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Assessing equity in regional railway corridors

Case study of the Noord-Holland Noord region

TU Delft

Provincie Noord-Holland

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Case study of the Noord-Holland Noord region

By

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Preface

During my study I became intrigued by the societal consequences of public transport planning decisions. Public transport planning initially seems simple. This is far from true however. There are many options to consider, which have consequences. These consequences reflect on society. Planning decisions have effects on peoples journeys. This can change people's behaviour, which could influence societal prosperity in the long run. Therefore it is important what effects are considered. Initially I was in favour of utilitarianism, which is rational and partly about monetizing effects. This changed over the course of the master program as I became aware of side effects of this approach. Therefore I am forever grateful to be able to conduct this research. I am happy to contribute to the fascinating emerging topic of transport equity. I hope that the conclusions of this research will contribute to society, provide a showcase how railway improvements could contribute to a greater good, improve equity within the Kop van Noord-Holland area and that the developed framework will be used to increase the fairness between inhabitant groups elsewhere as well.

Starting this thesis during a pandemic I knew it was going to be a challenge. It has indeed proved to be a challenge in more ways than I could have imagined beforehand. Some personal circumstances played a role, such as hospitalization, loss of grandparents, but also the happiness of the birth of my son. I would like to thank the committee for their patience, tips, feedback and support. I would especially like to thank the Provincie Noord-Holland to be able to conduct this research within their organization and to be included in meetings with stakeholders.

Enjoy reading.

L.J. Boertje

Haarlem, January 2023

Summary

Public transport (PT) connects inhabitants with society. Not everyone receives the same PT service, some are better served than others. Inhabitants of rural areas may be subject to long travel times, which has effects such as welfare reduction and social exclusion (KiM, 2018). This can be prevented with improvements to the PT service. It has to be determined what change is best to improve fairness between inhabitants of a partly rural region (Lucas, 2012). Transport equity is used to assess the distribution of opportunity between inhabitants. The problem is that there is neither a single definition of equity nor consensus on the best methods to improve regional PT services.
This thesis creates an equity improvement assessment method and applies it to the PT network of the Kop van Noord-Holland region. This is done on the basis of the following research questions:

How can equity of public transport network improvements in rural areas be assessed?

1. How to conceptualise equity and accessibility in rural / regional public transport?
2. What measures can be taken to improve the equity of a public transport service?
3. What are the effects of these measures and how does it impact equity in the Alkmaar – Den Helder corridor?

There is limited research on equitable regional PT planning, which is addressed with a literature review. Transport equity expresses the distribution of transport benefits over inhabitants in a specific region (Di Ciommo & Shiftan, 2017). The transport benefits are increased accessibility potential for selected key activities, which is determined by the minimum travel times between locations. Travel times are properties of specific PT network structures. Multiple indicators exist (van Wee & Mouter, 2021). It is decided to evaluate equity for location and for location plus income of inhabitants with the Theil index.
Transport equity is a long term effect, so strategic planning is evaluated. This includes route design, frequency setting, stop selection, rolling stock selection and strategic timetabling of a railway corridor (Hansen & Pachl, 2008). Path dependence limits travel time reduction to incremental changes. These require planning, timetabling, coordination between stakeholders and investment (Bruinsma, et al., 2008). Feasible timetables are required to predict travel times and compute equity. This can be done with mesoscopic modelling, which is aggregated but with a higher level of detail on some locations.

Methodology

The knowledge gained on operationalisations of transport equity and PT planning allows the formulation of a methodology. The designed methodology addresses the equity potential of PT planning options in a six step approach:

1. Identify travel motives and distinctions between inhabitants in the region.
2. Assess the range of infrastructure and rolling stock
3. Analyse the potential for travel time reduction
4. Determine timetables for each proposed change
5. Compute the accessibility potential within the region for each alternative
6. Asses equity effects for all inhabitants per alternative and compare change

Data is collected first in order to gain insight on which key activities are insufficiently available locally, which distinctions between inhabitants can be made and what railway infrastructure is present. Design alternatives with sets of measures are made in order to reduce the number of improvements options to be investigated. The alternatives have to meet two requirements;

lead to a feasible timetable and reduce travel times. Mesoscopic timetable modelling is chosen for its simplicity, while still delivering feasible timetables. This is most abstract with the begin / end locations of double tracked sections as exceptions. Accessibility potential is computed with exponential decay, this represents commuting (Östh, Reggiani, & Nijkamp, 2018). Transport equity is assessed by computing equity values for each alternative with the Theil index. This is compared with the current situation to compute equity gains possible, but also between design alternatives to assess the mutual rate of improvement. A diagram of the methodology is displayed in figure 1.

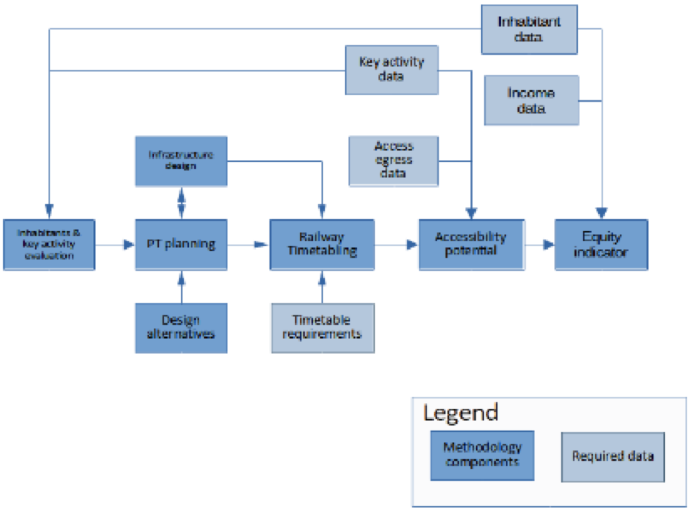


Figure 1: assessment methodology

Alkmaar – Den Helder case study

Employment is the key activity of interest, workplaces are in short supply in the Alkmaar – Den Helder corridor. Inhabitants are divided based on their location and if their income group is susceptible to transport poverty or not. The socio economic data has the lowest level of detail, in part due to privacy concerns. The current railway infrastructure has capacity constraints; it is single track North of Schagen, with short passing loops at intermediate stations. Rolling stock types VIRM and SLT are used in the area. Dynamic performance data is available for just these types of rolling stock. Travel time reduction is assessed per design alternative. The design alternatives contain sets of measures, including a desired frequency of 4 trains per hour. The design alternatives are;

1. Use of the current infrastructure with VIRM or SLT rolling stock;
2. Changed infrastructure with VIRM or SLT rolling stock and expanded double tracked passing loops where required;
3. New stations at either Waarland, Breezand or both with SLT rolling stock and expanded double tracked passing loops where required;
4. New stations at Waarland and Breezand, with a heterogeneous service and expanded double tracked passing loops where required.

Timetable are modelled manually for these design alternatives, which yields the location and distance of additional double track and travel times between stations. This is used to compute accessibility potential and investment cost. It is assumed that every inhabitant of a location uses the railway and has the same accessibility potential. In reality this may differ, but this cannot be evaluated with the available data. Timetables and computational models are made with the case data. Because the validation did not give any unexpected results the methodology is proved to work and results can be accepted.

Results

Feasible timetables are possible for all design alternatives, the desired frequency of 4 trains per hour is feasible for all alternatives. The amount of travel time saved differs between design alternatives. Limited travel time reductions are possible when using the current infrastructure due to holding caused by headway conflicts. Some travel time reductions are achieved when rolling stock is changed from VIRM to SLT. Substantial in vehicle travel time reductions are possible when double track gets expanded; between 3,8 and 6,2 minutes over the length of the corridor. The time savings diminish when new stations that are built. Some new stations increase the accessibility potential however, this proves the necessity of an equity evaluation.

Nearly all design alternatives improve fairness between inhabitants. The degree to which equity is improved over the base alternative differs. This is a result of the different minimum travel times between locations in the design alternatives. Change of rolling stock change offers some improvement over the base alternative, due to shorter run times over double tracked alignments. More significant equity improvements are achieved when the double track gets expanded where required. The shorter in vehicle travel times of these alternatives yield up to 7,3% of equity improvement. Design alternatives that include new stations have substantial equity improvements over all other alternatives, as showed in table 1. Equity gets improved by 12% on average when one of the new stations is built and with 16% when both new stations are built. This is caused by shorter access times to the new stations, which increases the accessibility potential at nearby locations. The equity improvements of these new station alternatives are substantially higher than the alternatives with expanded double track only. Reduction of access time has not have a greater influence on equity than in vehicle travel time in all circumstances. This relation is complex due to tradeoffs happening between inhabitants based on the location of origin. This is proven by the 7,4% equity difference between the mixed and SLT Waarland & Breezand alternative. The former has a heterogeneous service, where some trains skip the new stations. This yields the highest equity improvement. This is analysed with geographic information systems in appendix K of the main report. It is concluded that new stations reduce equity for inhabitants of Den Helder, Anna Paulowna and Schagen.

The results also show that transport equity should be assessed for both location and income. The case evaluation reveals that on average 50% less equity difference between inhabitants is measured when equity gets assessed for location only.

	Equity: location and income		Equity: location		Equity type
Alternative	equity (%)	improvement over current (%)	equity (%)	improvement over current (%)	Improvement difference (%)
Current	99,153%	0,00%	99,571%	0,00%	0,0%
VIRM	99,164%	1,06%	99,576%	0,57%	47,6%
SLT	99,191%	3,78%	99,590%	1,94%	52,6%
VIRM expanded	99,187%	3,39%	99,588%	1,70%	49,5%
SLT expanded	99,226%	7,32%	99,607%	3,67%	49,9%
SLT Waarland	99,274%	12,12%	99,632%	6,13%	50,7%
SLT Breezand	99,267%	11,43%	99,631%	6,03%	53,2%
SLT Wl. & Br.	99,316%	16,26%	99,656%	8,53%	52,8%
Mixed	99,390%	23,65%	99,693%	12,23%	51,9%

Table 1: Equity results

The design alternatives require investment. Only the cost of infrastructure investment is estimated due the availability of data. Doubling the remaining single track between Den Helder and Den Helder Zuid is required in any case. The existing passing loop at Anna

Paulowna station needs to be lengthened to the North for nearly all alternatives. The length required differs between alternatives, ranging between 1,1 and 4,4 km. The mixed alternative requires a considerable section of single track to be doubled between Schagen and Anna Paulowna as well. The doubling of single track is covered in section 6.1.2 of the report. Affiliated infrastructure investments are estimated to cost 18,9 million euros for the SLT with expanded infrastructure alternative, 22,4 million euros for the alternatives with one two new stations, 34,4 million euros for the SLT alternative with stations at both Waarland & Breezand and 67,2 million euros for the mixed alternative. This is put into perspective by computing the cost of marginal equity improvement. The SLT Waarland & Breezand has the highest equity gains for the infrastructure investments required, followed by the SLT Waarland and SLT Breezand alternatives. Others alternatives have a less good result, therefore the SLT Waarland & Breezand alternative should be endorsed.

Discussion

The improved equity scores indicate the need for change. Some results are open for interpretation. New stations have a stronger effect on equity than just expanding double tracks, but this does not mean that double track expansion can be dispensed with. They are a requirement to achieve feasible timetables and improve the accessibility potential around Den Helder, but also near Anna Paulowna and Schagen. The doubling of single track improves the quality of the provided transport services to these areas, which is shown with the equity improvements. Some of these improvements diminish when additional stations are opened without offering a mixed service of two train types. Opposition from inhabitants of Den Helder, Anna Paulowna and Schagen could expected when stations are opened without offering limited stop train services.

Two potential improvements to the model are the modes evaluated and inclusion of transport fares. These could not be included into the model due to a lack of data. Cars and other private motor vehicles have shorter travel times and thus a larger accessibility potential for their owners. Detailed traffic models are required, which do not exist for the corridor. The resistance function could include transport fares. This requires data on influence of transport fares on transport poverty, which is not available and recommended to do as follow up research. Some control mechanism over fare structure is required as well, either by price setting or via subsidisation. Therefore the results are a comparison of transport equity differences between the base and design alternatives of the railway corridor. This results in an underestimation of inequity, but this is not considered to be a problem.

Conclusions

The main question can be answered with the performed research. The three sub-questions follow up on each other and together answer the main question. The main question is answered as equity of public transport network improvements in rural areas can be assessed with the developed assessment methodology.

Question 1: How to conceptualise equity and accessibility in rural / regional public transport?

Transport equity express the distribution of transport benefits between inhabitants. The main benefit is increased accessibility potential to relevant key activities. This is not distributed equally. some inhabitants are disadvantaged due to their location or income. PT planning has a strong influence on equity because it determines the accessibility potential of locations. Timetables determine the minimum travel time and accessibility potential from locations. Operating and infrastructure constraints define which timetables are possible, especially for railways. Change is possible, but the extent of which depends on the case area evaluated.

Question 2: What measures can be taken to improve the equity of a public transport service?

Transport equity gets improved by measures that decrease travel time or improve network coverage. The exact specification and effect of measures depends on the evaluated case. Identification of measures is addressed in the developed methodology. Change of rolling stock, doubling of single track and providing additional station at Waarland and / or Breezand are identified to be promising measures on the Alkmaar – Den Helder corridor. Timetables are modelled for design alternatives with these measures to assess the feasibility and equity effects.

Question 3: What are the effects of these measures and how does it impact equity in the Alkmaar – Den Helder corridor?

It is concluded that improvement of coverage by providing new stations has a stronger positive contribution on equity than just travel time reduction. The equity effect of shortening in vehicle travel time is still substantial however. Shortening in vehicle travel time is best be done by reducing single track and using faster accelerating rolling stock. Double track expansions achieve in an equity improvement 7,3%, where just switching rolling stock achieves only gains 3,8%. Opening of new stations at Waarland and / or Breezand has a stronger effect; it improves equity with at least 11,4% to 16,3%. Building these new stations has shortcomings because some inhabitants will become disadvantaged. An additional 7,4% equity improvement is achieved when a service with two train types is offered. The infrastructure enhancements require investment. Opening both Waarland and Breezand stations served with a single type of service operated with SLT rolling stock is the most effective in terms of equity gained versus investment required.

The assessment model can be improved even further when transport fares are included and equity gets compared between inhabitants using PT and cars. This requires data which is not available for the case region, follow up research is recommended. It is also advisable to do a detailed microscopic railway simulation for the exact placings of points and block signals. A cost benefit and willingness to pay for fairness assessment are recommended to execute once all required input data is known. Collaboration between municipalities and PT partners is needed, it is advisable to do a stakeholder analysis in the evaluated corridor. Collaboration is the best way to address the strong case to improve equity between inhabitants of this regional railway corridor.

Samenvatting

Openbaar vervoer verbind mensen met de maatschappij. Niet iedere inwoner wordt even goed door het OV bediend, sommigen zijn beter verbonden dan anderen. Dit geldt onder andere voor inwoners van rurale gebieden en / of inwoners met een lager inkomen. Zij zijn vaker niet in het bezit van auto's of ander gemotoriseerd vervoer, het OV heeft een vangnetfunctie. De lagere graad van (OV) ontsluiting leidt op termijn tot een lagere kans op werk, en toename van sociale exclusie en verlies van welvaart in de regio (KiM, 2018). Dit kan voorkomen worden door het OV netwerk te verbeteren (Lucas, 2012). Het OV netwerk kan echter op verschillende manieren verbeterd worden, de vraag is hoe. Momenteel is de netwerkontwikkeling van het OV met name gericht op het verhogen van effectiviteit en efficiëntie, zonder de rechtvaardigheid tussen inwoners te overwegen. Dit leidt er in het algemeen toe dat vervoerders zich richten op OV verbindingen met hoge bezettingsgraden in verstedelijkte gebieden. Dit is in essentie niet eerlijk omdat inwoners van landelijke gebieden dan slechter bediend worden dan inwoners van stedelijke gebieden. Hierdoor raken inwoners van landelijke gebieden mogelijk achterop.

De rechtvaardigheid tussen inwoners kan verbeterd worden, maar de methode waarop is niet duidelijk. Hiervoor dient dit onderzoek. Meerdere onderwerpen zijn hiervoor uitgezocht. Er is namelijk geen overeenstemming in de wetenschappelijke literatuur hoe eerlijk / rechtvaardig vervoer, transport equity in het Engels, het beste uitgedrukt en gemeten kan worden. Daarnaast is er weinig onderzoek gedaan naar welke maatregelen het best genomen kunnen worden om de rechtvaardigheid van het regionale OV te verbeteren. Dit is door middel van een literatuuronderzoek uiteengezet in hoofdstuk 2 van het hoofdrapport. De conclusies hieruit zijn gebruikt om een algemeen toepasbare methodologie te ontwikkelen. Deze methodologie is gebruikt om de rechtvaardigheid van het OV netwerk in de Kop van Noord-Holland te verbeteren, specifiek op de Alkmaar – Den Helder corridor. Dit is gedaan aan de hand van de hoofd- en nevenvragen;

Hoe kan de rechtvaardigheid van regionale OV netwerken beoordeeld en verbeterd worden?

1. Hoe kan de rechtvaardigheid van het OV beleid geconceptualiseerd worden?
2. Welke maatregelen kunnen genomen worden om de rechtvaardigheid van het OV netwerk te vergroten?
3. Wat zijn de effecten van maatregelen en hoe veranderd het de eerlijkheid tussen inwoners van de Alkmaar – Den Helder corridor?

De rechtvaardigheid van mobiliteitsbeleid is een relatief nieuw onderzoeksveld. Het een complex begrip. Er zijn meerdere definities die het onderwerp op ieder op een andere invalshoek benaderen (van Wee & Mouter, 2021). Dit is een gevolg van welke ethische theorie in onderzoeken gevolgd wordt. Ook speelt de beschikbaarheid van gegevens een rol. Omwille van de praktische uitvoerbaarheid kunnen er concessies gedaan worden. De volledige uiteenzetting van relevante aspecten met betrekking tot de rechtvaardigheid van OV staat in sectie 2.1 van het onderzoeksrapport. De volgende definitie wordt in dit onderzoek aangehouden: de rechtvaardigheid van OV wordt gemeten door de verdeling van de bereikbaarheid tussen inwoners in een gebied uit te drukken (Di Ciommo & Shiftan, 2017). Hierbij is de genoten bereikbaarheid de som van het aantal activiteiten die met het OV netwerk bereikt kunnen worden. De bereikbaarheid is een afgeleide van de reistijd en daardoor afhankelijk van het door het OV netwerk aangeboden vervoer. De genoten bereikbaarheid verschilt tussen inwoners en is niet eerlijk verdeeld. De grootte van het verschil tussen inwoners wordt gemeten om de rechtvaardigheid van het OV netwerk te bepalen. Er zijn meerderde indicatoren om de bereikbaarheidsverdeling uit te drukken, in dit

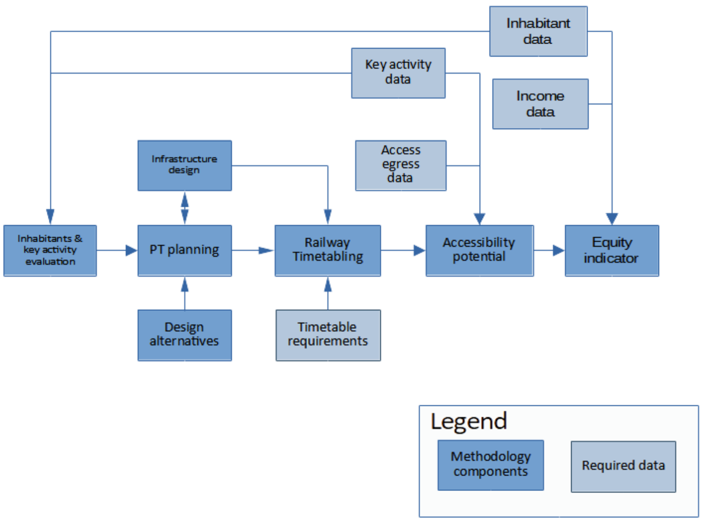
onderzoek is voor de Theil-index gekozen. De Theil-index is mede gekozen vanwege de mogelijkheid om willekeurig samengestelde groepen te maken en door bij kleine groepsgrootten betrouwbaar te blijven. Hierdoor is het mogelijk om ook in landelijk gebied inwoners te groeperen op basis van inkomen en locatie en de mate van rechtvaardigheid te bepalen.

De rechtvaardigheid van OV netwerk kan verbeterd worden door het netwerk aan te passen. Dit onderzoek richt zich op de strategische onderdelen van OV planning omdat de tijdshorizon daarvan overeenkomt met de snelheid waarop inwoners zich aanpassen aan veranderende omstandigheden. Strategisch zijn onder andere; route ontwerp, frequentie keuze, de locatie van stations / haltes, selectie van het rollend materieel en bepalen van de dienstregeling (Hansen & Pachl, 2008). De hoofdmodus is een spoorlijn, deze wordt in ontwikkeling beperkt door padafhankelijkheid. Hierdoor zijn alleen incrementele veranderingen mogelijk; het verdubbelen van enkelspoor, versnellen van de verbinding en aanleggen van stations is mogelijk (Bruinsma, et al., 2008). Aan deze maatregelen zijn voorwaarden verbonden en hebben beperkingen, welke beschreven zijn in het hoofdrapport. Een hiervan is het compromis tussen reistijd en halte afstand. De aanleg van een station verkort het voor / natransport voor een groep inwoners, wat ten koste kan gaan van de reistijd van overige inwonergroepen (Sharav, Givoni, & Shiftan, 2019).
Haalbare dienstregelingen van iedere voorgestelde wijziging zijn, met de noodzakelijke supplementen en vrijgavetijden. Dit is noodzakelijk om betrouwbaar reistijden te kunnen berekenen en te kunnen bepalen waar het verdubbelen van enkelspoor mogelijk zinvol kan zijn. Mesoscopische modellering wordt hiervoor toegepast. Dit is abstract maar met een hoger detailniveau waar nodig.

Methodologie & casus

De methodologie om de rechtvaardigheid van OV netwerk te verbeteren bestaat uit zes stappen. Deze is hieronder beschreven en weergegeven in figuur 1.

1. Bepaal de reismotieven en onderscheid tussen inwoners van de regio
2. Beschouw de aanwezige infrastructuur en materieel
3. Onderzoek de potentie voor reistijdreductie
4. Bepaal dienstregelingen voor iedere verandering
5. Bereken de bereikbaarheidspotentie voor ieder onderzocht alternatief
6. Bereken de rechtvaardigheidsindex en vergelijk verschillen tussen alternatieven



Figuur 1

Deze methodologie is toegepast in Kop van Noord-Holland op de Alkmaar – Den Helder corridor. De belangrijkste uitkomsten van de beschreven stappen worden toegelicht. Werkgelegenheid wordt als reismotief in het onderzoek opgenomen. De hoeveelheid bereikbare arbeidsplaatsen is gemiddeld lager dan elders, dit genereert verplaatsingen. Overige reismotieven blijken naar voldoende lokaal verzorgd te worden. Inwoners worden gegroepeerd op basis van locatie en inkomensgroep. Als eenheid wordt hier de eerste vier cijfers van de postcode en vatbaarheid van de inkomensgroep voor transportarmoede gebruikt. Dit is het hoogst haalbare detailniveau van de beschikbare dataset, details staan in hoofdstuk 3 en 4 van het hoofdrapport.
De spoorlijn Alkmaar – Den Helder vormt de hoofdas van de corridor. Deze heeft meerdere enkelsporige secties noordelijk van Schagen met korte kruisingsmogelijkheden bij tussengelegen stations. Dit beperkt de beschikbare capaciteit. In de regio wordt voornamelijk VIRM en SLT materieel gebruikt, hier is acceleratiedata voor beschikbaar waar rijdtijden tussen stations mee berekend zijn. SLT materieel kan sneller accelereren en het wordt aangenomen dat overig materieel deze acceleratie kan evenaren of overtreffen. Meerdere plaatsen langs de spoorlijn worden momenteel niet bediend, Waarland en Breezand worden potentieel kansrijk geacht en zijn in het onderzoek opgenomen. De potentie van reistijdreductie is onderzocht met opgestelde ontwerpalternatieven. Het uitgangspunt hiervan is dat alle ambitieniveaus onderzocht worden, waardoor er een bij benadering volledig beeld ontstaat. De onderzochte ontwerpalternatieven zijn:

1. Gebruik van de huidige infrastructuur met VIRM of SLT materieel
2. Gebruik van VIRM of SLT materieel met het verdubbelen van enkelspoor waar nodig
3. Het aanleggen stations bij Waarland en / of Breezand, bediend met SLT materieel
4. Het aanleggen van Waarland en Breezand in combinatie met een 2 treintypen dienstregeling

Voor deze alternatieven zijn treinpaden berekend en dienstregelingen opgesteld, op basis van een frequentie van vier treinen per uur per richting. De dienstregelingen genereren reistijden, plus de locatie en afstand van spoor dat verdubbeld moet worden. Het volledige proces staat beschreven in hoofdstuk 3 en 4 van het hoofdrapport.
De bereikbaarheidspotentie is berekend in meerdere stappen, voor ieder alternatief. Eerst is vanaf iedere locatie van oorsprong de korst mogelijke reistijd naar bestemmingen met werkgelegenheid bepaald, met fiets en OV als voor/ na transport. Vervolgens is de reistijd gewogen met een exponentiële vervalfunctie. Deze functie weegt de aantrekkelijkheid van iedere plaats van oorsprong. Naar mate de bestemming verder weg ligt neemt de aantrekkelijkheid af (Östh, Reggiani, & Nijkamp, 2018). De aantrekkelijkheid neemt geleidelijk af, maar er is geen harde grens en wordt nooit helemaal nul.
De Theil-index bepaald de rechtvaardigheid door de bereikbaarheid van een individu in een groep te delen door het groepsgemiddelde en dit te sommeren over de groepen. De volledige uitleg en formule staat beschreven in sectie 3.6 van het hoofdrapport. De waarden van de rechtvaardigheidsindex zijn berekend om de ontwerpalternatieven onderling en met de huidige situatie te vergelijken. Hierdoor is bepaald welk alternatief het meest eerlijk OV bereikbaarheid tussen de inwoners verdeeld.

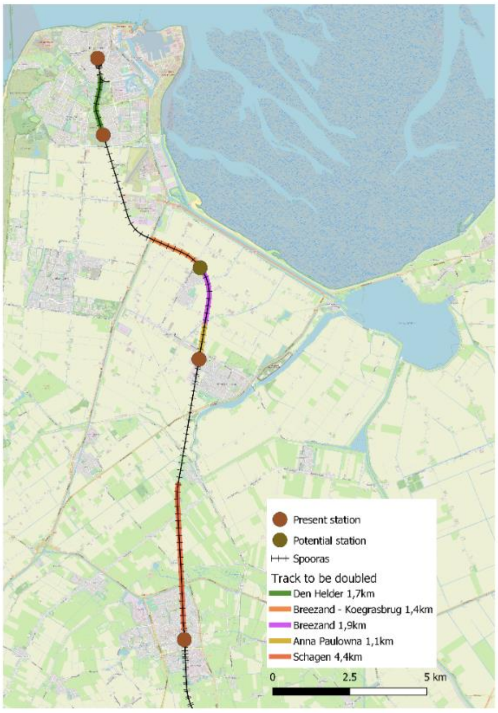
Resultaten

Het is mogelijk om de reistijd op de spoorlijn te verminderen, zelfs zonder aanpassingen aan de infrastructuur. De begin tot eind reistijden die gehaald kunnen worden verschillen per ontwerpalternatief, dit is weergegeven in tabel 1. Voor de ontwerpalternatieven die de huidige infrastructuur gebruiken geld wel dat zij gehinderd worden door tegenliggend verkeer ten noorden van Schagen. Deze hinder is opgelost in de alternatieven “VIRM expanded” en “SLT expanded” door het verdubbelen van enkelspoor te veronderstellen waar noodzakelijk, hierdoor is een substantiële reistijdverkorting van 6 minuten mogelijk. Het aanleggen van stations doet de gerealiseerde reistijdverkorting deels teniet. Iedere extra stop kost 1,9 minuut.

