on the E-line to 12 vehicles per hour per direction, giving a headway of 5 minutes for line E. Lines 3, 4, and 4K do not change, resulting in a frequency of 30 vehicles per hour per direction on the shared section.
- Timetable E: Change of headways of all lines on the shared section to 7½ minutes, so 8 vehicles per hour per direction for lines E, 3 and 4 (but no 4K). Additionally, line 3K is extended to run to Zoetermeer with a frequency of 8 trams per hour per direction. This gives a frequency on the shared section of 32 vehicles per hour per direction. The headway of lines 2 and 6 is also changed to 7.5 minutes, resulting in a frequency in the TTGM of 40 vehicles per hour per direction, the maximum capacity. Line 4K is not running in this scenario, as it is considered not possible to increase frequencies beyond 40 vehicles per hour per direction in the TTGM. To achieve constant headways on the TTGM section lines 2 and 6 are also assumed to run with 7.5 minute time distance.

A summary of the timetables is given in Table 5.1.

Table 5.1: Simulated timetables

		Frequency (vehicles per hour per direction)			Headway (minutes)	
Name	Lines on shared section	Shared section	TTGM	Zoetermeer	Line E	Other lines
Timetable A (base)	E, 3, 4, 4K	24	36	18	10	10
Timetable C (max)	E, 3, 3K, 4, 4K	36	36	24	5	10
Timetable C*	E, 3, 4, 4K	30	36	24	5	10
Timetable E	E, 3, 3K, 4	32	40	24	7.5	7.5

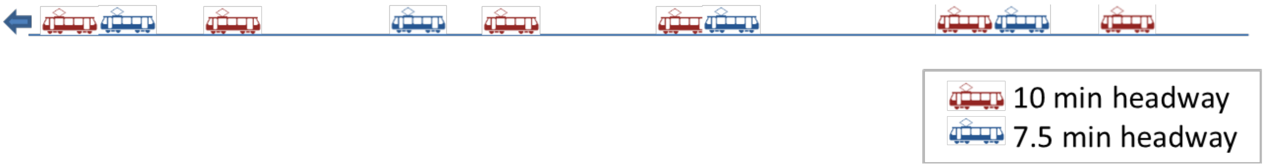
Source: Mott MacDonald

Two more timetable options were considered, but these were not suitable, so they were not simulated:

- Timetable B: increase capacity on line E to 8 vehicles per hour per direction and keep all other lines at a frequency of 6 vehicles per hour per direction. This means line E from RET runs with a headway of 7.5 minutes, while HTM-lines 3, 4 and 4K run with a headway of 10 minutes. Such a mixture of headways results in an alternation between dense operation and large gaps in service, as illustrated in Figure 5.3. This is not desirable, because the first vehicles after a gap will be extra crowded, while the following vehicles have less passengers resulting in further bunching of vehicles. Furthermore, given the requirement of a 1 minute time distance between two consecutive vehicles, the maximum achievable frequency with this mixed headways configuration on the shared section is 22 vehicles per hour per direction, less than in the current operation frequency on the shared section.
- Timetable D: Introduction of line EK (line E short, to run between Rotterdam and Leidschenveen) and extension of line 3K on the shared section. All these lines run with a 10 minute headway. Line EK only runs between Leidschenveen and Rotterdam (southern part of the shared section), resulting in a frequency of 30 vehicles per hour per direction on the shared section between Beatrixkwartier and

Leidschenveen and a frequency of 36 vehicles per hour per direction at stop Leidschenveen. This option has not been evaluated further because, from a passenger's perspective, it is not desirable that passengers from the direction of Rotterdam would need to change trains in Leidschenveen; and option C* provides gives the same service frequencies, whithout the mentioned need to change trains.

Figure 5.3: Undesirable mixture of 1 line with 7,5 minute headway and 2 lines with 10 minute headway



Source: Ramboll

5.4.2 Scenarios

Changes in the design of the timetable and the infrastructure were also studied with the operational model. The following operational and infrastructure changes were considered:

- **Timetable regulation**: introduction of timetable regulation points ('tijdhaltes'). Regulation will assure that the vehicle does not leave early at a stop or arrive late for its intended timetable slot. This has the advantage of creating equally distributed headways, which is of importance on the signalled sections. The departure time at the regulated stops contains an additional buffer to allow 75% of the vehicles to depart punctually at the regulation stop, whereas normally this value is about 50%. Regulation is applied in two variations:
  1. **At every stop** of the TTGM, shared section and Zoetermeer section; and
  2. **Before the entrance of the signalled sections** (TTGM and Shared section), hence the stops MCH Westeinde, Beatrixkwartier on the outbound direction, and Nootdorp, Voorweg Laag and Beatrixkwartier on the inbound direction.

- **Optimisation of signalling**: Three options are considered: optimisation, redesign or line of sight.
  1. **Optimisation of signal positions** at certain locations on Laan van NOI, Voorburg, 't Loo, TTGM and Seghwaert to avoid long distances between signals and to achieve an evenly distributed travel time through all sections. The objective is to achieve a better flow of vehicles and prevent vehicles from waiting for each other. This includes relocation of 12 inbound and outbound signals of the shared section and 6 new signals. Where possible, current signal positions are retained. Revision of the safety case is required.
  2. **Redesign of the signalling layout** with shorter section lengths on the shared section of 200 meters on average and mid-platform signals. This overhaul of the signal layout helps vehicles to run closer to each other, thus increasing capacity. Mid-platform signals enable RET metros and HTM trams to stop simultaneously on the high floor and low floor platforms of the shared section. Currently, vehicles have to wait until the whole platform, both the low and high floor platform, is available, before entering the station. Such a new signalling system can be best compared to a LZB system which has continuous feedback from the infrastructure to the vehicle and vice versa. Revision of the safety case is required, in particular regarding to the short distances between two

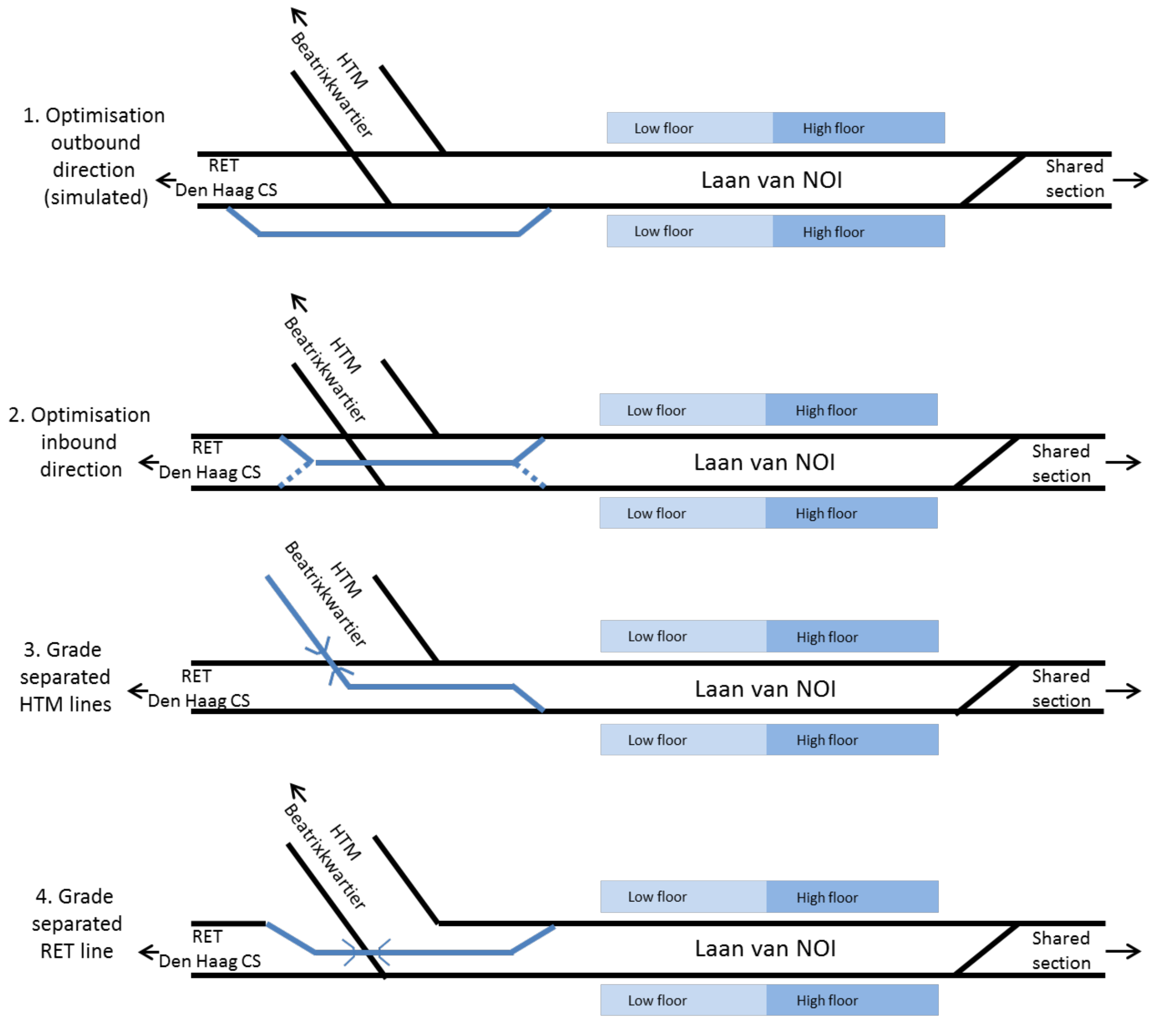
vehicles which is possibly within the braking distance of a previous vehicle. Training of drivers to drive on this new system will be required.

3. **Driving on sight** on the shared section allows reduction of the distance between vehicles down to the braking distance (and a safety margin) and simultaneous stopping of HTM and RET vehicles at the platforms (if arriving in the right sequence), which results in higher capacity. Interlocking will only be required at junctions, depot and stabling access and at terminal stops. For driving on sight on the shared section the maximum speed can only be 80 km/h. Drivers, in particular the metro drivers from RET, will need to be trained to be able to drive in such a system. It is the drivers responsibility to maintain the correct distance and speed to its preceding vehicle. A significant change in the safety case will be required.

- **Redesign and optimisation of junction Beatrixkwartier**. Four possibilities are considered, schematically shown in Figure 5.4:
  1. **Optimisation of the outbound direction**: metros from the E-line in direction of Rotterdam can use a third track at the junction which results, compared to the current layout, in less delay if a tram from line 3/4 and a metro from line E need to enter the shared section at the same time. This option is considered by HTM in ideas for further expansion of the network. This option is selected to be evaluated in the simulations, as it is expected to achieve a considerable improvement on the running of trams and metros, while having the least design impact on the surrounding. The costs of this design are estimated to be between €4.6 and €7.1 million, including track work, switches and a bridge over Beatrixlaan.
  2. **Optimisation of inbound direction**: metros in direction of Den Haag CS can wait at a third track before passing the crossing and therefore not delaying the inbound lines 3 and 4. This option is considered to be less effective than optimisation of the outbound direction, because in inbound direction line E is almost at their terminus stop and HTM lines are entering the CS signalling system which is less rigid in its design. Next to this, it does not provide any substantial improvement to the capacity of the shared section. The costs of this option are estimated to be comparable to that of the optimisation in the outbound direction. Since the previous option is more efficient, this one has not been evaluated further within the simulations.
  3. **Grade separated HTM-lines**: lines 3 and 4 in direction of Zoetermeer have an overpass junction with the E-line track in direction of Den Haag CS. The costs of this option are estimated to be between €26.0 million and €32.5 million, including the costs of a new bridge, excluding changes needed to the ProRail platform, the surrounding area and expropriation. This is a costly and significant change in infrastructure, while the initial simulations did not flag the junction as the main bottleneck. A grade separated junction alone will not provide extra capacity to the system. It is not expected that the improved capacity offset the costs of implementation. Therefore it has not been evaluated further within the simulations.
  4. **Grade separated RET-line**: line E in direction of Den Haag CS can overpass the trams from line 3 and 4 in direction of Zoetermeer. The costs are estimated to be approximately the same as for grade separation HTM-lines, so between €26.0 million and €32.5 million, including the costs of a new bridge, excluding changes needed to the ProRail platform, the surrounding area and expropriation. As with the grade separated HTM-lines, this is a significant and costly change in infrastructure and the improved capacity results are expected not to offset the costs, therefore it has not been evaluated further within the simulations.

A detailed description for optimisation of junction Beatrixkwartier is given in Appendix F.

Figure 5.4: Possibilities for redesign of junction Beatrixkwartier. In blue the schematic redesign of junction



Source: Mott MacDonald

5.4.3 Overview of model cases

The combination of different timetables and scenarios as described above, gives a large number of possible model cases. However, not all possible model cases are feasible or useful. Therefore, in various workshops with planners from HTM and RET, a set of model cases has been defined. Results from initial model cases informed the decision to which other model cases should be simulated. Table 5.2 provides an overview of the model cases.

Table 5.2: Overview of model cases

Model case		Frequency per hour TTGM + CS	Frequency per hour Shared Section	Frequency per hour Zoeter-meer	Headway line E (min)	Headway HTM-lines (min)	Lines on shared section
0	Base case – timetable A (current operations) – NO timetable regulation	36	24	18	10	10	E, 3, 4 and 4K
0a	Base case: – timetable A (current operations) – partial timetable regulation (beginning of shared section)	36	24	18	10	10	E, 3, 4 and 4K
0b	Base case: – timetable A (current operations) – timetable regulation at all stops	36	24	18	10	10	E, 3, 4 and 4K
1	Enhanced operation: – timetable E (7.5 min headway) – partial timetable regulation	40	32	24	7.5	7.5	E, 3, 3K, 4
2a	Enhanced operation: – timetable C* (double E-line) – without and with partial timetable regulation (beginning of shared section)	36	30	18	5	10	E, 3, 4, 4K
2b	Enhanced operation: – timetable C (max: double E-line & line 3K prolonged) – without and with partial timetable regulation (beginning of shared section)	36	36	24	5	10	E, 3, 3K, 4, 4K
3	Enhanced operation: – timetable C (max: double E-line & line 3K extended) – partial timetable regulation – driving on sight	36	36	24	5	10	E, 3, 3K, 4, 4K
4	Enhanced operation: – timetable C (max: double E-line & line 3K extended) – partial timetable regulation – redesign of junction Beatrixkwartier	36	36	24	5	10	E, 3, 3K, 4, 4K
5	Enhanced operation: – timetable C (max: double E-line & line 3K extended) – partial timetable regulation – optimisation of signals	36	36	24	5	10	E, 3, 3K, 4, 4K
6	Enhanced operation: – timetable C (max: double E-line & line 3K extended) – partial timetable regulation – redesign of signalling layout	36	36	24	5	10	E, 3, 3K, 4, 4K

Source: Mott MacDonald

5.5 Operational model: Results

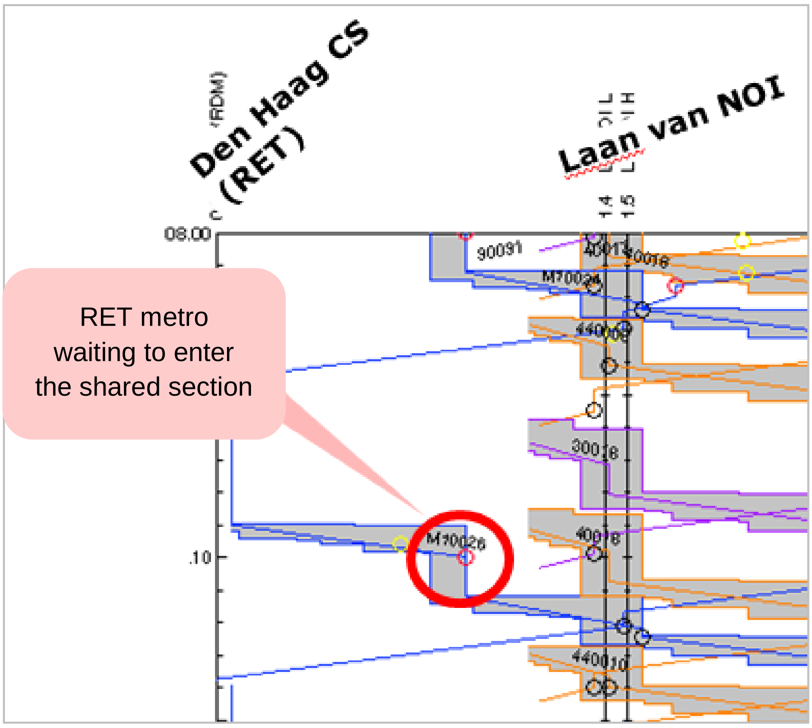
This section describes the results of the simulations of the model cases. The point of departure for all simulations is a non-disturbed operation; effects of disturbances on operation and recovery time should be considered in further studies.

5.5.1 Base case: timetable A, current operation

This paragraph describes the results of simulation of the base case. In the base case, the current timetable is simulated, without regulation (model case 0), with regulation at the start points of the shared section (model case 0a) and with regulation on all stops (model case 0b).

The simulation of the current time table showed that some optimisations can be made in the current timetable to improve operation. For example, the metros on the E-line in direction of Rotterdam have to wait before they can enter the shared section at Laan van NOI (as ilustrated in Figure 5.5). This can be improved by a one minute later departure of the E-line metros at Den Haag CS. Furthermore, it is advised to allow a larger headway before E-line services, compared to that of line 3 and 4, due to the different rolling stock characteristics.

Figure 5.5: Current timetable: line E waiting to enter shared section



Legend:
Grey: track occupied by vehicle
White: track not occupied
Coloured lines: individual trips

X-axis shows location, Y-axis time

Source: Ramboll

This enhancement is recommended in any case, both in the case of current service frequency and in case of higher frequencies. For all further simulations, the optimised timetable, based on the results of the simulation of the base case, has been used.

In the first regulation option (model case 0a), regulation is applied at the entrance of the sections with a high number of differet lines, which means it is applied at the last stop before entering the shared section and the TTGM. In the simulations, regulation is applied at MCH Westeinde (outbound), Beatrixkwartier (inbound and outbound), Nootdorp (inbound) and Voorweg Laag (inbound). This helps to avoid bunching effects and hence it increases the punctuality at intermediate stops. However, it will not increase capacity (merely increase the robustness). ,Due to the extended dwell times for some services, an increase of runtime of up to 30 seconds is possible. However, this increase is considered to be offset by the increased robustness of the system. An increased runtime could possibly result in the need for an additional vehicle, if buffer times at the terminus become too short.

When regulation is applied to every stop (model case 0b), it prevents vehicles from arriving too early. However, buffers cannot be used efficiently as vehicles have to wait at every stop, hence using their buffer, instead of using it when needed, e.g. after a busy stop. Secondly, it increases runtime significantly, by 1 minute on average for line 3 and 4. The consequence could be the need of an additional vehicle, if buffer times at the terminus become too short.