Reistijd Ontwerpalternatief	Den Helder - Alkmaar
Huidig	37,0
VIRM	35,0
SLT	33,6
VIRM expanded	33,2
SLT expanded	30,8
SLT Waarland	32,7
SLT Breezand	32,7
SLT Wl. & Br.	34,6
Mixed (SLT / VIRM)	34,6 / 33,6

Tabel 1

Voor de aanpassingen aan de infrastructuur zijn investeringen noodzakelijk. Voor alle (relevante) alternatieven is het nodig om het dubbelsporige passeerspoor bij Anna Paulowna met 1,1 km noordwaarts te verlengen en het resterende enkelspoor tussen Den Helder en Den Helder – Zuid te verdubbelen. Indien zowel stations bij Waarland en Breezand aangelegd worden is een verdubbeling van 3,0 km ten noorden van Anna Paulowna bij een 1 treintype bediening. Als er gekozen wordt voor een heterogene 2 treintype bediening, waarbij VIRM materieel niet stopt op de nieuwe stations en SLT materieel wel zijn er extra aanpassingen nodig. Hierbij moet het enkelspoor verdubbeld worden tussen Anna Paulowna en het Noordhollandsch kanaal en een verlenging van het dubbelspoor met 4,4 km vanaf station Schagen. De locaties zijn weergegeven in figuur 1. De investeringskosten zijn geschat op 18,9 miljoen euro zonder de aanleg van stations, 22,4 miljoen euro bij de aanleg van de stations Waarland of Breezand, 34,4 miljoen euro in geval van de aanleg van beide stations en 67,2 miljoen euro voor het alternatief met een twee treintypen bediening (“mixed” geheten in het hoofdrapport).



Figuur 2

Analyse van de bereikbaarheid potentie resultaten leid tot de conclusie dat alle ontwerpalternatieven de gemiddelde hoeveelheid bereikbare arbeidsplaatsen verhogen. Er is met name een verschil tussen de ontwerpalternatieven die wel of niet aanpassingen aan de infrastructuur doen. Tussen de alternatieven die aanpassingen aan de infrastructuur doen zitten onderling geringe verschillen. Dit geeft twee dingen aan; het verkorten van de reistijd is zinvol, maar er treden ook verdelingseffecten op. Dit is toegeschreven aan het compromis tussen reistijd en halte afstand. Een aantal inwoners gaat er dus bij de aanleg van een station op vooruit, maar anderen verliezen daardoor arbeidsplaatsen. Dit laat zien dat de eerlijkheid tussen inwoners beoordeeld moet worden. De rechtvaardigheidsindicator berekent of de toename ten goede komt van de inwoners die achterop dreigen te raken.

Ontwerpalternatief	Rechtvaardigheid: locatie en inkomen eerlijkheid (%)	Verbetering t.o.v huidig (%)	Rechtvaardigheid: locatie eerlijkheid (%)	Verbetering t.o.v huidig (%)	Indicator type Verbetering verschil (%)
Huidig	99,153%	0,00%	99,571%	0,00%	0,0%
VIRM	99,164%	1,06%	99,576%	0,57%	47,6%
SLT	99,191%	3,78%	99,590%	1,94%	52,6%
VIRM expanded	99,187%	3,39%	99,588%	1,70%	49,5%
SLT expanded	99,226%	7,32%	99,607%	3,67%	49,9%
SLT Waarland	99,274%	12,12%	99,632%	6,13%	50,7%
SLT Breezand	99,267%	11,43%	99,631%	6,03%	53,2%
SLT Wl. & Br.	99,316%	16,26%	99,656%	8,53%	52,8%
Mixed	99,390%	23,65%	99,693%	12,23%	51,9%

Tabel 2

De rechtvaardigheidsresultaten zijn weergegeven in tabel 2. Bijna ieder alternatief zorgt voor een betekenisvolle verbetering van de eerlijkheid tussen inwoners. De mate waarin verschilt echter. De toename in eerlijkheid bij het gebruik van de huidige infrastructuur blijken gering. De reistijd verkorten door gebruik van sneller accelererend SLT materieel in combinatie met het verdubbelen van enkelspoor leidt tot een toename van de eerlijkheid tussen inwonergroepen van 7,3%. De eerlijkheid tussen inwoners neemt echter veel meer toe als er ook nieuwe stations aangelegd worden. Het aanleggen van een van de potentiële stations zorgt voor een toename van 12%. Dit komt door de afname van de tijd die nodig is voor voor- / natransport in de betreffende plaatsen. Bij de aanleg van beide stations is een toename mogelijk van 16,2% bij een 1 treintype bediening en 23,6% bij een 2 treintype bediening. Het verschil in eerlijkheid van 7,4% tussen de alternatieven geeft aan dat een deel van de winst die geboekt wordt in Waarland en Breezand ten koste gaat van de inwoners van met name Den Helder, maar ook Anna Paulowna en Schagen. Het kan dus niet zonder meer gezegd worden dat het verminderen van de voor- / natransport een twee keer zo sterk effect heeft als reductie van de reistijd in de trein zelf, deze verhouding is complex.
Verder is het opnemen van inkomen naast locatie in de indicator relevant gebleken. Er worden hierdoor substantieel grotere verschillen in eerlijkheid gemeten.

De investeringskosten in de infrastructuur zijn in tabel 3 afgezet worden tegen de verbetering in eerlijkheid. Alternatief SLT Waarland en alternatief SLT Breezand blijken de laagste marginale kosten te hebben. Het wordt aanbevolen om het SLT Waarland & Breezand ontwerpalternatief met 1 treintype bediening uit te voeren. De marginale kosten van dit alternatief zijn niet substantieel hoger, maar de eerlijkheid tussen de inwonergroepen wel.

Alternatief	Verbetering (%)	Inversteringskosten (x1000)	Marginale kosten (x1000)
Huidig	0,00%	n.v.t.	n.v.t.
VIRM	1,06%	n.v.t.	n.v.t.
SLT	3,78%	n.v.t.	n.v.t.
VIRM expanded	3,39%	€ 12.471	€ 3.676
SLT expanded	7,32%	€ 18.990	€ 2.594
SLT Waarland	12,12%	€ 22.378	€ 1.847
SLT Breezand	11,43%	€ 22.378	€ 1.958
SLT Wl. & Br.	16,26%	€ 34.387	€ 2.115
Mixed	23,65%	€ 67.159	€ 2.840

Tabel 3

Discussie

De resultaten geven een duidelijke onderbouwing om verbeteringen aan de spoorlijn door te voeren aan. De uitkomsten zijn echter voor meerdere uitleg vatbaar. De aanleg van stations heeft een grotere invloed op de eerlijkheid van het verdubbelen van enkelspoor. Dit betekend echter niet dat de spoorverdubbelingen niet noodzakelijk zijn, want ze zijn een vereiste voor een haalbare dienstregeling. Daarnaast zorgt het extra dubbelspoor voor een vermindering van de reistijd, die met name ten goede komt aan de inwoners van Den Helder. Het slechts ten dele uitvoeren van ontwerpalternatieven is niet rechtvaardig. De eerlijkheid tussen inwonersgroepen verslechterd daardoor en kan voor lokale tegenstand zorgen. Overleg met alle belanghebbenden is mede hierom zinvol.

In de toekomst worden een aantal ontwikkelingen verwacht die van invloed worden op de huidige uitkomsten van dit onderzoek. Op termijn wordt het treinbeveiligingssysteem in heel Nederland vervangen, waardoor kortere opvolgtijden mogelijk worden. Daarnaast is er door de vervoerder NS nieuw dubbeldekker materieel besteld, wat op middellange termijn in gaat stromen. Hiervan wordt aangenomen dat het sneller kan accelereren dan het huidige VIRM materieel. Door deze ontwikkelingen zijn kortere reistijden mogelijk, waardoor de onderzochte ontwerpalternatieven met SLT materieel waarschijnlijker worden.
Het PHS Alkmaar – Amsterdam is vanzelfsprekend eveneens van invloed, maar kon niet opgenomen worden omdat een aantal aspecten nog niet duidelijk genoeg zijn.

Niet alle effecten konden in dit onderzoek meegenomen worden doordat data en / of modellen ontbraken. Dit geldt onder andere voor transportarmoede, auto gebruik en kostenbatenanalyses. Hiervoor zijn aanbevelingen geschreven na de conclusie, waarvan een aantal in deze samenvatting vermeld zijn.

Conclusie & aanbevelingen

De hoofdvraag wordt beantwoord aan de hand van de deelvragen.

Hoe kan de rechtvaardigheid van regionale OV netwerken beoordeeld en verbeterd worden?

> *Vraag 1: Hoe kan de rechtvaardigheid van het OV beleid geconceptualiseerd worden?*

De rechtvaardigheid van OV kan bepaald worden door de mate van eerlijkheid waarin de bereikbaarheid tussen inwoners in een gebied verdeeld is te meten. De som van het aantal relevante activiteiten die door inwoners bereikt kan worden verschilt. Niet alle inwoners worden even eerlijk bediend. Sommige inwoners raken achterop door bijvoorbeeld hun locatie en / of inkomen. OV beleid heeft hierop een sterke invloed omdat het via dienstregelingen de bereikbaarheidspotentie bepaald. Verandering is mogelijk, de mate waarin hangt af van het onderzochte gebied.

Vraag 2: Welke maatregelen kunnen genomen worden om de rechtvaardigheid van het OV netwerk te vergroten?

De rechtvaardigheid van het OV beleid kan verhoogd worden door de eerlijkheid tussen inwonersgroepen te verbeteren. Dit kan door het netwerkbereik te vergroten, waardoor de tijd die nodig is voor het voor- / natransport afneemt, of door de reistijd in de trein te verminderen met maatregelen die aan de hand van de methodologie bepaald zijn. Het verdubbelen van stukken enkelspoor, aanleggen van stations in Waarland en / of Breezand en het verwisselen van materieel is onderzocht op de Alkmaar – Den Helder spoorlijn. Dienstregelingen zijn gemoduleerd om de gevolgen van veranderingen te kunnen onderzoeken.

Vraag 3: Wat zijn de effecten van maatregelen en hoe veranderd het de eerlijkheid tussen inwoners van de Alkmaar – Den Helder corridor?

Het vergroten van het netwerkbereik heeft een groter effect op de eerlijkheid tussen inwonergroepen dan alleen de reductie van de reistijd in de trein zelf. Het verminderen van de rijtijd op de spoorlijn is altijd zinvol. Het verdubbelen van enkelspoor waar noodzakelijk in combinatie met de inzet van sneller accelererend materieel zorgt voor een toename van eerlijkheid tussen inwoners met 7,3 %. Wanneer station in Waarland en / of Breezand geopend worden neemt de eerlijkheid tussen inwoners met 11,4 tot 16,3% toe. Het aanbieden van een 2 treintype bediening in combinatie met de aanleg van beide stations bevordert de eerlijkheid met 23,7% het meest. Het verschil van 7,3% is een gevolg van de compensatie van inwonersgroepen hinder ondervinden aan de extra stops op de nieuwe stations. Het ontwerpalternatief “SLT Waarland & Breezand” heeft de beste combinatie van rechtvaardigheid afgezet tegenover de investeringskosten in de infrastructuur.

Er zijn een aantal verbeteringen mogelijk, maar deze vergen opvolgend onderzoek. Rechtvaardigheid kan beter onderzocht worden als de gemeten bereikbaarheid van het OV vergeleken wordt met auto’s en andere motorvoertuigen. Hiervoor zijn verkeersmodellen nodig die momenteel niet beschikbaar zijn in het benodigde detailniveau voor deze regio. Een andere uitbreiding is de opname van transportarmoede in de rechtvaardigheidsindicator. Dit kan door de invloed van transportkosten mee te laten wegen in de weerstandsfunctie die de bereikbaarheidspotentie bepaald. Hiervoor is aanvullend onderzoek naar de betaalbaarheid van vervoersbewijzen nodig in de regio. Door het opnemen van auto bereikbaarheid en invloed van transportkosten in het onderzoek zullen de verschillen tussen inwonergroepen toenemen.
Verder is het zinvol om een maatschappelijke kosten- baten analyse uit te voeren op de resultaten van dit onderzoek. Dit kan momenteel niet gedaan worden omdat gedetailleerde reizigersdata en kengetallen over het gebruik van spoorwegmaterieel ontbreken. Deze zullen door de relevante partijen gedeeld moeten worden.
Dit is slechts een deel van de aanbevelingen, meer staan beschreven in de hoofdtekst van het rapport.

Index

1 Introduction

1.1 Problem statement

Inhabitants of regional areas are connected with society via means of transport, as movement between places is required in order to participate. These movements need a mode of transport and suitable infrastructure. Some inhabitants do not own cars and rely on public transport (PT). The role of PT is therefore important, one of its functions is to act as a mobility safety net. Preservation of connectivity for all inhabitants is a goal of Dutch politics (KiM, 2018). This requires active involvement.

Long travel times contribute to social exclusion, especially in rural regions. Inhabitants suffer from social exclusion when their location of origin hinders participation in desired activities. There is a spatial mismatch between the needs and transport capabilities of inhabitants. This is mostly caused by the time required for travel (van Wee & Geurs, 2011). Inhabitants of rural areas, persons not in the possession of driving licences and people at the lower end of the income distribution are most susceptible of getting socially excluded due to transport poverty (CBS, 2018) (KiM, 2018). This should be prevented as this has effects on society in the long term. Local rural labour markets are at risk to become disrupted without sufficient transportation (Laird & Mackie, 2014). Lengthy travel times reduce welfare in rural regions (Maretić & Abramović, 2020). So, the risk of some inhabitants getting socially excluded is higher in rural areas and it has effects on the region.

The risk that inhabitants of rural areas become socially excluded can be prevented with PT improvements however. Shorter travel times enlarge activity spaces and lead to higher PT patronage (Lucas, 2012). This requires a paradigm shift; transport policy does not just focus on efficient transportation, but also on a fair distribution of accessibility across the population. When done right PT may be able to redistribute accessibility in order to achieve a more equal distribution of opportunity across the population (Lucas, 2012). Therefore PT or infrastructure projects should perform an ex-ante evaluation on long term social equity effects.
This is currently not a part of Dutch public transport policy. Public transport should be efficient for the operator and fair to all users (van Wee & Mouter, 2021). This requires action, because fairness collides with efficiency due to a trade-off. Operators are mainly interested in running a well-utilised PT network in an economical manner. Passengers benefit the most from an extensive service with a short travel time (van Nes & Bovy, 2000). Many properties of the PT service can be adjusted, which is elaborated upon in the literature review, see Chapter 2. When the PT network is designed with the objective of improving operator efficiency, it can reasonably be expected that this has side effects on the inhabitants in question. Some inhabitants are expected to be served better than others. This might become a problem if certain inhabitants live in locations that are not covered well by the PT network. The inhabitants that are ill covered do still travel, but need additional time to reach their destinations. This additional travel time has an effect on accessibility, which has to be avoided.

This leads to the question if a regional PT service can be considered as fair to all inhabitants involved. Also, the question can be asked what the exact effects of PT service improvements on the reduction of social exclusion might be. These questions tap into areas of research are currently unclear.

1.2 Research gap

How to express fairness of a PT service between inhabitants of a region and what can be changed to PT services in order to reduce social exclusion is covered by two research domains. Fairness between inhabitants is an important part of the concept of transport equity, with the presence of social exclusion being unfair. The effects of PT service improvements on the reduction of social exclusion is therefore a question of what influence do PT planning decisions have on transport equity. Transport equity and regional PT planning are research gaps. They are currently unclear or lack consensus in scientific literature. The following is an explanation on the unknowns of these key subjects.

Transport equity is intertwined with fairness between inhabitants and transportation induced social exclusion. Transport equity assesses if benefits of transport projects are distributed between groups in an equal or fair manner (Litman, 2021). Transport equity is relatively new as a transport concept. The way it is applied differs from case to case however (El-Geneidy, et al., 2015). Horizontal and vertical are common equity types, but more do exist. What type to apply depends on the case context. Transport equity can be used to evaluate impacts of PT planning and infrastructure improvements on rural social exclusion, but it lacks a common definition and implementation differs between case studies. Eleven definitions and seven evaluation methods are affiliated with some form of transport equity (van Wee & Mouter, 2021). None of them specifically target rural areas.
Even though equity transport equity is still a bit in its infancy, some key publications exist. El-Geneidy et al. (2015) used equity to verify the workplace accessibility effects of an PT timetable with improved early / late hour service for inhabitants at the lower end of the income spectrum in the greater Toronto area. Another key publication assessed which PT improvements in the San Francisco bay area closed the PT vs car accessibility gap best (Golub & Martens, 2014). The authors also elaborated on the point that equity and accessibility are ambiguous, indicators imperfect and argued that a sufficiency threshold for accessibility should be set. This got taken further by Karel Martens, who wrote a book on sufficient accessibility later. This has been picked up by a few case studies. Sharav, Givoni and Shiftan (2019) applied an sufficientarianism based indicator to evaluate BRT and regional rail propositions in rural Israel and van der Veen et al. (2020) applied the indicator to identify areas that featured insufficient accessibility for multiple trip purposes and modes in the city of Rotterdam. Some differences between these case studies are rooted in the ethical theories followed by the authors. Social exclusion is considered to be a part one of these ethical theories. This is expanded in the literature review of chapter 2.
The previously described equity research have in common that the studies have predominantly been carried out in urban areas. Only studies few target transport equity in rural areas. The lack of comparable research gets bigger when the Dutch context with a higher mode share of bicycles is considered. Transport equity is therefore a knowledge gap, it is not clear how equity should be assessed in Dutch rural areas.

Regional PT planning receives less attention in literature than urban PT planning. PT service improvements are achieved via travel time reductions. Travel time is a factor in need of elaboration and assessment. Regional PT travel improvements are noted to receive little attention in literature, despite the significance of travel time for the attractiveness of regional PT. Travel time reduction is explicitly listed as a research gap in a literature review by Hansson et. al. (2019). The reason for this absence in unclear to these authors. It is assumed that it can be partially explained by the focus on regional PT. Passenger preferences differ between regional and urban PT; higher priority has to be applied on coverage and travel time according to Hansson et. al. (2019). It is assumed that components of general PT planning research could apply, but this has to be taken with caution. Multiple publications contest the use of insights from urban research, it may be unsuitable for regional applications.

Another issue encountered in regional PT research is the risk that required data is not available. This hinders PT research in rural areas and is a reason that limited research has been done on PT networks in rural areas (Maretić & Abramović, 2020). Limited availability of passenger data has consequences. Without insight on specific passenger travel preferences PT service operators fall back to focussing on efficiency only (Maretić & Abramović, 2020). This is not optimal as it leads to a declining passenger numbers and a lower mode share of PT, which assumed to be undesirable from an equity perspective. Changing to user centric PT planning is proven to be a remedy however (Tao, Fu, & Comber, 2019).

The unexplored territory becomes clear when doing a search on the scopus.com scientific publication database, as an article search on scientific publications with both public transport, equity and rural yielded 48 results at the time of writing, of which only a few were relevant to this research. These publications are evaluated later, but the absence of sufficient reference material is clear. The research gaps need to be addressed.

1.3 Research objective

The research objective is to investigate how transport equity can be assessed and improved in rural areas. The contribution of this research is twofold. The first contribution is the development of an assessment methodology to evaluate transport equity in rural areas. This contribution is scientifically relevant as this research is one of the first to explicitly connect PT planning with equity impacts in rural regions. The second contribution is an evaluation which impacts PT network design decisions have on transport equity. This is tested with a case evaluation of an area that is partially rural.

This case evaluation is essential because the assessment methodology has to be operationalized and implemented in a rural context. The absence of data is expected to complicate research. A sound equity operationalization has to be found, that is able to provide valid results with the limited data available. The assessment methodology will be tested with a transport equity case evaluation in the Kop van Noord-Holland region. The methodology is considered to be working if the case evaluation can be executed and provides valid results. The case evaluation will also have societal relevance for this and similar regions. The case evaluation will provide insight on the accessibility effects and equity consequences of PT improvements in the case area.

1.4 Research scope

A long term time horizon is applied to this research. Transport equity is a long term effect, it reacts slowly to changes in the environment (Di Ciommo & Shiftan, 2017). It is therefore decided to address relevant strategic and tactical aspects of PT planning.

Because PT planning is either abstract or case specific a test bed area is chosen for further evaluation. For this the Alkmaar – Den Helder corridor is selected. This area is an peninsula, features limited urban development north of the city of Alkmaar and has an interesting PT network. The PT network features a combination bus and rail modalities, with the latter having substantial sections of single track. In order to achieve a positive societal contribution with this research it is assumed that any change proposals should be improving equity, so the focus should be to improvements to the PT network.

Some factors are not covered in detail. This includes governance and transport fares. Governance is not covered in detail because it does not have major research gaps. Socio-economic factors and infrastructure availability are known to have a larger influence on regional railway provision than the applied form of tendering (Seidenglanz, Nirgin, & Dujka, 2015). Dutch PT governance gets improved with the reduction of fragmentation, move to integrated tenders and better coordination between stakeholders (Veeneman, Developments in public transport governance in the Netherlands; the maturing of tendering, 2018). This

research therefore assumes a situation with good coordination and one integrated PT planning process.
Governance has a decisive influence on the fare structure. Fares are subject to regulation and difficult to change. Transport cost is an factor affiliated with social exclusion and transport poverty and covered qualitatively in section 2.2.2 of the literature review. Fares are not covered in detail because transport cost is assumed to be a derivate of travel time and accessibility potential. High transport cost is therefore assumed to be a consequence of having to travel far in order to access desired destinations.

1.5 Research questions

To bridge the research gaps it is necessary to answer with the following research question:

How can equity of public transport network improvements in rural areas be assessed?

This main question can be answered with the following sub questions;

1. How to conceptualise equity and accessibility in rural / regional public transport?
2. What measures can be taken to improve the equity of a public transport service?
3. What are the effects of these measures and how does it impact equity in the Alkmaar – Den Helder corridor?

1.6 Research outline

This remainder of this research is split into 6 distinct parts. Key concepts on equity, accessibility and PT planning have are set forth in the literature review chapter 2. Key steps of applicable theories are assembled together into a generalised transport equity assessment methodology in chapter 3. The developed assessment methodology is operationalised and filled in with case specific data on railways, infrastructure and socio demographics of the Kop van Noord-Holland case area in chapter 4. Timetables are modelled and accessibility potential plus equity indicators computed in order to validate and present results in chapters 5 and 6. Results and other notable findings of this research are discussed in chapter 7. This research is completed with a conclusion and recommendations in chapter 8 and 9. The flowchart of this thesis structure is displayed in figure 2.

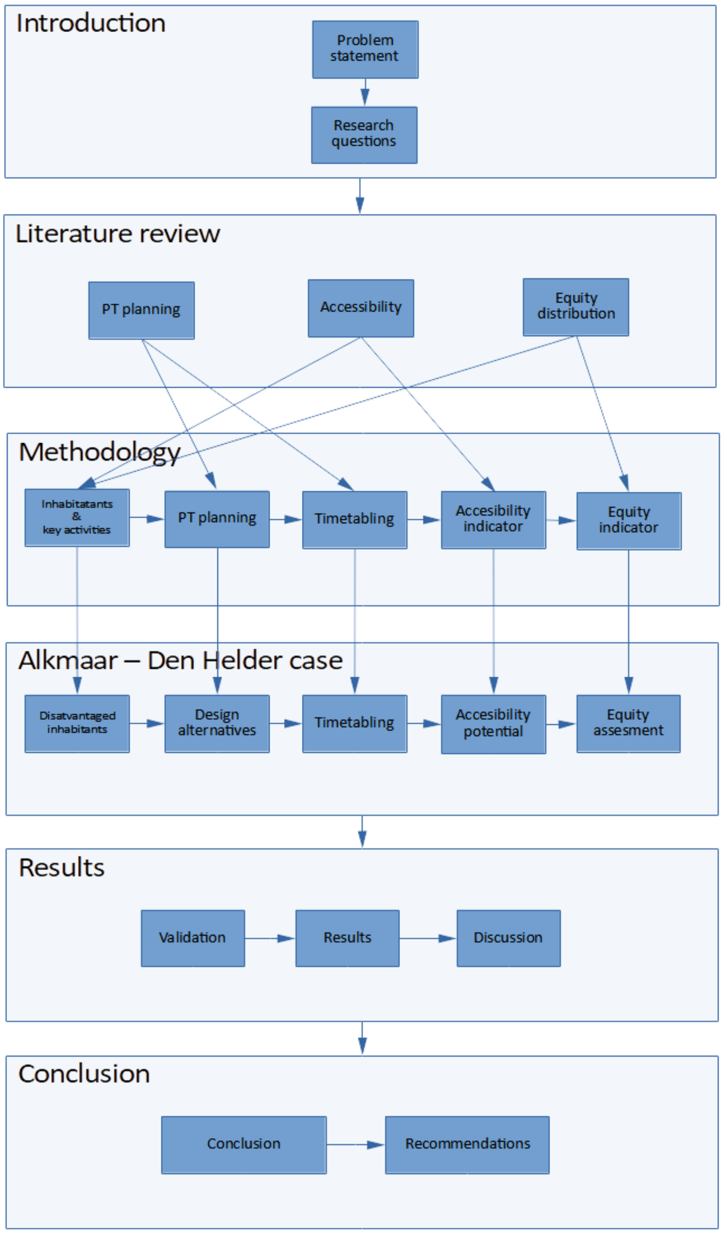


Figure 2: Thesis structure

2 Literature review

Insight in equitable PT planning is required in order to create a basis for further assessment. This chapter is therefore an analysis on previously conducted research. Equitable PT planning breaks down into the knowledge areas of equity, accessibility and rural / regional PT network planning. These key subjects form a chain, where one subject is dependent on the next. This chapter provides context and interpretation on research related to these key concepts. The aim is to investigate which theories are prevailing, if there is consensus on directions of research, sort what alternatives are possible and if a coherent approach is possible for addressing the key concepts. The knowledge gained from this literature review is used as a basis create a conceptual model, which results in a methodology to assess the case application with. Figure 3 gives an overview of which subjects are addressed to which extent in this literature review.

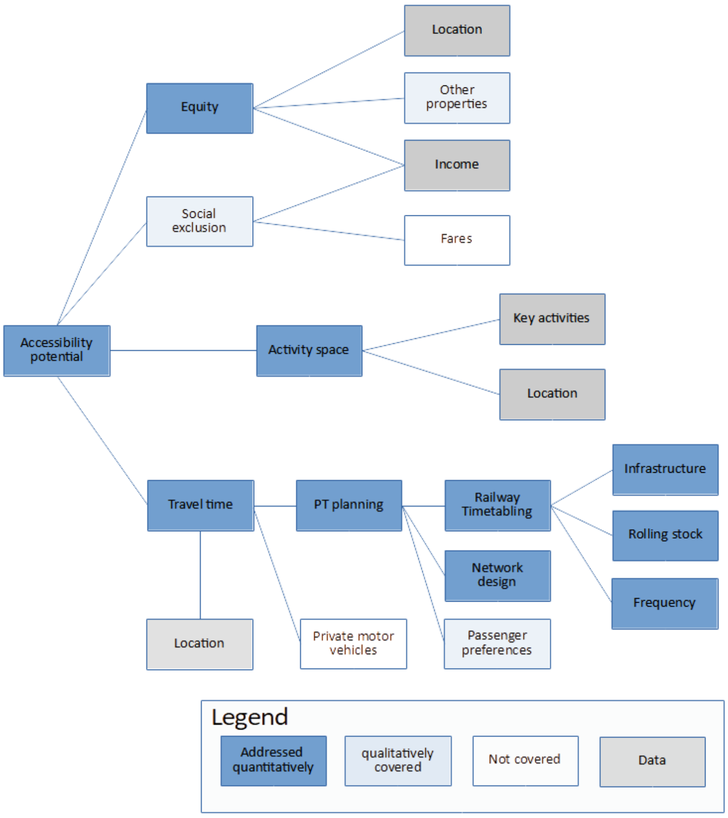


Figure 3: literature overview

2.1 Equity

Equity is a concept which can be used to evaluate reductions in social exclusion and fairness improvement of planned changes to the PT network, but challenges remain in how equity should be exactly defined and operationalized. A concise definition of equity proves to be a challenge since equity is relatively new, ambiguous and normative (van Wee & Mouter, 2021). It is also used in other fields than transportation, such as safety, healthcare and environmental assessments, which increases variations in versions of equity as an indicator. Furthermore; different expressions are used to address equity. The term equity is used to address fairness between inhabitants in this research. Transport equity is mainly used as an assessment method to analyse differences in transport benefits. This is ambiguous, which is addressed in the following section.

2.1.1 Equity assessment

Transport equity is about the distribution of accessibility over inhabitants of a specific region (Di Ciommo & Shiftan, 2017). This definition is broken down into three distinct parts. The question needs to be answered which exact transportation benefits should be evaluated. In addition, the population and subgroups to which the distribution of effects is relevant should be defined. Lastly, the exact method of distribution of effects over the population has to be defined.

The order of these sub steps varies between publications, there is no consensus. If the population groups are defined first, the transportation effects under review can be focused on the group that is at disadvantage. Transport equity aims to raise social welfare by improving the accessibility to key activities for specific disadvantaged groups (Martens & Di Ciommo, 2017), so the assessment has to start with the needs of inhabitants in question. This is similar to the framework of Van der Veen et. al. (2020), whom assess a research area and the population subgroups first, followed by destination selection and their version of the effect distribution mechanism. This approach has some drawbacks, it considers accessibility to be static. Assessment with PT planning is addressed by Gasparik et. al. (2020), who also start with needs and travel motives of inhabitants before addressing factors that influence PT services and accessibility. The selection of transportation effects has to be related to the burden that has to be overcome by the population (Martens, Bastiaanssen, & Lucas, 2019), which is inequality of opportunity for parts of the population. Inequality of opportunity is an effect of the PT service. Therefore it is concluded that the needs of inhabitants need to be evaluated before assessing effects of transportation and evaluation of these effect with an equity distribution mechanism.

The definition of the research area and population subgroups can be considered as straightforward, when applying the framework in this case. The research area is indicated in the research scope section of chapter 1.4 and applied in the methodology. Relevant is the assignment of specific focus groups in the population, on which is consensus in academic and grey literature. Inhabitants with an income in one of the lower incomes categories, people without driving licences and youth, elderly inhabitants (CBS, 2018) are of concern, plus rural areas and regions with population decline (KiM, 2018) are at the risk of developing transport poverty.

The transportation effects to be evaluated are factors that determine the PT service delivery, or weigh the consequences. Equity is defined as accessibility to relevant destinations of inhabitants. Accessibility is a valuation of the dynamic relation between trip distance and travel time (Niedzielski & Boschmann, 2014). For a PT network this involves timetabling. Successful execution of a timetable requires PT planning, which is an extensive process with many constraints. PT planning, timetabling and accessibility are important subject and addressed in an subchapter of their own.

2.1.2 Equity distribution mechanism

Evaluation of transport equity requires a distribution mechanism. This is a challenge, as there is no universally acclaimed method to distribute effects of transportation over the population. This is due to the ambiguity of equity as a concept. In fact, there are many equity types and indicators that aim to distribute some effects between defined groups, however none of them is rural or PT specific. So, a applicable transport equity distribution mechanism has to be found. This starts with an analysis on equity types.

The wide applicability of transport equity is a reason that eleven equity types and seven evaluation methods can be identified. A review by Wee and Mouter (2021) concludes that horizontal, vertical, territorial and spatial equity are the best transport equity types. In short; horizontal equity adheres to the principle that comparable (groups of) inhabitants should be served in an comparable manner. Vertical equity departs from horizontal by identifying groups of inhabitants at an disadvantage and to whom improvements should be targeted. Territorial/ spatial is focused on differences between comparable geographical regions instead, assuming a homogeneous population.

The review of Mouter and van Wee would have been more relevant for this research if the authors judged on the differences between the common equity types. This is given by Camporeale et. al. (2016), whom argue that the frequently applied horizontal and vertical equity indicators commonly overlap or contradict with each other. This potential for conflict depends on which criteria are evaluated or left out and to what extent assessment of these criteria is done. Essentially, transport equity is an assessment on the distribution of accessibility to relevant destinations across the population. It is therefore assumed that vertical equity is complementary to horizontal equity and selection for one over the other depends on the availability of data. Ex-ante equity evaluations op PT network are possible, but these are seldomly done since 2016 (Camporeale, Caggiani, Fonzone, & Ottomanelli, 2016).

Literature is inconclusive in how to evaluate equity, especially in rural / regional research. Relevant publications that are currently available are scarce and inconclusive in a choice for horizontal or vertical equity. Searching on the scopus.com scientific publication database, with the search string *public AND (transport OR transit) AND (bus OR rail OR train) AND (equity OR fairness) AND (rural OR region OR regional)* yielded 48 results at the time of writing. When filtered for publications that fit the non-urban purpose of this research, assuming that countries in the wider European region have similar land use compositions distinct from elsewhere, four accessible publications remain. These are summed up in table 2.

Authors	Title	Year	Source title	Area	Equity type	Assessment
Flipo A., Sallustio M., Ortar N., Senil N.	Sustainable mobility and the institutional lock-in: The example of rural France	2021	Sustainability (Switzerland)	Drôme and Ardèche, France	Territorial	Did not do a horizontal or vertical equity evaluation. Addressed travel cost and PT fare setting.
Danesi A., Tengattini S.	Evaluating accessibility of small communities via public transit	2020	Archives of Transport	Cesena, Italy	Horizontal	Focussed mainly on travel impedance function for bus and rail. Favoured travel time over GTC. Addressed equity impacts of their results briefly.
Sharav N., Givoni M., Shiftan Y.	What transit service does the periphery need? A case study of Israel's rural country	2019	Transportation Research Part A: Policy and Practice	Haifa and Ber Sheva, Israël	Horizontal	Did a horizontal equity evaluation. Article applies Potential Mobility Index, which has sufficiency tresholds. Evaluated for both bus and rail however
Schoon J.G., Mcdonald M., Lee A.	Accessibility indices: pilot study and potential use in strategic planning	1999	Transportation Research Record	Hampshire, UK	Horizontal	Did not do a horizontal or vertical equity evaluation. Mainly focused on time effects of car accessibility, but evaluated bus and cycling as modes. Was inconclusive on travel time or GTC as travel resistance function.

Table 2: scopus.com yield

This low number of publications found is partly explained by considering the circumstances in which equity research is conducted. Transport equity assessment is compulsory for major infrastructure projects in the US and UK, but not in the Netherlands (Alonso González, Jonkeren, & Wortelboer-van Donselaar, 2022). It is assumed that this is a cause why most equity research is focused on major urban infrastructure projects in these countries. Of the applicable papers 4 did equity research with a case application and two evaluated both bus and rail modes. Most applied horizontal equity, some with remarks on the unavailability of suitable income data needed for vertical equity evaluation. The article of Sharav, Givoni and Shiftan (2019) provides an interesting assessment of transport equity effects. It assesses the accessibility and equity impacts of proposed bus rapid transit and heavy rail services, including the potential of connecting transfers to onward destinations. The research would have been more relevant if the authors differentiated the between income groups and underpinned their choice of equity indicator, as their PMI indicator uses sufficiency thresholds, which could be debatable and is discussed later.

Vertical equity, thus differentiating between inhabitants and their susceptibility to transport poverty, has not been found with the specified search criteria. Vertical equity is researched in urban cases however. Vertical equity will generally reveal a higher inequality value, when horizontal and vertical equity are compared directly. This proves useful when effects of PT provision have to be evaluated for specific groups. An example is testing if the PT is supplied equally, specifically to disadvantaged groups in the greater Melbourne area (Delbosc & Currie, 2011). Vertical equity is better in identifying areas where PT supply that is disadvantageous for the opportunities of the population groups that are focused upon. The authors could only compare internally and not to other studies, as the equity factor lacks an interchangeable unit. The point that computed equity values are ill comparable with other research is repeatedly discussed in studies. This could be due to the experimental design of these studies, as the calculated equity depends on the transport modes, routes, travel time and socio demographic data used.

In general, a couple of observations are made in the investigated research; rural equity evaluations depend on the availability of demographic data, higher levels of aggregation may be used, some evaluated the main effects of their study only and rural equity is handled differently between studies. Equity is either computed for all subjects of analysis or via an indicator that assesses subjects with sufficiency thresholds, which may void equitability.

Some of the differences in addressing equity can be explained with the underlying ethical theory followed. In general, travel time improvements are valuated with utilitarian methods (Martens & Di Ciommo, 2017). Alternative theories take distance from the common utilitarianism, which is the theory on which cost benefit analysis (CBA) is based for example. Utilitarianism, in short, states an act to be right if it maximises the total common good. While it allows for straightforward evaluation, since all effects are monetized and summed up, which has major drawbacks. Di Ciommo & Shiftan (2017) point out that utilitarianism favours highly mobile people and inhabitants with a higher net worth. While transport projects yield the same time savings for all inhabitants, inhabitants of higher net worth skew the effect monetization because of their higher value of time (van Wee & Geurs, 2011). This is an example of distributional impacts between socio-economic groups, which is a shortcoming of utilitarianism as this gets ignored (Shortall & Mouter, 2021).
Egalitarianism is an alternative theory, which advocates that everyone should be treated equal (van Wee & Geurs, 2011). Within egalitarianism, the theory of justice of Rawls is influential. It proposes a strive that the greatest benefit of transportation should go to society members that are advantaged the least, as opposed to maximizing a cumulative indicator. In addition certain social goods are considered to be essential and need to be supplied to disadvantaged inhabitants. As such, egalitarianism can be seen as the underpinning of vertical equity, whereas general egalitarianism is horizontal.
Another major ethical framework is sufficientarianism, which advocates that any member of society should have a minimum level of PT service. The rationale being that some unequal

distribution is seen as inevitable and not a bad thing perse. Only if the benefits of transportation are distributed unequal and substantially disfavour specific subgroups van der Veen et. al. (2020) consider this to be problematic. Social exclusion is part of this theory. Defining which equity difference is considered to be acceptable is arbitrary, case specific and could get political sensitive (Golub & Martens, 2014). What should be done with inhabitants that are just above the exclusion threshold is unclear.

The main issue of these ethical frameworks is that there is no consensus on which is best in which situation (Alonso González, Jonkeren, & Wortelboer-van Donselaar, 2022). Some researchers promote why the chosen framework fits their case study, but still leaves policymakers in doubt it is fit for their purpose (van Wee & Mouter, 2021). Because there is no consensus on the selection process both van Wee and Mouter and Golub and Martens (2014) conclude that ethical framework selection should be done after empirical research in the population. As the availability of data can be scarce, it could best to apply the most extensive ethical framework, provided that it fits with the available data. Vertical equity is considered the most detailed in general, as it is able to direct equity to the inhabitants at the risk of getting transport impoverished. Sufficientarianism might be unsuitable in the rural context, since the arbitrary set cut-off value could generate unprecise or biased equity values if set wrongly, or be difficult to set at all due to aforementioned risk of data scarcity.

A total of seven indicators have the potential to be used for an equity evaluation. The Gini, Theil and Atkinson index are commonly used (Souche, Mercier, & Ovtracht, 2015), of which the Gini index gets applied the most often (van Wee & Mouter, 2021). When vertical equity is applied in a rural context risk of insufficient data will surface, which may hinder evaluation. This can be countered with the Theil-index, which receives acclaim for its ability to asses equity within and between arbitrarily assigned groups, without residue (Camporeale, Caggiani, Fonzone, & Ottomanelli, 2019). The grouping property is beneficial when data on inhabitants is limited. Grouping of inhabitants is probably necessary in rural areas, as it allows the use of data with a higher level of aggregation. This could be essential because rural areas generally lack data with a high level of detail.

In general; it is possible to asses equity by computing the distribution of transport equity over the population. Equity can be evaluated if the area and groups are defined, effects identified / known and distribution mechanism selected. Equity remains ambiguous, each of the theories has advantages and critiques, but egalitarianism is without major downsides. In practice the choice of an equity evaluation method is more likely to be given by the availability of data for the effects evaluated, in which rural areas are at a disadvantage due to their backlog in data collection. This should be considered when selecting an equity indicator. A choice needs to be made between the Theil index, Gini coefficient and Atkinson index early in the methodology. However; the method of accessibility computation and PT planning process with timetabling needs to be operationalized before a methodology can be made.

2.2 Accessibility

The distribution of accessibility within a region is a substantial component of equitable PT planning. Accessibility effects have to be exactly known for equity to be computed. This introduces a challenge, as accessibility is ambiguous and open for interpretation (Geurts & van Wee, 2004). This section determines which accessibility definition is applied.

Accessibility valuates the interaction potential of inhabitants by calculating the ease or difficulty to get from point to point in an area, for a specific trip purpose and mode (Miller, 2018). Some assumptions are required. These are how travel should be measured and how the cost of travel is being accounted for. Miller (2018) identifies that measurement of trips is either with distance or travel time per mode between points. Attractiveness of a trip destination can be evaluated for one or multiple purposes, with or without accumulation. Furthermore, the way travel resistance is weighted varies. Multiple types of resistance functions exist and application varies between studies.

2.2.1 Measurement of travel

Differences exist in the operationalisation of accessibility because accessibility is composed of multiple components. Geurts & van Wee (2004) identify land use, transportation, temporal and individual components. Land-use applies to the distribution of both inhabitant demand and supply of opportunities over a region, transportation covering travel resistance, temporal period of day variations and individual socio economic factors that predict travel demand of individuals. These components interact with each other in the long term. Focus is applied, as considering all components in detail is impractical. Focus should be applied to specific aspects that fit the scope of research.

Location, social category and personal aspects of inhabitants are factors that are associated with equity and social exclusion (Lucas, 2012) . These should be included in an equitable accessibility indicator, but it would be better if the relation between place and opportunity of individuals is made explicit as they are correlated. Further definition is given by Kamruzzaman et. al. (2016), whom conclude that accessibility should consider the potential for inhabitants to participate in activities. Therefore; activity-space of inhabitants has to be evaluated. Activity-space expresses how the transportation resistance reduces the potential to access activities in other locations on an individual scale. As such, it is an combination of land use, transportation and individual components. Some aggregation may be required in practice, as data may be unavailable for certain rural areas.
The accessibility potential should be evaluated for key activities. Common trip purposes are work, education, shopping, recreational, social or healthcare related (Di Ciommo & Shiftan, 2017). These are key activities to which the PT network should facilitate access. Activity-space is evaluated by computing the accessibility potential for these activities. In practice it may be advisable to only evaluate the accessibility potential for activities that require substantial travel with the PT network.

2.2.2 Travel resistance

The accessibility potential is not infinite, as travel is bounded by a resistance. Multiple methods are possible to express travel resistance. Cumulative opportunity within distance or time, gravity regression and maximum random utility as the most commonly applied indicators (Miller, 2018). Di Ciommo & Shiftan (2017) have a preference for gravity regression over cumulative opportunity and utility. This is defendable for multiple reasons. Firstly, gravity regression has no suspect behaviour at an arbitrarily chosen boundary value, which is a shortcoming of cumulative opportunity (Xi, Miller, & Saxe, 2018). Secondly, indicators need to be theoretically correct, but also interpretable and communicable by researchers and policymakers (Geurts & van Wee, 2004). Gravity regression is easier to interpret and communicate than utility (Hoogendoorn-Lanser, Schaap, & Gordijn, 2011) (Camporeale, Caggiani, Fonzone, & Ottomanelli, 2016).

Gravity models use a decay function to calculate cumulative opportunity. This could be done with either the sum of travel time or by using a generalised travel cost (GTC) function. Usage of the sum of travel time is relatively straightforward and unbiased way of computing travel impedance (Danesi & Tengattini, 2020). Travel time has multiple components, in vehicle travel time (IVTT) and access egress time from a location to a stop are relevant. IVTT is particularly important, but does receives little attention in scientific literature on regional PT accessibility according to Hansson et. al. (2019). This has to be addressed and is assumed to require insight in PT planning, which is case dependent.

GTC is another method to model a resistance function. GTC is able to use different components, which contribution is weighted. Weighing has to be done with passenger preference data. Passenger preferences differ in rural areas according to Hansson et. al. (2019). This is an complication when preference data of the specific case region is unknown. GTC has the option of including transport cost, but this is not recommended by Hansson et. al. (2019). PT fares are considered to be an inelastic good (Nuworsoo, Golub, & Deakin, 2009). Ability to pay could be assessed by computing the share of transport cost on income. Easing the budget constraint could ease participation but it would require changing fare structures, which are complex and subject to institutional lock in (Flipo, Sallustio, Ortar, & Senil, 2021). Furthermore the causality of transport fares needs to be addressed. Laird & Mackie (2014) argue that transport costs are a consequence of the trip required to access opportunity. High transport fares are a result of not having sufficient opportunity close to the place of origin, requiring inhabitants to travel far into their activity-space. This research will therefore assume that transport fares are a derivate of accessibility. This favours using the sum of travel time and recommending to do fare studies as follow up work. Therefore it is proposed to use the sum of travel time in the decay function. This is a property of a specific PT network structure, which depends on PT planning and timetabling. This is covered in the next section.

2.3 PT Planning

Ex-ante research on equitable PT planning is very limited, transport equity is seldom included in PT planning (Camporeale, Caggiani, Fonzone, & Ottomanelli, 2016). It can be included by assessing how PT network improvements influence travel time and change the shortest path between locations. This has to be analysed for a specific PT network. It is therefore necessary to analyse the PT planning process, because timetables are essential. They contain travel times between locations. Specific attention is paid to network improvement measures, because implementation will lead to equity improvements. These measures have to meet criteria, it is required that they reduce travel time and lead to a timetable that is feasible. This section explains relevant PT planning processes fist, followed by timetabling.

2.3.1 Planning process

The absence of a comprehensive equitable PT planning methodology for equitable planning has to be addressed. Part of this is done by a study of Gasparik et. al. (2020), whom assess travel needs and motives first, followed by a determination of the current infrastructure, analysis of factors of influence and finally timetable modelling. While this method is brief it does fit with transport equity and accessibility potential theory. The steps can be used, but for this research it is necessary to consider measures that reduce travel time and asses relevant aspects of the PT planning process.

The absence of a comprehensive planning process is due to the complexity of planning, which is usually divided in many studies on distinct subcomponents, who apply changes in small iterative steps. Some studies start with a quantitative analysis of the current infrastructure and apply changes from thereon. Changes like provision of a new station of run time reductions are compared to a situation with minimal change. Other research, predominantly in studies that apply accessibility and LUTI model perspectives on PT planning, attempt to address planning by outlining an aggregated approach followed by arguing for coordination and strong collaboration between parties involved. Clean sheet designs are usually made for high speed rail or urban light rail transport evaluations, but adoption of these methods may cause issues, as this taps in an argument of Hansson et. al. (2019) that urban PT research forms a paradigm which may produce incorrect results when used regionally.

The PT planning process has therefore have to be outlined for the components that apply to scope of this research. This is important as not all aspects of PT planning are relevant.

The planning process can be divided in steps with different time horizons. Generally, strategic, tactical and operational are considered as planning phases. Strategic planning starts at least 5 years in advance and considers main effects, some of which are unknown or drafts (Hansen & Pachl, 2008). One year prior to a project the planning phase becomes tactical and later short term operational. These horizons require a different level of detail, with the shorter the time horizon gets the higher detail on operational conditions required. The effects of equity are considered to change over a longer time period (Di Ciommo & Shiftan, 2017). This is due to the relatively slow and complex behavioural reaction of passengers to PT service change, depending on the intensity of the effect (Guihaire & Hao, 2008). This slow and complex adaptation suggests that focus should be applied major change, which is covered in strategic planning.

The PT planning process is complex and commonly divided into sub steps, which is outlined in table 3. The PT network design and frequency setting steps are generally considered to be strategic and timetabling tactical. The physical design features of railways require strategic evaluation, because they are constraints to an operation (Bruun, Allen, & Givoni, 2018). These features are the infrastructure, stations or stops, and supporting facilities.

TNDSP Step	Time horizon	Short description
PT network design	Strategic	Definition of route layout, rolling stock type, spaces between stops
Frequency setting	Strategic	Definition of operation period, on peak / off peak departure frequency
Network timetabling	Strategic / Tactical	Define arrival and departure of vehicles at all stops on the network, should meet operational constrains in relation to frequency, capacity – demand, transfers
Vehicle scheduling problem	Tactical	Assign combinations of vehicles to routes or circulations, so that minimum are required for the operation
Driver scheduling problem	Operational	Define daily duties that cover all trips in an optimised manner
Crew rostering	Operational	Assign duties per location to schedules of drivers at minimal cost

Table 3: process steps and time horizon, adapted from: Ibarra-Rojas et. al. (2015)

The network planning steps of table 3 is simplistic, the outlined steps are covered with dedicated optimisation models in with a high level of detail. These optimisation models either target one or a combination of subproblems. Only route / line design, frequency setting and timetabling are considered to be fundamental (Guihaire & Hao, 2008). Vehicle and crew scheduling are only covered in limited extent, if at all in strategic studies. Because of the interaction between sub models, combined models are made (Kepaptsoglou & Karlaftis, 2009). Interaction between steps, which is expected due to infrastructure capacity limitations, makes it an iterative process.
Often a single corridor is evaluated, with services linking major stations with intermediate stops. This is considered advantageous, because PT networks usually have few important railway corridors on which the rest of the network elaborates (Cacchiani & Toth, 2012). Planning is done by selecting or modifying departure times at key locations or network edge. Multiple objective functions exist, but given the transport equity scope focus should be applied to the maximum travel time reduction possible for the given PT network capacity and desired frequency.

Changes to the PT service are possible. These can consist of increasing the frequency or altering the cyclic pattern, changing the path sequence, reducing train path conflicts with capacity enhancements and providing of additional railway stations. This requires extensive evaluation however.
The feasibility for each proposed change should be analysed, requiring timetable modelling.

Railway timetable modelling distinguishes pre design and basis hour pattern design phases in the Netherlands (Planting, 2016). These are part of the strategic time horizon. The design phase allows changes to the infrastructure, the basis hour pattern phase assumes infrastructure as given. Both phases should be executed, as train path conflict reduction could require significant change and providing of new stations certainly contains major changes to the railway infrastructure. This limits the scope to the strategic long term time horizon, due to factors affiliated with path dependence.

Path dependence of infrastructure

PT planning, railways in particular, are restricted by the current land use pattern and constraints to the infrastructure. The spatial location and properties of the alignment and stations dictate the extent of rail services possible. The introduction of new or additional services is path dependent if they require changes to the existing railway infrastructure (Bruinsma, et al., 2008). For new services infrastructure changes are often needed, which require substantial investment, coordination and an extensive period of planning (Weik, 2020). Due to these long lead times and high investment cost getting it right first time is essential.

Path dependency occurs a number of situations. Introduction of additional services is restricted by infrastructure if the required train paths are not available, due to sections of railway occupied by trains working other services. Sites where stations could be built require a synergy between land use and transportation infrastructure, for Priemus this entails (2008) the location of the station relative to populated places and supporting road infrastructure to access the station. New railway lines with accompanying stations are according to Bertolini (2008) only feasible as part of a large coordinated development scheme, targeting at spatial properties found in urban regions. Schemes in rural regions should aim at connecting populated places with multimodal, incremental developments. Incremental improvements of the current railway alignment remain achievable. The minimum travel time can be reduced by increasing the speed over the alignment, shorten access times by providing new stations and remove limitations of single tracked sections. Path dependence therefore limits the potential for improvements to corridors present in rural areas. Case evaluation is needed to determine if proposed measures are feasible and lead to an equity improvement.
PT governance is subject to path dependence as well. It desires the modes, spatial scope, organisational form and duration of PT concessions. Awarding of concessions is split over multiple governmental institutions, with the majority of the railway network being directly awarded to NS (Veeneman, 2018). Other operators of passenger or freight services exist, whom consume capacity as well. Capacity allocation is a tactical process and is done yearly by the infrastructure manager (Veeneman, 2016). This process is subject to tight regulation. Operators need to submit requests for all their desired train paths for the entire network. All path requests are compared and allocated when there are no conflicts or rejected when path conflicts between operators exist (Prorail, 2017). Rejected paths either receive a minor adjustment or rendered infeasible. This process may trigger infrastructure expansion when train paths gets rejected for an extended period (Planting, 2016). Here; fragmentation is considered to be suboptimal, for which this thesis assumes an integrated PT network with coordination between stakeholders. This is also addressed in section 1.4.

Station spacing & travel time trade-off

There is a trade-off between network coverage and operating speed. The PT network can be improved by reducing the in vehicle travel time with network improvements or by extending coverage with the provision of new stations. These two options essentially compete with each other over accessibility potential. Regional PT passengers have a strong preference for a short in vehicle travel time, but also value a short access time to stations. The relative importance between these two components is undetermined for rural applications (Hansson, Pettersson, Svensson, & Wretstrand, 2019). It is difficult to include specific passenger preferences, unless (i.e. stated choice) research on preferences of inhabitants of a region is conducted.

In principle; the question has to be answered if net effect of improving access times for passengers by creating a new stop is greater than the time lost by inhabitants already using the service and passing through. Providing a station reduces the access times for inhabitants in proximity, but lengthens the IVTT for the passengers already on board the train service due to the additional time required for the stop (Sharav, Givoni, & Shiftan, 2019). So if the equity gains of enlarging the activity space for some is worth sacrificing the activity space of others. This is partly covered by stop spacing optimisation models that are part of TNDSP models (Guihaire & Hao, 2008). These are mainly made for urban PT and bus networks and address bus stop spacing or stop skipping of existing stations by some services, but are absent for rural railway applications. This is partly explained by the path dependence of railways and assumed to be case depended. The net equity effect between improving access for some inhabitants, while scarifying travel time of others depends on multiple factors; the distribution of inhabitants over populated places, the travel time achievable by the PT service and decay function of the accessibility potential. Improving coverage by providing a new station is only wise if it leads to a net equity improvement. This can only be assessed with a case evaluation.

The best locations for new railway stations in rural / regional areas are locations that facilitate multimodal transfers and enable the station to be incrementally added to the infrastructure, meaning without or with minimal change to the right of way to (Bertolini, 2008). Locations with supporting infrastructure, populated places nearby and the possibility of expansion are of good transfer potential (Priemus, 2008). This commonly requires change or redesign of an area.

Single track infrastructure

One important limiting property of railway infrastructure are sections of single track. Care must be taken when operating train services over these sections, as crossing of opposing services should be carefully timed at stations or other locations with suitable crossing sections in order to avoid a deadlock (Landex, Kaas, & Hansen, 2006). The distance between crossing sections is important, since trains can only run in one direction at a time over the single track section. The single track section can only switch to trains in the opposing direction when empty. The track occupation of a single tracked section is high, when train paths are scheduled in both directions. This limits capacity, the shortest headway possible is at least twice the running time over a single tracked section (Landex, 2009). The longest section of single track determines the capacity when multiple sections of single track are in consecutive order. Capacity over a single track section can be increased by shortening the run time over these sections with (Landex, Kaas, & Hansen, 2006);

- Faster acceleration and higher speed of rolling stock
- Increase the number of crossing sections
- Enable parallel movement at crossing sections
- Extend the length of double tracks at crossing sections
- Increase the deflecting speed of switches

Most of these measures reduce the time a train spends in one single track section. Another option is to increase the number of crossing sections, because it reduces the longest section of single track. This removes a bottleneck, if done at the right location. A timetable with fixed intervals and little variation is required (Landex, 2009). Another possibility is parallel movement operation, which could reduce running times by reducing the necessity of required interlocking time supplements. This is done with separation enforcement at the end of double tracked crossing sections, either with placing an exit signal before the start of the single track section and / or with a switch to a dead-end track. A Swedish comparative study yielded addition of additional crossing sections as the most significant improvement, followed by partial double tracking (Lindfeldt, 2012). Partial double tracking is noted to be advantageous however, due to better flexibility.