Table 5.3, below, compares the results of the two scenarios for regulation with the current timetable. Based on these results, it is recommended to apply partial regulation at the shared section and the TTGM, also during current operation. It increases punctuality and decreases variability of the service, and it only results in a slight increase of running times.

Table 5.3: Results model case 0: regulation.
Legend: (+)+ improvement (–)– deterioration, 0 comparable to reference

Model case		Frequency shared section (tphpd)	Punctuality	Run time	Occupation of stops	Complexity of implement-tation	Conclusion
0	Base case – timetable A (current operations) – NO timetable regulation	24	Reference	Reference	Reference	N/A	Current situation
0a	Partial regulation	24	++	–	0	0	Implement
0b	Full regulation	24	+	– –	0	0	Do not implement; no buffer and extended run times

Source: Mott MacDonald

5.5.2 Model case 1: timetable E, 7.5 minutes headway

In model case 1, simulation has been performed of a timetable where all lines have a headway of 7.5 minutes (timetable E), instead of 10 minutes in current operation. This increases service from 24 vehicles per hour per direction to 32 vehicles per hour per direction on the shared section and from 36 to 40 vehicles per hour per direction on the TTGM. This means the TTGM is running at its maximum design capacity.

The increase of frequencies on the lines has a large effect on the operation on the whole network, because not only line 3, 4 and E, but all other lines have to increase frequency to 8x per hour (e.g. metro network RET and most parts of HTM tram net). As described in paragraph 5.4.1, a mixture of 7.5 and 10 minutes headways limits capacity to below current levels and is therefore not feasible. An increase of frequencies will also occur at the branches where it is not desired due to lower demands and therefore less occupied vehicles. Next to this, in the dense Tram net of HTM at some street tracks it will result in very short headways.

The results of the simulation show that the TTGM is able to cope with a frequency of 40 vehicles per hour per direction. The increased frequency on the shared section of 32 vehicles per hour per direction can also be operated, but only with the preconditions of applying timetable optimisation and regulation at the beginning of the shared section and the TTGM.

Table 5.4: Results model case 1: Headway of 7.5 minutes.
Legend: (+)+ improvement (–)– deterioration, 0 comparable to reference

Model case	Frequency shared section (tphpd)	Punctuality	Occupation of stops	Complexity of implementation	Conclusion
0 Base case – timetable A (current operations) – NO timetable regulation	24 Reference	Reference	Reference	N/A	Current situation
1 Enhanced operation: – timetable E (7.5 min headway) – partial timetable regulation	32 +	0	–	Difficult (increased frequency on all lines)	Do not implement; too large impact on rest of network

Source: Mott MacDonald

5.5.3 Model case 2: timetable C and C*, maximum capacity scenario

Evaluation of the maximum capacity scenarios is done in two steps. Firstly, frequency on the shared section is increased to 30 vehicles per hour per direction, by doubling frequency of the E-line to 12 vehicles per hour per direction (timetable C*). Secondly, line 3K is extended to Zoetermeer, so it also runs on the shared section, which results in 36 vehicles per hour on this section (timetable C). For both frequencies, the timetable with and without regulation at the beginning of the shared section have been tested using the operational model. In all timetables, the optimisation of the timetable as described in the section on timetable A is applied.

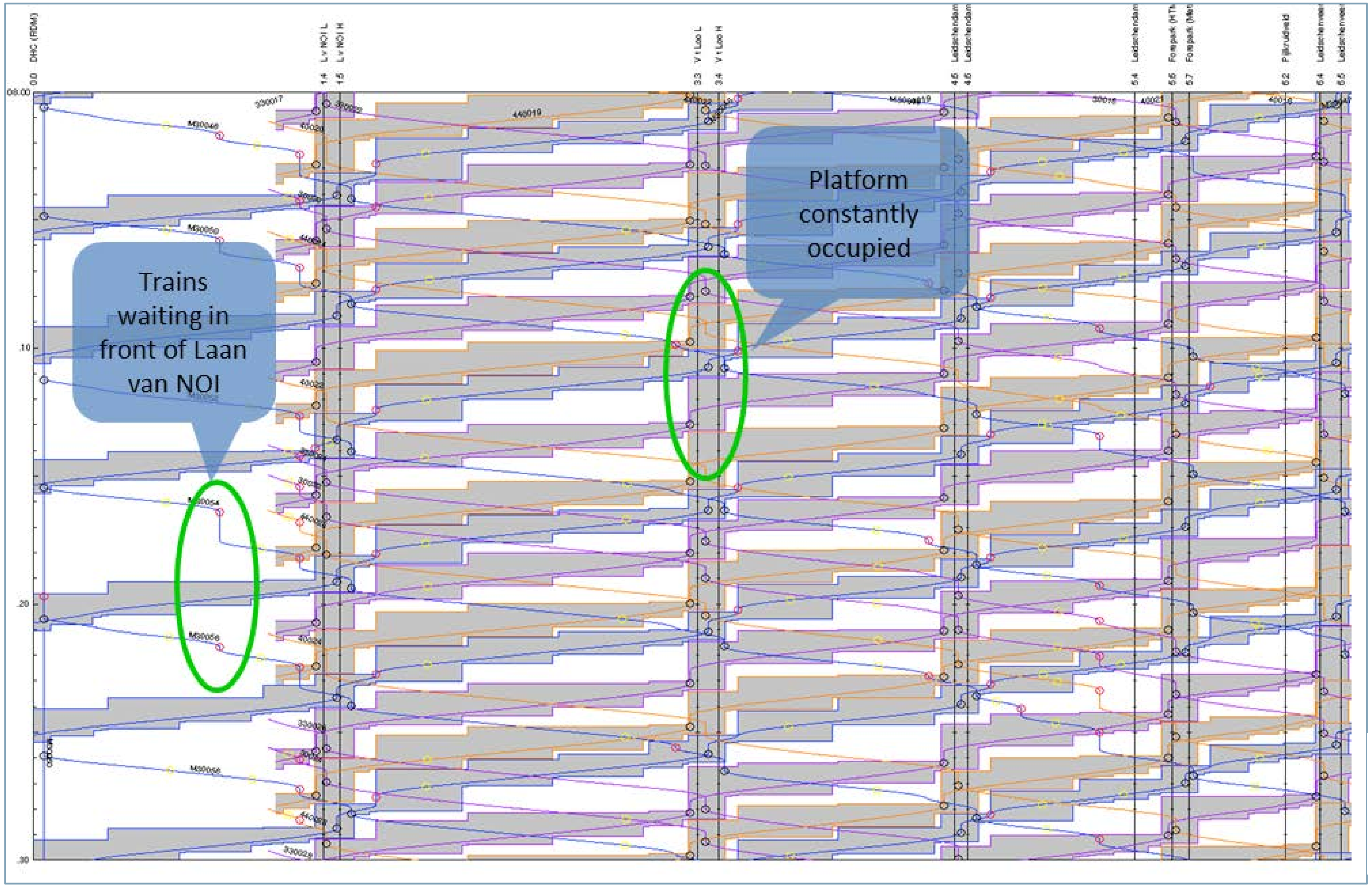
The simulation results show that for both timetables (C*: 30 and C: 36 vehicles per hour per direction on the shared section), applied without regulation at the entrance of the shared section causes more vehicles to arrive late and the length of delays increases, compared to the current timetable. It is clear that this does not provide a punctual service. It is therefore not recommendable to increase the frequency to 30 or 36 vehicles per hour per direction without regulation at the entrance of the shared section.

The simulations show that it is feasible to operate at a frequency of 30 vehicles per hour per direction on the shared section if timetable regulation at the entrance of the shared section is implemented. Results show a punctuality comparable to the punctuality in the current timetable and no extended run times. However, with these high frequencies, the occupation time of stops by a vehicle becomes critical. The high occupation rates of the platforms will, in case of any (small) disturbance, directly affect the operation of subsequent vehicles coming after the disturbed vehicle as they have to wait before they can enter the stop. The effect potentially exacerbates throughout the network and affects other lines (‘the harmonica effect’). Further research will be needed to determine how disturbances affect the operations, what the recovery times are and if extra mitigation measures are required.

Although disturbed scenarios were not studied with simulation, it can be expected that it is possible to perform a limited number of extra runs of the E-line during peak hours (order of magnitude of three individual trips). With this limited number of extra runs, the system can recover during the lower frequency period. However, this should be considered a short term temporarily solution before more long term solutions are implemented to increase the capacity of the system.

A frequency of 36 vehicles per hour per direction (timetable C) with regulation at the entrance of the shared section results in the occupation time of some stops on the shared section to exceed the UIC-threshold of 85% occupancy, as can be seen in Figure 5.7. Vehicles have to wait outside the stops on and the shared section because the platform is still occupied by the previous vehicle, as can be seen in Figure 5.6. Given these results, it is advised not to implement a timetable with a frequency of 36 vehicles per hour per direction without changes to the capacity of the stops.

Figure 5.6: Occupation diagram of shared section for timetable with 36 vehicles per hour on shared section.

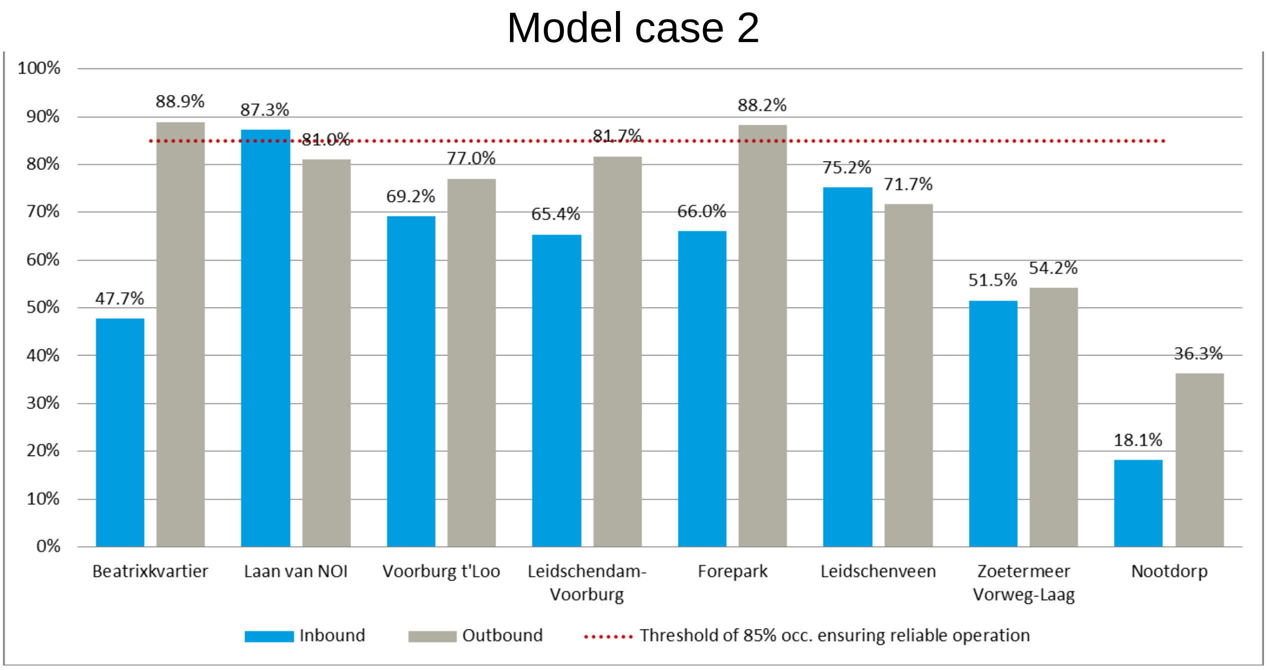


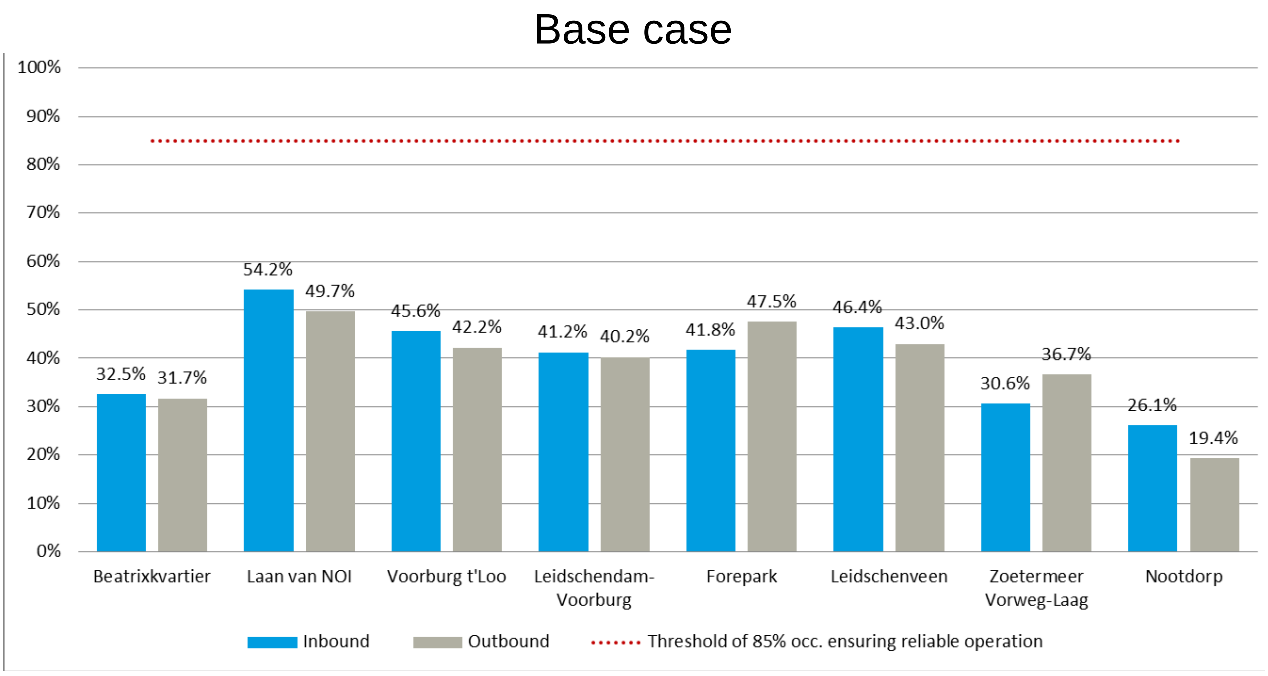
Legend:
Grey: track occupied by vehicle
White: track not occupied
Coloured lines: individual trips
X-axis shows location, Y-axis time

Less grey and more white means less occupancy and is therefore considered better.

Source: Ramboll

Figure 5.7: Stop occupancy shared section model case 2 compared to base case





Source: Ramboll

Table 5.5: Results model case 2: Maximum capacity with and without regulation.
Legend: (+)+ improvement (–)– deterioration, 0 comparable to reference

Model case		Frequency shared section (tphpd)	Punctuality	Occupation of stops	Complexity of implementation	Conclusion
0	Base case – timetable A (current operations) – NO timetable regulation	24 Reference	Reference	Reference	N/A	Current situation
2a-	Enhanced operation: – timetable C* (double E-line) – NO timetable regulation	30 +	–	–	N/A	Do not implement; no punctual and robust service possible
2a	Enhanced operation: – timetable C* (double E-line) – partial timetable regulation	30 +	0	–	Easy	Viable option, further research required to perturbed scenarios
2b-	Enhanced operation: – timetable C (max: double E-line & line 3K extended) – NO timetable regulation	36 ++	–	– –	N/A	Do not implement; no capacity at stops
2b	Enhanced operation: – timetable C (max: double E-line & line 3K extended) – partial timetable regulation	36 ++	–	– –	Easy	Do not implement; no capacity at stops

Source: Mott MacDonald

5.5.4 Model cases 3 to 6: timetable C with infrastructure measures

The following sections describe model cases 3 to 6. All of these model cases are based on timetable C (maximum frequency), each in combination with a different infrastructure measure on the shared section, to determine the effect infrastructure measures in order to increase capacity on the shared section.

5.5.4.1 Model case 3: driving on sight on shared section

In this model case, the signalling system is removed and replaced by a line of sight system. In such a system the driver is responsible for the correct speed and distance to its preceding vehicle. Only interlocking near switches will be required (e.g. near depot access, junction Beatrixkwartier, etc.). The maximum speed cannot exceed 80 km/h, which is the current maximum speed in this section. In this model case, RET and HTM vehicles can occupy the same platform track at more or less the same time, with the

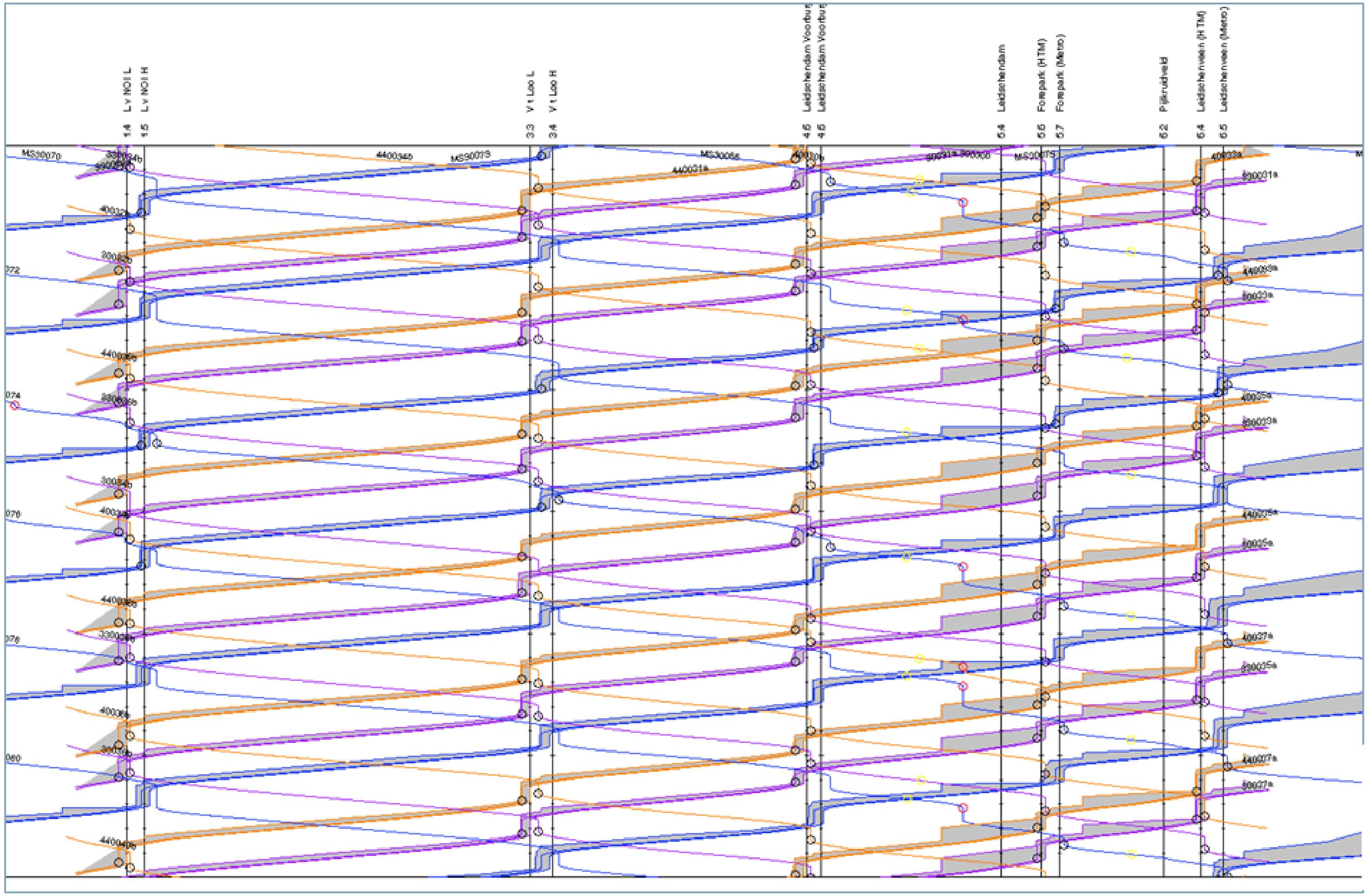
RET vehicle using the higher platform and the HTM vehicle using the lower platform simultaneously. This principle only works with a combination where the correct vehicle enters the platform track first (high floor RET metro first in direction of Den Haag CS, low floor HTM tram first in direction of Rotterdam). In this scenario the timetable can be optimised by a more even distribution of vehicles per hour per direction.