The length and location of new or extended passing loops have an influence on the travel time over the section of a railway line if it eases the crossing of opposing train services. Short passing loops are noted to require substantial additional travel time, because trains have to come to a stop (de Heus, 2016). It is expected that this has an adverse effect on equity and should be avoided. The effect can be mitigated either by building a station at the passing loop where trains stop anyway, or by lengthening the passing loop to allow trains to cross each other at their original speed. Both have potential side effects. The length and location of the new or extended passing loops has to be evaluated on a case basis.

2.3.2 Railway timetabling

Railway timetabling is required to compute travel times between stations and possible extension of double track for any service change. Timetables need to consider all relevant infrastructure and operational constraints in order to get a stable service. Strategic line planning uses a defined route, stop sequence and frequency to determine if a feasible timetable exist for the operational and infrastructure constraints. Constructing a timetable requires some form of modelling, the extent and detail of which depends on the applicable planning horizon.

Strategic line planning

Strategic line planning usually expresses the railway network on a highly aggregated level and uses macroscopic modelling. Stations and junctions are reduced to nodes in these models and the intermediate line as a single link, with properties such as location, length, number of tracks (Hansen & Pachl, 2008). More detailed modelling is needed if the proposed timetable is macroscopically feasible according to applicable norms and may get executed. This is done with microscopic modelling, which contain the highest level of detail on link and nodes, covers blocking and includes stochastic variables in order to test for minor disturbances.

Dedicated railway planning models exist in the Netherlands. DONS is mesoscopic and used for strategic purposes, while DONNA is for microscopic and for tactical / operational planning (Planting, 2016). The use of DONNA is specified in the access requirements to apply for train paths (Prorail, 2017). It recently got an overhaul with more detailed follow-up times specific for each section of infrastructure, allowing for tighter planning and thereby increasing capacity. These models are proprietary however and not available to the author. Other simulation software exists, but is usually closed source as well. Publicly available alternatives are available in the form of model specifications from scientific and grey literature. This assumed to have some caveats including less detailed information available and possible non-conformity with Dutch railway planning standards, but could still be able to generate feasible timetables. This means that follow-up research in the form of microscopic simulation for a preferred design alternative is needed later. Given the research scope on strategic assessment of equity effects this is considered to be acceptable.

Microscopic modelling is considered to be out of scope, since it is not required for strategic planning and assumed to be too detailed and resource intensive for the strategic objective and preliminary nature of this research. Mesoscopic modelling is an intermediate method, which uses macroscopic modelling, but with microscopic detail where required (Hansen & Pachl, 2008). Situations like variations in permitted line speed and conflict detection at capacity constrained points require a form of microscopic modelling. Mesoscopic modelling is considered to be a better fit for the research scope compared to macroscopic modelling.

Mesoscopic timetable planning

Mesoscopic modelling is essentially abstract, but with key areas that are evaluated in higher detail. Feasible timetables can be constructed for a railway corridor using an iterative two-step process. First a sequence of consecutive train paths is defined, which is analysed for headway conflicts. Present conflicts are resolved after this initial phase. The process should repeated till all conflicts are removed, measures may have knock-on effects (Botte & D'Acierno, 2018). Train paths can be made in a number of steps. Dynamic train properties such as acceleration, maximum speed and braking rates of rolling stock are used to calculate run times over segments of the line, between stations for example. This is the minimum run time, to which time supplements are added to run times for stability reasons (Landex, Kaas, & Hansen, 2006). The supplemented run times are used to create a train path for the service concept with applicable minimum station dwell at each stop, plus other time components prescribed by the infrastructure manager. The train paths are duplicated in a sequence for the agreed frequency and clockface cycle. This forms a basic timetable, which is likely to result in situations where headway conflicts between train paths occur, for which the iterative two step detection and resolution process conflict is needed.

Deterministic timetable modelling is sufficient for strategic network design (Botte & D'Acierno, 2018). Mesoscopic modelling is able to execute deterministic timetable compression for a railway that is partially single tracked. This is important, as deterministic timetable compression is the UIC standard for computing conflict free train paths with minimum headway (Goverde, Francesco, & D'Ariano, 2013). Since capacity is limited by the single track sections it is assumed that compression is done by evaluating the entrance and exit of trains in single tracked sections. For the Dutch context it is assumed that the access requirements of infrastructure Prorail adhere to UIC norms. Modelled path sequences that meet the access requirements of Prorail are assumed to be compliant with UIC standards.

Modelling of single track and new stations

Single track line segments require special attention in the timetabling process. First, the desired frequency is limited by the run time over the longest section of single track. The headway of consecutive services should be should be higher than double the run time between stations for the longest single track section (Landex, 2009).

Secondly; the headway of opposing services requires specific attention. Begin / endpoints of single tracked sections are protected with signalling and have to be assessed at a higher detail. Dutch timetable planning applies a default minimum headway at the begin / endpoint of the double tracked sections; the release time. This added to the headway and may be of hindrance for travel time when trains have to wait out a headway conflict at standstill. Time loss is reduced when the crossing section is expanded to a length that allows both trains to cross without slowing down. It needs to be determined if trains can safely come to a stop before entering the single tracked section. This requires transmission of movement authority and line release, which is done per block section of the railway line (Hansen & Pachl, 2008). It is assumed that each track of the passing loop at least has one block. Multiple time elements apply. Signal realising time is the time train drivers need to acknowledge a signal, which may vary, plus time for braking depends on the braking properties and speed of the train (Landex, Kaas, & Hansen, 2006). It is assumed that a crossing loop should be extended to a distance that allows acceleration for the duration of the original headway conflict (including signal release), plus signal realising time and time for braking. Trains are able to run at their original minimum run time for the section while being able to come to a stop when end signals remains unsafe for any reason.

It is recommended to evaluate the location of points or stations in a timetable model with the creation of dummy nodes (Sparing, 2016). These dummy nodes have to have to meet all feasibility constraints. Finding the right location for these dummy nodes is an iterative process. This process has to be repeated for every PT design alternative under evaluation, as the spatial location of dummy nodes varies between evaluated alternatives

2.4 Literature review conclusion

Transport equity is a moral judgement on the distribution of transport benefits between groups in the population. Equity is complex, but essentially consists of three parts. Subgroups in the population that are at a disadvantage have to be distinguished. This is followed by identification of which exact accessibility effects these inhabitants are subject to. If this changes for the better transportation benefits are assumed to be enjoyed. Lastly, the benefits of transportation are distributed over the groups in the population. This workflow is applied in the remainder of this research.

How population groups are distinguished depends on the situation. Rural research generally applies horizontal equity, which differentiates just on location. Vertical equity is able to reveal more inequalities between inhabitants because it also considers socio-demographic differences between people. What division is possible depends on the availability of specific case data. Evaluating for vertical equity is better, provided that this is possible with the data available. Whom are considered to be disadvantaged has to be defined. Generally; inhabitants are disadvantaged due to socio-economic status or location. Other factors exist, but these might correlate with the former. The difference in accessibility potential is calculated with an equity indicator, for which multiple exist. The Theil-index is proposed for the equity evaluation, as it is able to assign inhabitants into arbitrary groups. This is advantageous when data on inhabitants is limited and sample sizes are small. The Theil-index yields in a value that expresses the level of (in)equity in the population. While this index value is relatively meaningless for one application, this changes when the effects of different measures or modes are evaluated. Then equity values can be compared between each other.

The ambiguous concept of accessibility is defined here as the activity-space of inhabitants from a location of origin to specific key opportunities. The activity-space is bounded by transport resistance, which reduces the attractiveness of opportunities further away. Resistance is expressed with a decay function, which exist in multiple forms. Gravity models suit this research well. Travel time is the main transport effect to be evaluated, which the decay function will weigh.

Travel time between locations is a result of PT planning. Travel time reductions are desired, as it leads to equity gains. The potential to achieve travel time reductions is somewhat limited however, because railways are subject to path dependence. Path dependence restricts the opportunity for travel time reductions to incremental changes to the rolling stock or infrastructure. Possible travel time reductions are shortening the vehicle run time between stations and improving coverage of the PT network by reducing access times to villages with new stations along the railway corridor. While the effect of the former is straightforward, the latter has an inherent trade-off. New stations may improve the travel time for some but lengthen travel time for others. The net effect depends on the situation, which has to be evaluated in a case application. Which exact measures are evaluated is expanded upon in the methodology.

Railway timetables are required to compute travel times. Equity is a long term effect, which corresponds to the strategic planning horizon. The timetables need to be basically feasible, thus without conflicts, but do not need to be of the very highest level of detail. This corresponds with mesoscopic modelling. Mesoscopic modelling defines a train sequence first, followed by more detailed train path finetuning. Locations where path conflicts could occur have to be analysed in higher detail. The beginning and end points of single track line segments are a notable examples. Timetables are required for every proposed change to the service. This means analysing the current infrastructure, proposing a measure and modelling the effects. Measures either suggest a new station, aim to reduce run times, or assume a do minimal scenario. While a sound theoretical basis exists for conflict reduction of railways, consensus is lacking for provision of new stations.

3 Methodology for equitable PT planning

In this chapter a methodology for equitable PT planning is proposed. This is the synthesis of the literature review and results in a generalisable methodology to asses equity gains of PT network improvements. A methodology is formulated that explicitly connects PT improvement measures with their equity effects. This methodology for equitable PT planning starts with identifying groups of inhabitants that are at a disadvantage, followed by an exact determination of transport benefits. These benefits are distributed over the groups in the population on which equity is calculated. This done for multiple sets of measures, which are grouped into comprehensive design alternatives. The effect determination and distribution is done for each alternative, allowing for equity scores to be compared in a rural case evaluation. The steps of the methodology are summarised below.

The needs and differences between groups of inhabitants in the population are investigated first. This is done by identifying travel motives, destinations and distinctions between inhabitants. These are location in the research area and a prosperity indicator. This gives a general direction of the cause of passenger trips and differences between inhabitants. Additionally, this step provides insight in the format and detail level of data, which determines the extent of analysis possible. What follows is an estimation of travel time, which is the main factor to determine activity-space and equity.

Because railways are the core of a PT network and their development is constrained by path dependence an assessment of the range of railway infrastructure and rolling stock is made first. The physical properties of infrastructure and rolling stock dynamics determine which travel times are currently possible. Then an iterative planning process is applied to the railway line. The planning process is executed with the objective of reducing total travel time by providing new stations and / or reducing train path conflicts where possible. This is evaluated with design alternatives, which contain a comprehensive set of measures that fit the planning objective. Core elements of the railway network are modelled at a mesoscopic scale in order to construct feasible timetables for each proposed design alternative. Design alternatives are comprehensive sets of measures.

The accessibility potential for each alternative is calculated by computing the activity-space of locations. This is done by expanding the PT timetables with access and egress transport first. These travel times between locations are then weighted with a decay function for the key activities under evaluation. Timetables of alternatives vary, resulting in different accessibility potentials.

Equity; the systematic difference of accessibility potential within the population, is computed by assessing the distribution of accessibility potential between the earlier identified groups of inhabitants in the population. The Theil-index which assesses the difference in activity-space between inhabitants income groups and location. Equity differences between design alternatives are compared by calculating the percentage of Theil index change. This is used to draw a conclusion on which design alternative is shifting the equity burden the best.

This process is summarized in a methodology, which consists of the following steps;

1. Identify travel motives and distinctions between inhabitants in the region.
2. Assess the range of infrastructure and rolling stock
3. Analyse the potential for travel time reduction
4. Determine timetables for each proposed change
5. Compute the accessibility potential within the region for each alternative
6. Asses equity effects for all inhabitants per alternative and compare change

The conceptual model of the methodology is displayed in figure 4. Detailed description of these outlined follows in the next sections. These have their design choices, formulas and sub steps. This generalisable methodology is tested in an extensive case application later.

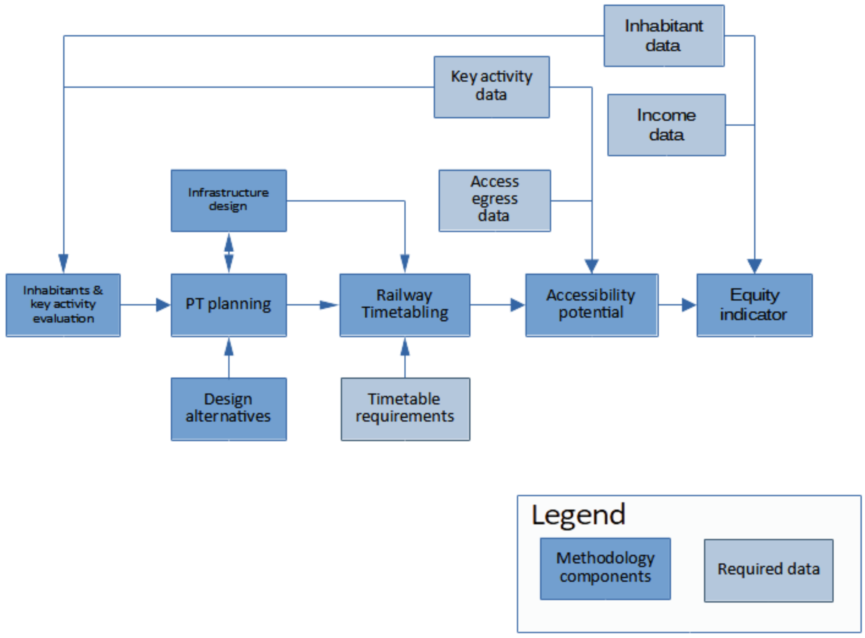


Figure 4: conceptual model of assessment methodology

3.1 Inhabitants & travel motives

Equity evaluates the distribution of accessibility between specific groups of inhabitants. Accessibility indicators are used to do so, these have to express relevant needs of the population. The activity-space should be evaluated for relevant activities that require the use of transport and are not supplied equal in a region. Two questions have to be answered; what exact benefit or burden is evaluated and how to differentiate between groups of inhabitants (Martens, Bastiaanssen, & Lucas, 2019).

Differentiation between inhabitants of the population has to be focussed on properties that point out a disadvantage of inhabitant groups accessing relevant key opportunities. Lucas (2012) identified multiple social factors that indicate transport poverty and thus equity risks. Notable factors are income, age, gender, disability and education level. The social factors are very likely to have overlap between each other or add up. Most social factors correlate with income however (Martens, Bastiaanssen, & Lucas, 2019), which is a reason to apply welfare as primary social distinction factor. Other factors could be applied when required, if they are sufficiently distinctive and do not correlate strongly with welfare.
The accessibility to key activities is related to place of origin of inhabitants. For Lucas (2012), spatial location is a separate distinctive factor. Some relation between spatial location and

welfare exists, as inhabitants with lower welfare generally live in lesser desirable locations (van Wee & Geurs, 2011). KiM (2018) especially refers to rural areas in this respect.

The principal burden to evaluate is the distribution of accessibility to key activities for specific disadvantaged groups (Martens & Di Ciommo, 2017). These key activities are primary social goods, for which van Wee and Geurs (2011) identify access to jobs, shopping, medical treatment facilities and education. This list is not exclusive, but later additions of researchers are not universally acclaimed. What type of key activities are chosen as destinations depends on the relevancy to the groups distinguished in the population. At least access to jobs should be evaluated, since income is identified to play a key role. Others, such as education/skill and health/disability could be evaluated as well, provided that sufficient data is available and no collinearity occurs between these factors and income.

In conclusion; distinctions between groups of inhabitants are primarily made on welfare status and location. Since job accessibility is related to welfare, it is the best initial opportunity indicator. More opportunity types could be added when required though.
The feasibility of the evaluation depends on the availability of data. Detailed data on the main properties is needed for evaluation to be successful. Since jobs and inhabitants are fixed at a location, the unit size will be spatial.

3.2 Current railway infrastructure and rolling stock

Travel times are generated with the operation of PT services, which need coordination and network planning. Feasible timetables are a prerequisite to reliably predict travel times. Regional PT networks often contain few important corridors, on which the rest of the network expands on or connects to. This is often a railway, to which primarily focus is applied. The infrastructure and services currently offered are the result of previous steps and decisions taken by stakeholders. There is path dependence, since the potential to expand services is limited by the infrastructure and capacity available. As extending or improving the railway requires substantial investment, which could be prohibitive, the present railway infrastructure dictate what services are possible. Any optimisation should therefore start with analysing consider current situation of the main railway corridor.

The current infrastructure and rolling stock are important input parameters for the planning process. Factors of interest are the spatial location of stations, length and permitted speed of line segments, the number of tracks of line segments, location of supporting infrastructure and the type of rolling stock used or easily available to the operator. These define the railway corridor, capacity available and service patterns possible. This information is required to compute timetables incorporating service improvements at a later stage. If any of this data is not available alternatives need to be sought.

Additionally; the current service pattern is of interest for multiple reasons. This is the base situation and will remain if no change is applied. The stopping pattern and travel times between stations of this base scenario should at least be covered by the design alternatives. Any design alternative will be compared to this base scenario. Furthermore; the current service in the area is of interest due to the transfers offered to connecting services.

3.3 Potential for travel time reduction

Change to PT services are required in order to improve equity. Travel time reductions are needed. Different types of change can be applied; either improve the in vehicle travel time or address access / egress travel time. Given path dependence of railways two directions of change are achievable; reduction of the in vehicle time and shorten the access / egress time. Reduction of in vehicle time can achieved by shortening the run time between stations and / or removing any headway conflicts. The (unrestricted) run time between stations is influenced by distance, maximum line speed and acceleration / braking characteristics of rolling stock. This has complications; some measures cannot be conceived beforehand. The location where the doubling of single tracked sections is required depends on specific timetables and the location of a timetabled crossing of trains. Some measures are expected to interact with each other. Identifying concise sets of measures are both feasible and achieve a travel time reduction is thus a challenge due to the iterative nature of PT planning process.

In order to reduce the number of options to evaluate 4 objectives to reduce travel time are formulated. The objectives are used to construct design alternatives, which are comprehensive sets of measures that fit the planning objective. The timetabling process needs to be executed for each alternative. Timetabling takes time and may result in some timetables being almost identical, which is not efficient. The design alternatives reduce the number of options that have to be analysed, while they capture the full scope of expected equity change. The design alternatives are investigated and compared with a base scenario. The base scenario consists of the travel times of the current timetable.

The objectives are, in successive order of expected travel time reduction potential:

1. Base scenario; the current rail service is analysed.
2. Rolling stock; timetable optimisations are made with the current railway infrastructure and present types of rolling stock.
3. Double track expansion; Shorten travel time by removing headway conflicts by doubling single track where required.
4. Additional stations; identify underserved settlements and provide new stations in these locations. May require additional measures such as the expansion of double track or a heterogeneous service to achieve short access and in vehicle travel times.

Most objectives have multiple options; the type of rolling stock has to be selected, the frequency should be set, service patterns determined and sites where providing new stations is advantageous has to be selected. Feasibility of the service has to be tested for each alternative, requiring timetabling with mesoscopic modelling. It is impractical to evaluate every possible measure and execute the timetabling process for all possible options, especially if it is expected to some alternatives will generate nearly identical equity values. Therefore it is proposed to consider important design choices in alternatives of one objective and apply the best in others. The generated timetables and equity values of the left out options are assumed to be covered by other design alternatives. Therefore the full scope of expected equity effects gets analysed. It is proposed to evaluate the design alternatives in successive order of expected travel time reduction, starting with the least ambitious alternative.

The design alternatives are identified in the case description, with their timetables modelled, accessibility potential determined and equity evaluated with the methodology steps below.

3.4 Timetabling process

The railway timetabling process essentially consists of a constructing and finetuning of a train path sequence for the defined frequency. This is done for each design alternative, since they contain specific parameters. It is chosen to apply mesoscopic modelling here, since it fits the objective and alternatives are not available to the author. Timetable modelling is required to obtain run times for all types of rolling stock between current and proposed stations. These cannot be obtained from existing timetables.

Timetabling with mesoscopic modelling defines an aggerated macroscopic train sequence first, followed by evaluation of key points in greater detail. These points commonly are points where tracks merge, which could cause headway conflicts and are identified as a factor that limits the capacity available. Headway conflicts must be resolved for a timetable to become feasible. A feasible timetable is a requirement, as this prevents delay propagation. The method requires information on the state of infrastructure, rolling stock and operator specific rules (Landex, Kaas, & Hansen, 2006). Specifically; the distance between station nodes, number of tracks, permitted line speed of each link, dynamic performance of rolling stock, headway requirements and timetabling supplements are needed.

Calculation of station to station running times is done first, followed by timetable construction. This is a simplified approach, which does not offer the highest level of detail. Assessment of the feasibility of timetables is possible however and the level of detail is sufficient for the long term time horizon scope of this research. More detailed modelling will be required if a design alternative for the corridor is chosen to be built. This level of detail is not required for this equity evaluation however.

Run time calculation

Insight in the dynamic performance of trains is needed, for the station to station run times to be computed. Specifically; the acceleration, top speed and braking parameters for each type of rolling stock that is selected for evaluation are required. These are available for selected Dutch rolling stock, which is elaborated upon in the case description.

Trains could either accelerate in order to achieve a set speed, have a constant speed, coast with no traction applied or brake so that it may come to a standstill. The traction applied at the wheel rim has to exceed its weight, rolling, air resistance and line curvature plus slope (where applicable), for a train to accelerate. The equilibrium of movement forces on a train is expressed by:

$$f_\rho * m * dv/dt = F_{tr}(v) - F_r(v) \qquad (1)$$

Rotating mass factor is denoted by f_ρ, mass m is expressed in kg and speed v in m/s. Traction $F_{tr}(v)$ and resistance $F_r(v)$ are functions of speed v in m/s. The derivative of speed dv/dt indicates acceleration a, which has the unit m/s^2. Separate terms F_r exist for curve and incline resistance, these have to be added when required. This equilibrium of train movement forces forms the basis of formulas to calculate the distance s and time t rolling stock needs to accelerate or brake to or from a defined speed v. For the scope of this research simplifications in these formulas are made, since mesoscopic modelling does not require the very highest detail.

Acceleration and braking are derived from equation 1, except for the direction and value of parameter a. Equation 2 gives the time taken to change from speed v_1 to v_2 and distance covered between speed v_1 and v_2 by equation 3 when a is constant between speed v_1 and v_2.

Time between speed v_1 and v_2, for constant a: $t = (v_2 - v_1) / a$ (2)
Distance between speed v_1 and v_2, for constant a: $s = (v_2{}^2 - v_1{}^2) / 2a$ (3)

At constant speed the equation 4 yields the time required between point s_1 and s_2, while equation 5 gives the distance covered between time t_1 and t_2.

Time between distance point s_1 and s_2: $t = (s_2 - s_1) / v$ (4)
Distance between time t_1 and t_2: $s = (t_2 - t_1) * v$ (5)

These formulas are used to the acceleration, constant speed and brake phases of the station to station run time. The station to station run times are calculated for every station or potentially developed station pair, for every type of rolling stock. Given the objective of short

IVTT acceleration is assumed to be done till the maximum line speed is reached. Should stations be in such close proximity that acceleration to line speed cannot be achieved due to the distance required for braking at this speed, a reduced target speed should be selected so that the trajectory of the train does contain a cruising at constant speed portion.

Timetable composition

The first step is to construct train paths for the desired services patterns. These basic train paths describe the movement of a train sequence through the infrastructure. Train paths are essentially the sequential order of arrival and departure times for the stations where the train stops on its run.

The train paths begin at the first station of a service with a start event (Hansen & Pachl, 2008). Arrivals and departures at successive stations are related to this start event by adding time to this start event. Time supplements are added to the basic station to station run times when required by the infrastructure manager. Furthermore; prescribed dwell time is applied for the time calling at stations. The process of adding time from preceding to the successive station is repeated till the end station is reached, yielding a time distance path of the service on the line.

The train path of a return service mirrors the previous outbound path, but is not the same. This is most notably due to the different order and location of line speed changes for the return trip. The train path of the return service has a own start event, but is in part determined by turning times. Turning times describe the minimum dwell time for a terminating service or the arrival depart headway of opposing services that continue out of the researched corridor area.

A basic timetable is made by adding paths at the desired train frequency. These successive paths are duplicates of the initial, but with a start event that is shifted with the depart-depart headway that corresponds with the agreed frequency.

These train paths describe the movement of a single train so far. This does not consider headway conflicts between train paths. Headway conflicts are expected to occur, especially when the infrastructure contains sections of single track line. These potential conflicts need to be identified and resolved. The first step is to asses where conflicts between train paths are likely to occur on the network. Identified path conflicts during the timetabling process need to be resolved. This is done by either adding sufficient dwell time to one of the train paths at a double track location or by advancing / delaying the start event of the train path. These changes may have knock on effects, because the train could create headway conflicts elsewhere. Therefore the remainder of the train path needs to be checked for additional conflicts that have arisen due to the dwell added. This is a iterative process of finetuning and either converges to a feasible timetable or is rendered infeasible. Limited options are available for infeasible timetables. Either the frequency needs to be reduced or conflicts resolved by extending double tracked passing loops that are near the capacity constrained single track line section.

The distance to extend the double tracked passing loop with has to be computed. An exact calculation of distance to extend double tracked sections or passing loops with is not required to assume a feasible timetable. Therefore the length of double track extension can be approximated. It is advisable to do an overestimation. This will lead to some redundancy, but increases the potential to mitigate or compensate for delay. It is assumed that this can be done by calculating and summing up the distance for activities of trains that are required before entering the single track. The sum of distance travelled with acceleration, signal realisation and stopping before the signal will yield an approximation. Acceleration for the duration of the headway conflict is assumed, in which a distance is covered. Furthermore, any train needs be able to come to a stop before entering the single tracked section. The distance to come to a stop needs to be added as a safety precaution. Sight and reaction time and distance needed for braking to a stop have to be factored in and any intermediate product should be rounded up. This method has a consequence in that it should be verified with microscopic simulation when follow up research on a preferred alternative is conducted. This is assumed not to be a problem. Additionally; this estimation does not hinder the calculation of required investment cost.

Feasible path sequences are assembled into a basic hour pattern timetable, which is a synthetic timetable containing one hour of operations. This basic hour pattern is repeated throughout the period of operation. This basic hour pattern is used to station to station travel times in the network, in addition to determining feasibility.

3.5 Accessibility potential

Computation of the accessibility potential is essential. Travel times are used to evaluate opportunity in locations and the resulting accessibility potential is distributed over inhabitants in the population in order to execute the equity assessment. Accessibility is expressed as the activity-space from a location of origin to key opportunities elsewhere. This is a cumulative function, calculating the number of relevant opportunities accessible from a location of origin, such as a populated place. This is computed with a gravity model. Accessibility potential from a location is weighted by assigning progressively diminishing values to opportunities further away. This is important since inhabitants value key opportunities to be nearby. The accessibility potential has to be calculated for all locations of origin in a case area, for all evaluated alternatives. Railway timetables are the major factor determining activity-space. Timetables are used to compute the minimal time required to travel from one station to another. With any timetables change, activity-space and thus cumulative number of opportunities change as well.

Insight is gained by comparing the accessibility potential between base and design alternatives. It is considered an improvement if the total accessibility potential of one design alternative is greater than another. This total accessibility potential does not consider inhabitants living in the locations of origin or the distribution of accessibility between inhabitants however. Evaluating if accessibility potential is distributed fair between inhabitants is part of the equity assessment.

The composition of the opportunity decay function is addressed first, followed by an explanation of trip travel time and how it is applied in the model.

3.5.1 Gravity model specification

The span of activity-space of locations of origin is limited by travel resistance. Travel resistance is used to weigh opportunity to selected key activities. The cumulative opportunity from a location of origin is the sum of opportunities weighted with their resistances.
It is chosen to perform weighing travel time with gravity regression. Gravity regression models express the likelihood that an opportunity is relevant in a certain place of origin. They apply a decay function that assigns diminishing likelihood values to opportunities further away (Geurts & van Wee, 2004).

Gravity models have the following form:

$$A_i = \sum_{j=1}^{y} D_j f\left(C_{ij}\right) \qquad (6)$$

The accessibility potential A_i of place i is defined by the sum of the potential opportunity in other places j. This is represented by the number of opportunities D_j at zone j, multiplied by the decay function f, for the ‘cost’ C_{ij} of travel on the network between i and j. The range of opportunities ranks from 1 to Y.

Determination of the relevance of opportunities depends on the composition of the distance decay function f, of which multiple exist. Exponential, power, Gaussian, log-normal, exponential-square root, log-logistic are common distance decay functions (Levinson & Wu, 2020). The choice for a decay function and associated parameters depends on the case in which it is applied and the data available. The decay function and parameters should have good fit with the case data, which requires insight in the spatial structure of the evaluated case region (Tóth & Kincses, 2015).
Exponential decay proved to be a good representation of Dutch commuting behaviour (Östh, Reggiani, & Nijkamp, 2018). Function f takes the form of equation 7.

$$f(C_{ij}) = e^{-\beta c_{ij}} \quad (7)$$

Time cost component C_{ij} is multiplied with parameter -β in the exponent of the function. A well-founded choice of decay parameter β is essential, as parameter value determines distance decay. Scaling of the β parameter depends on the situation and is open to debate. Some variation is unavoidable as the parameter is fitted onto data that that depends on the special scale, socio economic variables and travel behaviour of the case area. With a suitable β parameter the decay function can be applied to any region, irrespective of spatial scale. So, with the right parameters the gravity model is able to reliably compute the cumulative opportunity of travel time C_{ij} between place i and j. With additional steps a model of a case region can be made; by means of composing a matrix with minimal travel times from location to location. When this model is fed with travel times of the evaluated design alternatives differences between alternatives can be computed for the specific location. Additionally it is possible to include other modes, such as the use of cars. Assessment requires the routing and travel time to be known. and comparing for al evaluated alternatives. This requires sufficient data.

3.5.2 Trip travel time

Exponential decay requires travel times between all locations that are connected with the PT network. The total travel times need to be computed. Since it can be assumed that not all places are in the vicinity of the main railway corridor access / egress times with transfers have to be computed to these locations. If multiple routes be available between locations i and j the shortest path is best to be chosen (Camporeale, Caggiani, Fonzone, & Ottomanelli, 2016). The model requires a form of onward PT services if substantial travel out of the case area is expected. These connecting services may be modelled in an aggregated method, as the main contribution is to offer residual opportunity from cities further away. The effect of this residual opportunity from major urban areas elsewhere could prove significant, when design alternatives contain transfers or onward travel (Sharav, Givoni, & Shiftan, 2019).
The trip travel time of PT consists of the access time from the defined locations of origin to the nearest station, the timetabled travel time between stations and egress time to a location of opportunity (within or out of the case region). Travel times are influenced by the design alternatives of section 3.3. This is especially true for railway timetables, which are modelled for a specific design alternative. Access and egress times only change if when shortest paths change. This only occurs in the design alternatives that include potential new stations. Other modes can be evaluated as well, when data on the routing and travel time is available.

3.5.3 Application

Accessibility potential serves two purposes. The accessibility potential of every zone in the case region is required to calculate the equity score. It can also be used on its own to express the average accessibility from places of origin to places of destination. Both require the accessibility of all places of origin in range *O* to be known. This is calculated by decomposing equation 7 for each travel time component and substituting this travel decay function into equation 6, resulting in equation 8. This is done because access and egress times remain constant for all zones in most of the design alternatives.

$$A_i = e^{-\beta c_{access(i)}} * e^{-\beta c_{TTL}} * \sum_{j=1}^{y} D_j * e^{-\beta c_{egress(j)}} \quad (8)$$

Any place of origin *i* will have one shortest path to a station thus a constant $c_{access(i)}$. Per origin -destination pair one shortest path between stations exist, defined by the railway timetable and indicated with c_{TTL}. Parameter $c_{egress(i)}$ is the same for every place *i* in case area A. Equation 8 should be computed for any place *i* in case area O, for all design alternatives.

3.6 Equity assessment

Transport equity is assessed by distributing the accessibility potential between groups in the population. This assessment requires a dedicated equity indicator. The Gini coefficient is the most popular indicator in recent transport equity research, but has drawbacks. Small sample size may bias the indicator (Souche, Mercier, & Ovtracht, 2015). The Theil index is also common and has the advantage to bypass some data shortage issues due to its capability of evaluating with arbitrarily assigned groups. The grouping property of the Theil-index advantageous, as it may bypass some data inconsistencies. This is especially useful in a regional / rural context, where the risk is real that data may be unavailable or very aggregated. Therefore the Theil Index is applied.

The Theil index expresses equity in a distribution by comparing accessibility between groups (van Wee & Mouter, 2021). For this equity indicator inhabitants are assigned into groups based on location and social factors. Any location has an accessibility potential and a number of inhabitants that are categorised based on the social factors, number of inhabitants per welfare class for example. The accessibility potential varies per evaluated design alternative, the number of inhabitants and social indicators are assumed to remain constant.

The Theil index evaluates equity by comparing the contribution of each location against the average share of accessibility in the population. In the most basic form the Theil index consists of:

$$T = \frac{1}{P_T} \sum_{k=1}^{N} \frac{A_k}{\bar{A}} ln(\frac{A_k}{\bar{A}}) \quad (9)$$

With P_T being the total population, which is composed of N inhabitants *k*, A_k the accessibility of inhabitant *k* to the desired area and Ā the average per capita accessibility in the research area. It results in a division by the population over the sum over all the inhabitants accessibility in locations divided by the population average of the product of inhabitants in a location divided by the population, times the natural logarithm of the latter. This Theil index computes horizontal equity.

The major refinement of equation 9 is that it can be decomposed into distinct subgroups (Hamidia, Camporeale, & Caggiani, 2019). The population can then be divided between assigned social groups. The equity within and between these groups can then be computed. The expanded Theil index has the form:

$$T = within + between = \sum_{l=1}^{M} \sum_{k=1}^{N_k} \frac{1}{P_T} \frac{A_{lk}}{A_l} ln\left(\frac{A_{lk}}{A_l}\right) + \sum_{l=1}^{M} \frac{P_l}{P_T} \frac{A_l}{\bar{A}} ln\left(\frac{A_l}{\bar{A}}\right) \quad (10)$$

In equation 10 there are M population groups *l*, with N inhabitants *k*. The total population P_T can be divided into the number of people *l* that belong to subgroup P_l. A_{lk} is the accessibility of a single inhabitant in a group and A_l the per capita average accessibility of said group.
In this setup a distinction can be made between multiple factors that cause inequity, such as location and income. This makes equation 10 a vertical equity evaluation. The root cause of inequity is either due to the contribution of specific inhabitants within a group or between the

groups in general. The index has the value zero if total equality is achieved and ln (N) in a situation with a high level of inequity. A unfairness score is obtained by dividing the computed T value with ln (N). Therefore Theil-index yields in a value that expresses the level of (in)equity in the population.

The assessment on the distribution of accessibility between inhabitants in a region is executed by assigning inhabitants to groups and comparing the accessibility potential between design alternatives. It is proposed to use location and income class as groups, if possible with the available data. Inhabitants are assigned to locations of origin, ideally with inclusion of their income class.
Equity scores are calculated by applying the standard Theil index of equation 9 and expanded Theil index of equation 10 on the dataset. Any equity change is attributed to the timetable of the evaluated design alternative, since other factors remain constant. The observed equity values can be compared within this research, enabling the calculation of percentage change and ranking. Differences in results between the standard and expanded Theil are attributed to the distribution of income classes in the case region.

3.7 Summary

This chapter presents a transport equity assessment and improvement methodology. Transport equity distributes accessibility potential between groups of inhabitants in a region. Inhabitants are grouped using properties that indicate a disadvantage, location and income are common. Accessibility potential is computed for key activities that are insufficiently supplied locally, they trigger travel. A regional PT network has to be analysed for improvement potential. Pending ambition the following objectives are identified; change rolling stock, double sections of single track and build new stations. Design alternatives, which are specific to a case evaluation, have to be constructed for these objectives. Evaluation of any alternative is based on a feasible railway timetable for the respective alternative. The constructed timetables are used to compute shortest path networks between places in a case area. The total accessibility potential is calculated with an exponential decay function for these places in the case area. The Theil index is then used to asses which inhabitants fall behind in receiving access to key activities compared to other inhabitants in the region. These differences from the mean are summed up, yielding an equity score. As travel times and accessibility potential vary per location between design alternatives, the equity score can be used to compare equity differences between alternatives. The design alternative that highest net Theil index improvement is better than other alternatives and able to improve equity between inhabitants best. Therefore the methodology will be able to assess how equity gets improved best. A test bet evaluation of the methodology is done in the next chapters, starting with a introduction of the case.

4 Case description

This section will implement the research methodology in the Dutch province of North-Holland. The Kop van Noord-Holland region is partly rural and could experience population decline in the foreseeable future (Rijksoverheid, 2019). These conditions have a negative impact on equity and might induce transport poverty (KiM, 2018). These conditions make this area relevant to investigate. Further scoping the research area is required however, which is done first.

The area is composed distinct sub regions, some of which have limited mutual cohesion. This is probably due to the relation between land use patterns and infrastructure on the peninsula. In the Kop van Noord-Holland region locations either have a spatial relation with the city of Alkmaar or Hoorn. Therefore, further scoping on the Alkmaar – Den Helder corridor is done. Inhabitants from the city of Alkmaar are excluded, since Alkmaar is a major regional urban centre (Stec, 2021). Some other locations in the Kop van Noord-Holland region are excluded due to their prevailing land use interactions. This is the case for municipality of Bergen, Opmeer and Wieringermeer area of Hollands Kroon. Bergen is attracted to Alkmaar, but not over the evaluated corridor. Opmeer and Wieringermeer are either located equidistant between the cities of Alkmaar and Hoorn, or closer to Hoorn. In these cases interaction with Hoorn is assumed due to a shorter travel time to the city of Amsterdam. The resulting area and internal divisions is further discussed in appendix F.

Numerous assumptions and data dependencies have to be addressed in order to evaluate the resulting case area with the previously outlined methodology. This is an assessment on the extent of data needed for each of the steps. Evaluating the availability of data is essential, as lack of relevant data is mentioned frequently in comparable research. This process is a first test for the methodology. Points that arise and have to be addressed are therefore retrofitted into the methodology.

For simplification case application of the methodology is addressed in the subchapters Inhabitants and travel preferences, PT planning and timetabling, plus distribution of effects.

4.1 Inhabitants & travel motives

A number of key activities are important for inhabitants to have good access to. The need for additional travel is induced if these are not supplied well within the case region. Job accessibility is found to be a key activity in short supply. Distinction between inhabitants is based on their location and income group.

4.1.1 Key activity identification

Analysis on the accessibility of key activities for municipalities in the region results in the observation that some key activities could be assumed to be distributed equal, but some do not. Table 4 indicates that job accessibility differs substantially and secondary schools, hospitals deviate incidentally from the average observed in the province or national level.

Key activity	Nederland	Noord-Holland	Alkmaar	Heerhugowaard	Den Helder	Hollands Kroon	Schagen
Healthcare: general practitioner (km on average)	1	0,8	0,9	1	1	1,4	1,1
Healthcare: hospital (km on average)	4,7	3,6	3,9	2,3	4,1	14,5	6
Shopping: groceries (km on average)	0,9	0,7	0,8	0,8	0,9	1,5	1,3
School: primary (km on average)	0,7	0,6	0,6	0,6	0,7	1,1	0,9
School: secondary (km on average)	2,4	2	2	1,9	2,2	7,4	4,8
Employment: jobs x 1000 within 10 km	130,4	245,8	84,1	79,9	29,4	9,6	19,3

Table 4: key activity accessibility (CBS, 2021)

The relatively low level of employment opportunities North from the city of Alkmaar requires attention. The low number of jobs nearby is probably a reason for inhabitants commuting out of the region. Commuting mainly takes place in the direction of Amsterdam (Provincie Noord-Holland, 2021). The passenger load on the Alkmaar – Den Helder railway line increases to the South (NS, 2019). The number of companies in the Kop region is decreasing, and offices account for only 1% of the total employment opportunities (Stec, 2021). Furthermore, the labour market in the Kop area is not as tight compared to other regions in the Province (Provincie Noord-Holland, 2020). Employment is therefore of concern and evaluated as key activity.

Healthcare has some deviations, but these are mainly due to the location of hospitals, which is not considered to be a major issue. The increased average distance to secondary schools in the Hollands Kroon municipality could partially explained by the absence of such schools in the village of Anna Paulowna and a few villages in the Wieringermeer area. The absence in Anna Paulowna is not inherently problematic, because it is connected with Schagen by rail. For secondary schooling a student number reduction in excess of 10% is expected in the long term (Provincie Noord-Holland, 2020). Given the previous and the fact that some bus lines specifically target pupils the distance to secondary schools is not considered to require attention. Recreation is assumed to be sufficiently available. Which type of destinations are relevant for this key activity differs from person to person, making an assessment almost impossible.

Regarding personal factors it is assumed that income is the main factor of interest, which is directly related with job accessibility. Some locations feature a relatively higher share of less prosperous households, such as the town of Den Helder (de Voogd & Cuperus, 2021). Aging of inhabitants could become a factor, which is expected to occur in the municipalities of Den Helder and Schagen (PBL, 2019). Since elderly do not commute, healthcare and shopping are assumed to be their key activities. These are well covered by the network tendered by the Province, because busses and other forms local PT have sufficient coverage and cater to people with disabilities by warranting step free access on most parts of the network.

Employment data is available and sourced internally at the Province of North-Holland. This data is used for two purposes; inside the case area and for onward connections. These need a different level of detail. Detailed data is used in the case area, for which the employment dataset is assembled into jobs per PC4 postal code. This matches the detail level of the socio demographic data. Outside of the case area aggerated data is used, which is discussed at effect distribution. The employment data at PC4 postal code level is included in appendix F.

4.1.2 Population groups

Differentiation between inhabitants is done by dividing the population in groups based on income per location. From the introduction it is recalled that insufficient transport has effects

on rural labour markets, causing an exclusion process at the lower income groups. The risk of being socially excluded or impoverished is high in the lowest two quintiles of the income distribution (Eurostat, 2022). The number of inhabitants in these income quintiles is available for the year 2017 (CBS, 2019), grouped per the first 4 digits of postal code (PC4). This data is used for the reasons that 2017 is the most recent year available and PC4 is the highest level of detail that can be achieved with current privacy restrictions. This dataset can be used with the assumption that the income distribution does not change significantly and that PC4 is an unbiassed spatial partition of the case area.
Other distinctions can be applied, but these are deemed to be either correlating with income or insignificantly distinctive. The dataset is given in appendix F.

4.2 current railway infrastructure, rolling stock and service

The regional PT network in the area is designed around the Alkmaar – Den Helder railway line. Most regular bus lines and other forms of PT converge at railway stations. Few bus lines run parallel to sections of the railway line. At Alkmaar the rail service continues towards Zaandam and Amsterdam. Furthermore an transfer on a service to Haarlem is possible at Alkmaar.

The Alkmaar – Den Helder railway line is 41,3 km long, mostly suitable for a 140 km top speed and partly double tracked. Sections of single track are North of Schagen station, with each intermediate station having passing loops. Some stations have local speed reductions due to deflecting tracks on points, but these are only restrictive near Alkmaar station. This is indicated in Table 5. Stabling and depot facilities are available at Alkmaar and Den Helder.

Station	Length (km)	Track number (#)	Permitted speed (km/h)
Den Helder			
	2,60	single	80
Den Helder Zuid			
	3,80	single	130
	4,90	single	140
Anna Paulowna			
	9,20	single	140
Schagen			
	13,90	double	140
Heerhugowaard			
	5,00	double	130
Alkmaar Noord			
	1,30	double	100
	0,60	double	40
Alkmaar			

Table 5: railway infrastructure. Sourced from Prorail (2020) & Openrailwaymap (S.D.)

Services on the railway line are almost exclusively operated with VIRM type double deck rolling stock currently. There is generally one service, with some additional rush hour expansions. The service stops at all intermediate stations in the corridor, but continues as a limited stop service from Alkmaar to Amsterdam. Opposing trains of this service have a 8 minute headway at Alkmaar. This should be used as turning time during timetabling for services aim to continue out of the corridor. The service from Den Helder is bundled at Heerhugowaard with a railway from Obdam and Hoorn, which is commonly worked with SLT type of rolling stock. This service continues from Alkmaar to Haarlem and stops at all intermediate stations.

The railway line generally has a half hour frequency, with two additional rush hour services in one direction, tow to the South in the morning peak and two to North in the evening peak. This construction receives some criticism, because this is a service reduction when compared to earlier (Locov, 2020). There is political desire to improve the service. The provincial coalition agreement includes an frequency increase from 2 to 4 trains per hour per direction throughout the day. The Province wants to expand the double track section on the long term, but is currently lacking funds to do so. Previous cost estimations are in the order of 400 million euro (Provincie Noord-Holland, 2019). There is also a lobby for building a new station on the railway line in the Waarland area, but this was unsuccessful (Zut, 2019). A full description of services in the corridor and properties of the infrastructure is given in appendix B.

4.3 Travel time reduction potential

A travel time reduction and equity increase can be achieved with different types and combinations of measures. Section 3.3 of the methodology outlines 4 objectives for travel time reduction, which are used to create comprehensive design alternatives in this section, which will be analysed further. This approach is chosen because analysing all combinations of measures is impractical. This sections covers the details of travel time reduction first, followed by the construction of the design alternatives.

4.3.1 Time reduction

Reduction of timetabled travel time trains can achieved in multiple ways, pending the situation. Either by changing rolling stock, raising the line speed, skip stations or by removing headway conflicts.

Acceleration of rolling stock

Change of rolling stock is feasible and can be advantageous. Currently the VIRM type is used, but this train type is relatively slow in accelerating. Other rolling stock of the NS inventory accelerates faster. Alternatives are the types SLT, SNG and FLIRT-3. Of these types the acceleration data of the SLT is available. It is assumed that SLT has representative dynamic performance of modern rolling stock. The difference in maximum acceleration between the VIRM and SLT is indicated in figure 5 (Huurman, 2013). Braking can be done with different strengths, is weather dependent and some coefficients are rolling stock specific. A average deceleration of -0,66 m/s^2 realistically achievable under all conditions (Henning van Steenis, 2010). Some studies apply stronger brake coefficients for SLT rolling stock, which are without mutual consensus on the extent of the parameter. Therefore -0,7 m/s^2 is applied, which is conservative.

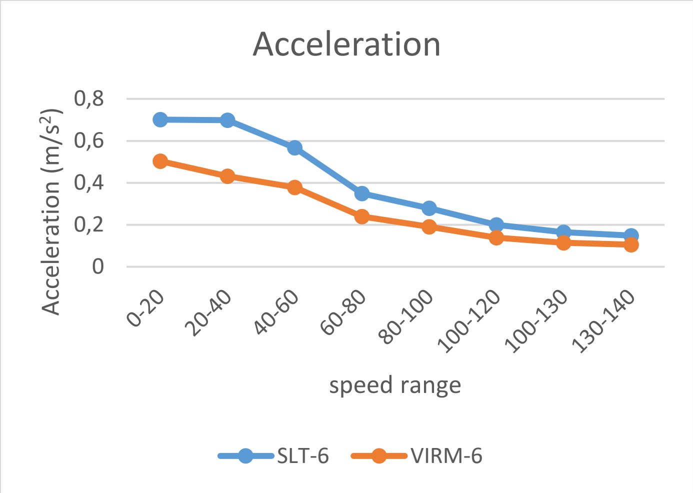


Figure 5: Acceleration, adapted from Huurman (2013)

The difference in maximum acceleration between these types has a substantial influence on the run time between stations. With the help of the formulae at section 3.2.2 of the methodology the time and distance for acceleration and braking to a set speed are computed for the VIRM and SLT rolling stock in table 6. This is elaborated upon in appendix C.

	VIRM				SLT			
Speed	Accelerate		Brake		Accelerate		Brake	
km/h	t(s)	dst (m)	t(s)	dst (m)	t(s)	dst (m)	t(s)	dst (m)
0-20	11,0	31	8,4	23	7,9	22	7,9	22
20-40	12,9	107	8,4	70	8,0	66	7,9	66
40-60	14,7	204	8,4	117	9,8	136	7,9	110
60-80	23,2	450	8,4	164	15,9	310	7,9	154
80-100	29,1	729	8,4	210	19,9	497	7,9	198
100-120	39,8	1215	8,4	257	27,7	847	7,9	243
120-130	24,3	844	4,2	146	16,9	586	4,0	138
130-140	26,3	987	4,2	158	18,7	700	4,0	149

Table 6: Acceleration and braking parameters

This acceleration data is used in section 4.4 to compute station to station run times, which is required for timetabling. The acceleration data does not yet contain required run time supplements. These are specified in appendix C and added to the run times in section 4.4.

One potential shortcoming of changing the type of rolling stock is that the change could make continuing the current service to Amsterdam impossible. At present the service is run with VIRM and continues as an intercity towards Amsterdam and other parts of the country. While SLT trains accelerate significantly quicker, they are designed for regional / suburban services. They may lack seating capacity for intercity service. VIRM accelerates slower, but offers greater capacity and comfort than SLT. Some effects of a rolling stock change can be mitigated by offering a high quality transfer on a Amsterdam bound VIRM intercity at Alkmaar, ideally in combination of continuing the SLT service. Optimising timetables for these types of rolling stock might yield a travel time reduction, so they are evaluated as a design alternative.

Raising of line speed

Raising the line speed is not considered because most of the railway corridor already permits 140 kph, which is the maximum speed possible for the present ATB-EG interlocking. Speed could be raised on other sections, for which conditions apply. Infrastructure manager Prorail (2016) considers a larger stop spacing, homogeneous service and lower frequencies or single track to be requirements. A qualitative analysis yields that Alkmaar – Alkmaar Noord plus Den Helder – Den Helder Zuid void the stop spacing criterion, while Alkmaar Noord – Heerhugowaard has a heterogeneous service with a local service to / from Hoorn. The section Den Helder Zuid – Breezand does qualify, but is assessed to offer less than 10 seconds of run time reduction potential due to accelerating or braking due to nearby Den Helder Zuid station. Furthermore it is assumed that the movable Koegrasbrug is a limiting factor. The line speed changes at this bridge (Openrailwaymap, S.D.). Raising the speed over this bridge could induce substantial investment due to the state of the bridge.

Single track headway optimisation

Single track sections limit capacity, as opposing trains can only cross each other at stations with passing loops. This is the case between Den Helder and Schagen. Here, trains can only enter the single tracked section after opposing trains clear it and interlocking is released. This process takes time, which is added to the station dwell. This additional dwell is considered to be time lost. The shortest possible travel time of trains can be achieved if these time losses are reduced.

One method to reduce time loss due to signal dwell is to change the start event of one of the crossing trains, the other lengthen the double tracked crossing section at stations. Shifting the start event is practically free of cost, but offers limited timetabling flexibility. Lengthening double track does come at a cost, but is capable of solving any conflict when lengthening of double track is rightly chosen. The required length of double track depends on the time lost due to the crossing conflict.

Currently; most double tracked passing loops in the railway corridor have a usable length that is approximately as long as the station platforms. Anna Paulowna and Den Helder are exceptions. At Anna Paulowna the double track continues for 500 metres to the South, in the form of an unused siding rated for 60 km/h. Routing trains over tracks of the stabling area of Den Helder could lengthen double track by 300 metres. These are currently used for shunting and have a top speed of 40 km/h. It is expected that these tracks require work to bring them to main line standard, but this is assumed to cost less than a new alignment of equal distance.

Any conclusion on the length and location of extended or additional double tracked passing loops depends on the outcome of the timetabling process. The timetable process will generate arrival / departure times that void headway requirements at some stations. The time duration of these conflicts determines the best solution. For conflicts with a shorter time duration the double tracked passing loop from the station in question should be extended. For longer lasting conflicts it could be shorter to build a new passing loop in the single tracked section than to lengthen a passing loop to this point.

The amount of double track needed is obtained by calculating which distance trains cover during the conflict, plus the distance trains need to come to a stop after the conflict ends. The distance to come to a stop is a safety precaution and is composed of sight and reaction time plus braking to a stop. Sight and reaction time is assumed to be 9 seconds (Goverde, Francesco, & D’Ariano, 2013). Braking depends on the speed achieved. The average deceleration parameters in section 4.3.1 are used. This is conservative, because shorter reaction time and stronger braking could be applied. It should be noted that the distance to

be double tracked is not a definitive answer, because an exact estimation requires a microscopic simulation that is out of scope of this study. The distance is to be double tracked is therefore an approximation.
Distance and location of new track required, plus number and speed over the points are major factors that determine the cost of an intervention. In general; cost will increase proportional with the distance of new track needed. It is observed that most right of way of the railway corridor has a provision for a second track. Objects such as railway level crossings and bridges over waterways are present at a number of locations however. Double tracking these objects will increase cost. The speed achievable at the end of the crossing section is important for the design of points. One of the tracks of a point merges into another. This is a deflecting track, which has a maximum speed. A higher deflecting speed requires a wider radius, which comes at a greater cost. Intuitively, additional double tracking is best kept as short as possible.

The optimum of maximal travel time reduction and minimal added double tracking has to be found with timetabling. This can require multiple iterations. This is done in a design alternative using VIRM rolling stock and another using SLT rolling stock.

4.3.2 New station feasibility

Additional railway stations are possible at a number of locations. When considering nearness of populated places and supporting infrastructure four potential locations are identified in appendix D. The Hasselaarsweg in Heerhugowaard near Zuid-Scharwoude, Weelweg in Waarland, Sportlaan in Oudesluis and Zandvaart or Burgemeester Lovinkstraat in Breezand are in or near populated places and have railway crossings, allowing for access to potential railway station platforms with minimal supporting infrastructure redesign. Figure 6 contains a map with present and potential station sites.
Some of these locations are less ideal from an overall PT system perspective however. This is due to the trade-off between improving access time for some inhabitants while sacrificing the in vehicle time of other passengers. The full extent of this effect can only be determined with an equity evaluation for all alternatives. In practice; populated places with only a small number of inhabitants or station locations with a short amount travel time saved is expected to generate a negative effect however. This is expected to be the case in a few potential railway station locations.

Railway stations in Breezand and Waarland are expected to be cautiously positive, for which they remain to be considered as a potential railway station location. The location of Waarland station has some added potential if bus routes are rearranged, as it offers a shorter connection to Alkmaar for some locations. Railway stations in Zuid-Scharwoude and Oudesluis are expected to have a negative outcome. Calling at Zuid-Scharwoude is not expected to generate enough travel time savings to be justifiable. Oudesluis has too few inhabitants. These are excluded from further assessment.
Waarland and Breezand are therfore considered as potential station locations to be included in design alternatives, for which timetables are designed. The location of the stations on the railway alignment is given in table 25 of appendix D. In short; Waarland station is 6,8 km from Schagen and 7,1 km from Heerhugowaard, Breezand is projected 6,0 km from Den Helder Zuid and 2,2 km from Anna Paulowna.