The results of the simulations show that the punctuality increases when applying driving on sight on the shared section with 36 vehicles per hour per direction, in comparison to the current timetable with 24 vehicles per hour per direction. Too high occupation of platforms, as could be seen in model case 2 (36 trams per hour), does not occur in this model case, especially not if the timetable is optimised to a more even distribution of trams over the hour (see also Figure 5.8). This is due to the possibility of a HTM and RET tram stopping at the same time and the reduced driving distance; in Figure 5.9 the occupancy diagram of this model case is given with the results separated for the low floor platform (HTM) and the high floor platform (RET).

The results above make the operation with a combination of 36 vehicles per hour per direction and driving on sight feasible from an operational point of view. However, it is very well possible that, from a safety and risk perspective, driving on sight with such high frequencies will not be authorised, especially given the difference between the bigger and heavier metro vehicles of the E-line compared to the smaller and lighter tram vehicles of lines 3 and 4.

Figure 5.8: Occupation diagram of shared section with driving on sight on shared section

Occupation diagram with driving on sight

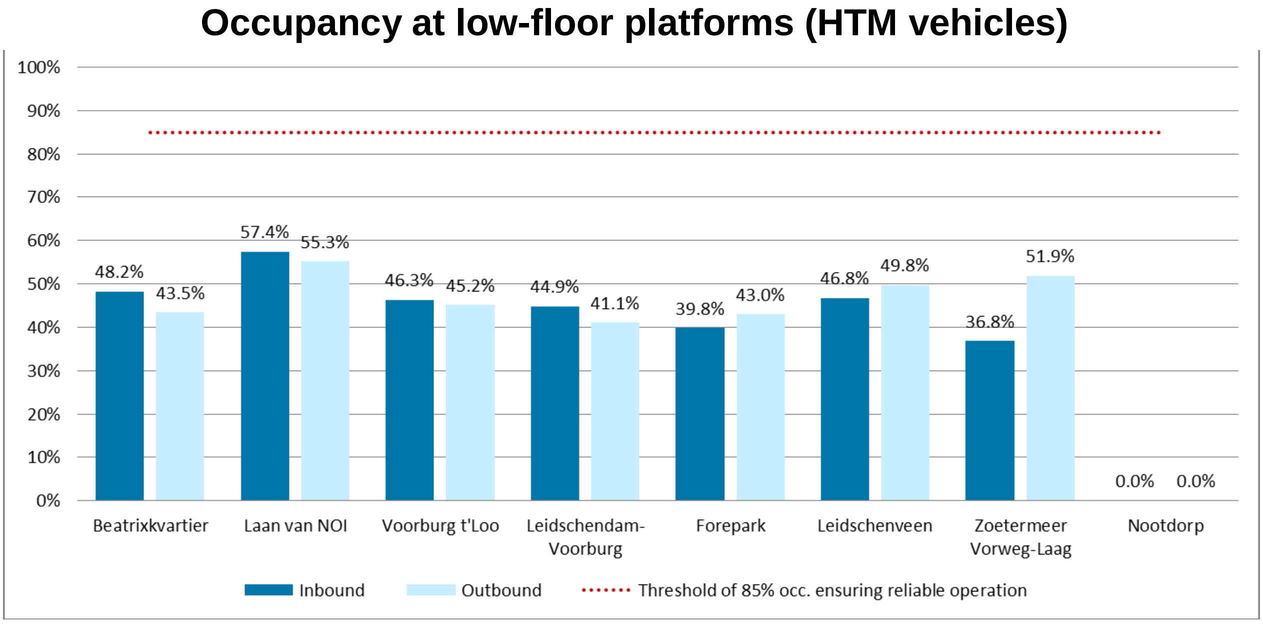


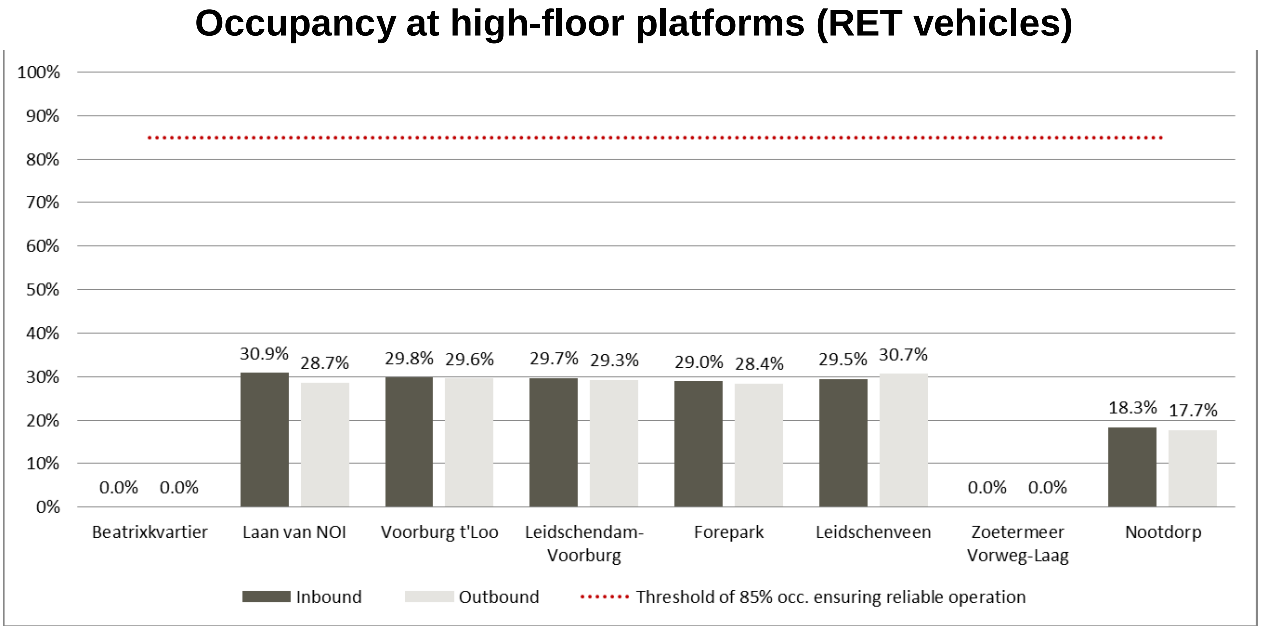
Legend:
Grey: track occupied by vehicle
White: track not occupied
Coloured lines: individual trips
X-axis shows location, Y-axis time

Less grey and more white means less occupancy and is therefore considered better.

Source: Ramboll

Figure 5.9: Station occupancy shared section model case 3, for the low floor platforms and the high floor platforms





Source: Ramboll

Table 5.6: Results model case 3: Driving on sight.
Legend: (+)+ improvement (–)– deterioration, 0 comparable to reference

Model case	Frequency shared section (tphpd)	Punctuality	Occupation of stops	Complexity of implementation	Conclusion
0 Base case – timetable A (current operations) – NO timetable regulation	24 Reference	Reference	Reference	N/A	Current situation
3 Enhanced operation: – timetable C (max: double E-line & line 3K extended) – partial timetable regulation – driving on sight	36 ++	++	0	Difficult (safety case)	Viable option; Further research required to safety case

Source: Mott MacDonald

5.5.4.2 Model case 4: redesign of junction Beatrixkwartier

The junction Beatrixkwartier is an at grade crossing, where vehicles have to cross vehicles from the opposite direction, thus resulting in a bottleneck at either the beginning or the end of the shared section. To study the effect of removing this bottleneck, four options have been investigated, as described in section 5.4.2 and Appendix F. Evaluation without simulation showed that the only feasible redesign is one where outbound vehicles can approach closer to Beatrixkwartier. Therefore, the effect of such a measure on the maximum timetable is simulated.

The results from the simulation show that a junction redesign at Beatrixkwartier will help to reduce delays of the outbound metro services (RET), when compared to a frequency of 36 vehicles per hour without the redesigned junction. This would therefore be useful to increase punctuality and reliability as an accompanying measure, also during current operation. However, it has only a very minor effect on operation, compared to the situation without redesign of the junction. Given the marginal effects on regular operations it is not recommendable to implement this to increase the frequency as a stand-alone measure. It should be reconsidered as a mitigation measures for disturbed scenarios.

Table 5.7: Results model case 4: Redesign junction Beatrixkwartier.
Legend: (+)+ improvement (–)– deterioration, 0 comparable to reference

Model case	Frequency shared section (tphpd)	Punctuality	Occupation of stops	Complexity of implementation	Conclusion
0 Base case – timetable A (current operations) – NO timetable regulation	24 Reference	Reference	Reference	N/A	Current situation
4 Enhanced operation: – timetable C (max: double E-line & line 3K extended) – partial timetable regulation – redesign of junction Beatrixkwartier	36 ++	–	– –	Hard	Do not implement as standalone measure; no capacity at stops; nor significant improvement for normal operations

Source: Mott MacDonald

5.5.4.3 Model case 5: optimisation of signals

In this model case, the locations of signals have been optimised, in order to increase capacity. 12 inbound and outbound signals are relocated and 6 new signals are implemented. The simulation results show no significant effect on operation as the current design is already optimised to handle 30 vehicles per hour per direction. A frequency of 36 vehicles per hour per direction on the shared section cannot be achieved by this measure alone. Given its lack of overall effect and the results of the other model cases, it is not considered a useful measure in general for the shared section but could amend the current operation.

Table 5.8: Results model case 5: optimisation of signals. Legend: (+)+ improvement (–)– deterioration, 0 comparable to reference

Model case	Frequency shared section (tphpd)	Punctuality	Occupation of stops	Complexity of implementation	Conclusion
0 Base case – timetable A (current operations) – NO timetable regulation	24 Reference	Reference	Reference	N/A	Current situation
5 Enhanced operation: – timetable C (max: double E-line & line 3K extended) – partial timetable regulation – optimisation of signals	36 ++	0	– –	Moderate	Do not implement; no capacity at stops; no punctual and robust service possible

Source: Mott MacDonald

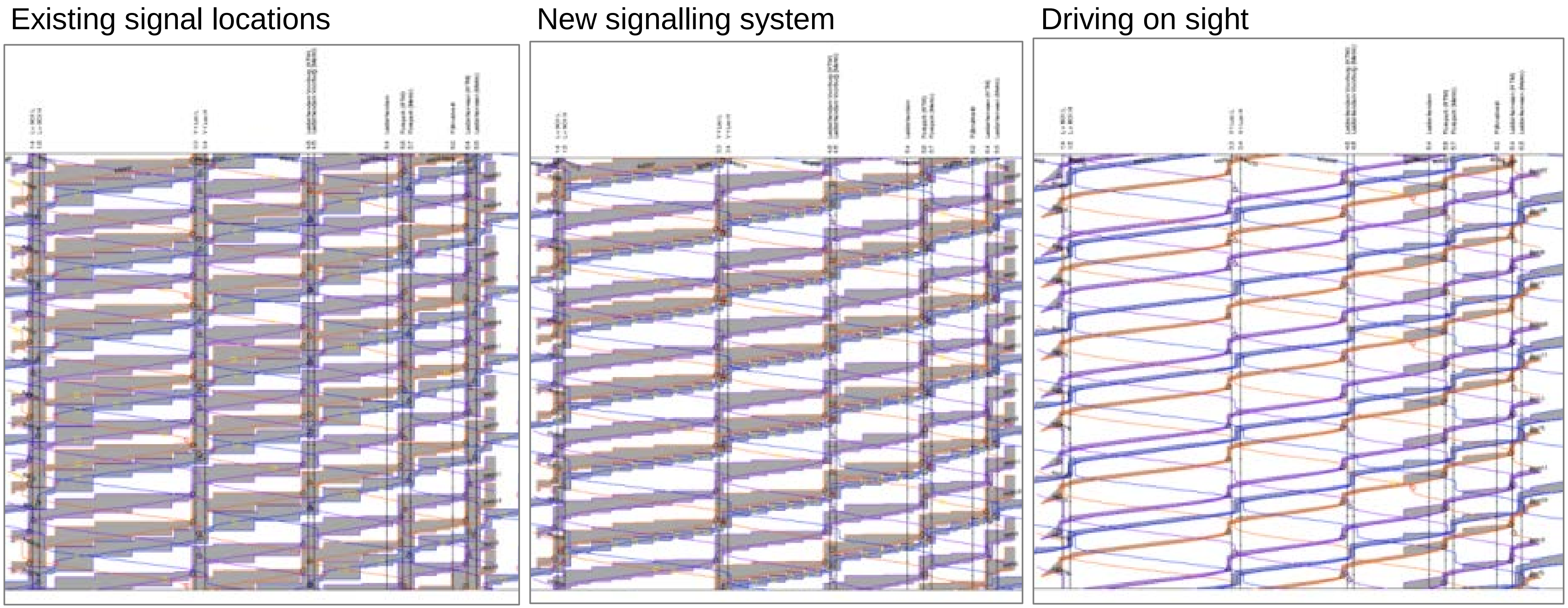
5.5.4.4 Model case 6: redesign of signalling layout, including mid-platform signals

The sixth model case simulated a complete redesign of the signalling layout with section lengths on the shared section of 200 meters on average and mid-platform signals to enable simultaneous occupation of the same platform track at more or less the same time, with a RET vehicle using the higher platform and a HTM vehicle using the lower platform. This overhaul of the signal layout helps vehicles to run closer to each other, thus increasing capacity. This measure is an alternative to the driving on sight.

Application of this measure in a simulation with 36 vehicles per hour per direction on the shared section shows a higher punctuality compared to the situation with the existing block lengths. Occupation levels of the platforms and sections decrease as well. This is illustrated in Figure 5.10, where the occupation diagrams are shown of three settings: the simulation without infrastructure measures, the simulation with shorter section lengths and the simulation with driving on sight.

The results of the simulation with reduced block lengths and mid-platform signals show a significant improvement of operation, in combination with increased punctuality. The measure allows a frequency of 36 vehicles per hour per direction on the shared section. However, the technical feasibility of very short block lengths is questionable and mid-platform signals can be a safety issue considering the zero overlap for following vehicles, given the difference between the bigger and heavier vehicles of the E-line and the smaller and lighter HTM-vehicles.

Figure 5.10: Occupation diagrams of 36 vehicles/hour/direction on the shared section, comparison between existing signal locations, section lengths of 200 meter and driving on sight



Legend:
Grey: track occupied by vehicle
White: track not occupied
Coloured lines: individual trips
The X-axis shows the location, while the Y-axis time
Less grey and more white means less occupancy and is therefore considered better.

Source: Ramboll

Table 5.9: Results model case 6: New signalling system.
Legend: (+)+ improvement (–)– deterioration, 0 comparable to reference

Model case	Frequency shared section (tphpd)	Punctuality	Occupation of stops	Complexity of implementation	Conclusion
0 Base case – timetable A (current operations) – NO timetable regulation	24 Referenc	Reference	Reference	N/A	Current situation
6 Enhanced operation: – timetable C (max: double E-line & line 3K extended) – partial timetable regulation – redesign of signalling layout	36 ++	+	0	Difficult (safety case and technical feasibility)	Viable option; Further research required to costs, safety case, technical feasibility

Source: Mott MacDonald

5.6 Consequences of increase in service frequencies on the shared section

An increase in capacity, and especially an increase in frequency, means at the same time a higher network load. This has consequences for the network. This paragraph describes necessary adjustments to the traction supply power system, maintenance and operational impact, including safety case.

Furthermore, more vehicles will be needed to drive with higher frequencies. The exact increase is not determined within this study,.

5.6.1 Traction power supply

With increased service frequencies, the traction power supply system is unable to provide enough traction power support. Therefore, a high level analysis of possible solutions to ensure adequate increased traction power supply has been made. The analysis has been performed for service frequencies of 30 (timetable C*), 32 (timetable E) and 36 (timetable C) vehicles per hour per direction on the shared section, in comparison with the current frequency of 24 vehicles per hour per direction (timetable A). Below, a summary of the results is given; more details can be found in Appendix E.

The analysis is based on limited information and was carried out using simplified calculations. A detailed traction power upgrade should be done by computer-aided modelling and simulation before increasing frequencies.

It has been found that under both the existing and proposed operational scenarios, the network is unable to provide enough traction power to support the full services in case of a non-functioning substation (N-1 feeding conditions cannot be handled; the loss of a single substation has effects on the operation of RandstadRail).

The result for an increase to 30 vehicles per hour per direction show that the substation Haagse Poort is overloaded and that in case of a failing substation the voltage drop between Schipholboog substation and Westvliet substation and between Veenweg substation and Recreatieweg substation is too large. Therefore it is suggested to add another substation and apply a parallel feeder configuration. The rough order magnitude costs of these measures are estimated to be between €3.8 and €5.2 million.

For an increase of service frequency to 32 vehicles per hour per direction, the voltage drop appears to be too large between Schipholboog substation and Westvliet substation and between Segwhaert substation and Javalaan substation, which can be resolved by configurations such as parallel feeders or doubling of contact wire. For the too large voltage drop between Veenweg substation and Recreatieweg substation in case of a failing substation, a new substation between Veenweg substation and Recreatieweg substation is suggested. The rough order magnitude costs of above mentioned measures are estimated to be between €5.7 and €7.8 million.

For a service frequency of 36 vehicles per hour per direction, all challenges and possible measures described for 30 vehicles per hour per direction apply. One additional challenge arises, namely the Schipholboog substation is overloaded under normal feeding conditions. It is suggested that a new substation be placed between Schipholboorg substation and Westvliet substation. This will also solve the voltage drop between Schipholboog substation and Westvliet substation. The rough order of magnitude costs of the measures are estimated to be between €8.4 and €11.4 million.

5.6.2 Maintenance

Hihger service frequencies will increase the wear of electro-mechanical and mechanical components, which can result in a higher failure rate if the maintenance regime is not adjusted accordingly. Increasing the number of vehicles per hour per direction from 24 to 30, or even to 36 vehicles per hour per direction, is a 25 to 50% increase. Below an estimate of the effect of increased frequencies on wear of different infrastructure parts is given, if relevant with recommendations for the maintenance regime. In general, it can be said that reliable measurement data and analysis of the data, is the key factor in an adequate, predictive maintenance regime.

5.6.2.1 Rail wear in switches and crossings

It is anticipated that the rail wear will increase slightly with the increased traffic. Side wear or gauge widening in switches and crossing areas may lead to detection issues at switch machines if not corrected through regular preventative maintenance activities. The effects of other contributory factors such as track voiding and alignment issues through increased traffic need also be accounted for when assessing the level of maintenance required.

5.6.2.2 Switch machines

Increased wear of switches due to increase frequencies is only likely to occur at switches which are used during normal operation, not at switches mainly used in case of disruptions. This leaves a small number of switches at two key junctions that will see increased use/movement namely switches 815 and 816 at

Beatrixkwartier and switches 860 and 861 at Leidschendam Voorburg. It is advised to closely monitor the switch machines before and after a change in frequencies, so changes can be addressed in time.

As is elaborated on in paragraph 0, regular maintenance of switches and switch machines is necessary, at the least covering for seasonal changes and regular wear. With higher service frequencies and higher numbers of movement of switches, it is even more important to maintain switch machines in time. In order to fully understand and manage the impact of the change, asset performance data is required to be collated over time and regularly reviewed. Based on this data, the life expectancy and the number of switch operations per time unit, it can be forecasted when failures can be expected and the maintenance regime can be based on these expectations.

5.6.2.3 Axle counters

Assets such as axle counters are passive devices and the number of operations should not directly affect the performance. However, it needs to be ensured that wheel and rail wear is within the rail/wheel profile limits for the axle counter.

5.6.2.4 Relays

Where interface relays are used between the hardware and the trackside components on the sections with increased capacity, these are expected to be subject to increased numbers of operation and therefore subject to accelerated wear. Manufacturer's data should indicate the typical life expectancy or number of operations of the relay. Based on the expected number of operations according to the timetable, relay re-servicing plans need to be implemented, in order to prevent failures from relays and in particular from the high used high risk relays.

5.6.3 Operational impact

In general, an incident will have a larger impact on passenger services with increased frequencies. It takes longer to recover to normal operations and, usually, more passengers are affected by a disturbance. Increasing frequencies will therefore require reliable infrastructure and rolling stock to minimise the number of incidents occurring. If an incident occurs, an adequate response from control and maintenance should be carried out to reduce the impact of an incident as much as possible.

In case of a disruption on the shared section passengers have minimal access to a limited number of alternative travel options. It is also suggested that the location of various turnback facilities is not optimal nor is sufficient. In particular near Laan van NOI and Leidschenveen more turnback facilities could be implemented, although the need could differ depending on the signalling system (when driving on sight, more switches means more signals and thus increase of capacity during normal operation). To identify the optimal location and solution it is recommended to simulate perturbed scenarios with the operational model.

5.7 Conceptual alternatives to further increase capacity

To increase capacity above 36 vehicles per hour, a parallel route for the shared section is required. This would introduce an alternative travel route, hence, reducing the impact of disturbances on the shared section. Three conceptual ideas have been developed on possibilities to increase capacity of the shared section even further:

1. Construction of a parallel track next to the existing tracks on the shared section (see the purple line in Figure 5.11). This option would enable to run lines 3 and 4 separate from line E on the shared section. Advantages are that the frequencies can increase significantly (up to 30tph per track), the system can be simplified as it only has to cope with RET-metro or HTM-tram vehicles (there is no interaction between the vehicles anymore) and the high quality connection of all three lines (3, 4 and E) remains. Construction of such a parallel track will have a very high impact and will be of high costs; an initial estimate notes that the cost will exceed €200 million. This is mostly due to the part Den Haag Centraal Station – Laan van NOI – Crossing with heavy rail to Leiden, where there is lack of space and the light rail track crosses and runs parallel with heavy rail infrastructure.
2. A connection from the Light Rail net from Zoetermeer to the tram track of line 19, just before the start of the shared section at Leidschenveen. The vehicles from lines 3 and/or 4 can use lines 19 and 2 to reach Den Haag Central Station. Advantages of this option are that it introduces an alternative travel option to passengers in case of a disturbance, it mostly uses existing infrastructure and construction seems to be feasible. It can relieve the capacity of the shared section as well and a new connection between Zoetermeer and Delft can be introduced. Disadvantage is an increase in travel time for passengers in the line(s) running via the current line 19 and 2, hence, losing the high quality connection between Zoetermeer and Den Haag and no ability to reduce the complexity of the infrastructure of the shared section. In Figure 5.11 a sketch of the new route for line 3 and/or 4 and the location of new connecting track is provided. A high level estimate of the costs for the new infrastructure is between €25 and €30 million.
3. A third option to consider is to turn around the E-line at Pijnacker to avoid shared use of the current shared section. Most important advantage of this option is the possibility to simplify the system and drive on sight on lines 3 and 4 on the current shared section and in the Zoetermeer area. Therefore resulting in an increase in capacity and a lower likelihood of disturbances. Another advantage is that this option is relatively cheap; only costs are a turn back facility in Pijnacker and redesign of the Pijnacker station. However, it result in an enormous deterioration for travellers between The Hague and Rotterdam: they lose the direct connection between The Hague and Rotterdam and need to change vehicles at Pijnacker. Next to this, is does not introduce a parallel track to the current shared section, so although the likelihood of a disturbance decreases, the impact of disturbances remains the same.

Figure 5.11: Sketch of new route for line 3 and/or 4

Legend:

- Shared section, currently line 3, 4 and E
- Line 19
- Line 2
- New connecting track
- New route of line 3 and/or 4

Source: Google Earth (adapted by Mott MacDonald)

5.8 Conclusions and recommendations

The operational model has been used to determine the effect of various measures on the operation of the RandstadRail, especially on the shared section. The evaluation is based on normal operation, which means that there are no disruptions during operation.

It is advised to introduce timetable regulation at the entrance of the shared section and TTGM, both for the current and future timetable. This measure increases punctuality significantly and improves robustness of operation, also with the current timetable and frequencies. The negative effects are very limited with a run time prolongation of up to 30 seconds. The same applies for optimisation of the timetable to prevent the E-line from waiting at Laan van NOI to enter the shared section and consider the junction Seghwaert in planning lines 3 and 4. Timetable regulation is a proven concept and is considered technical feasible at almost no additional costs and could be implemented at the start of the next timetable.

Three model cases allow punctual and robust operation with increased frequencies:

- Increase service frequency to 30 vehicles per hour per direction on the shared section by doubling the frequency of the E-line seems feasible if regulation at the entrance of the shared section is implemented. However, it also means an increase of occupation of the stops and the effect of incidents is exacerbated due to the increased number of services running. Therefore, implementation should only be considered when the infrastructure and rolling stock is sufficiently reliable. Further research is needed to determine recovery of the operation in case of disturbances, for example by simulating perturbed scenarios. In addition, attention should be given to the capacity of the traction power supply which seems to be insufficient to cope with a higher frequency in combination with coupled vehicles. The maintenance regime should be adjusted to address the effects of the higher frequencies on wear. There are no technical complex or safety case issues foreseen in implementing these measures. Costs and timescales depend on the required investments in traction power supply, required mitigation measures for disturbed scenarios (i.e. turnback facilities) and the number of vehicles to be procured. An initial estimates that infrastructure costs are not expected to exceed € 5 million. The procurement of any additional vehicle costs between € 2 and 3 million per vehicle.
- Increase service frequency to 36 vehicles per hour per direction on the shared section by doubling the frequency of the E-line and extending line 3K to Zoetermeer will require driving on sight or a new signalling system with significantly reduced block lengths. Besides this, a frequency of 36 vehicles per hours per direction is technically challenging and will require state of the art infrastructure to cope with these numbers of vehicles. In case this frequency is desired, these measures require further research, with respect to passenger demands, costs, type of system, safety issues, traction power supply and the maintenance regime. An investment in infrastructure is expected to be in the order of €20 to €50 million, including a new signalling system and additional traction power supply capacity, excluding procurement of vehicles.
- The highest increase in frequency can be achieved by designing a parallel track for the E-line, so the trams of HTM and the metros of RET do not have to share the track anymore. Capacities can reach 40 to 60 vehicles per hour per direction. This has the additional advantage that an alternative travel option is created in case of disturbances and that simplification of the system of the current shared section becomes possible. However, this is a very far-reaching measure in terms of costs, design and spatial

planning. Alternatively, it can be considered to connect the Light Rail net from the Zoetermeer area with the Tram net line 19 and 2. This would give a parallel travel option with less new infrastructure, but would at the same time increase travel times significantly for passengers from Zoetermeer.

- As described in paragraph 5.2, an increase of passenger capacity can also be established by increasing the length of the vehicles to accommodate more passengers. It is recommended to consider the option of running line 3(K) in coupled mode in parallel to further research of increasing capacity to 36 vehicles per hour per direction and determine the business case for the different solutions.

Although disturbed scenarios were not studied with simulation, it can be expected that it is possible to perform a limited number of extra runs of the E-line during peak hours (order of magnitude of three individual trips). With this limited number of extra runs, the system can recover during the lower frequency period. However, this should be considered a short term temporary solution before more long term solutions are implemented to increase the capacity of the system.

The results of the different model cases are summarised in Table 5.10. Per model case, the effect of the measure on punctuality and the occupation of stops are given, in comparison to current operational situation. Furthermore, an indication of the complexity of implementation and a conclusion is given. The conclusions were drawn in a workshop with the planning specialists of HTM and RET and the specialists of Ramboll[6].

[6] Workshop 'Simulatie RandstadRail', 11 November 2016, Den Haag

Table 5.10: Results and conclusion per model case

Model case		Punctuality	Occupation of stops	Complexity of implementation	Conclusion
0	Base case – timetable A (current operations) – NO timetable regulation	Reference	Reference	N/A	Current situation
0a	Base case: – timetable A (current operations) – partial timetable regulation	+	+	Easy	Implement
0b	Base case: – timetable A (current operations) – timetable regulation at all stops	+	0	Easy	Do not implement; no buffer and extended run times
Frequency of 32 vehicles per hour per direction on the shared section					
1	Enhanced operation: – timetable E (7.5 min headway) – partial timetable regulation	0	–	Difficult (increased frequencies on all lines)	Do not implement; too large impact on rest of network
Frequency of 30 vehicles per hour per direction on the shared section					
2a*	Enhanced operation: – timetable C* (double E-line) – NO timetable regulation	–	–	N/A	Do not implement; no punctual and robust service possible
2a	Enhanced operation: – timetable C* (double E-line) – partial timetable regulation	0	–	Easy	Viable option, further research required to perturbed scenarios
Frequency of 36 vehicles per hour per direction on the shared section					
2b	Enhanced operation: – timetable C (max: double E-line & line 3K extended) – NO timetable regulation	–	– –	N/A	Do not implement; no capacity at stops
2b	Enhanced operation: – timetable C (max: double E-line & line 3K extended) – partial timetable regulation	–	– –	Easy	Do not implement; no capacity at stops
3	Enhanced operation: – timetable C (max: double E-line & line 3K extended) – partial timetable regulation – driving on sight	+ +	+	Difficult (safety case)	Viable option; Further research required to safety case

Model case		Punctuality	Occupation of stops	Complexity of implementation	Conclusion
4	Enhanced operation: – timetable C (max: double E-line & line 3K extended) – partial timetable regulation – redesign of junction Beatrixkwartier	–	– –	Hard	Do not implement as stand alone measure; no capacity at stops; nor significant improvement for normal operations
5	Enhanced operation: – timetable C (max: double E-line & line 3K prolonged) – partial timetable regulation – optimisation of signals	0	– –	Moderate	Do not implement; no capacity at stops; punctual and robust service possible
6	Enhanced operation: – timetable C (max: double E-line & line 3K prolonged) – partial timetable regulation – redesign of signalling layout	+	0	Difficult (safety case, technical feasibility)	Viable option; Further research required to costs, safety case, technical feasibility

Source: Mott MacDonald

6 Conclusions and recommendations

RandstadRail is a considered a success by passengers and stakeholders. Passenger numbers exceed expectations and are expected to grow even further. In general, passengers are satisfied with the product. However, the system also has a lot of disruptions. The operator HTM has therefore requested Mott MacDonald to give a high level review of the performance of the RandstadRail, e.g. with respect to infrastructure, rolling stock and operations. This review is divided in two parts, namely part one on the performance of current operations and part two on possibilities to increase capacity. Per part the main conclusions and recommendations are given below, more detailed conclusions and recommendations are given in the various chapters.

6.1 Performance of current operations

The performance of the current operations has been assessed by Mott MacDonald in terms of passenger satisfaction, punctuality and reliability.

6.1.1 Passenger satisfaction

RandstadRail provides a high frequency connection between The Hague, Rotterdam and Zoetermeer. This is highly valued by passengers, as for example can be seen in the score of 7.4 out of 10 for RandstadRail in the ‘OV Klantenbarometer’. The satisfaction is also stated in interviews with stakeholders, such as local governments and passengers’ representative organisation Rover.

The interviews with stakeholders show that communication to passengers and passenger information, especially during disturbances, requires improvement. Therefore, in the short term it is recommended to make better use of the personal announcement system in vehicles and at stops to better inform passengers in case of disturbances and appoint a communications officer at the operational control centre. The recent implementation of the new passenger information system ‘InfoActueel’ is a good improvement and should be continued.

6.1.2 Punctuality

The punctuality on a 2-minute basis has been determined for the period of January to April 2015. Depending on the line and the stop, the punctuality ranges between 63 and 88 %. This value is too low, which does not meet the concession requirements nor the design specification of RandstadRail. Considering the high service frequencies, it means vehicles are often delaying each other. Improvement is possible by optimisation of the joint timetable of HTM and RET and by applying regulation to enter the shared section and the of Tramtunnel Grote Markstraat (TTGM). Further improvement can be gained if less disruptions occur; as discussed in the paragraph on reliability.

6.1.3 Reliability

By design RandstadRail is a complex system. It has many dependencies and variations on nearly all aspects. Evaluation of the causes of failure[7] shows that rolling stock causes the highest number of cancelled trips, followed by a similar amount for infrastructure and external factors. Evaluation of the incidents with the highest impact shows that all three causes, rolling stock, infrastructure and external factors, occur in a similar number of occasions. When the failures are divided after location, there is also no significant difference in the number of failures on the light rail net, the tram net and the TTGM and Den Haag CS. This results in the conclusion that there is not a single cause for the high number of disruptions.

Analysis of the available failure data shows that the root cause of failures is often unknown, for example, the component of the switch that caused a failure. Repairs are often done in a corrective manner, e.g. a direct reset of a system in case of a failure. By doing so, the root cause is not determined, which results in a high possibility of recurring failures. By determining the root cause of failures and solving them in a structural manner, a high reduction of failures can be expected. This starts with reliability analysis, as part of a shift to a preventative and predictive maintenance regime.

Rolling stock failures account for the highest number of cancelled trips. Analysis of failures of rolling stock shows that the Mean Time Between service affecting Failure (MTBSF) is on average 9,000 kilometres, which is very low compared to other tram systems which achieve at least 21,000 kilometres. Failures are often solved as standalone incidents, with no root cause analysis conducted and no permanent solution identified and implemented across the fleet. Based on the failure data, reduction of failures can start with paying more attention to brakes and door systems.

With respect to infrastructure, the RandstadRail infrastructure and in particular the shared section has a technically complex design, due to the use of two types of vehicles, two operators and various signalling systems. As a result, the safety case puts stringent requirements on the infrastructure in order to facilitate the two different vehicle types of HTM and RET vehicles and the different wheel profiles. This has resulted in a complex design of e.g. switches, with a lot of possible failure causes. Improvement seems possible by modification and more frequent maintenance of the switches and interlocking. Furthermore, it is advised to investigate the possibilities to adjust the requirements in the safety case, so the system can be simplified, resulting in reduced probability of failures occurring.

Even when the above recommendations are implemented and the number of failures is reduced significantly, incidents will still occur. The impact of an incident on the shared section will be significant, as there are no viable alternative travel options; it can therefore be considered as a bottleneck. However, there are more factors resulting in a long recovery time and large impact of a failure for passengers:

- In case of a failure, there are no good predefined recovery scenarios how to proceed with operations. This results in unnecessary long recovery times, including vehicles with passengers standing in open fields. It is advised to develop such predefined recovery scenarios and possibly the design of mitigation measures (e.g. turn-back facilities).

[7] April up and until October 2015

- In case of a failure in infrastructure or rolling stock, the driver cannot contact a technician to help solving the problem. Therefore it is advised to appoint a technical coordinator at the operational control centre to coordinate in resolving technical incidents.

6.2 Possibilities to increase capacity

In order to determine the capacity of RandstadRail and especially the shared section and the Tramtunnel Grote Marktstraat, an operational model has been developed. In this model, the timetable, infrastructure, rolling stock and operations are modelled and evaluated. The evaluation is based on normal operation, which means that there are no disruptions during operation.

The results of the simulations show that the current timetable can be optimised and better regulated to improve punctuality and robustness. Improvement of current operation is possible by applying regulation just before the entrance to the shared section and the TTGM. It is recommended to better align the timetables of RET and HTM and jointly implement the improvements.

Increase of service frequency to 30 vehicles per hour per direction on the shared section by doubling the frequency of the E-line, in accordance to the design requirements, is possible if time regulation on the entrance of the shared section is applied. However, it also means an increase in occupation of the stops, which causes vehicles requiring to wait before they can enter the stop due to an occupation by a previous service. Further research is required to determine if and how operations can recover in case of disturbances with such a high frequency, for example by simulating perturbed scenarios and possibly the design of additional mitigation measures (e.g. turnback facilities). In addition, measurements need to be taken to ensure sufficient traction power supply is available and to determine required changes to the maintenance regime. The costs of these measures are expected not to exceed € 5 million, excluding the possible procurement of rolling stock.

Although disturbed scenarios were not studied with simulation, it can be expected that it is possible to perform a limited number of extra runs of the E-line during peak hours (order of magnitude of three individual trips). This should be considered a short term temporarily solution before more long term solutions are implemented to increase the capacity of the system.