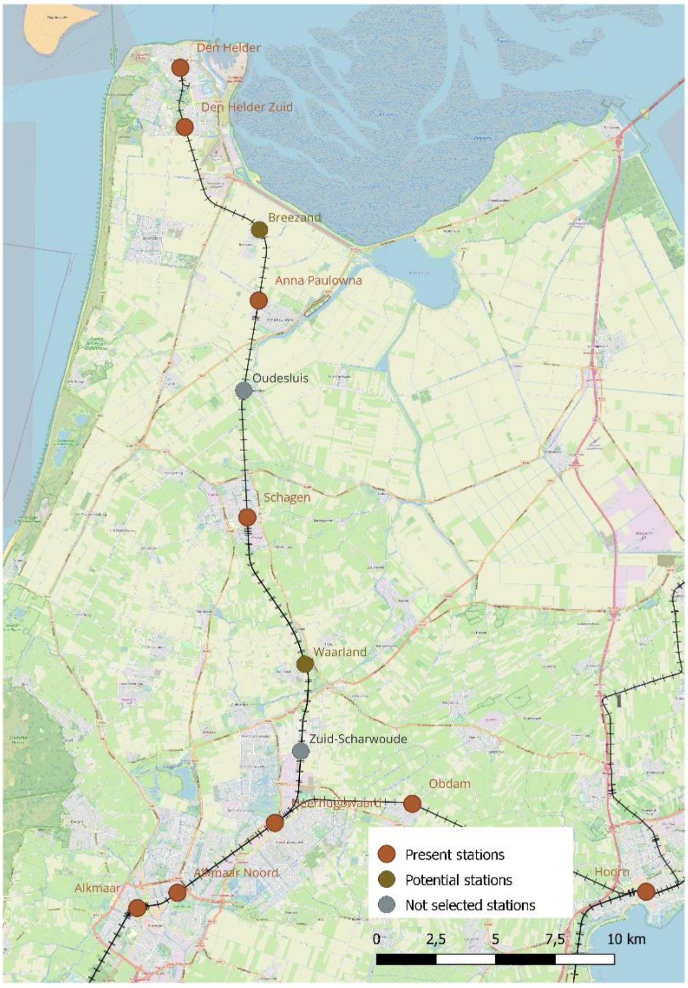


Figure 6: location of present and potential stations (PDOK, 2022 & OpenStreetmap contributors, S.D.)

4.3.3 Design alternatives evaluated

It is decided to evaluate 8 design alternatives and one base alternative, of which 2 asses the current infrastructure, 2 with double tracked expansions and 4 with the provision of new stations. Two alternatives evaluate the current infrastructure with VIRM or SLT types of rolling stock. One alternative evaluates the use of VIRM rolling stock with the doubling of single track where required, while another evaluates the same but with SLT type of rolling stock. Some simplifications are made for the four design alternatives that provide new stations. Most alternatives are evaluated with SLT rolling stock, because this type has faster acceleration. Design alternatives consider the following; Waarland station, Breezand station, Waarland & Breezand station and Waarland & Breezand station with a heterogeneous service where VIRM rolling stock skips the two new stations but SLT rolling stock calls at all stations. The alternatives evaluated therefore are:

0. Current situation
1. VIRM with current infrastructure
2. SLT with current infrastructure
3. VIRM with expanded infrastructure
4. SLT with expanded infrastructure
5. SLT with Waarland station
6. SLT with Breezand station
7. SLT with Waarland & Breezand station
8. VIRM and SLT with Waarland & Breezand station

The exact details of the design alternatives is dependent on the timetable process as interaction between measures is expected, especially the spatial location of additional partial double tracking. A conclusion on the effectiveness of measures can be drawn after completion of the timetable process.

4.4 Timetabling

Timetable construction depends on the specific design alternative followed. These alternatives have to work with mostly the same infrastructure, share data and are subject to the same operating procedures. While infrastructure and performance of rolling stock are addressed in section 4.2 and 4.3 some aspects of timetabling remain. This section addresses the remaining requisites for timetable construction. These are; required data for timetable construction, station to station run times, explanation of train path sequences and lastly some considerations related to headway conflict resolution with double tracking.

Data that describes the required duration of processes train paths is addressed first. This is followed by presentation of the station to station run times. Both are used in path sequences. Path sequences in succession are essentially a timetable, this process is described next. Some design alternatives allow solving headway conflicts with double tracking. Since headway conflicts are a consequence of the timetable process this is discussed last.

4.4.1 Timetable process data

Timetables have to comply with standards set by the infrastructure manager, which is Prorail in this case. The values of these standards are determined in such a manner that they should account for variation of operation and prevent some initial delay. Therefore applying the standards published in access requirement documents will help the construction of feasible train paths and facilitate a stable operation. So, by applying appropriate standards feasible timetables can be made in a deterministic way. Relevant factors for timetable construction are minimal dwell times, run time supplements interlocking release, turning times and minimum headway. These are addressed below.

Station dwell

Station dwell is the time allocated for a stop at a platform. The allocated dwell time originates from a distribution, as the boarding alighting process varies. This depends on the rolling stock type and station category. This research uses the minimum, since all intermediate stations in the corridor are classified as small. VIRM rolling stock requires a station dwell of 49 seconds, for SLT a minimum dwell of 42 seconds is assumed (Planting, 2016).

Run time supplements

Run time supplements are required by the infrastructure manager to compensate for uncertainties and minor disturbances. Supplements are added to the run time of rolling stock, it prevents the spread of delay and safeguards the feasibility of a timetable. This supplement is a percentual increase to the bare station and station run times and introduces slack. This slack will mitigate some delay and allows for energy efficient driving under normal operations.

The network statement of 2019 requires a time supplement of at least 5% (Prorail, 2017). More recent data is not publicly available, in part due to the move to a proprietary and more detailed computation method. The method of a general run time supplement is used as it is straightforward and available. The required 5 percent supplement is a minimum. It is discussed in appendix B that the supplement should be raised to 7% to account for variations in sub fleets of rolling stock and incline of the line.

Interlocking release

Train protection with line block sections is not addressed in detail as this is not required for the aggerated mesoscopic modelling approach. Some locations are an exception to this rule and require a more detailed evaluation. These are the at the points where single track sections start/end and at the begin / end of crossing sections on single tracked alignment. Here, capacity is affected by interlocking because the process to verify that the single tracked block sections are clear of trains and can be released takes time.
It is required to have a minimum of 60 seconds for the release of interlocking (Prorail, 2017). This is the minimum headway of opposing traffic, applied at points where single traced sections of railway begin or end.

Turning time

Train paths begin or end at either Den Helder or Alkmaar. Trains that terminate at these stations can be used for a new train path that is scheduled later. A terminating train can only be used for a new train path after a set amount of time. This is called turning time, for which 10 to 15 minutes is considered optimal and 4 minutes the bare minimum (Prorail, 2016). Shorter times between arrival and departure at a terminus are possible, require an additional train and crew, which increases cost.

Continuation of the current service to Amsterdam requires an additional constraint at Alkmaar station. In appendix B it is defined that the train towards Amsterdam arrives 8 minutes before departure of the train to Den Helder. So the turning time at Alkmaar station should at least be 8 minutes in order to maintain continuation of the intercity service to Amsterdam.

Minimum headway

Verifying if the headway of the requested train paths complies with the minimum set by the infrastructure manager allows for feasibility evaluation without block sectioned train protection of the railway infrastructure. Checking if the headway is greater than the minimum is straightforward and assumed to be sufficient for the purpose. Microscopic evaluation with all block sections of the railway infrastructure is needed for a follow-up study however.
The minimum headway for successive trains was 3 minutes (Prorail, 2017). The 15 minute headway of the frequency of 4 trains per hour is not a problem, given the assumed minimum of 3 minutes for successive trains. This minimum headway also allows for continuation of the local service from Alkmaar to Hoorn. As this service shares tracks with the corridor between Heerhugowaard and Alkmaar the condition of sufficient separation applies. This is considered not to be a problem, as there are 9 minute time windows for the operation of this service.

4.4.2. Run time

For timetable modelling the station to station run times need to be known. This depends on the distance between stations, permitted line speed and acceleration and braking performance of rolling stock. Trains accelerate to line speed, unless the infrastructure makes this unfeasible A lower target speed is selected on sections where trains are unable to achieve the line speed because they need to apply brakes. This is the case on some line sections with a short distance between stations or with an intermediate line speed reduction. The station to station run times are computed in appendix C for the current situation and with the inclusion of Waarland and / or Breezand station. Table 7 contains the minimal run times with an applied 7% run time supplement for the current stations. Table 8 contains the supplemented minimal run times with inclusion of Waarland and Breezand station. Run time between stations varies because of the difference in acceleration and braking of VIRM and SLT rolling stock and due to the spatial location of changes in line speed.

Run time between stations (in minutes)				
Station	VIRM	SLT	VIRM	SLT
Den Helder (departure)			Den Helder (arrival)	
	2,85	2,68	2,85	2,68
Den Helder Zuid				
	5,66	5,31	5,75	5,36
Anna Paulowna				
	5,88	5,49	5,88	5,49
Schagen				
	8,04	7,64	8,04	7,64
Heerhugowaard				
	3,95	3,60	3,95	3,60
Alkmaar Noord				
	2,70	2,53	2,66	2,53
Alkmaar (arrival)			Alkmaar (departure)	

Table 7: minimum run times of rolling stock for the current infrastructure

Run time between stations (in minutes)				
Station	VIRM	SLT	VIRM	SLT
Den Helder (departure)			Den Helder (arrival)	
	2,85	2,68	2,85	2,68
Den Helder Zuid				
	4,42	4,07	4,45	4,10
Breezand				
	2,75	2,45	2,75	2,45
Anna Paulowna				
	5,88	5,49	5,88	5,49
Schagen				
	4,78	4,39	4,78	4,39
Waarland				
	4,92	4,52	4,92	4,52
Heerhugowaard				
	3,95	3,60	3,95	3,60
Alkmaar Noord				
	2,70	2,53	2,66	2,53
Alkmaar (arrival)			Alkmaar (departure)	

Table 8: minimum run times of rolling stock with Waarland and Breezand stations

Station to station run times are essential for the construction of path sequences and modelling of timetables. Modelling of timetables that are composed of feasible train paths requires formulation of the path sequence, which is addressed next.

4.4.3 Path sequence

Trains run according to a path sequence, which describes what activity the train does at which time, in time lapsed from the start of the path sequence. A timetable is essentially an successive set of path sequences in both directions, which needs to be feasible for the agreed frequency. The next section describes the selection of start and end points of the path sequences, the successive station calling order and processes required to achieve a feasible basic hour pattern timetable. The basic path sequence is described first, followed by properties that vary in design alternatives.

Basic path sequence

For almost all design alternatives the modelled path sequence is a rail service calling at all stations between Alkmaar and Den Helder. This is done for the frequency of four trains per hour. The start event for the services is either Alkmaar or Den Helder. Both have a depot with stabling facilities for rolling stock and posted staff. Den Helder is chosen as the primary starting point because of the continuation of the service out of the area, towards Amsterdam. This requires a special turning time of at least 8 minutes, to mimic the continuation of trains out of the corridor area. This constraints Alkmaar station, whereas using Den Helder as a starting point has a greater degree of freedom.

Path sequences are constructed from Den Helder. The initial path sequence contains the run time between stations and dwell time at each intermediate station. The path is calculated in time lapsed from the starting event. Arrival in a next station is computed by adding the station to station run time for the specific rolling stock, departure by adding the prescribed station dwell for the type of rolling stock. This is done for each station till Alkmaar is reached. At Alkmaar the required turning time of 8 minutes is applied initially, followed by a path sequence returning to Den Helder. This path sequence is then copied multiple times with each successive path sequence starting 15 minutes after the previous path. A 15 minute headway is chosen in order to achieve the frequency of 4 trains per hour and comply with the Dutch requirement that timetables should be cyclic, called clockfase.

This procedure generates an basic hour pattern, but it cannot be used outright. It is likely that opposing headway conflicts exist, especially at the single tracked sections. In order to achieve a feasible timetable these headway conflicts need to be resolved. This requires adjusting. This is done with changing the timing of one of the start events, adding dwell time on top of the minimum station dwell, or by lengthening / constructing double tracked passing loops to avoid the headway conflict. These measures are addressed in the next section, because measures to remove headway conflict from path sequences varies between design alternatives.

Adjusting the path sequences into a conflict free timetable is expected to take multiple iterations. Solving headway conflicts has knock on effects, which need to be mitigated in a later iteration. Also equity needs to be considered; large activity spaces are an objective. A solution with minimal travel time within the corridor needs to be sought for all design alternatives.

Design alternative variations

The design alternatives use different measures in order to achieve a feasible timetable. The design alternatives use shifting the start event of a train sequence and either holding or doubling parts of single tracked sections. Delaying the start event can be used by all, but applying holding is exclusive to design alternatives that use the current infrastructure only. The same is true for computing the distance and location of additional double tracking, which is exclusive to alternatives with double tracking, with or without new stations. Installation of any additional double track is prohibited in the current infrastructure scenarios for obvious reasons. Usage of holding is not recommended for scenarios that do permit double tracking. Holding wastes time by standing still at a station for an extended period of time, thereby reducing activity space and possibly deteriorating equity. Providing additional stations is evaluated with double tracking and shifting start events where required. It is assumed that these are needed to mitigate potential travel time loss.
The three measures are discussed in this section. What should be considered is that

application and combination of methods requires optimisation to achieve a feasible basic hour pattern with minimal interventions to the infrastructure or minimal holding time. This is done appendix E on a case basis.

Delay of path start event

Some opposing headway conflicts can be reduced or removed by delaying the start event of a train path. This may result in different conflict times as this train arrives and departs later at each successive station. The advantage of this method is that it does not change the station to station travel times. These remain the same, as the entire train path is shifted in time. The disadvantage is that delaying the start event might reduce or eliminate a headway conflict at one location, but create conflicts elsewhere. Furthermore it is unable to solve conflicts that arise from trains crossing each other at short passing loops within a single tracked area. Short passing loops are susceptible for headway conflicts, as the minimum station dwell time is shorter than the interlocking release time.

Holding

Holding is increasing the time trains stop at a station beyond the minimum dwell time needed for boarding / alighting of passengers. The train in question waits till the headway conflict is ended. The conflict time between arriving train 1 and departing train 2 is computed by: $t_{conflict} = t_{arrive1} + t_{interlocking\ release} - t_{depart2}$. The advantage of holding is that it does not require any change to the infrastructure. The disadvantage is that it has knock on effects. The remaining of the path sequence is delayed, which might create new headway conflicts that need resolving, what can be done by applying holding there. Another knock on effect is that it increases station to station run times within the corridor, which negatively affects the activity space of inhabitants.
An option of holding is to use the holding time for energy efficient driving, when possible. Slower acceleration and driving at a slower top speed increases the run time, but reduces energy consumption. Energy efficient driving is not evaluated further as it does not contribute to the feasibility of timetables or improves activity spaces. This could be included in future work.

Double track

Extending existing or providing new double tracked passing loops or assumes that that most headway conflicts take place at the start of single track sections. The conflict is removed by computing the location where the conflict ends, not by changing the timetable. A feasible basic hour pattern timetable can be assumed if the new or extended passing loops are sufficiently long. The main objective of timetabling is to find feasible basic hour patterns that allow for the computation of the accessibility potential. The computation of required length of passing loops is simplified, because it not essential for the computation of activity-spaces. Existing passing loops needs to be lengthened to allow for acceleration of the departing train during the headway conflict plus to come to a stop. This is assumed to be approximated by calculating which at which time trains would cross, add one minute for release of interlocking and assume acceleration till this point. The acceleration time should be rounded up till the next available speed step available. Distance covered during 9 seconds at constant speed for sight reaction and application of a service brake to come to a stop need to be added as well. It is acknowledged that this is not the most precise estimation but assumed to yield a feasible timetable. This is also assumed to be safe as trains are able to apply stronger braking than is used for this calculation.
When conflicts at stations take very long it might be shorter to install a new passing loop, than to lengthen an existing one. These have to allow a crossing at speed. One Dutch example is situated between Leiden Lammenschans and Alphen aan den Rijn station, near Zoeterwoude (geocode 103/24.600-28.700), is rated for 130 km/h and measures 4,1

kilometres (PDOK, 2022). For 140 km/h, which is 7,7% faster than 130 km/h, it is assumed that a crossing section does need to be approximately 4,4 km long.

4.4.4 Timetable modelling

Timetables can be modelled manually, with PESP or dedicated software. These approaches have their pros and cons. Manual timetable modelling requires a regular service pattern with limited variation, is tricky for large networks and risks missing some conflicts in complex railway yards (Hansen & Pachl, 2008). Optimisation models such as PESP are required when multiple objectives have to be achieved that do conflict with each other.

Manual timetabling is chosen given the relative simplicity of the assessed railway corridor, single service pattern for most design alternatives and predominantly macroscopic modelling approach. The objectives and constraints are not expected to conflict. The constraint is that any timetable should be feasible. The main objective is to achieve a as short as possible run time over the corridor, secondarily that doubling of single track is kept as short as possible (when applicable for the alternative). The first objective needs the sum of holding time to be kept short. The second objective is assumed to be achieved when holding is distributed equally at applicable locations. These objectives are complementary.
Timetables are modelled with the following heuristic procedure. An initial path sequence is composed. The initial path is duplicated with the agreed headway, so the duplicates have the timing of the initial path plus the set headway. The initial path sequence and duplications are assessed for headway conflicts. This process begins at the start event of the initial train path sequence at Den Helder. The conflict the furthest from the start event is evaluated first, followed by any conflicts that are the conflict addressed first and the start event. Trains are treated first in first out when a conflict is present over a single tracked section. Measures are then applied to remove the headway conflict. Design alternatives that do not permit the doubling of single track let the train arriving first advance through the single tracked section to the next station with passing loop, while measures are applied to remove the headway conflict at the train that arrived later. Measures are either holding at a station or delaying of the return path. Design alternatives that do permit the doubling of single track asses the optimum delay of the start event for the return trip.

This heuristic procedure is used for each alternative, except the mixed alternative. The mixed alternative uses a variation; two initial path sequences are created, one SLT calling at all stations and one VIRM skipping Waarland and Breezand. The start event of the VIRM path is 15 minutes after the SLT and all duplicates have a headway of 30 minutes of from their initial path. The location and length of required additional double track is calculated followed the completion of timetable modelling. The process is executed and reported in Appendix E.

4.5 Distribution of effects

Distribution of the transport effects can be computed with a sequence of three steps. The method to compute location to location travel times is done first, as it is required to compute activity spaces. Travel time is followed by accessibility potential and equity assessment.

4.5.1 Travel time

Total travel time of a trip consist of multiple components. These are access time to a station / stop, transfer time, in vehicle time and egress time from the last station to the final destination. These are obtained and composed in a minimum travel time matrix. This matrix varies per design alternative.

Computing the total travel time of a trip requires a number of assumptions. Trips are unlikely to start or end at a station location, but at the spatial location of employment or inhabitants place of residence. These locations are not determined in space however, which is a challenge as precise and consistent travel time predictions are needed. The area is covered in some models, like VENOM and NRM-West, but their mesh size is less detailed than the PC4 postal code level. Using PC4 is possible, if the inhabitant numbers and employment opportunities can be linked to an exact location. This is achieved with google maps, entering the postal code yields an exact location. It is assumed that the search engine query yields a location that is the weighted average of the PC4 code. While this is not the most precise method, it is commonly available and consistent. The inhabitants and number of jobs of the PC4 area in question are assigned to the location yielded by the query. This location is then used as a start / end point for trips and travel time computations.

Bus and cycling are evaluated as access modes. These are prevalent in the case area. For these access modes the route of minimal travel time from the spatial location of the PC4 code to a railway stations on the case corridor is determined. These vary per access mode. Inhabitants all pick the option with the shortest travel time. Walking is not included as a main mode, because it is assumed to be slower than cycling.

Cyclists average 16 km/h (Decisio, 2018). They are assumed to cycle the shortest route from the spatial location of the PC4 code to the nearest station, unless a Southward station is less than a kilometre further away (this is assumed to be closer to employment).

Bus passengers walk from spatial location of the PC4 code to the nearest bus stop assigned by google maps. In the literature review it is identified that bus timetabling is not considered to be part of the strategic time horizon on which this research applies focus. Initially it is therefore assumed that bus timetables are operated at pulse with railway services and have good transfers between each other and current actual timetables are assumed to be optimal. Bus services are subject to road congestion, which is taken into account by systematically selecting weekday departures at the start of the afternoon peak period. It is assumed that bus services in the area addressed average congestion when designing timetables. Therefore the bus route which takes the shortest travel time is chosen. Transfer time at the railway station is included.

The evaluated corridor ends at Alkmaar station. At Alkmaar station onward connections are offered, currently to Haarlem and Amsterdam. These are either with a transfer or additional scheduled dwell for timetable stability reasons. These onward connections provide access to additional employment opportunities, which is relevant for the accessibility potential assessment. Therefore timetables of these connections are taken over from appendix B. These railway lines have intermediate stations, with employment opportunities. These stations are important, even though only a fraction of these jobs is expected to be relevant for the inhabitants of the case region. This is caused by the transport resistance, whish assigns diminishing relevance to opportunities further away from inhabitants from the case region. It remains relevant because the jobs opportunities accessible at stations on these railway lines do contribute to the activity space at the locations of inhabitants in the case region. The job opportunities are assumed to have an egress journey of ten minutes from external railway stations. This is not a really precise parameter, but assumed to be an acceptable average of egress times.

4.5.2. Accessibility potential

Calculation of accessibly potential integrate employment data with travel time of the modelled PT network. This is done per design alternative. Internally travel time and number of jobs per PC4 location are known. Two attributes remain to be addressed; residual opportunity, the exact composition of the exponential decay function and application of the gravity model.

The decay function, equation 7 from section 3.5.1, is composed of transport 'cost' c_{ij} and parameter β. The c_{ij} cost function is the travel time in minutes from location to location and varies per trip and design alternative. The beta is a constant parameter, which has to be scaled so that is represents Dutch commuting behaviour. A gradual beta of 0,003-0,01 is mostly affiliated with international scales, steeper betas (β=0,02-0,05) with interregional applications and steep β's of +/- 0,1 are used in interurban settings (Kotavaara, 2012). Given the composition of the region scaling of β should probably be between interregional and interurban. A β of 0,039 has previously been associated with a Dutch context (Rosik, Stępniak, & Komornicki, 2015), which is in line with a β prediction of 0,03105 made in promotion research on long term effects of telecommuting (Muhammad, 2007). Therefore a β of 0,03 is applied.

The spreadsheet program Excel is used to compute the accessibility potential. This program is chosen because it is readily available, has an easy interface and directly yields results for the design alternatives. Computation of the accessibility potential is done with equation 8 of section 3.5.3, for all locations in the case area. Equation 8 is shown again below:

$$A_i = e^{-0{,}03 c_{access(i)}} * \sum_{j=1}^{y} D_j * e^{-0{,}03 c_{egress(j)}} * e^{-0{,}03 c_{TTL}} \quad (8)$$

This is broken up into sections; the decay function of access time ($e^{-0{,}03 c_{access(i)}}$), decay function of timetables in vehicle time ($e^{-0{,}03 c_{TTL}}$) and decay function of egress time multiplied with the number of jobs at the location of opportunity ($\sum_{j=1}^{y} D_j * e^{-0{,}03 c_{egress(j)}}$).

Any postal code location is both an location of origin and destination of opportunity, external locations are destination of opportunity only. Each postal code has a travel time to the nearest station and travel times to other stations. Each of these stations is affiliated with multiple locations of opportunity, to which it offers the shortest path. The opportunity at any destination station is the sum of opportunity at affiliated egress locations, thus the decay function multiplied with the number of jobs, summed up for all destinations to which the station provides egress. This sum is multiplied with the decay function of access travel time from the location of origin to the associated station of origin and decay function of the timetabled travel time between both stations. This is done for every station pair and all postal codes that are part of the case region.

Computation of the accessibility potential has to be executed for every design alternative. Most alternatives will change the railway timetable component of the cost function only. Alternatives that provide Waarland, Breezand or both new stations are an exception, they also change the access and egress shortest path to some locations. These locations are marked in appendix G. The basic accessibility potential does only give information of for places of origin, this cannot be interpreted directly. Intrepetation is done with the average number of workplaces accessible per capita as a proxy variable. This is a weighted average.

4.6 Equity assessment

Calculation of equity values is essentially the integration of accessibility potential with inhabitant and income data. This is mainly an evaluation of the accessibility potential. Equity of the design alternatives is evaluated both horizontal and vertically. The basic Theil index in 9 of section 3.6 addresses location of inhabitants only, which is horizontal equity. Equation 10 allows for grouping in income classes and is therefore suitable to evaluate vertical equity. Evaluating both horizontal and vertical equity serves multiple purposes. It is an direct comparison between the two equity types which, as discussed in section 2.1 of the literature review, has seldom been done for PT projects. Additionally; it allows to compare the transport poverty reduction potential of the design alternative for this specific case study.

This is possible because the equity types differ in the inclusion of income groups, which are grouped in the subset of inhabitants that are and are not at risk of developing transport poverty in this case application.

Valuation of equity requires assumptions. It is assumed that both income groups have the same accessibility potential when they live in the same location. This allows the accessibility potential of this specific place of origin to be used for A_{lk} of the vertical Theil index. In reality accessibility potential of places of origin may vary between income groups. Inhabitants that own cars have different travel times to destinations and inhabitants that suffer from social exclusion caused by transport poverty have a different decay function. The limitation is that this results in an overestimation of equity, there is a higher level of unfairness in the case region. Inclusion would require detailed car traffic models and very precise income data. None of these are available. The model is usable nevertheless, with the imperfection that it is not able to assess the full range of equity within the Kop van Noord-Holland region.

The equity score is also computed with the Excel spreadsheet program. Each location of origin is placed on a dedicated row, with the accessibility of the location, number of inhabitants (total, lower and higher net worth) and accessibility times the inhabitant number (of total, lower and higher net worth) used as input. This allows for computation of general accessibility per capita. Computation of $\frac{A_{lk}}{A_l}$ of vertical and $\frac{A_k}{\bar{A}}$ of horizontal equity of each location is done by dividing the accessibility potential of the location by the respective general accessibility per capita. With a few additional steps the equity contribution of the location of origin is computed. By summing up for all locations the horizontal equity and within portion of vertical equity are obtained. Then only the between group component remains to be added to the computed within component to obtain the vertical equity value. The computed equity values are divided by the natural logarithm of population to retrieve the (in)equity of accessibility distribution in the case area.

The resulting equity values of design alternatives are compared between one another by ranking the alternatives and calculating the percentage of improvement between alternatives.

5 Validation

The outcome of the model can only be adopted if the model is validated to have correct behaviour. This is done with a sensitivity analysis, which consists of a series of tests targeting different aspects of the model. These tests are designed to test how the model reacts to situations with different assumptions. The tests target specific parameters that have a substantial impact on the outcome. These are; access / egress, in vehicle travel time on the railway corridor, demographics and employment opportunities. For each parameter values are chosen that differ substantially. Additionally; expected model behaviour is formulated for the changed parameter values.

By evaluating the model for the substantially different parameter values, it can be tested if the constructed model reacts in line with expectations. The results are validated and can be accepted if the model reacts in line with the expectations. One validation test is done at a time.
Some of these tests serve a dual purpose. They also contain questions that are relevant in the case context, but could not be included in the main model. It is not likely that any of the events will happen however. The tests do not contain predictions.

5.1 Validation test specification

1. Access / egress time reduction. Access / egress times are lengthy for a substantial number of locations. The model is sensitive to access / egress time change, as the minimum of bus and bicycle travel times are used. The model reaction to easier access / egress travel is tested by changing the access / egress time parameter. The default 16 km/h average is changed into 22 km/h, which is used for ebikes by a number of scba studies. It is expected that the accessibility potential will increase significantly due to the shorter access time. Accessibility differences between design alternatives might decrease because the relative share of access egress time decreases. Equity will increase, because access / egress is less of an limitation for villages further away from the railway.
2. Change of β parameter. The resistance function is increased by 20% to β = 0,036. Accessibility potential is assumed to decrease substantially. Equity differences are expected to increase overall. Equity might also increase between alternatives.
3. Speed increase of trains within the corridor. The timetabled travel times are reduced by 20%. The accessibility potential will increase. Equity will increase as well, albeit slightly. This is expected as some villages will still have lengthy access egress times, this will reduce the potential for equity increase.
4. Speed slowdown of trains within the corridor. 20% added to timetabled travel times. The accessibility potential and equity will decrease, probably with a greater magnitude than the previous test.
5. Inhabitant growth of Waarland. Waarland will receive an additional 2000 inhabitants, all at the lower end of the income distribution. It is expected that the model becomes more sensitive to changes for inhabitants of Waarland, and that any alternative that includes a station at Waarland will have a significant equity increase. The accessibility per capita and equity of other design alternatives will decrease.
6. Inhabitant growth of Den Helder. In this test the inhabitant number of Den Helder is doubled. This will make the model more sensitive to design alternatives that have travel time improvements on the single tracked railway sections, mostly to alternatives without new stations. Limited equity improvements are expected.

7. Employment growth in Alkmaar. Alkmaar will feature a 25% employment increase. The accessibility potential will increase, equity is not expected to change significantly.
8. Employment growth in Haarlem. Haarlem will have a 25% higher number of jobs available. Accessibility potential will grow a bit, but substantially less when compared to the previous test.

5.2 Validation results

The accessibility test results are reported in table 9 and equity in table 10. The majority of test result is in line with prior expectations. Deviations from expectations and other interesting behaviour are discussed below.

Validation:	Average accessibility							
Test Alternative	1 Access	2 Resistance	3 Railway timetable -20%	4 Railway timetable +20%	5 Inhabitants Waarland +2000	6 Inhabitants Den helder x2	7 Oppertunity Alkmaar +25%	8 Oppertunity Haarlem +25%
Current	12056	-28096	12693	-11269	-255	-1623	3246	717
VIRM	13235	-30517	11903	-9995	-283	-2022	3493	836
SLT	13457	-31382	11408	-10013	-300	-1998	3594	878
VIRM expand.	13322	-30673	11882	-10002	-289	-1698	3517	841
SLT expanded	13600	-31637	11358	-10013	-311	-1448	3634	888
SLT Waarland	13146	-31556	12014	-10224	313	-2022	3597	879
SLT Breezand	13342	-31701	11595	-10187	-314	-2201	3641	890
SLT Wl. & Br.	12899	-31619	12244	-10391	1320	17340	3604	881
Mixed	12968	-31600	12377	-10451	1367	17841	3650	874

Table 9: Accessibility validation results

Validation:	Equity							
Test Alternative	1 Access	2 Resistance	3 Railway timetable -20%	4 Railway timetable +20%	5 Inhabitants Waarland +2000	6 Inhabitants Den helder x2	7 Oppertunity Alkmaar +25%	8 Oppertunity Haarlem +25%
Current	0,173%	-0,260%	0,113%	-0,123%	-0,003%	0,117%	-0,003%	-0,002%
VIRM	0,171%	-0,269%	0,120%	-0,131%	-0,002%	0,113%	-0,007%	-0,002%
SLT	0,167%	-0,264%	0,110%	-0,127%	-0,003%	0,111%	-0,006%	-0,001%
VIRM expand.	0,173%	-0,264%	0,111%	-0,121%	-0,003%	0,118%	-0,006%	-0,001%
SLT expanded	0,170%	-0,256%	0,095%	-0,111%	-0,004%	0,117%	-0,005%	-0,001%
SLT Waarland	0,135%	-0,234%	0,114%	-0,129%	0,003%	0,097%	-0,007%	-0,002%
SLT Breezand	0,149%	-0,244%	0,097%	-0,116%	-0,005%	0,095%	-0,005%	-0,001%
SLT Wl. & Br.	0,114%	-0,222%	0,118%	-0,135%	0,003%	0,073%	-0,007%	-0,002%
Mixed	0,114%	-0,200%	0,097%	-0,106%	-0,001%	0,071%	-0,006%	-0,001%

Table 10: Equity validation results

The accessibility and equity improvements of the access speed increase are in line with expectations. The slight increase of equity for design alternatives that do not include additional stations over alternatives that include stations is not surprising, because of the variations in access times between design alternatives.
Change of the resistance function did not cause unexpected accessibility behaviour. Equity

did behave in line with expectations, differences between alternatives did not increase significantly.
Equity reacts in line with expectations when the timetables are changed. The increase in travel time has a slightly larger equity effect than a comparable time reduction. The inverse is true of the accessibility potential in this test. This is analysed and can be explained by accessibility to external locations not being subject to change. The relatively small changes in this test are attributed to the substantial number of inhabitants of Heerhugowaard, whom only get a small time change.
The test of additional lower net worth inhabitants does reveal some sensitivity to accessibility potential change of the Waarland and Breezand station alternatives. The magnitude of this effect was not really expected, but assumed to be a result of the significantly shorter access to Breezand and Julianadorp.
Doubling the inhabitant number of Den Helder did not reveal any unexpected behaviour. The short access time to the station does contribute to a marginal equity increase. The slightly decreased accessibility potential is attributed to Den Helder being at the end of the railway line and having a slightly lower accessibility potential overall. The results between design alternatives are in line with expectations.

The accessibility and equity differences between the Alkmaar and Haarlem tests are striking. A substantial difference in average per capita accessibility potential was expected, but not a factor four difference. The difference is interesting because Alkmaar and Haarlem roughly have the same number of workplaces. This behaviour is attributed to the gravity model, decay function assigns a substantial penalty to the 46 minute travel time between Alkmaar and Haarlem. Since this is nearly double the time of an average Dutch commute this model behaviour is considered to be normal.

It is concluded that het model behaves realistically and the modelled results can be adopted.

6 Results

This chapter evaluates timetables, accessibility potential and equity effects for the design alternatives. Based on the objectives outlined in section 3.3 of the methodology the design alternatives are identified in section 4.3.3 of the Alkmaar – Den Helder case description. The modelled timetables enable the accessibility potential and equity value of each design alternative to be computed. The equity assessment is concluded by comparing the equity values of the design alternatives. While individual measures are enclosed in the design alternatives and cannot be seen independently of the design alternatives, some general conclusions can be drawn. This is done following the equity assessment.

6.1 Railway timetabling

Key outcomes of the timetabling process are reported first. These are modelled timetables and measures required for each design alternative. The timetables of design alternatives contain feasible travel times between stations, if conditions are met. These conditions are executing the measures outlined in the design alternatives, which apply to the infrastructure in particular. This is reported after details on the modelled timetables.

6.1.1. Timetable modelling

Results indicate that feasible timetables are possible for all design alternatives with the frequency of 4 trains per hour. Most of the timetables modelled for the design alternatives feature significant travel time savings on the railway corridor, when compared to the current situation. The timetabling process, which contains initial path sequences, headway conflict resolution, feasible timetables and time distance diagrams is presented in appendix E for each design alternative. Key aspects of the resulting timetables are reported below.

Feasible timetables proved to be possible for all design alternatives. This means that the desired services are achievable with the measures included in the design alternatives. The timetables of the design alternatives have different path sequences and basic hour patterns due to the application of required measures. This results in a difference in travel times between stations on the railway corridor. The average travel time between Alkmaar and Den Helder is given in table 11.

Travel time Alternative	Den Helder - Alkmaar
Current	37,0
VIRM	35,0
SLT	33,6
VIRM expanded	33,2
SLT expanded	30,8
SLT Waarland	32,7
SLT Breezand	32,7
SLT Wl. & Br.	34,6
Mixed (SLT / VIRM)	34,6 / 33,6

Table 11: Alkmaar – Den Helder travel times of modelled design alternatives

Table 11 gives an indication of what end to end travel times can be expected, when the design alternatives are implemented. This is only part of the equation, as it does not specify the arrival and departure at intermediate stations. Additional interpretation is given in the time-distance diagram where a single train path of each placed over each other. This is displayed in figure 7 for paths to Alkmaar and in figure 8 for paths to Den Helder. These figures and the full timetables, TD diagrams for each alternative in appendix E are used to evaluate and explain the outcomes of the timetable process.

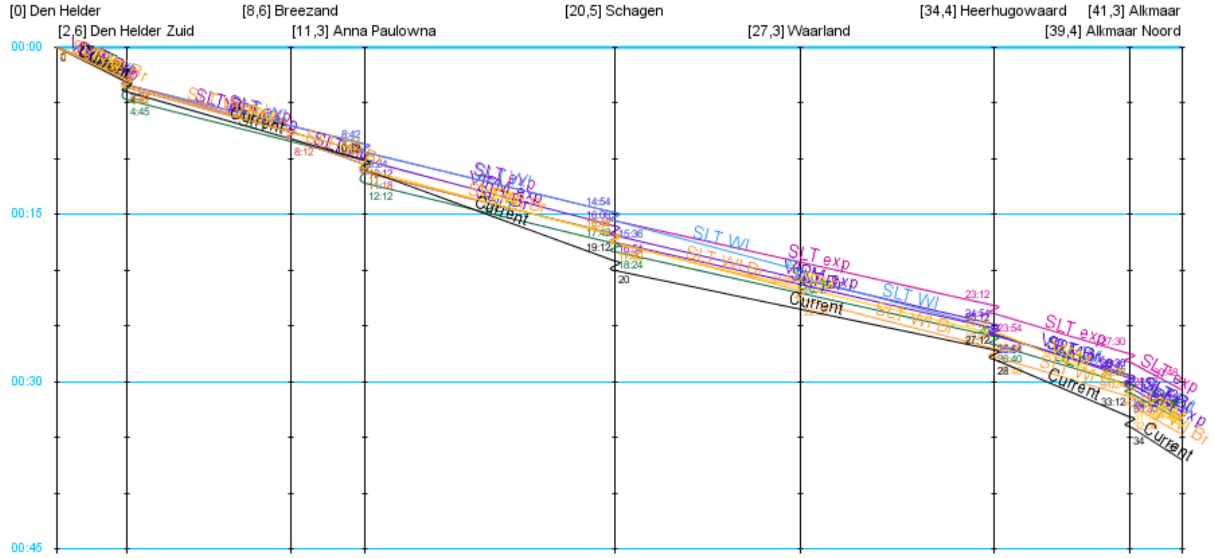


Figure 7: TD overlay diagram Den Helder to Alkmaar

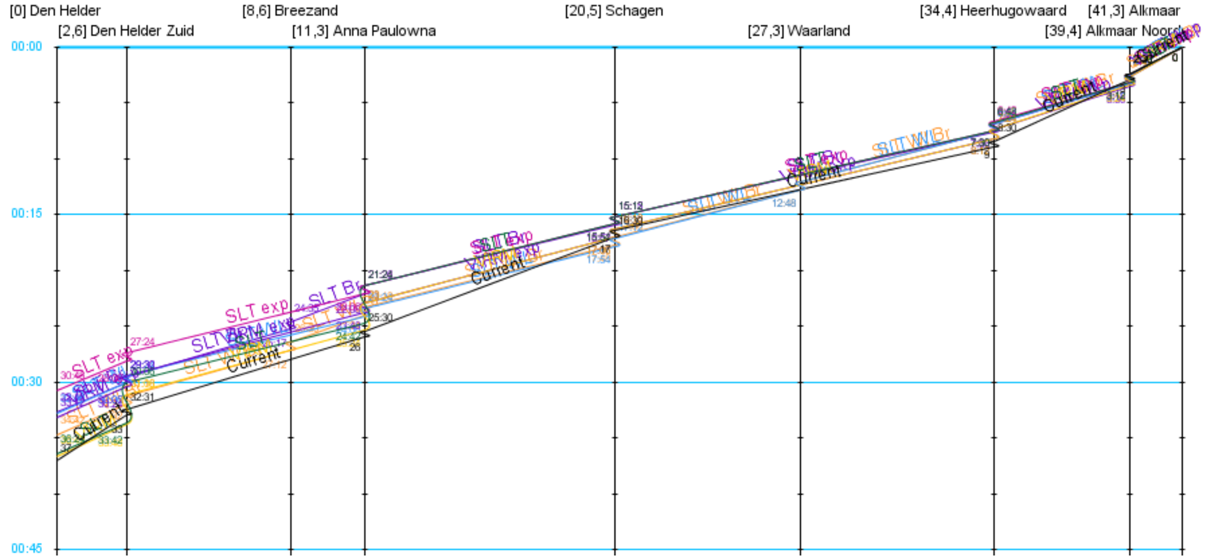


Figure 8: TD overlay diagram Alkmaar to Den Helder.

From the modelled timetables the conclusion is drawn that significant travel time reductions are achievable, even without changing the infrastructure. Design alternatives without changes to the infrastructure have limitations. The SLT alternative is able to achieve shorter travel times between Alkmaar and Schagen, but these time reductions are largely lost on the single tracked sections due to headway conflicts. Any conflict has to be waited out during a station call, which adds up. While the SLT with current infrastructure is one of the faster alternatives from Alkmaar till Schagen, the application of holding at Anna Paulowna and Den Helder Zuid results in this alternative being one of the last to arrive at Den Helder. The longer travel time will have a influence on fairness between inhabitants, especially for disadvantaged inhabitants who live North of Schagen. The net equity effect could still be positive due to the short travel times achieved between Schagen and Alkmaar, in which case changing rolling stock is recommendable.

Doubling of single track enables substantial travel time reductions throughout the entire railway corridor. The SLT expanded and VIRM expanded assume an unrestricted train paths between stations, with headway conflicts resolved by means of doubling single track where required. The length of double track required is minimised by delaying the start of the return trip to Den Helder at Alkmaar. The location and cost of constructing new or extending existing double tracked passing loops is discussed in appendix H and the next paragraph. The unrestricted train paths result in a run time reduction of 3,8 minutes for the VIRM expanded and 6,2 minute for the SLT expanded alternative over the length of the railway corridor.
Improving coverage of the PT network by the opening of new stations has effects on timetables and travel times. The SLT Waarland and SLT Breezand alternatives feature an increased travel time of 1,9 minute compared to the SLT expanded alternative. This is rooted in the train paths. Slowing down, dwell at the platform and reaccelerate takes time compared to pass by the new station. The effect is visible in figure 7; SLT Waarland & Breezand is comparable to most other design alternatives, but arrives nearly at the same time as slow as the (current) at Heerhugowaard due to the additional stations called at. This will have an effect on inhabitants that have to pass by these new stations. The accessibility potential gets reduced, which has a negative effect on equity. The time loss due affiliated due to the additional station stopped at is mitigated by offering a heterogeneous service, which is tested with the mixed alternative. The mixed alternative consists of an alternating VIRM and SLT service. The VIRM service skips Waarland and Breezand stations and has a total run travel time of 33,6 minutes over the corridor, while the SLT stops at the new stations and has a total travel time of 34,6 minutes over the corridor. The mixed alternative therefore enables the Waarland and Breezand to be opened but also recoups some time that would otherwise been lost for inhabitants of Den Helder, Anna Paulowna and Schagen. The mixed alternative requires the most single track to be doubled of all alternatives however. This is outlined in the next section.

6.1.2 Required infrastructure measures

Implementation of measures is required in order to execute the assessed design alternatives. The change of rolling stock is considered to be relatively straightforward when suitable types and quantities are available to the operator. The costs cannot be estimated due to the unavailability of unavailability of operating data, they are assumed to be lower or comparable to the currently deployed VIRM rolling stock however.
Changes to the infrastructure have long lead times and require careful planning plus substantial investment. The six design alternatives that use doubling of single track to minimise travel times need the doubled track at the right location for their timetable to be feasible. The spatial location and required length of doubled track is assessed in appendix E, of which table 12 contains the results.

Doubling of single track: alternative	Schagen North (km)	Anna Paulowna South (km)	Anna Paulowna North (km)	Breezand South (km)	Breezand North (km)	Den Helder Zuid South (km)	Den Helder Zuid North (km)	Den Helder South (km)
VIRM expanded		0,4						1,7
SLT expanded			1,1					1,7
SLT Waarland			1,1					1,7
SLT Breezand			1,1				1,1	
SLT Wl. & Br.				2,7	0,3		1,1	
Mixed	4,4			2,7	1,7			1,7

Table 12: location of required double track extensions

Most design alternatives have a degree of overlap in where they require single track to be doubled. This is considered to be advantageous, because this reduces the risk of double track expansions becoming of little use under normal operations and cost sunk. Given the results of table 12 it is decided to consider track expansions at a limited number of locations, which are set forth.

Doubling of the single tracked section between Den Helder and Den Helder Zuid is required for all six alternatives. Trains either cross halfway, or in the vicinity of Den Helder Zuid station when Breezand station gets opened. By rearranging the sidings of Den Helder station that remains to be double tracked is reduced to 1,7 km. Doubling the entire 1,7 km is considered to be a no regret option, as the project cost are only marginally higher and required when no station is opened in Breezand. Extending the passing loop of Anna Paulowna is required as well. It is proposed to only consider the doubling of track to the North, as VIRM rolling stock could be replaced with other types that feature faster acceleration. It is advised to lengthen the passing loop with 1,1 kilometre unless stations at both Waarland and Breezand are opened, which requires 3,0 km or 4,4km pending on the design alternate. Lengthening of the double track with 4,4 km from Schagen is only advised when the mixed alternative is executed. The spatial locations are displayed in figure 9. Appendix H contains detailed views of the sub sections.

Figure 9: Map of single track to be doubled (PDOK, 2022 & OpenStreetmap contributors, S.D.)

The required infrastructure measures come at a cost. Details on the estimation of investment cost are included in appendix H. Doubling 1,7 km between Den Helder to Den Helder Zuid is expected to cost 12,5 million euros, which includes interlocking cost for the entire project. Lengthening the passing loop at Anna Paulowna does cost 6,5 million euros for the SLT expanded, SLT Waarland and SLT Breezand alternatives. The SLT Waarland & Breezand alternative requires an additional 8,6 million euro and the mixed alternative another 7,6 million euros. The lengthening of double track North of Schagen needed for mixed alternative is expected to cost 23,9 million euros. Stations are estimated to cost 3,4 million euro each. The total cost of design alternatives is given in table 13.

Investment cost Alternative	SLT Expanded infrastructure	SLT Waarland	SLT Breezand	SLT Waarland & Breezand	Mixed
Alignment	€ 18.990.000	€ 18.990.000	€ 18.990.000	€ 27.611.000	€ 60.383.000
Stations	€ 0	€ 3.388.000	€ 3.388.000	€ 6.776.000	€ 6.776.000
Total cost	€ 18.990.000	€ 22.378.000	€ 22.378.000	€ 34.387.000	€ 67.159.000

Table 13: Investment cost of design alternatives

Intuitively the change of rolling stock should be considered as a no-regret solution. Change of rolling stock can be implemented within the present infrastructure and does result in significant travel time reduction on parts of the railway corridor. This may have severe equity implications for inhabitants that use the single tracked sections of the railway corridor however. Therefore it is advised to at least consider the SLT expanded infrastructure alternative, since it requires the least investment and provides a substantial reduction of the minimum travel time over the corridor. This is not a definitive answer, other alternatives yield better accessibility potential and equity scores. Therefore the SLT Waarland, SLT Breezand and SLT Waarland & Breezand alternatives should be seriously considered as well, provided that the travel time trade-off between passengers does not have a major negative influence on equity. The equity assessment needs the measured accessibility potential, this is addressed next.

6.2 Accessibility potential

Accessibility potential is mainly a property of locations, it expresses the number of workplaces accessible from locations of origin. As such it does not directly yield relevant information, other than providing input data for the equity assessment. Despite this conclusion can be based on the accessibility potential with a proxy variable however. This is done with the average number of workplaces accessible per capita, which is a weighted average for case region. The average number of workplaces accessible per capita and original accessibility potential data is reported in appendix I. The average workplace accessibility per capita is reported in table 14 per design alternative.

Alternative	Accessibility potential Average workplaces per capita (#)	Increased average workplaces per capita (#)	Percentual increase in workplaces accessible (%)
Current	91279	0	0,00%
VIRM	100250	8971	9,83%
SLT	104143	12864	14,09%
VIRM expanded	101036	9757	10,69%
SLT expanded	105469	14190	15,55%
SLT Waarland	105218	13939	15,27%
SLT Breezand	105659	14380	15,75%
SLT Wl. & Br.	105413	14134	15,48%
Mixed	105647	14368	15,74%

Table 14: Average workplace accessibility per capita

Several things stand out. The societal relevance and desirability for improving the PT network becomes immediately clear. Executing any design alternative is better than maintaining the current service. Trends in the order of improvement are also visible. Alternatives that use VIRM rolling stock or do not double single track have a lower average workplace accessibility per capita than other design alternatives. Travel time reduction with faster accelerating rolling stock and partial doubling of single track pays in a higher average workplace accessibility. SLT design alternatives that do consider the doubling of single track have a roughly similar rates of improvement, with SLT Breezand and mixed alternatives having the highest average number of workplaces accessible. This relative proximity between alternatives is an indication that distribution effects are occurring. Several design alternatives with new stations have a slightly lower increase in workplaces accessible than the SLT with expanded infrastructure alternative. This means that local improvements due to the opening of new stations are offset elsewhere. Timetables and access times to stations are the only factors of change between alternatives, so the change in accessibility potential is attributed to the measures of the alternatives. Alternatives SLT Waarland and SLT Waarland & Breezand have a lower percentual increase in workplaces accessible than the SLT expanded alternative. This means that while inhabitants some inhabitants win due to a substantially shorter access time to a shorter station others lose due to their in vehicle time becoming longer. The trade-off between inhabitants is not necessarily bad if disadvantaged inhabitants gain more than other inhabitants loose. This is the case when disadvantaged inhabitants receive a proportionally higher accessibility potential improvement than other inhabitants. This can only be addressed with the equity assessment, which follows next.

6.3 Equity evaluation

The results are concluded with the assessment of equity effects, which is done by computing the distribution of accessibility potential within the population of the case region. Equity indicates the degree in which accessibility is distributed fairly between groups of inhabitants. The equity values and indicators are discussed first. This is followed by describing what causes the differences between alternatives, ranking the design alternatives and drawing general conclusions based on the design alternatives.

Equity is computed with the Theil index and has the option of evaluating for either for location and income class or location only. Both indicators are computed and presented in table 15, which is computed in appendix J. Equity is computed as how far the alternatives are from a 100% fair distribution of accessibility potential. The closer the equity indicator of a design alternative comes to 100% the better. This is the opposite between the two equity indicators, which use the same accessibility potential and socio-economic data, minus prosperity data.

The vertical equity indicator uses the inhabitants income and location, while horizontal equity uses the location of inhabitants only. There are substantial differences observed between horizontal and vertical equity. The vertical equity indicator is able to identify twice as much inequity compared to the horizontal equity indicator. This is systematic for all design alternatives. Therefore income or other prosperity indicators should always be included in an equity assessment, as using location only will lead to a significant underestimation. The remainder of this report therefore uses the vertical equity indicator, thus with a distinction made between the location and income of inhabitants.

	Equity: vertical (location and income)		Equity: horizontal (location)		Equity type
Alternative	equity (%)	improvement over current (%)	equity (%)	improvement over current (%)	Improvement difference (%)
Current	99,153%	0,00%	99,571%	0,00%	0,0%
VIRM	99,164%	1,06%	99,576%	0,57%	47,6%
SLT	99,191%	3,78%	99,590%	1,94%	52,6%
VIRM expanded	99,187%	3,39%	99,588%	1,70%	49,5%
SLT expanded	99,226%	7,32%	99,607%	3,67%	49,9%
SLT Waarland	99,274%	12,12%	99,632%	6,13%	50,7%
SLT Breezand	99,267%	11,43%	99,631%	6,03%	53,2%
SLT Wl. & Br.	99,316%	16,26%	99,656%	8,53%	52,8%
Mixed	99,390%	23,65%	99,693%	12,23%	51,9%

Table 15: Equity results

The equity scores of design alternatives yield valuable insights. Any design alternative is an improvement compared to the current situation. The equity improvements are attributed to the measures of included in the design alternatives, which determine the accessibility potential of specific places. Mutual comparison results in the conclusion that some improvements are made by changing rolling stock only, but that more significant equity improvements are possible by expanding double track where required as well. A 7,3% improvement over the present situation is possible by changing to SLT type of rolling stock and double single track where required. This difference is caused by the removal of headway conflicts on the single tracked railway sections, allowing for shorter travel times on the entire railway corridor. This particularly beneficial for the inhabitants of Den Helder, which has a relatively larger proportion of inhabitants with a lower income to which the equity indicator is sensitive.

More substantial equity improvements are possible with the opening of new stations. The increase in equity between the alternatives with new stations and the SLT with just expanded infrastructure is remarkable, because the accessibility potential did not increase significantly between these alternatives. This means that accessibility is distributed more fairly. Improving coverage by reducing access times with new stations generally outweighs a lengthier in vehicle time of some inhabitants. The effect of opening new stations at Waarland or Breezand is approximately twice as strong effect when compared to the SLT with just expanded double track alternative. Equity improves with 11,4% for Breezand to 12,1% for the Waarland alternative, compared to the current situation.

The highest equity improvements are possible when both Waarland & Breezand are opened, but side effects occur however. Opening stations at Waarland & Breezand will have a substantial impact on the inhabitants of these locations, despite the relatively minor accessibility potential effects in the entire case region. Diminishing returns apply to the SLT Waarland & Breezand design alternative however. This alternative has with 16,3% one of the highest equity increases, but travel time side effects do have an influence on some inhabitants. The cause is visible in the time distance diagram overlays; at figure 8 it is observed that the path of the SLT Waarland & Breezand alternative features a comparable travel time as the SLT expanded alternative, but loses time due to the additional calls at the new stations. Between Den Helder and Heerhugowaard this adds up to an extent that the travel time becomes comparable to the train paths of the current situation. This mainly affects inhabitants of Den Helder, but also inhabitants of Anna Paulowna and Schagen. Their accessibility potential gets reduced by the increased travel times, which leads to a lower rate of equity improvement. This point is proven by the mixed alternative, which consists of a service that calls at Waarland & Breezand operated with SLT rolling stock, plus a limited stop express service operated with VIRM rolling stock which skips the new stations. The mixed alternative has with a 23,7% equity improvement compared to the current situation, which is the highest of all alternatives considered. This is attributed to the heterogeneous service pattern, which mitigates the negative travel time effects for inhabitants that pass by the new stations. So removing the travel time tradeoff between inhabitants results in a 7,4% equity increase in this case. Therefore it is best to prevent time loss due stopping at Waarland and Breezand by offering two limited stop intercity services and two local services that stop at each station per hour. Appendix K contains a geographic information systems analysis of the main outcomes.

Given the equity assessment of table15 it seems logical to conclude that the mixed alternative ranks best, followed by the SLT Waarland & Breezand alternative. The two alternatives with one of the new stations also have favorable results, followed by the SLT expanded infrastructure alternative. The SLT with current infrastructure and both VIRM alternatives do have a relatively minor effect. This was expected for the VIRM with current infrastructure alternative, as it closely resembles the present situation.
Ranking of alternatives becomes more interesting when investment cost are considered as well. This is done by computing the cost of marginal equity improvement. This puts the equity improvements into perspective. Table 16 contains the marginal cost of equity gains, which is the infrastructure cost divided by the equity improvement for the applicable design alternative. This applies to alternatives that require infrastructure change only, which is considered to be acceptable as these alternatives feature the largest equity gains.

Alternative	Improvement (%)	Infrastructure cost (x1000)	Marginal cost of equity gains (x1000)
Current	0,00%	n/a	n/a
VIRM	1,06%	n/a	n/a
SLT	3,78%	n/a	n/a
VIRM expanded	3,39%	€ 12.471	€ 3.676
SLT expanded	7,32%	€ 18.990	€ 2.594
SLT Waarland	12,12%	€ 22.378	€ 1.847
SLT Breezand	11,43%	€ 22.378	€ 1.958
SLT Wl. & Br.	16,26%	€ 34.387	€ 2.115
Mixed	23,65%	€ 67.159	€ 2.840

Table 16: Marginal cost of equity gains

There is reason to change the order of alternatives based on the marginal cost of equity gains. Alternatives SLT Waarland, SLT Breezand and SLT Waarland & Breezand have a significantly lower marginal equity cost than other alternatives. These alternatives differ within 15% from each other, whereas other alternatives have a significantly higher difference. The mixed alternative has a 50% higher marginal cost of equity than the SLT Breezand alternative and SLT expanded 40%. The VIRM expanded alternative is practically eliminated. Given the comparable marginal cost of equity and high equity gain achieved it is argued to rank the SLT Waarland & Breezand as the highest. Second best is the SLT Waarland alternative, since it has the lowest marginal cost of equity gains. For further ranking it is assumed that the original equity order could be followed. Therefore the tentative order becomes;

1. SLT Waarland & Breezand
2. SLT Waarland
3. Mixed
4. SLT Breezand
5. SLT expanded
6. SLT
7. VIRM expanded
8. VIRM

Caution applies however. The equity improvement and marginal infrastructure investment cost of equity gain do only give part of the equation. A definitive answer can only be given with a cost- benefit or multi criteria analysis. This requires detailed passenger and cost of rolling stock operation data, neither of which is available. It is recommended to obtain the required data and do follow up research.