Increasing to 36 vehicles per hour per direction on the shared section by doubling the frequency of the E-line and extending line 3K to Zoetermeer will require driving on sight or a new signalling system with significantly reduced block lengths. Notwithstanding this, a frequency of 36 vehicles per hour per direction is technically challenging and will require state-of-the-art infrastructure to cope with these numbers of vehicles. In case this frequency is desired, these measures require further research, with respect to passenger demands, costs, type of system, safety issues, traction power supply and the maintenance regime. An investment in infrastructure is expected to be in the order of €20 to €50 million.

The highest increase in frequencies can be achieved by designing a parallel track for the E-line, so the trams of HTM and the metros of RET do not have to share the track anymore. This has the additional advantage that an alternative travel option is created in case of disturbances and that simplification of the system of the current shared section becomes possible. However, this is a very far-reaching measure in terms of costs, design and spatial planning. As an alternative, it can be considered to connect the Light Rail net from the Zoetermeer area with the Tram net line 19. This would provide an alternative travel route in case of a disturbance and can create extra capacity between Zoetermeer and the Hague with less new infrastructure. However, it increases travel times significantly for passengers from Zoetermeer using this new route and is therefore less attractive compared to the shared section. Finally, an increase in passenger capacity can be achieved by driving line 3 in coupled mode, requiring longer platforms in the Tram net area, the possibility to couple vehicles and procurement of additional rolling stock.

6.3 Summary of proposed measures

The table below provides a summary of the proposed measures to increase performance of the RandstadRail.

Table 6.1: Summary of proposed measures

Measure	Effect	Costs
Prevent failures: ▪ Rolling stock: implement preventative maintenance, solve failures at their root cause ▪ Infrastructure: more intensive maintenance of switches and signalling, simplification of the system	Increased availability and reliability	Limited (< €1 million), possible modifications of vehicles or simplification of infrastructure require additional investments
Optimisation of current timetables at the entrance of shared section and TTGM; in cooperation between HTM and RET	Increased punctuality and robustness	Minimal
Increase of frequency to 30 vehicles per hour per direction on the shared section; requiring: optimisation of the timetable, partial timetable regulation, sufficient ability to recover from incidents and increased capacity of traction power supply	Increased capacity	Moderate (< €5 million); excluding procurement of additional vehicles
Increase of frequency to 36 vehicles per hour per direction on the shared section; requiring: optimisation of the timetable, new signalling philosophy, simultaneously stopping of HTM and RET, sufficient ability to recover from incidents and increased capacity of traction power supply	Increased capacity	High (€ 20-50 million); excluding procurement of additional vehicles
Parallel track for the E-line: ▪ Parallel to current shared section ▪ Connection of Zoetermeer section to line 19	Increased capacity and alternative travel options. ▪ For parallel to shared section: higher reliability due to simplification of the system. ▪ For connection to line 19: longer travel times.	For parallel to shared section: Very high (> €200 million) For connection to line 19: High (€25-30 million)

Source: Mott MacDonald

Appendices

Appendix A. List of interviews

Table A.1: List of interviews. Multiple interviews have taken place with those marked with an asterisk (*).

Name	Organisation	Department	Date (2015)	Place
Dennis den Elzen*	HTM	Bijsturing	31 March	The Hague
Marijke Poppelier	HTM	Corporate Communicatie	01 April	The Hague
Hilbert Veldhoen	HTM	I&P	31 March	The Hague
Kas Blezer*	HTM	Middelen	01 April	The Hague
Jimmy de Jong*	HTM	Middelen	03 April	Arnhem
Paul Segaar	HTM	Middelen	14 April	The Hague
Rick van der Schie*	HTM	Middelen	15 April	The Hague
Eric van Zanten	HTM	Middelen	19 May	The Hague
Colin Hessels	HTM	Middelen	19 May	The Hague
Gerrit Keuzenkamp	HTM	Planning	17 April	The Hague
Ritsert Harsveld*	HTM	Planning	17 April	The Hague
Tim Jongerius	HTM	Planning	17 April	The Hague
Hans Fens	HTM	Planning	13 May	The Hague
Hans van der Stok	HTM	Planning	9 July	The Hague
Rien van Leeuwen	HTM	Reizigers	31 Mar	The Hague
Bas Bussink*	HTM	Reizigers	31 Mar	The Hague
Ronald Coelman	HTM	Reizigers	01 April	The Hague
Hans Rodrigo*	HTM	Reizigers	14 April	The Hague
John van Rijn	HTM	Rijdienst Rail	01 April	The Hague
Wytze de Vries	HTM	Taskforce	30 March	The Hague
Ronald van de Berg	HTM	Voormalig projectleider RandstadRail	13 May	The Hague
Pim Uijtdewilligen	MRDH	Concessie – assets	08 April	The Hague
Peter Dubbeling*	MRDH	Concessie – exploitatie	08 April	The Hague
Jake Franken	RET	Verkeersleiding	09 April	Rotterdam
Stephan van Ijperen	RET	Verkeersleiding	09 April	Rotterdam
Maarten Strooper	gem. Den Haag	Beleid	13 May	The Hague
René Teule	gem. Den Haag	Beleid	13 May	The Hague
Don de Greef	gem. Leidschendam-Voorburg	Beleid	09 April	Zoetermeer
Ed Kroet	gem. Zoetermeer	Beleid	08 April	Zoetermeer
Arnold van der Heijden	Rover Den Haag	Nvt	03 July	The Hague
Mark Schram	Rover Den Haag	Nvt	03 July	The Hague
Emilio Tuinenburg	Siemens	Contractmanager	09 April	Zoetermeer
Erik van de Luijtgaarden	Siemens	Customer service	09 April	Zoetermeer
Arthur Stam	VolkerRail	Contractmanager	08 April	Utrecht
Gwen Ververs	VolkerRail	Projectleider	08 April	Utrecht
Dirk Hengeveld	Movares	Voormalig projectleider Elektrotechniek RandstadRail	15 June	The Hague
Max van Asch van Wijck	voormalig RET	Nvt	08 May	Arnhem

Appendix B. List of received documents

Table B.1: List of received documents

Title/subject	File name	Date	Status/version/reference
Received from HTM - Infrastructure			
Average recovery time A failures January to November 2015	QLIK_KPI_8_gem_duur_A_storingen _lightrail		
Characteristics of the power transformer	vermogens trafo		
Decompositie locatie structuur Maximo	Decompositie locatie structuur HTM 131022_Maximo		
e-mail: Info onderzoek RandstadRail	Info onderzoek RandstadRail	03/04/2015	
e-mail: Lightrailstoringen Infra maand November-2015	Lightrailstoringen Infra maand November-2015	04/12/2015	
e-mail: Systeembeschikbaarheid spoorbeveiliging en reactietijd bij problemen verbeteren / optimaliseren	brainstormcessie	11/11/2005	
Expertmeeting spoorbeveiliging samenlooptraject RandstadRail	Knelpuntenlijst samenloop RandstadRail A40-AWE-KA-1300196	19/08/2013	Reference A40-AWE-KA-1300196
Functionele tabellen en seinconfiguratie TTGM tbv RandstadRail	Functionele tabellen TTGM 3 d.d. 22022006.doc	22/02/2006	Versie 3
HTM Sporenplan Schematisch	20141202 rt022249r4	02/12/2014	Version 4; reference TR022249
HTM storingsproces – Vervolgsessie 2 op de VSM van 19 februari 2015	20150219 storingsproces communicatie doorlooptijden storingsherstel		
Inhoudsopgave opleverdocumentatie SBR	n/a	05/10/2007	
Managementinformatie	Ontwerpuitgangspunten perceel 2 + TTGM d.d	06/12/2010	Version 1.0
Modelling of the RandstadRail signalling system for supporting capacity studies	Operational Model - Final Graduation Presentation T_Jongerius v3		
Ontwerpuitgangspunten Spoorbeveiliging			
Ontwerpuitgangspunten Spoorbeveiliging TTGM - CS - J.v. Stolberglaan - Beatrixlaan (perceel 2)	ONTWERPU.PDF	06/12/2010	1
Ontwerpvoorschrift ARI systeem	20120210 Ontwerpvoorschrift systeem ARI.pdf	10/02/2012	
Overview of cancelled trips	IncidentenNick		
Overview of reports in Incman August to September 2015	IncmanLijst20142015		
Overview of reports in Incman Januari 2015	Incman Januari		
Overzicht areaal Lightrail	HTM Infrastructure - OverOverzicht areaal Lightrail		
Overzicht instelwaarden snelschakelaars RandstadRail	Instelling snelschakelaars	22/07/2014	Version 3.0

Title/subject	File name	Date	Status/version/reference
Overzicht knooppuntnummering Stadsnet	20131025 rt020248 - knooppuntnrs en afkortingen	25/10/2013	Version 4; reference RT020248
Overzicht rijdraden contractgebieden Volker Utrecht	HTM Infrastructure OLE - Rijdraden totaal overzicht RandstadRail	27/08/2013	Revisie 4
Overzicht seinen	HTM Signals - Seinen - Baanvak 20141208		
Overzicht shouw lijnennet lijn 2 Kraayenstein - Centrum Den Haag	rt025429-BLAD 33.pdf	2014	
Overzicht shouw lijnennet lijn 2 Kraayenstein - Centrum Den Haag	rt025429-BLAD 34.pdf	2014	
Overzicht shouw lijnennet lijn 6 Leidschendam - Leyenburg	7) rt025429_BLAD 69_2015.pdf	2015	RT925428
Overzicht wissels RandstadRail Contec – Siemens	HTM Switches - Wissels Randstadrail Contec-Siemens		
Performance verbetering RandstadRail Perceel 1	Briefsiemensverbetervoorstellen	03/07/2009	Reference /09-51897909
RandstadRail – Algemene systeembeschrijving beveiligingssysteem	1.13 Algemene_ systeembeschrijving_v5.4 - Signalling	23/10/2012	Status definitief; version 5.4; reference 5600 17 360
Rapportage 4e kwartaal 2014 Exploitatie	N/A	30/01/2015	Version 2.0
Rapportage meting aan W816 bij de HTM – HTM IXL 1, Den Haag	SI141197 - HTM, metingen aan wissel 816 v0.3 CONCEPT	28/10/2015	Status concept, version 0.3
Report work orders technical failures April to November 2015	QLIK_Werkorders_technische_storin gen		
RR WS&T Beatrixlaan – detail ontwerp seinstelsel	Tekening 3 Beatrixlaan BV015550	13/02/2007	Version 06
RR WS&T CS Muzenviaduct Resident – detail ontwerp seinstelsel	Tekening 2 CS Resident BV015658	13/02/2008	Version 06
RR WS&T J van Stolberglaan – Ternoot – detail ontwerp teinstelsel	Tekening 4 Juliana van Stolberglaan Ternoot BV015643	13/02/2008	Version 06
Schematic track layout Randstadrail – Hofpleinlijn V29 – Asbuilt	IXL-12_Hofpleinlijn_V29_asbuilt	22/07/2010	Version 29
Schematic track layout RandstadRail – Leidschendam V16	RR Depot Leidschendam V16	26/06/2008	Version 16
Schematic track layout RandstadRail – Samenloop V34	Shared section Samenloop V34_A6Z08110364438_Rev_P	01/02/2012	Version 34
Schematic track layout Randstadrail – Zoetermeerlijn V35	Zoetermeer_V35_KOM6	20/06/2013	Version 35
Script Siemens service centrale	OCC - script Siemens service centrale		
Seinstelsel TTGM – Detaillering – koppeling met perceel 2	Tekening 1 TTGM BV012524	31/01/2008	Version 9
Signalling design RandstadRail	Gebruikershandleiding spoorbeveiliging RR.pdf	13/02/2006	Version 0.4
Single line diagram – RandstadRail – Bleizo (GS ZBZ)	15. Bleizo		Status as-built; reference RandstadRail-A-ZBZ-3-

Title/subject	File name	Date	Status/version/reference
			260-A
Single line diagram – RandstadRail – Centrum West (GS ZCW)	12. Centrum West		Status as-built; reference RandstadRail-A-ZCW-3-260-A
Single line diagram – RandstadRail – Haagse Poort (GS HPT)	9. Haagse Poort		Status as-built; reference RandstadRail-A-HPT-3-260-A
Single line diagram – RandstadRail – Javalaan (GS ZJL)	14. Javalaan		Status as-built; reference RandstadRail-A-ZJL-3-260-A
Single line diagram – RandstadRail – Klapwijkselaantje (GS KLL)	3. Klapwijkselaantje		Status as-built; reference RandstadRail-A-KLL-3-260-A
Single line diagram – RandstadRail – Nieuwkoopseweg (GS NKW)	5. Nootdorp		Status as-built; reference RandstadRail-A-NKW-3-260-A
Single line diagram – RandstadRail – Pijnacker (GS PAK)	4. Pijnacker		Status as-built; reference RandstadRail-A-PAK-3-260-A
Single line diagram – RandstadRail – Recreatieweg (GS ZRG)	10. Recreatieweg		Status as-built; reference RandstadRail-A-ZRG-3-260-A
Single line diagram – RandstadRail – Schipholboog (GS SHB)	8. Schipholboog		Status as-built; reference RandstadRail-A-SHB-3-260-A
Single line diagram – RandstadRail – Segwaert (GS ZSW)	13. Segwaert		Status as-built; reference RandstadRail-A-ZSW-3-260-A
Single line diagram – RandstadRail – Veenweg (GS VWG)	6. Veenweg		Status as-built; reference RandstadRail-A-VWG-3-260-A
Single line diagram – RandstadRail – Voorweg (GS ZVL)	11. Voorweg		Status as-built; reference RandstadRail-A-ZVL-3-260-A
Single line diagram – RandstadRail – Westvliet (GS WTV)	7. Westvliet		Status as-built; reference RandstadRail-A-WTV-3-260-A
Sporenplan RandstadRail – Schematisch overzicht	General RR - 201301	Jan-13	Drawing number 6.02.06.6
Storingsanalyse HTM	2013 STG_RR_01012013_YTD	01/01/2013	
Storingsanalyse infrastructuur HTM	HTM Failure data - Infrastructure STG_RR_01012013_YTD		
Track alignmentTTGM	osp-0075 Tunnel Grote Marktstraat.pdf		
Track horizontal alignment Central Station	rt015083_CS.pdf		RT015083
Track horizontal alignment Ternoot	rt018920_Ternoot.pdf	08/02/2007	RT018920
Track layout Peatrixlaan	2-015000_E_Beatrixlaan.pdf	16/03/2006	E

Title/subject	File name	Date	Status/version/reference
Track vertical alignment Central Station	rt015084_CS.pdf		RT015084
Track vertical alignment Central Station	rt015085_CS.pdf	02/11/2005	RT015085
Track vertical alignment Ternoot	rt018921_Ternoot.pdf	08/02/2007	RT018921
TTGM – CS – J. v. Stolberglaan – Beatrixlaan (perceel 2)			
Vervanging wisselstellers RandstadRail	SGH 20130522 Notitie vervanging wisselstellers RR	16/05/2013	
VO Spoorbeveiliging keersporen Zcw	Tailtrack Zoetermeer TL VO Zcw v2.0 vrijgegeven	02/04/2013	Version 2.0 vrijgegeven
Wisselproblematiek in het buitengebied van het Haagse deel van RandstadRail	RvdB 20130507 Rapport wissels HTM	07/05/2013	Reference 100/IO010180
Wisselstoringsboom voor HTM / Randstadrail	Foutcodeboom Defectenboom Maximo 75		
Received from HTM - Rolling stock			
Dynamic kinematic envelope Regio Citadis	Bijlage IV rt024576.pdf	03/06/2013	RT024576
e-mail: Technical specifications GTL	FW_ Gegevens GTL tbv Operationeel model.pdf	24/06/2015	
e-mail: Technical specifications Siemens Avenio	RE Gegevens RegioCitadisFlexityGTL.msg	16/07/2015	
e-mail: tractie-snelheidscurve GTL	Tractie-snelheidscurve	01/07/2015	
Omwisselmatrix Regio Citadis	Omwisselmatrix Regio Citadis	29/10/2014	Status eerste uitgave; version 1.0; reference RM100-01-13 001
Performance data sheet Regiocitadis	Rolling stock.docx		
Planning revisie Regio-Citadis draaistellen 2014	Planning revisie draaistellen 2014	07/10/2014	
Planning revisie Regio-Citadis draaistellen 2015	Planning revisie draaistellen 2015	05/02/2015	
Planning revisie Regio-Citadis draaistellen 2016	Planning revisie draaistellen 2016	05/02/2015	
Productflyer Regiocitadis	RC Productflyer.pdf		
RandstadRail Rimses data 2014 and 2015	RR Rimses data deel 2 2014		
RandstadRail Rimses data 2014 and 2015	RR Rimses data deel 2 2015		
RandstadRail Rimses data 2014 and 2015	RR Rimses data deel 3 2014_15		
Regio CITADIS – Technische Daten und Hauptabmessungen	Regio Citadis - IVOSRV0145_DWF01PRI0001_2969_001		
Regio CITADIS – Technische gegeyens en belangriikste	Regio Citadis - IVOSRV0145_DWF01PRI0001_2970		

Title/subject	File name	Date	Status/version/reference
afmetingen	_001		
Revisie overzicht RegioCITADIS	Revisie overzicht Regio Citadis 2014-2030	15/09/2014	
Statistieken voertuigen week 1 2015	GTL & RR week 1-2015		
Statistieken voertuigen week 2 2015	GTL & RR week 2-2015		
Statistieken voertuigen week 3 2015	GTL & RR week 3		
Statistieken voertuigen week 4 2015	GTL & RR week 4		
Statistieken voertuigen week 5 2015	GTL & RR week 5		
Statistieken voertuigen week 6 2015	GTL & RR week 6		
Statistieken voertuigen week 7 2015	GTL & RR week 7		
Statistieken voertuigen week 8 2015	GTL & RR week 8		
Statistieken voertuigen week 9 2015	GTL & RR week 9		
Statistieken voertuigen week 10 2015	GTL & RR week 10		
Statistieken voertuigen week 11 2015	GTL & RR week 11		
Statistieken voertuigen week 12 2015	GTL & RR week 12		
Statistieken voertuigen week 13 2015	GTL & RR week 13		
Statistieken voertuigen week 30 2014	GTL & RR week 30		
Statistieken voertuigen week 31 2014	GTL & RR week 31		
Statistieken voertuigen week 32 2014	GTL & RR week 32		
Statistieken voertuigen week 33 2014	GTL & RR week 33		
Statistieken voertuigen week 34 2014	GTL & RR week 34		
Statistieken voertuigen week 35 2014	GTL & RR week 35		
Statistieken voertuigen week 36 2014	GTL & RR week 36		
Statistieken voertuigen week 37 2014	GTL & RR week 37		
Statistieken voertuigen week 38 2014	GTL & RR week 38		
Statistieken voertuigen week 39 2014	GTL & RR week 39		
Statistieken voertuigen week 40 2014	GTL & RR week 40		
Statistieken voertuigen week 41 2014	GTL & RR week 41		
Statistieken voertuigen week 42 2014	GTL & RR week 42		
Statistieken voertuigen week 43 2014	GTL & RR week 43		
Statistieken voertuigen week 44 2014	GTL & RR week 44		
Statistieken voertuigen week 45 2014	GTL & RR week 45		
Statistieken voertuigen week 46 2014	GTL & RR week 46		
Statistieken voertuigen week 47 2014	GTL & RR week 47		
Statistieken voertuigen week 48 2014	GTL & RR week 48		
Statistieken voertuigen week 49 2014	GTL & RR week 49		
Statistieken voertuigen week 50 2014	GTL & RR week 50		
Statistieken voertuigen week 51 2014	GTL & RR week 51		
Statistieken voertuigen week 52 2014	GTL & RR week 52		

Title/subject	File name	Date	Status/version/reference
Statistieken voertuigstoringen	Storingen Regio Citadis 01-10-2014 tm 01-04-2015		
Received from HTM - Operations			
Aansluitschema RR voor simulatie met 32 ritten op samenloop versie 2	Aansluitschema RR voor simulatie met 32 ritten op samenloop versie 2		
Capaciteit op het samenloopdeel van RandstadRail	Capaciteitsprobleem op Zoetermeer v5		
Frequentieverhoging RandstadRail	Frequentieverhoging RandstadRail A4 laatste concept	23-01-2015	
Months report – departure discipline maandoverzicht vertrekdiscipline rail blauw februari 2015	Months report - departure discipline Maandoverzicht VERTREKDISCIPLINE RAIL BLAUW per lijn februari 2015		
Months report – departure discipline maandoverzicht vertrekdiscipline rail rood februari 2015	Months report - departure discipline Maandoverzicht VERTREKDISCIPLINE RAIL ROOD per lijn februari 2015		
RandstadRail raakt het plafond – Studie naar capaciteitsverhoging metrolijn E	n/a	23-03-2015	Version 1.1
RandstadRail – Verbetermaatregelen gesimuleerd	2009 simulaties RandstadRail	20-07-2009	
Simulatie Frequentieverhoging Samenloop RandstadRail	Notitie simulaties frequentieverhoging samenloop RR A40-AWE-KA-1300204 v2	05-11-2013	Reference A40-AWE-KA-1300204
Simulatie verbeterpunten	Simulatie verbeterpunten	10-06-2009	Version 3
Timetable Saturday RandstadRail	Drg RR za	20-04-2015	
Timetable Sunday RandstadRail	Drg RR zo	20-04-2015	
Timetable weekdays RandstadRail	Drg RR mavr	20-04-2015	
Update simulatie frequentieverhoging samenloop RandstadRail	Notitie simulaties frequentieverhoging samenloop RR A40-AWE-KA-1300204 v1 def	27-02-2014	Reference A40-AWE-KA-1300204
Verbeterpunt 1: Frequentieverhoging RandstadRail (RR)	Bijlage 02b - SvZ Verbeterpunten Netwerk		
Voorstellen om na een calamiteit de exploitatie sneller op orde te hebben	Voorstellen om NA een calamiteit de exploitatie sneller op orde te hebben.3.0		
Received from HTM - Other			
50% achterblijvende opbrengsten RR	20110311 achterblijvende opbrengsten RR	11-02-2011	Reference IM 03/11
Agenda OV- en Spoortafel Zuidelijke Randstad	150212 agenda ov- en spoortafel zuidelijke randstad		
Communicatie RandstadRail	20150316 - concept publieke opinie en communicatie over RandstadRail		
Conclusies Analyse fase 1a Taskforce RRR	Resultaat fase 1a + vervolgaanpak TF v2 150323	03-2015	
Eisenspecificatie RandstadRail	RR 200603 PvE RandstadRail	21-03-2006	Status definitief; version

Title/subject	File name	Date	Status/version/reference
			1.2/0.0
e-mail: OV barometer ; per lijn per aspect & ritoordeel alle tramlijnen in NL	OV barometer ; per lijn per aspect & ritoordeel alle tramlijnen in NL	23-04-2015	
Evaluatie resultaten RandstadRail	201050527 memo RR evaluatie 1.3 SGH	27-05-2010	Reference IM04/10
Factsheet organisatie structuur	Organisation - Factsheet Organisatiestructuur		
Het RandstadRail-project: Lightrail, Zware Opgave	TUD 20080226 RandstadRail Eindrapport	26-02-2008	ISBN 9789056381929
Invalshoeken besluit toekomst ov chipkaart	Presentatie chipkaart naar wal samengevat op 1 a4		
MELDPUNT RANDSTADFAIL – Overzichtsrapport van klachten over de RandstadRail	Groenlinks - 20150413 - rapport GroenLinks inzake RandstadFail	10-04-2015	
Nota van uitgangspunten Concessie Rail Haaglanden december 2016	n/a	24-04-2013	
Ontsporingen bij RandstadRail	OVV 200811rapport_randstadrail Safety related document	11-2008	Project number M2006RV1129-04
Procedureboek RandstadRail	OCC - Procedureboek RR versie 2 1	04-2014	Version 2.1
Procesanalyse Robuust RandstadRail	20150317 rapportage RRR procesanalyse 0.1	17-03-2015	Version 0.1
Taskforce RandstadRail – Fase 2: verbeteringen	TF fase 2 verbeteringen+acties 150409	09-04-2015	
Taskforce Randstadrail – Opdracht en Aanpak	Opdracht+aanpak Taskforce RRR 150304	05-03-2015	
Taskforce Randstadrail – Opdracht en Aanpak	Presentatie DT Taskforce RRR v2 150310	10-03-2015	
Taskforce Robuust RandstadRail – Conclusies fase 1a en vervolgstappen	TF-RRR DT presentatie 150324 (3)	24-03-2015	
Taskforce Robuust RandstadRail – Proces-KPI model	KPI proces-kpi model v0.2 150422	22-04-2015	
Technisch deel aanbesteding ET Beveiliging traject Den Haag CS – Ternoot / Beatrixlaan	[HTM_p2_02] Technisch deel aanbestedingsdossier versie 2 deel 1 digitaal...	20-08-2004	Reference 2004 – 2031; DIGITALE VERSIE deel 1
Technisch deel aanbesteding ET Beveiliging traject Den Haag CS – Ternoot / Beatrixlaan	{HTM_p2_03] Technisch deel aanbestedingsdossier versie 2 deel 2 digitaal...	20-08-2004	Reference 2004 – 2031; DIGITALE VERSIE deel 2
Tramlijn Scheveningen Haven / Norfolk-terrein – Informatiebijeenkomst tracéstudie	Tramlijn Norfolk terrein Presentatie Informatieavond	03-06-2015	
Vervoerontwikkeling RandstadRail tot 2023 – Prognose, realisatie en toekomstige ontwikkeling	Vervoerprognose RandstadRail, versie 8	18-12-2013	Status eindrapport, version 8.0
ITCS line 2	Lijn 2 ri Anthoniushove.def.xlsm		Rijtijdenmodel 6.2
ITCS line 2	Lijn 2 ri Kraayenstein.def.xlsm		Rijtijdenmodel 6.2

Title/subject	File name	Date	Status/version/reference
ITCS line 3	Lijn 3 ri Loosduinen.def.xlsm		Rijtijdenmodel 6.2
ITCS line 3	Lijn 3 ri ZCW.def.xlsm		Rijtijdenmodel 6.2
ITCS line 4	Lijn 4 ri De Uithof.def.xlsm		Rijtijdenmodel 6.2
ITCS line 4	Lijn 4 ri Javalaan.def.xlsm		Rijtijdenmodel 6.2
ITCS line 6	Lijn 6 ri Leyenburg.def.xlsm		Rijtijdenmodel 6.2
ITCS line 6	Lijn 6 ri LNO.def.xlsm		Rijtijdenmodel 6.2
Timetable line 2	Timetable feb-mr JD2015 line 2.pdf	07/07/2015	
Timetable line 3, 3k, 4, 4k	Timetable feb-mr JD2015 line 3-3k-4-4k.pdf	07/07/2015	
Timetable line 6	Timetable feb-mr JD2015 line 6.pdf	07/07/2015	
Departing deadhead trips	Departing deadhead from LDA_feb-mr 2015.xlsx		
e-mail details operational model	Email T Jongerius met toelichting.pdf	17/06/2015	
Received from HTM – confidential			
Bijdrage Beheer & Onderhoud 2012 – 2013 en subsidieaanvraag 2014	IVOSRV0145_FBW01PRIO011_0297_001	17-12-2013	Reference SH 13.9539
Concessie openbaar vervoerdiensten en beheer en onderhoud railinfrastructuur voor tram en RandstadRail in het stadsgewest Haaglanden voor het concessiegebied Agglomeratie Den Haag/Zoetermeer Rail – in de zin van artikel 19 Wet personenvervoer 2000 – Ingaande 1 januari 2006, eindigend op 31 december 2016	1. CONCESSIE HTM RAIL 2006-2016 incl. 10 bijlagen; CONCESSIE HTM RAIL printen		
EXPLOITATIEOVEREENKOMST – voor de uitvoering van de concessies Bus en Rail tussen Stadsgewest Haaglanden en HTM Personenvervoer NV – 2006 tot 2017	Expl-contract printen	12-2005	
Offerte B&O 2014 – 2016	Offerte B&O 2014 – 2016		
Offerte Beheer en onderhoud Railinfrastructuur 2014 – 2016	Brief SGH aanbieding offerte B&O 2014		
Performance datasheet RegioCitadis	RC voertuigperformance.pdf	16/12/2003	1
Received from MRDH			
Concessie Haaglanden Regio – Veolia Transport – Vervoerplan 2016	P-#4046-v1-Vervoerplan_2016_Veolia_18_maart_2015	18-03-2015	
e-mail: Toekomstbeeld MRDH	RandstadRail - data en projecten	27-05-2015	
Samenvatting Vervoerplan 2016	P-#4540-v1-Vervoerplan_2016_Samenvatting_VP_Gemeenten_150401	01-04-2015	
Received from RET			
Dynamic kinematic envelope RSG3	VRIJRUIMTE PROFIEL SNELTRAM met RSG3.dxf		

Title/subject	File name	Date	Status/version/reference
ITCS line E	RE Rijtijden lijn 3 en 4.msg		
ITCS line E	rijtijden E GVC-PAK jan mrt 2015.xlsx		
Performance data sheet RSG3	Performance data sheet RSG3 - rev 03.doc	09/09/2009	3.0, Doc: 5.050.106
Timetable line E	DR lijn E GVC-PAZ jan-mrt 2015 in seconden.prt		
Timetable line E	DR Lijn E in sec GVC-NDP jan-mrt 2015.pdf		
Received from VolkerRail			
Aanpak om wisselstoringen te verminderen	Switches - PropositionpPerformance improvement	01-04-2015	Version 1.0
Storingsanalyse HTM – Januari 2013 t/m december 2014	Jaaranalyse HTM 2014	24-03-2015	Status concept
Verhogen prestatie infrastructuur	Verhogen prestatie infrastructuur v1	21-04-2015	
Received from Siemens			
Performance verbetering Randstadrail Perceel 1	Operational model improvements Brief HTM Performance verbetering 2009-07-09	09-07-2009	Reference /09-51897909
RandstadRail Spoorbeveiliging – FALKO: resultaten simulatie	FALKO resultaten simulatie_v2	17-01-2006	Status definitief, version 2.0, reference 5600_17_028
Received from Siemens – confidential			
Annex 1 – RAM berekening inclusief Safety document (Engelstalig)	Annex 1 - RAMS	29-09-2014	Status definitief; version 1.6; reference Annex 1 RandstadRail RAM(S) berekening
Annex 2 – Onderhoudsdocument (OHD)	Annex_2_-_Onderhoudsdocument	29-09-2014	Status definitief; version 6.5; reference 730 529
Annex 4 – Service Level Agreement RandstadRail Beveiligingssysteem	Annex 4 - Service Level Agreement	29-09-2014	Status definitief; version 6.3; reference 730 529
Maandrapportage Spoorbeveiliging RandstadRail – Augustus 2014	Storingsrapportage (HTM) Augustus 2014	15-09-2014	Version 1.0
Maandrapportage Spoorbeveiliging RandstadRail – September 2014	Storingsrapportage (HTM) september 2014	09-10-2014	Version 1.0
Maandrapportage Spoorbeveiliging RandstadRail – Oktober 2014	Storingsrapportage Oktober (HTM) 2014	06-11-2014	Version 1.0
Maandrapportage Spoorbeveiliging RandstadRail – November 2014	Storingsrapportage November (HTM) 2014		Version 1.0
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Received from municipality of Zoetermeer			
Lijst met aandacht- / verbeterpunten, zoals door de gemeente Zoetermeer opgemerkt en ervaren	HTM lijst		
Overzicht van HTM Twitterberichten die betrekking hebben op lijn 3 / 4 en, voor zover van toepassing, op RET lijn E en/of algemene meldingen	150316 storingoverzicht rr vanaf oktober 2014 -6-	Up to and including 07-04-2015	Version 6.2

Appendix C. Description of operational model

This appendix gives a description of the operational model.

C.1 Datasources

The following data has been used as input for the model (document names are given in list of received documents in Appendix B):

- Infrastructure
  - Drawings with kilometrisation/mileage indicating
  - Stops (platforms)
  - Turnouts
  - Crossings (road traffic, pedestrians)
  - Signals
  - Signalling elements (e.g. loops, axle counters, balises, release points)
  - Gradients or vertical profile with height/altitude
  - Maximum allowed speed (including switches)
  - Signalling systems to apply
  - Special signalling requirements (breaking distance, route release, ZUB)
- Rolling stock
  - Type (supplier, model)
  - Length
  - Weight
    - Empty
    - Loaded
  - Capacity
    - Seating and standing passengers
    - Percentage of occupation
  - Axle formula (which axles/bogies are motorised?)
  - Adhesion Load
  - Tractive effort curve (force or acceleration as function of speed)
  - Maximum speed
  - Maximum acceleration
  - Resistance (as function of speed)
  - Braked weight percentage and/or other braking characteristics
  - Deceleration in function of speed
  - Number of vehicles to be coupled
  - Description of special driving behaviour if needed (e. g. coasting)
- Operation
  - Time period (morning or afternoon peak, whole day, which day of the week)
  - Timetable
  - Dwell times at stations (average or distribution)
  - Minimum turnaround time
  - Overview of operational preferred routes at terminal stops

- Stopping probability and stopping time (average or distribution) at junctions
- Specific operational requirements if to be considered (e. g. connections between different lines)
- Driving performance (speed vs allowed speed) for regular/delayed vehicles

This information has been delivered by the inframanagers of HTM. Subsequently Ramboll has added the data into the model, in cooperation with Tim Jongerius, planner at HTM.

C.2 Model design

The following paragraphs give a description of the design of the various elements of the model.

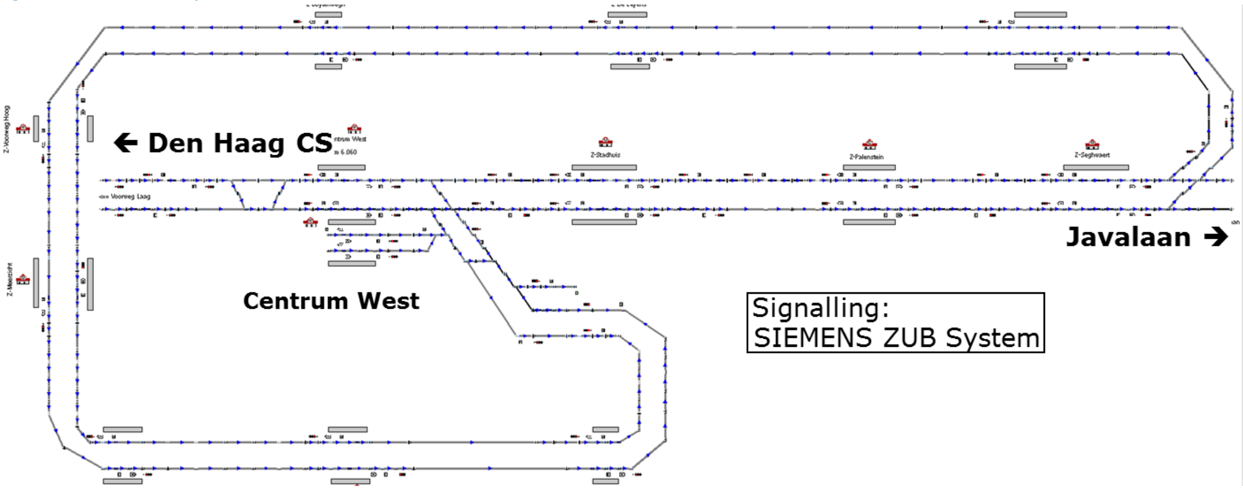
C.2.1 Track layout

Line 3 and 4 are simulated in total, so from Arnold Spoelplein to Centrum West vice versa and from De Uithof to Javalaan vice versa respectively, although it is done in a simplified manner west of Westeinde. Line E is simulated from Nootdorp to Den Haag Centraal Station vice versa. Lines 2 and 6 are simulated on the part where they interact with lines 3 and 4, which means between Ternoot and Westeinde vice versa for line 2 and between Ternoot and Brouwersgracht vice versa for line 6. For both lines 2 and 6, simulation in the TTGM section is done in detail and outside this section in a simplified manner. In Figure C.1 an example of the visualisation of the infrastructure in the model is given.

C.2.2 Signalling system

In the operational model, the signalling systems are modeled in detail. In the city area it is moddeled as driving on sight, in the TTGM section as the BBR System and in the shared section and Zoetermeer as the Siemens ZUB system, including the specialities of the RandstadRail tracks.

Figure C.1: Example of visualisation of infrastructure



Source: Ramboll

C.2.3 Rolling stock

For each of the lines, the characteristics from the rolling stock which runs on the line, are fed to the model. These characteristics contain the type of vehicle, the required traction power, the weight, the length, the passenger capacity and the maximum speed, and if needed this is done seperatly for single and double vehicles. The used vehicletypes per line are given in Table C.1.

Table C.1: Rolling stock in operational model

Line		Current Headway	Operator	Vehicle	Voltage	Manu-facturer	Max. speed
2	(Krayenstein –) Westeinde – CS – Ternoot (– Leidschendam)	10 min	HTM		600 V	Siemens	80 km/h
3	(Den Haag Loosduinen –) Westeinde – CS – Zoetermeer Centrum West 3K: (Den Haag, De Savornin Lohmanplein –) Westeinde – Den Haag Centraal)	10 min + 10 min Line 3K in peak hour	HTM		600 V + 750 V	Alstom	80 km/h
4	(Den Haag De Uithof -) Westeinde – CS – Zoetermeer Javalaan 4K: (Den Haag Monstersestraat –) Westeinde – CS – Zoetermeer Javalaan	10 min + 10 min Line 4K in peak hour	HTM		600 V + 750 V	Alstom	80 km/h
6	(Leyenburg –) Brouwersgracht – CS – Ternoot (- Leidschendam Noord)	10 min	HTM		600 V	BN	70 km/h
E	Den Haag Centraal (CS) – Nootdorp (– Rotterdam Centraal – Slinge)	10 min	RET		750 V	Bombar-dier	100 km/h

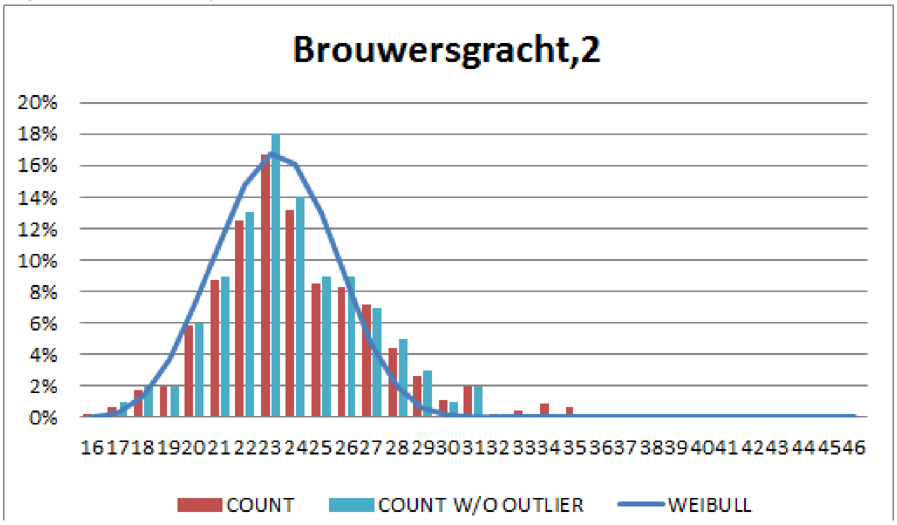
C.2.4 Timetables

The timetables of the simulated lines were imported in the model. Furthermore, rules were given as to how the vehicles needed to react to the timetables. These rules include the answers to questions such as: ‘At which stops do the trams and metros need to wait for their departure time?’, or ‘Which driving speed is allowed?’

C.2.5 Operation

During a run of the model, all vehicules were simulated individually. Stochastic (random) values, based on real, live distributions from ITCS-data, were applied to, for example, dwell times at stops, waiting times at junctions and variation at entrance times at lines E, 2 and 6. The stochastic values were calculated based on ITCS-data, where a distribution was made of e.g. the dwell times and for each vehicle run in the model, a dwelltime was randomly chosen from this distribution. In Figure C.2 an example of a distribution of dwell times, in this case at Brouwersgracht, is given. In this example, in red the total count is given, in light blue the count wihout outliers, where an outliers is defined is longer the 95-percentile. Based on the count without outliers, a distribution is made, visualised as the blue line, and this distribution is used as input for the model.

Figure C.2: Example of distribution of dwell times

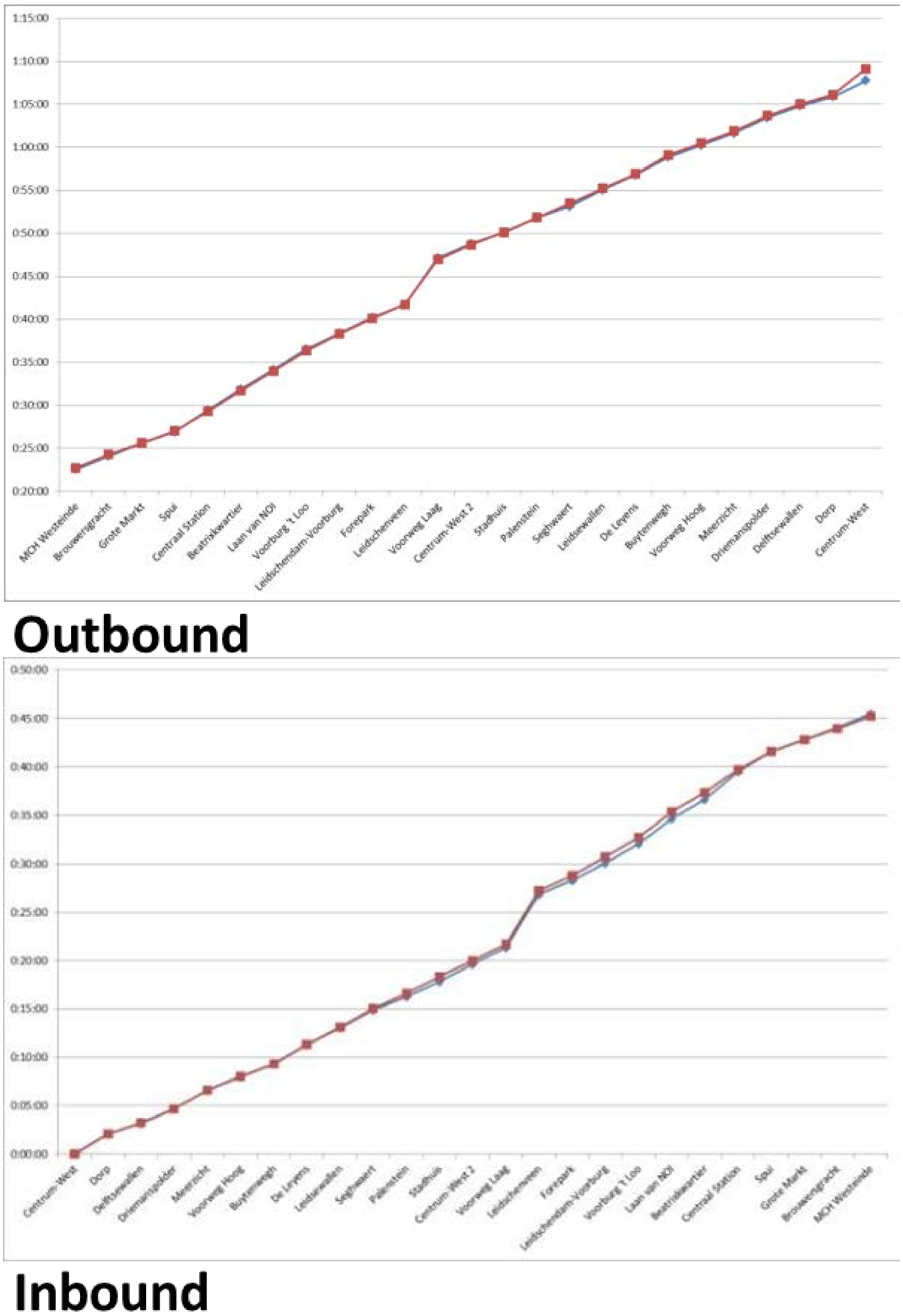


Source: Ramboll

Appendix D. Calibration of the operational model

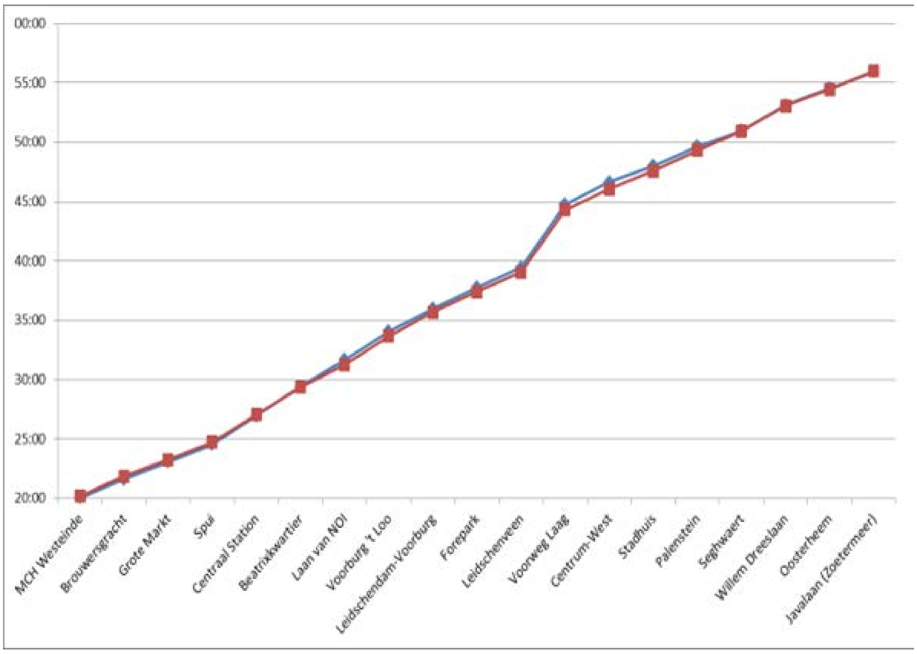
Below, the calibration graphs of line 3, 4 and E for both directions are given.

Figure D.1: Comparison between ITCS-data and model for line 3, MHC Westeinde – Centrum West; blue: ITCS-data, red: model run

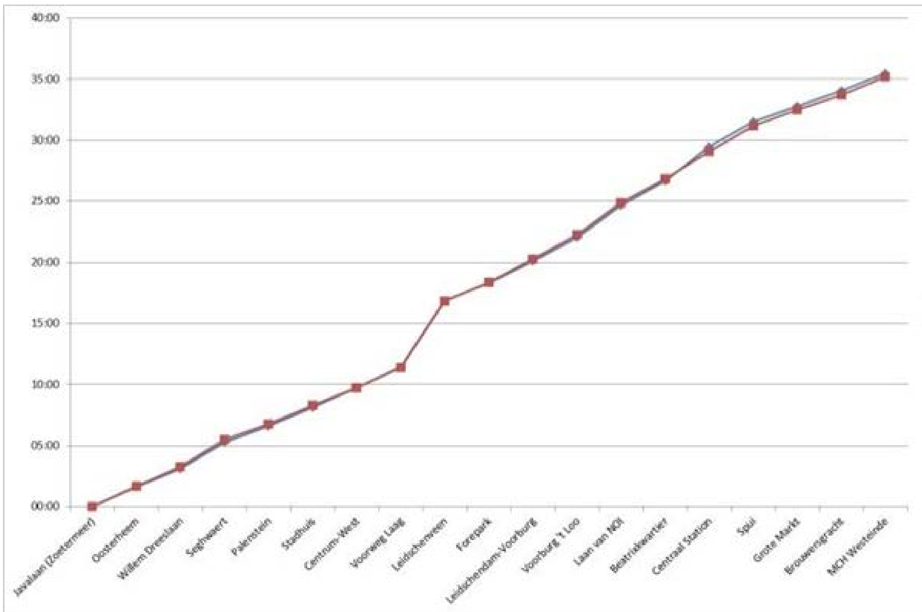


Source: Ramboll

Figure D.2: Comparison between ITCS-data and model for line 4, MHC Westeinde – Javalaan; blue: ITCS-data, red: model run



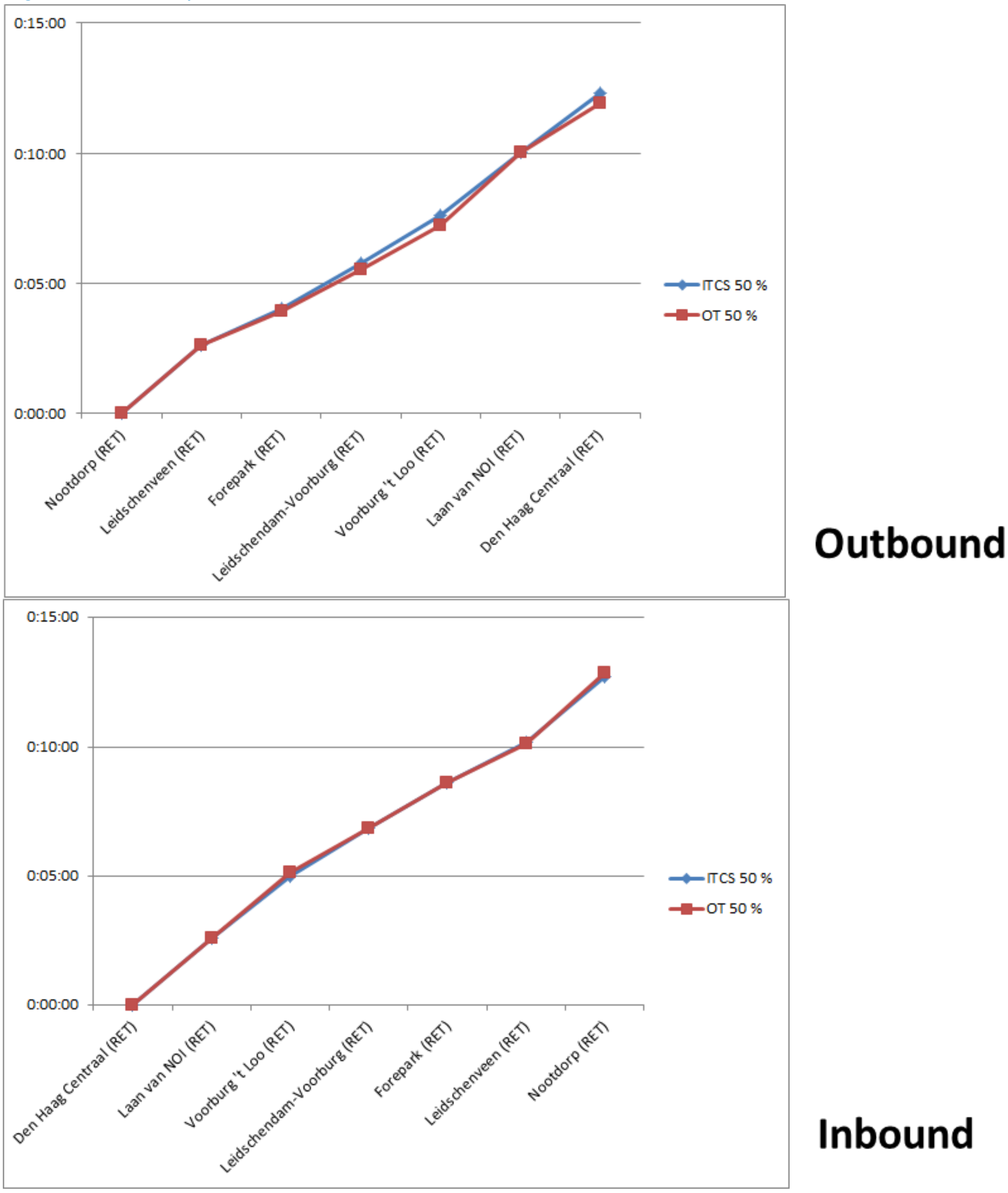
Outbound



Inbound

Source: Ramboll

Figure D.3: Comparison between ITCS-data and model for line E; blue: ITCS-data, red: model run



Source: Ramboll

Appendix E. Traction power supply

For the timetables with increased frequencies (C, C* and E), the traction power supply system will be unable to provide adequate (extra) traction power support. Therefore, a high level analysis of mitigation measures to ensure traction power supply has been made. The results of this analysis are described below.

The analysis is based on limited information and was carried out using rough calculations. A detailed traction power upgrade can be done by computer-aided modelling and simulation.

The analysis has been performed for frequencies of 30 (timetable C*), 32 (timetable E) and 36 (timetable C) vehicles per hour on the shared section, in comparison with the current frequency of 24 vehicles per hour (timetable A).

E.1 Assumptions

- The calculations determine traction power requirements and voltage levels by assuming the network is at its worst case. This worst case occurs when:
  - the maximum possible number of vehicles are in a section of track between two substations (assuming that the maximum number of vehicles in a section is limited by headway and that vehicles are evenly separated along the network, i.e. no bunching);
  - the vehicles in the section are those with the highest power requirements; and
  - all vehicles are accelerating at the same time.
- The recommendations do not include for spare capacity within the substations; this is a subsequent risk based management decision based on the outcome of a detailed simulation and knowledge of network-wide traction power supply considerations over a long timeframe.
- The recommendations do not include for a topology of full traction power supply under N-1 feeding conditions (there is always one substation extra available to supply power).
- Bombardier RSG3 to be run as coupled trains only.
- Each double RSG3 consists of 8x 130kW traction motors = 1.04MW.
- Each single RegioCITADIS is 0.75MW.
- Each double RSG3 constitutes a 70kW auxiliary load.
- Each single RSG3 constitutes a 100kW auxiliary load.
- Traction supply to Leidschendam Depot is not accounted for.
- Calculations do not account for future line extensions beyond Bleizo.
- Traction loss is based on a vehicle being on both tracks, at midpoint between substations, drawing maximum current.
- I^2R losses (power lost in the form of dissipated heat in conductors) in feeder return cables are not accounted for.
- The number of vehicles per hour as given in input data are per direction only.
- Nieuwkoopseweg substation has not been analysed.
- Class VI transformers supply traction power to the applicable parts of the network (100% continuous, 150% 2 hours, 300% 60s).
- The busbar voltage at substations is 790V dc.
- Lowest and highest voltages:
  - Lowest non-permanent voltage is 500V dc.

- Lowest permanent voltage is 500V dc.
- Nominal voltage is 750V dc.
- Highest permanent voltage is 900V dc.
- Highest non-permanent voltage is 1000V dc.

- Analysis does not account for regenerative breaking.
- Analysis assumes all vehicles are evenly separated on the network (i.e. no bunching).

It has been found that under both the existing and proposed operational scenarios, the network is unable to provide enough traction power to support for full services in case of a non-functioning substation (N-1 feeding conditions cannot be handled; the loss of a single substation has network-wide effects). The proposed mitigation measures outlined below do not attempt to solve traction power shortage permutations at substations under N-1 conditions, and it is assumed that under N-1 the network will operate with a reduced timetable. The below proposals do include mitigation measures to maintain minimum voltage at each vehicle under N-1.

E.2 Results

The results of the three vehicle service frequencies are given below. Per vehicle service frequency case, problems and possible mitigation measures are stated.

E.2.1 30 vehicles per hour (timetable C*)

The Haagse Poort substation is overloaded under normal feeding conditions (rated at 1.6MVA, but requires 2.0MVA). This is due to Haagse Poort substation having to feed the entire section between Haagse Poort substation and Den Haag Centraal without being able to share this load with another substation. It is therefore suggested that the rating of Haagse Poort substation be increased. From a technical perspective, this could either be done installing additional traction power capacity in the substation, or by adding another substation in the affected section.

The voltage drop between Schipholboog substation and Westvliet substation (2.675 km apart) is too large if a substation fails (under N-1 the calculated line voltage falls to 476V, which is below the 500V minimum as per EN 50163:2004). As the voltage drop is not too severe, it is suggested that this problem is resolved by configurations such as parallel feeders or doubling of the contact wire (assuming these measures have not been applied already).

The voltage drop between Veenweg substation and Recreatieweg substation (3.875 km apart) appears to be too large if a substation fails (under N-1 the calculated line voltage falls to 310V, but requires 500V minimum as per EN 50163:2004). Note that as the analysis did not take into account the contribution from Nieuwkoopseweg substation, further computer-aided modelling should be performed to verify this result. In the absence of the influence of another existing substation such as Nieuwkoopseweg, it is suggested that a new substation be placed between Veenweg substation and Recreatieweg substation.

The rough order magnitude costs of abovementioned measures (such as a new 3.2MVA transformer, a new 1.6MVA substation and a parallel feeder configuration over a distance of 2.6km)) are estimated to be between €3.8 and €5.2 million.

E.2.2 32 vehicles per hour (timetable E)

The voltage drop between Schipholboog substation and Westvliet substation (2.675 km apart) appears to be too large if a substation fails (under N-1 the calculated line voltage falls to 476V, but requires 500V minimum as per EN 50163:2004). As the voltage drop is not too severe, it is suggested that this problem is resolved by configurations such as parallel feeders or doubling of the contact wire (assuming these measures have not been applied already).

The voltage drop between Veenweg substation and Recreatieweg substation (3.875 km apart) appears to be too large if a substation fails (under N-1 the calculated line voltage falls to 310V, but requires 500V minimum as per EN 50163:2004). Note that as the analysis did not take into account the contribution from Nieuwkoopseweg substation, further computer-aided modelling should be performed to verify this result. In the absence of the influence of another existing substation such as Nieuwkoopseweg, it is suggested that a new substation be placed between Veenweg substation and Recreatieweg substation.

The voltage drop between Segwhaert substation and Javalaan substation (3.470 km apart) appears to be too large if a substation fails (under N-1 the calculated line voltage falls to 469V, but requires 500V minimum as per EN 50163:2004). As the voltage drop is not too severe, it is suggested that this problem is resolved by configurations such as parallel feeders or doubling of the contact wire (assuming these measures have not been applied already).

The rough order magnitude costs of above mentioned measures (such as a new 3.2MVA transformer and two new 1.6MVA substation units) are estimated to be between €5.7 and €7.8 million.

E.2.3 36 vehicles per hour (timetable C)

For this frequency, all challenges and possible measures described for 30 vehicles per hour (timetable C*) apply. One additional challenge arises.

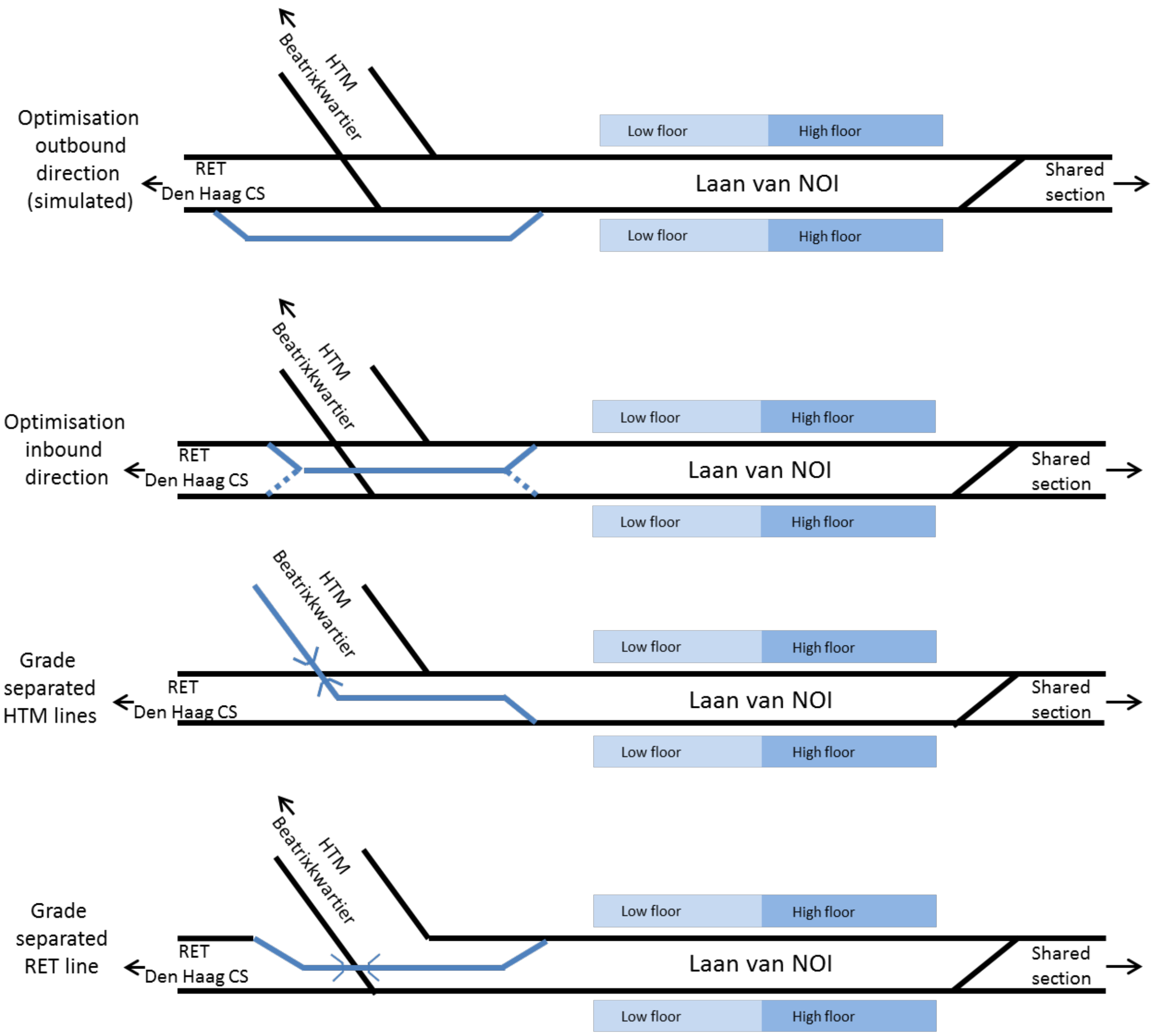
Schipholboog substation is overloaded under normal feeding conditions (rated at 2.0MVA, but requires 2.1MVA). It is suggested that a new substation be placed between Schipholboorg substation and Westvliet substation. This will also solve the voltage drop between Schipholboog substation and Westvliet substation.

The rough order of magnitude costs of the above mentioned measures (such as a new 3.2 MVA transformer, 3 new 1.6 MVA substation units and a parallel feeder configuration over a distance of 2.6km) are estimated to be between €8.4 and €11.4 million.

Appendix F. Options for redesign of junction Beatrixkwartier

The options for redesign of junction Beatrixkwartier are described below. Figure F.1 provides a schematic overview of the options.

Figure F.1: Options for redesign of junction Beatrixkwartier



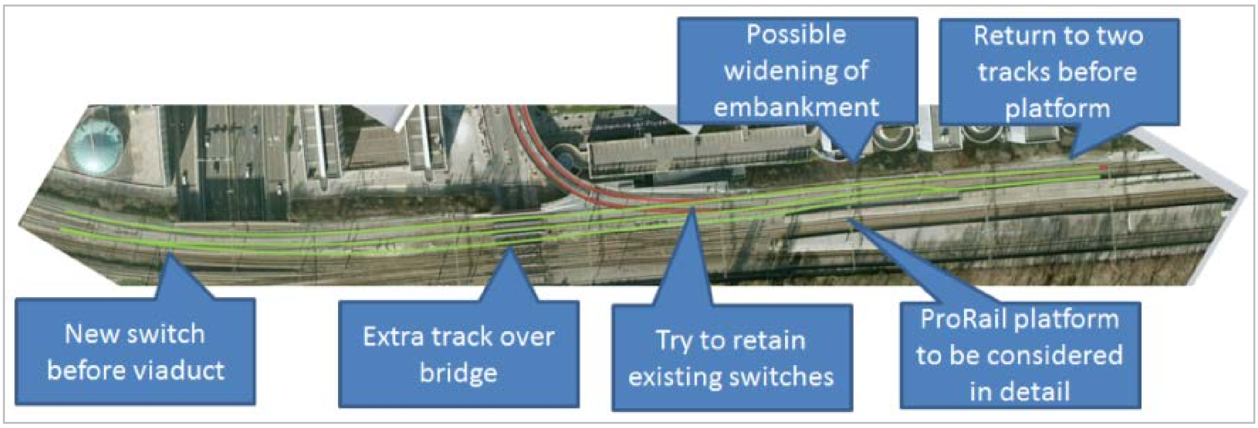
Source: Mott MacDonald

F.1 Optimisation of the outbound direction

This optimisation allows metros from the E-line in direction of Rotterdam to pass the junction. This prevents delays if a tram from line 3/4 and a metro from line E need to enter the shared section at the same time.

During the simulations of the operational model, this change in infrastructure was evaluated. This particular option was chosen, because it would have the least design impact on the environment among the available options and at the same time it is expected to have a considerable improvement on the running of trams and metros. This infrastructure configuration change is also desired by HTM and is already included in their long term vision.

Figure F.2: Track layout of design of Beatrixkwartier for optimisation of outbound direction



Source: Mott MacDonald

A preliminary design of this option has been made, with the track layout visualised in Figure F.2. In this preliminary design, it is assumed that the crossing at the Pr. Beatrixlaan can accommodate a new bridge with an additional track at the current location of the mesh grating in between the current light rail tracks and heavy rail tracks.

Below is a list of assumptions and remarks applicable to the design:

- It has been assumed that the south-west end of one of the RandstadRail platforms (which is understood to be inoperative) can be demolished in order to accommodate the additional track.
- In UK heavy rail practice, the introduction of an additional running line would normally require the spacing between groups of two adjacent tracks to be increased to accommodate a position of safety. Such a configuration also allows the use of OLE masts and signal poles in the wider track separation channel. However, the need for such a configuration might not be necessary for the HTM light rail network, with the assumption of a risk-mitigation decision under CSM-REA, considering factors such as the proposed operational requirements and risk of a vehicle failing in this area. The current proposal does not provide such a position of safety as this appears to enable the existing northern track to be retained. This issue needs to be discussed with HTM and the layout modified if necessary.
- It is assumed necessary to provide a fence to separate the light rail and heavy rail corridors. There are areas where the introduction of an additional track is likely to preclude the provision of a lineside maintenance access path next to such a fence. This affects both the light rail and heavy rail corridors. Further work is needed in order to confirm where maintenance paths are necessary next to the fence.
- The impact of the proposed track modifications on existing equipment needs to be considered. It appears that some overhead line equipment (OLE) support structures, which are shared between

RandstadRail and ProRail, will have to be replaced/repositioned. Other lineside equipment, such as that associated with signalling, is likely to be affected.

- The layout must also be reviewed by other design disciplines (such as those responsible for OLE and signalling) to identify further constraints on the alignment. For example, it may be necessary to widen the track separation distance in order to accommodate signals.
- It may be possible to re-use two of the existing turnouts (one being repositioned and one left in place. It may also be possible to retain the existing diamond crossing. However, further information (including a detailed topographical survey and drawings of the switches and crossings) are required to confirm these assertions. At this preliminary stage, two new turnouts would definitely be required. The layout is currently based on these being one R190 1:9 turnout and one R300 1:9 turnout; however, further work is needed to confirm the types.
- The impact of the proposed track geometry on running speeds needs to be assessed. The proposed geometry may require existing permanent speed restrictions to be strengthened.

The rough order magnitude costs of this design are roughly estimated to be between €4.6 and €7.1 million, including track work, switches and the bridge over the Beatrixlaan. This rough order magnitude costing does not yet include a full, cross-disciplinary view of possibly required infrastructure changes and does not include the costs arising from construction complexity on the site.

F.2 Optimisation of the inbound direction

This optimisation aims at a system where metros in direction of Den Haag CS can pass the crossing, which results in less delay for the E-line in direction of Den Haag CS. This option is considered to be less effective than optimisation of the outbound direction, because in the outbound direction the metro's of RET still have a long route to go, while in the inbound direction they are almost at their terminal stop. The costs of this option are estimated to be comparable to that of the optimisation in inbound direction. The first option above therefore is expected to provide more benefit for roughly the same cost and effort.

F.3 Grade separated HTM-lines

The option of grade separated HTM-lines allows lines 3 and 4 in direction of Zoetermeer to overpass the junction with the metros from the E-line in direction of Den Haag CS. In this option, the HTM-line (coming from the stop Beatrixkwartier) needs to be elevated to +7.00 meter compared to the current tracks. On a gradient of 6%, this would require a linear distance of 130 meter. In order to retain the stop at Laan van NOI, the track needs to be at +0.00 meter when entering the station.

A preliminary design of this options has been made, considering track layout and structures. The HTM line on approach to the junction from the north is already on a viaduct structure (which appears to be a continuous structure across its supports). There are various options here, the main two being to either modify the existing structure (probably involving demolishing a length of the existing viaduct) to accommodate the increased change in vertical alignment of the track, or to build a parallel viaduct down Pr. Beatrixlaan and leave the existing structure (and track) intact.

The Pr. Beatrixlaan is wide enough to accommodate another structure, but there would have to be a change to the road alignment to accommodate structure supports. Fitting some form of structural support around the track arrangement just past the junction is tricky. It is suggested to increase the track separation distance to allow a structure to land. It seems possible to recover the elevated position back to +0.00 meter just before the existing platforms. A more detailed analysis is required.

The costs of this option are estimated to be between €26.0 million and €32,5 million, including the changes needed to the ProRail platform and the surrounding area and building, excluding expropriation and costs arising from construction complexity. This is a severe change in infrastructure and results are expected not to account for the costs, therefore it has not been evaluated further within the simulations.

F.4 Grade separated RET-line

Grade separation of the line E in direction of Den Haag CS allows the metro to overpass the trams from line 3 and 4 in direction of Zoetermeer. To accommodate this, the E-line has to be +7.00 meter above the current tracks.

Elevating the existing track level to +7.00 meter on a 6% gradient would require a linear distance of 130m. A new structure would be required across Utrechsebaan to the north of the existing bridge along with a new crossing at Pr. Beatrixlaan. These two crossings would be on increasing vertical level at the eastern side of Pr. Beatrixlaan.

It is possible to use area north of the lines (that is currently embankment) and extend the embankment out (likely requiring the space that is currently used for parking for the office block). On approach to the Utrechtsebaan and between Utrechtsebaan and Pr. Beatrixlaan, it would probably be necessary to build a new earth-retaining structure. be possible to use an earth-retained structure. Where the two lines cross, the E-Line would have to be on an elevated structure for a short distance. Placement of bridge columns with the existing track arrangement at the junction would be challenging, and may require the two most northern lines to be spaced out towards the north to accommodate adequate clearance to the supports. It would then also be possible (given enough room), to have the structure and tracks return from its elevated position just ahead of the existing platforms. It should be noted that increased track separation to accommodate structural supports will likely mean adjusting the layout of the platforms.

The costs of the design are estimated to be between €26.0 million and €32,5 million, including the changes needed to the ProRail platform and the surrounding area and building, excluding expropriation and excluding costs of construction complexity. As with the grade separated HTM-lines, this is a severe change in infrastructure and results are expected not to account for the costs, therefore it has not been evaluated further within the simulations.

Appendix G. Possible root causes

Below possible root causes, which could be further investigated by the enhanced reliability improvement program, are given. They are based on the interviews with HTM employees and review of available data and documents.

G.1 Shared drive/detection contacts

The switch machines utilise a four wire system for both the motor drive and detection circuit of the switch machine. Therefore the cabling and contacts are required to support the 400VAC and 60VDC element. The quality of the control contact surfaces could adversely affect the performance of both motor and detection; however the effects of voltage drop through degradation of the contact surface is expected to be realised much earlier with the detection circuit performance. It is recommended that the lifecycle of these contacts is examined to identify a typical number of operations expected before failure, and the results from the study considered for introducing a routine replacement of the contact component in the DEWEMO during planned preventative maintenance. Consideration should be given, based on a root cause analysis and business case, whether a modification of the DEWEMO, separating the 400VAC and 60VDC elements, is beneficial and reduces the number of switch failures.

The length of cable runs for drive/detection circuits is in some cases over 1 kilometre which is not ideal in terms of volt drop for the DC element and EMI susceptibility. It is suggested to measure in great detail:

- Typical/allowed voltage drop across 60VDC detection circuits at high/low failure sites;
- Current rating of DEWEMO and the switch motor contacts;
- Typical and maximum expected motor start-up current, noting this may differ for old and new machines;
- The life expectancy/typical number of operations expected of the DEWEMO unit;
- The construction of the Motor Drive / Detection cable i.e. shielded / non-shielded; and
- The number of motor/detection cables sharing the same cable run at problem sites and other cables sharing the cable run.

It is recommended that the investigation also considers performing non-intrusive dynamic (during switch movements) earth test measurements with a high impedance multi-meter and shunt to be conducted:

- During routine maintenance visits to achieve a reference and to identify any change;
- At high failure sites when the air temperature ≥ 21°C as part of the on-going investigation; and
- During fault investigation.

G.2 Safety case: switch detection settings to 2mm or 3mm

The lock detection settings used on RandstadRail switch points are 2mm pass, 3mm fail, which means that if a switch has more than 2 millimetre space when closing, it reports a failure. It is suggested to review these switch detection settings in detail and see if any relaxation of the norms is feasible and what the impact is. Possible questions to be asked are:

- Is there a variance between primary drives, secondary drives (where fitted) and frogs?
- What is the rationale behind these settings, e.g. historic, local instruction, manufacturer instruction, requirement of Department of Transport?

G.3 Wheel profile

The differences in wheel profile and possibly the wheel set back to back dimensions between the vehicles of HTM and RET complicate the infrastructure and possibly reduce the reliability of the infrastructure. HTM RegioCITADIS has a tram wheel profile whereas the RET Flexity Swift metros have a heavy rail version with different flange and wheel tread sizes. The wheel diameters of HTM and RET are also different and the wheel base is smaller on the RegioCITADIS than the Flexity Swift.

At the design stage it was considered to move to a single wheel profile for both types of rolling stock. It was deemed not feasible to move to such a wheel profile due to the required changes either on the RET metro network or the HTM tram network. Based on an analysis by Projectorganisatie RandstadRail it was decided not to implement a uniform wheel profile, but to design the infrastructure according to the two different wheel profiles, including a special switches with moving frogs. This switch layout requires three different interlocking components which detects the position of the switch, instead of the standard of one component,.

If the reliability of the switches and their interlocking components cannot be improved, it is suggested to reinvestigate the impact of a uniform wheel profile for both types of rolling stock with the objective to reduce the complexity of the switch layout by removing the moving frog and parts of the interlocking system. This could potentially reduce the number of failures occurring in the switch significantly. However, care should be taken that the effect of such a change is validated for the whole system, including the other tram lines of HTM and the metro lines of RET.