6.3.1 Equity conclusion

Some general conclusions can be drawn despite the degree of case dependence of this conclusion. Case dependence is considered to be inevitable, given the PT planning and timetabling process for the design alternatives, spatial composition and socio economic data of the case region. General conclusions are drawn with a few assumptions. Specific measures apply to specific design alternatives. The design alternatives are made according to a specific objective of successive travel time reduction ambition. The measures evaluated are the only factor of change within the design alternatives. The measures applied determine the accessibility potential and equity outcome. Therefore it is concluded that general conclusions can be drawn based on the type of measure and resulting accessibility potential and equity effect.

In general it is concluded that equity provides valuable insights into the distribution of accessibility between inhabitants. Equity is able to to distinguish how accessibility potential differs between groups of inhabitants of a region. Equity should be assessed with at least location and income as units of division between groups of inhabitants, if possible. Inclusion of prosperity in the equity indicator resulted in a 50% higher measurement of equity differences, which was in line with expectations and other literature. The performance of measures included in the equity assessment results in the following observations. Equity can be improved by reducing travel time, by targeting vehicle travel time and / or improving the coverage of the PT network by reducing the access time with new stations. Reducing travel time by using improved rolling stock is considered to be a no regret option, but its capabilities to improve equity may be hindered by infrastructure constraints. This was the case in this research. Reducing in vehicle travel time has a significant impact on equity, which is best achieved by a combination of rolling stock with improved acceleration and the doubling of single track where required in order to avoid headway conflicts. Improving coverage by reducing access time with new stations proved to have a twice as strong as strong effect compared to reducing in vehicle travel time only. This ratio does not always remain the same, diminishing returns apply in the form of a trade-off between inhabitants. Some some passengers make an extra unnecessary stop that takes time and ultimately has a negative effect on equity. This differs per situation however.

7 Discussion

The results, contribution and potential improvements of this research are discussed in this section.

7.1 Results

The case application proves that an equity assessment in rural areas is possible with the developed methodology and yield interesting results. This research is one of the first rural equity assessments of a PT network. The scientific contribution of this research is the identification of rural transport equity and explicit formulation of the assessment method, which identifies PT improvement measures and quantifies their equity effects. It connects the distribution of accessibility between groups of inhabitants with travel time consequences of PT planning. It leads to new insights as it clarifies societal consequences of railway timetabling and network planning decisions. The conclusion that improvement of coverage had a stronger effect than just reducing in vehicle travel time is also very interesting.
It should be noted that this study used current socio economic data though. Circumstances may change. It is not expected that autonomous developments will cause significant change to the foundations of this research in the near future. What could be done is change conditions with policy interventions. This includes not only transport policy but also housing development and employment promotion. This may change initial conditions, after which this study should be repeated.

7.2 Contributions

The main societal contribution of this research is the identification and measurement of equity effects from PT planning decisions. Welfare of region can be improved by considering equity implications when designing PT networks. This results in the measurement of equity effects from planning decisions for the Alkmaar – Den Helder case area. The improved equity scores of most design alternatives indicate that change is advantageous. While the effect of only changing rolling stock proved to be relatively minor, this does not mean it should not be considered. This measure requires relatively little effort and does still improve equity within the corridor. Double track needs to be expanded for substantial equity improvements however. This can be expanded with additional stations at Waarland and Breezand for even greater equity gains. The doubling of single track is also considered to be a no regret option, because most design alternatives have overlap in where they require doubling of single track. Additionally the local doubling is expected to cost substantially less than doubling the entire railway.
Opening of new stations has significant side effects however. The results indicate that opening stations has negative side effects on other inhabitants. Inhabitants that do use the railway service but not from the new station are subject to a trade-off as they feature a small accessibility potential decline. This reduces the equity score in the area a bit. This could apply to inhabitants of Den Helder, Anna Paulowna and Schagen, pending the design alternative implemented. These in inhabitants are also relevant stakeholders. Opposition may arise when their interest is not taken into account. Stakeholder consultation is necessary. This research proposes the implementation of the mixed alternative when Waarland and Breezand are opened, which has a heterogeneous service. The local train is mixed with a limited stop express service, which mitigates the accessibility potential effects for inhabitants that do not use new stations. This alternative requires the most investment however, as many infrastructure measures are needed.

7.3 Limitations

Data

The main improvement potential for this research is the use of better data. Some data and models do not exist yet, other data was not (publicly) available to the author at the time of writing. This was expected, the scarcity of desired data is a common problem when executing research on rural areas. Infrastructure manager Prorail restricts access to data on their online portal. Public access to a lot of relevant data and maps on this portal is closed off. Also detailed passenger data of local railway operator NS proved to be unavailable for this research. Some data is released to the general public, but very aggregated. Data available only indicates that the railway line fills with passengers when going south, giving the average number of weekday users of current stations. This absence of data is a major hindrance, requiring assumptions and workarounds in this research. This is a pity and not completely in line with open data policies of Dutch government.
The unavailability of passenger and rolling stock operating data is particularly detrimental. It is not possible to execute a cost benefit assessment without insight in passenger numbers and economics of specific rolling stock. This has a consequence that limited conclusions can be made on the effectiveness of equity investment.

Transport poverty

Improvements can be made with more detailed socio demographic and income data. Sources available are fragmented and not of high detail, partly due to privacy concerns. Income statistics are available on a PC4 postcode level of detail only. This has the consequence that a higher level of detail is not possible, this restriction is the main reason why this research has been carried out at PC4 level of detail.
Better data will enable the evaluation of transport poverty. Transport cost for the end user is a major factor for transport poverty, next to location of origin. Evaluation requires insight in the ability to pay for of transport fares, which is not possible with the data available. Additionally; railway fares are set at a national level however and are strictly regulated. Change is of railway fares is expected to require a lot of effort. Bus travel could be subsidised and schemes to buy e-bikes at a reduced rate could be offered to inhabitants that are susceptible to transport poverty. This is considered to be out of scope of this research however. The effects of these schemes can only be tested with stated and revealed choice experiments. In order to address transport poverty it is recommended to execute additional research. Inclusion of transport poverty into the resistance function will result in increased accessibility potential differences, which will increase differences between the equity scores of design alternatives.

Car use

Inclusion of the use of private motor vehicles requires additional research. Not considering this is a bit of a shortcoming, as car ownership is skewed towards the upper end of the income distribution. A substantial number of inhabitants are not captive users of the PT network. They have the option of using a car or PT. It can be expected that inhabitants that own cars will have far shorter access times to any of the evaluated opportunity locations. The accessibility potential of inhabitants with cars will therefore be much higher, leading to a different A_{lk} for the two income groups. This would have increased differences in the measured equity between alternatives substantially. This can only be evaluated with sufficient data however. Incorporating private motor vehicles requires a dedicated traffic model and fused income and car ownership dataset, which was unfortunately unavailable for the case region and obtaining or creating this will require a lot of effort. Therefore equity is assessed without the option of car transport. This is not of influence for the evaluation of PT options, but has a slight drawback for extrapolating results. Despite the absence of a car null alternative the observed equity results can be compared between each other, since the current railway timetable is used as a base scenario. It should be considered that the total equity gain of the design alternatives is greater than the percentage reported.

Railway

The railway timetabling component of this research has been constrained by the availability of data on dynamic properties of rolling stock. Secondarily, the use of common prescribed microscopic railway simulation was infeasible. Given the focus on equity and strategic scope this is considered to be acceptable, but a more detailed microscopic railway simulation of the preferred design alternative is required. This is in line with standard practice, as the microscopic feasibility has to be tested as well. This has to include evaluation of block sections with signalling. Also stochastic variables have to be applied to the arrival and departure of rolling stock, in order to evaluate the capability to which extent the measures will compensate the spread of delay over the corridor due to discrepancies in the timetable keeping of train services. This is deterministically covered by the adding of time supplements in this research, for tactical and operational evaluation this hold be elaborated with stochastic simulation.

Also the proposed railway measures cannot be seen independently from the evaluated design alternatives. This design choice was made for valid reasons, because the alternatives to consider would have become too large otherwise. This would lead to a situation where some alternatives yielding infeasible timetables or not delivering an equity improvement. The approach with a limited number of design alternatives has the implications that some measures cannot be seen independently of each other however.

Future railway developments should be considered as well. These are service concepts elsewhere and expected future run time reductions. The PHS project Amsterdam – Alkmaar will result in an increased frequency of 6 trains per hour. Given the constraints of the single tracked railway sections it is assumed to be not feasible to continue this frequency to Den Helder without doubling of all remaining single tracked sections. Additionally demand might be lacking for such a high frequency. It should be considered to test a frequency of 4 trains per hour first. Another option could be to continue every other train to Den Helder, which is a frequency of 3 trains per hour. A concise evaluation that a doubling of single track will be required North of Anna Paulowna, but could be dispensed with between Den Helder main and South station. This alternative has not been assessed in detail because it voids the required headway of 4 trains per hour. Furthermore the (internal) turning time requirements at Alkmaar station remain unknown. Equity results will probably be similar to design alternatives (with required expanded infrastructure), as the run times between stations will probably be similar. The Amsterdam – Alkmaar PHS project also represents an uncertainty in the form onward travel and travel times from Alkmaar. It could improve the accessibility potential due to different stopping patterns, but could also have negative effects if the onward connections get deteriorated or severed. The case area would benefit from skipping stations South of Alkmaar because it shortens travel times, which increases the accessibility potential.

Lastly; it can reasonably be expected that future developments will enable run time reductions, due to advances with both rolling stock, interlocking and denser planning practices. This research is executed for current rolling stock, in part for practical reasons and data available. VIRM (and DDZ) are expected become life expired within a decade however. So do parts of the railway infrastructure. This might lead to an opportunity window where a set of key decisions can be taken to accelerate change. Recently the winner of the new intercity service rolling stock contract was announced; manufacturer CAF from Spain. It is expected that operator NS will gradually replace rolling stock, after a period of testing. Proactive lobbying for using the Alkmaar – Den Helder railway corridor as a test and initial deployment area is favourable. It is assumed that this rolling stock will have quicker acceleration than the current VIRM type, which will reduce unrestricted station to station run times. Also the ATB-EG interlocking system is slated to be replaced with ECTS interlocking in the future. Because ECTS is more advanced than present ATB-EG interlocking it is expected that required run time supplements and release times can be reduced, which allows for shorter travel times within the corridor. Therefore the SLT alternatives with expanded infrastructure should be seriously considered, as they allow for faster train paths with less opposing headway conflicts. Not executing infrastructure improvements and extensions of double tracked passing loops might lead to a sub optimal situation, where new trains are unable to use their full potential. This will negatively affect activity-space and accessibility potential in the Northern bit of the evaluated railway corridor, which is shown to benefit most as indicated by the improved equity values.

8 Conclusion & recommendations

8.1 Research conclusions

The main question this research aims to answer is:

"How can equity of public transport network improvements in rural areas be assessed?"

This is addressed with three sub-questions, which are in successive order. Each question uses different components of this research. The developed assessment methodology is the synthesis of this research and is used to answer the first sub question. The second and third sub-questions are covered by the assessment methodology and case evaluation. The sub-questions together answer the main question.

1: How to conceptualise equity and accessibility in rural / regional public transport?

Transport equity is expressed by the distribution of transport benefits between inhabitants of a region. The distribution of transport benefits is not equal between inhabitants, there are differences between inhabitants. Some are disadvantaged due to their income and / or location, especially in rural regions. Expanding the activity-space to key activities is beneficial, which is measured by a change in accessibility potential. Only key activities that are supplied insufficiently in a region are relevant, because this is the burden that disadvantaged inhabitants in the population have to overcome. The distribution of accessibility potential between inhabitants is computed with an equity indicator, for which the Theil index is recommended in the equity assessment methodology.
Public transport planning has a very strong influence on the accessibility potential of locations. PT planning determines timetables, which generates minimum travel times between locations. The minimum travel time between locations is an input of the resistance function, this is an essential component to compute the accessibility potential. The travel time between locations is therefore determined by the PT network design. The shortest possible travel time between locations depends on operating and infrastructure constraints, whom determine which timetables are possible, especially in railway corridors. This is case dependent and varies when multiple alternatives are evaluated. This is set forth in the developed equity assessment methodology of chapter 3.

2: What measures can be taken to improve the equity of a public transport service?

Which measures are feasible and advantageous depends on the evaluated case region, measures are case specific. In general; equity gets improved if measures improve network coverage or reduce in vehicle travel time. Network coverage gets improved by providing new stations at populated places that are underserved, because access time gets reduced. In vehicle travel time is reduced with measures that speed up the service or remove infrastructure constraints. For railways two important measures are changing to rolling stock with faster acceleration and doubling of single track. The exact location of infrastructure expansions has to be determined for measures to be effective. This is done in the methodology by proposing a desired service and modelling corresponding timetables for design alternatives first, followed by assessing what infrastructure is required and where.
Application of the methodology on the Alkmaar – Den Helder case corridor resulted in multiple advantageous measures. Rolling stock with faster acceleration can be used without other actions necessary. New stations are possible in Waarland and Breezand, significant access travel time reductions are possible at these locations. Doubling of single track enables substantial travel time savings; this is required at least North of Anna Paulowna and between Den Helder main to South station, for most of the design alternatives. Additional

doubling of track is required for an alternative with a heterogeneous service, this is outlined in chapter 6 of the report.

3: What are the effects of these measures and how does it impact equity in the Alkmaar – Den Helder corridor?

Application of the assessment methodology on the Alkmaar – Den Helder corridor results in the conclusion that most measures have a substantial impact on transport equity. As measures are grouped into comprehensive design alternatives the differences between these alternatives are analysed and compared between each other and a base alternative, which is the current situation.

In general it is concluded that most evaluated measures will aid a more fair distribution of accessibility between inhabitants, the extent in which equity gets improved differs. Reducing travel time by a change of rolling stock has some effect, but gets counteracted when single tracked sections limit capacity. The equity effect of improved coverage with the provision of new stations is approximately twice as strong compared to just the reduction of in vehicle travel time with doubling of track where required. New stations improve equity to a larger extent than just expanding double track. New stations do have substantial side effects however; they provoke a trade-off between inhabitants. This can be avoided by offering a heterogeneous service, where a service that calls at all stations is alternated with a limited stop service that skips the new stations. This improves equity with approximately 7%, compared to a situation where one type of service is offered.

The use of present infrastructure allows for only minimal equity improvements. Single tracked sections limit equity gains to an improvement of at most 1,06% over the current situation. This can be improved a bit when different rolling stock is used. Significant equity improvements are achieved when single track gets doubled where required. Travel time reductions of up to 6,2 minutes are possible and equity gets improved by 7,3% when SLT rolling stock is used. These equity gains are reduced when VIRM rolling stock is continued to be used, therefore changing to rolling stock with faster acceleration is considered to be advantageous. Rail services of design alternatives that include stations come with an time penalty of 1,9 minute per additional station called at, but this is more than made up for by the equity gained for inhabitants that live nearby the new stations. Equity gets improved with 12,1% for Waarland station, 11,4% with Breezand station and an equity improvement of 16,3% is possible when both stations are built. Side effects of opening these new stations are not negligible though. Equity gets improved with 23,65% when a heterogeneous service is introduced of which some services skip by the new stations. This equity difference of 7,4% with the single service alternative is attributed to inhabitants of Den Helder, Anna Paulowna and Schagen avoiding time loss by skipping the new stations. The trade-off between inhabitants at these different locations should not be neglected, as it may lead to opposition. The preferred alternative changes when the equity improvements are compared with the infrastructure investment required. This results in the conclusion that opening both Waarland and Breezand while offering a single type of service is the most effective in terms of equity gained versus infrastructure investment required.

Final conclusion

In conclusion it proved to be possible to identify and quantify equity gaps between inhabitants of regions with a partly rural composition. This is done with the developed assessment methodology, which explicitly connects the distribution of accessibility between groups of inhabitants with travel time consequences of PT planning. The developed equity assessment methodology is the synthesis of this research and scientific contribution, as it is one of the first applications of transport equity improvement methodology on a regional railway corridor in a partly rural region. The societal contribution of this research is the evaluation of the case area, for which it is advised to improve equity between inhabitants in the Alkmaar – Den Helder corridor by reducing travel time with at least faster accelerating rolling stock and preferably a partial extension of double track on the railway corridor. New stations are also advantageous, but the interest of inhabitants that pass through should not be forgotten. While equity proved not to be quantifiable in an absolute sense, the outcomes of this research prove that substantial equity improvements are possible within the evaluated regional railway corridor. As such it is able to contribute to the improvement of equity between inhabitants and affiliated societal challenges such as the prevention of transport poverty and social exclusion. The developed equity assessment methodology is able to evaluate most transport equity effects with application of the following recommendations.

8.2 Recommendations

The equity assessment can be improved even further by conducting follow-up research in subjects that could not be included in this study. These remain to be addressed due to a number of reasons, of which a lack of data is the most important. This is noted to be a common hindrance for rural research. While the open ends did not hinder the PT evaluation and equity assessment, it should be considered that equity differences could be larger than currently measured. Recommendations for follow up research are made, split between scientific and societal research.

8.2.1 Scientific recommendations

Transport equity is related with transport poverty. This thesis follows the theory that transport poverty is the result of not having sufficient opportunities nearby, requiring lengthy travel. High costs are therefore the result of the long travel times. This is assumed to be measurable by inclusion of transport fares into the resistance function. Ideally this expanded resistance function includes the affordability of fares for specific population groups. This will an accessibility potential that is distinctive between income groups, which is expected to result differences between inhabitants becoming larger and equity reduced. Little research has been done on the subject, especially in regional transport. There is also no consensus because different ethical theories are applied among the studies conducted. It is therefore recommended to research how the affordability of public transport could be included into resistance functions.

This research produced its own generalized equity improvement methodology, which is a novelty. The PT planning component used in the methodology could be taken further however. Equity can be included in other PT planning research via TNDSP models. TNDSP models are optimisation models that use an objective function. Multiple objective functions exist, but not one that considered the equity implications of network planning decisions. It is suggested to create a new objective function that includes socio demographic data and considers equity effects of PT planning decisions.

8.2.2 Societal recommendations

Additional research is needed on the affordability of PT fares and presence of transport poverty in the evaluated corridor. Data can be obtained with the execution of stated and revealed choice research. This study should have multiple objectives. Knowledge on the presence or severity of transport poverty has to gained. It could also asses the expected effectiveness of different PT fares or e-bike subsidization schemes. The research should also aid the creation and validation of an detailed resistance function that is able to assign inhabitants a standard or restricted accessibility potential based on their susceptibility to become transport impoverished.

Furthermore it is strongly recommended to assess how accessibility potential differs between transport modes within the corridor. Accessibility potential is expected to differ substantially between PT passengers and users of cars or other private motor vehicles. Inhabitants that do have the option of using cars are likely to have an increased accessibility potential because their travel times will most likely be shorter than with inhabitants that are captive users of PT. Inclusion of car users will therefore have a significant adverse effect on equity measured between inhabitants. This is not necessarily considered to be bad because it reflects reality closely. Inclusion requires a road traffic simulation model with a high level of detail within the case area. The case region is covered by some traffic models, NRM-West and VENOM for example, but not in the level of detail used in this research. Therefore it is recommended to obtain a model of at least a PC4 level of detail. A higher level of detail is preferred however, as this allows a more detailed equity evaluation when socio-economic data with a higher level of detail becomes available as well.

For the railway component of this research it is recommended to do a microscopic simulation for the preferred design alternatives, in order to verify the feasibility of the desired timetables and measures of alternatives with a high level of detail. This is required, in part because this research is preliminary and block sections were not considered to be required given the strategic scope. This requires dedicated software, which has to be sourced. It is also advisable to include expected innovations when details become available. Examples are the replacement of interlocking and new rolling stock.

The final recommendation is to carry out a societal cost-benefit and multi criteria analysis on the results of this thesis and compute the willingness to pay for fairness. The societal cost-benefit analysis could not be executed within this study due to the absence of available data. Rolling stock operation and passenger data are required at least. Detailed key figures on the economics of operating SLT and VIRM rolling stock are needed to compute the cost of operation. Passenger data is required in order to estimate the sum of benefits due to the travel time reductions. It is commended to include and weigh the outcomes of the societal cost-benefit analysis, equity improvements and passenger plus stakeholder preferences with a multi criteria analysis. This requires stakeholder consultation. Required data is available at stakeholders, so collaboration is required. Caution should be applied when monetizing effects however, for the reason that societal cost-benefit and multi criteria analysis are utilitarian methods. Utilitarianism has drawbacks that have been discussed in the ethical theory section of the literature review. Care must be taken that the equity outcomes not get diluted within follow up research.

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Appendix A: Scientific paper

Assessment methodology to improve equity within regional PT networks

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Abstract:

Public transport is important for society, it provides accessibility to opportunities. Accessibility is not distributed evenly. Some inhabitants are disadvantaged, which has negative impacts on society. The distribution of accessibility between inhabitants can be measured with transport equity. The PT network should be improved in order to reduce the disadvantage of inhabitant groups. It is not defined how this could be done for regional PT networks. A six step assessment methodology is created for this purpose. The assessment method addresses what objective focus should be applied to, what improvements are possible in PT networks, what measures should be applied and what the equity effects of these measures are. Application of the assessment method yields that substantial equity improvements are possible within the Alkmaar – Den Helder railway corridor. Marginal equity improvements are achieved by changing rolling stock, significant improvements with local doubling of single track and substantial improvements when additional stations are opened. The assessment methodology is also able to identify the presence of trade-offs between inhabitants by mutual comparison.

Keywords: equity, fairness, PT planning, railway timetabling, public transport policy, accessibility, regional PT, rural area

1.Introduction

People depend on public transport, especially the fraction of inhabitants not in possession of private motor vehicles (CBS, 2018). There is a difference in how inhabitants are served by PT. Accessibility is not spread evenly within regions. Some are better served than others. This is especially true for inhabitants living within rural regions (KiM, 2018). Inhabitants of rural regions are subject to long trip times. Inhabitants may become disadvantaged, which has societal implications (van Wee & Geurs, 2011). This can be prevented by improvements to PT networks. It is not clear how regional PT networks should be assessed and improved (Hansson, Pettersson, Svensson, & Wretstrand, 2019). An evaluation should be done to assess how accessibility is distributed between inhabitants and regional PT networks can be improved. It is proposed to evaluate the equity within regional PT networks. The problem is that there is neither a single definition of equity nor consensus on the best approach to achieve regional PT improvements. Most literature is not directly applicable, most research is that if done in urban networks.
Preferences, coverage and operating practices may differ improved (Hansson, Pettersson, Svensson, & Wretstrand, 2019).

This research addresses two aims. The first is to express what aspects of transport equity apply specially to regional PT networks. Benefits of transportation are not distributed equal (Litman, 2021). Equity is complex however, it differs between cases and needs to be decomposed (El-Geneidy, et al., 2015). This is essential because at least 12 indicators exist (van Wee & Mouter, 2021)The second objective is to address the potential of PT network improvements specifically for regional networks. Planning should be user centric (Tao, Fu, & Comber, 2019). Insights from urban planning cannot be applied outright because passenger preferences differ (Hansson, Pettersson, Svensson, & Wretstrand, 2019)

After drawing up these starting points a methodology must be drawn up in order to identify and asses the effects of PT planning measures. The lack of consensus on transport equity assessment and application to regional PT planning represents a knowledge gap. This knowledge gap will be filled with the research question:
How can equity of public transport networks in rural areas be assessed?

2. Literature
Transport equity assesses how transport benefits are distributed between inhabitants (Di Ciommo & Shiftan, 2017). This is generally decomposed into three components. Which inhabitants are evaluated and how do inhabitants differ, what effects are assessed and how is this distributed between the inhabitants in question (Martens & Di Ciommo, 2017). The assessment should start by identifying the specific disadvantage according to Van der Veen et. al. (2020). Common examples of these are inhabitants with a lower net worth, people without driving licences, elderly and inhabitants of rural regions (KiM, 2018). It should be considered that factors correlate with income and location. The effects transportation are distributed between inhabitants with an equity indicator of which multiple exist, which are written to specific ethical theory (Alonso González, Jonkeren, & Wortelboer-van Donselaar, 2022). This study adheres to egalitarian theory, all inhabitants should be treated equal and the greatest benefit should go to inhabitants who are at an opportunity disadvantage. This is chosen over sufficientarianism because this avoids an arbitrary set cut-off value. The Gini coefficient, Atkins-index and Theil-index are common (Souche, Mercier, & Ovtracht, 2015). Theil index is chosen, because it is better in arbitrarily assigning groups and is not susceptible for bias with small group sizes (Camporeale, Caggiani, Fonzone, & Ottomanelli, Quantifying the impacts of horizontal and vertical equity in transit route planning, 2016).

Transport equity valuates the accessibility distribution for a specific network structure. Accessibility should be measured for a particular PT network. Accessibility is the expression of interaction potential of inhabitants for trips between points for specific purposes (Miller, 2018). Accessibility is conceptualised by expressing the cumulative number of opportunities to relevant key activities. Assessment with activity-spaces are preferred because allow for the evaluation of location and social factors (Lucas, 2012). Accessibility is therefore best measured by computing activity-spaces for key activities from locations of origin. The cumulative opportunity of these spaces is limited by transport resistance (Danesi & Tengattini, 2020).

Transport resistance is expressed best with gravity models applying an regression function on the total travel time (Östh, Reggiani, & Nijkamp, 2018). This is chosen over a generalized transport cost function that could include transport fares. This choice is made because the weights of components are unknown and fares are considered to be an derivate of travel time. Transport fares are not included because they are inelastic (Nuworsoo, Golub, & Deakin, 2009), the total fare paid is considered to be a derivate of the length of the required trip (Laird & Mackie, 2014).

Ex-ante research on equitable regional PT planning is limited (Bruinsma, et al., 2008). This is partly because PT planning is usually divided in sub steps that are treated independently from each other. Strategic PT planning should be evaluated because equity changes slowly and is a long term effect (Di Ciommo & Shiftan, 2017) (Guihaire & Hao, 2008). Strategic planning contains network design on a railway corridor, with route design, frequency setting, stop selection, rolling stock selection and strategic timetabling (Hansen & Pachl, 2008). Changes to the service are desired, these should reduce the minimum travel time realised by the PT network. Changes should be considered per railway corridor (Cacchiani & Toth, 2012).
The possibility for change is limited by path dependence, especially with railways. Incremental change is possible however (Bruinsma, et al., 2008). For regional railways these are; changing the number of tracks, reducing the travel time over the alignment and changing the stop spacing with building new stations. This requires planning, timetabling, coordination between stakeholders and investment (Weik, 2020). Two factors are of influence on the minimum travel time; a trade-off between the travel time of passengers and limitations of single track. The trade-off between passengers manifests itself when a new station is built and stop spacing gets changed. Some inhabitants will reduce their access time substantially when a new station is built, but others receive a significant in vehicle time increase when their service stops at a new station (Sharav, Givoni, & Shiftan, 2019). Single track limits capacity, the run time over these sections should be shortened (Landex, 2009). Run time reduction can be done with either faster acceleration and higher speed of rolling stock, building new crossing sections, lengthening existing crossing sections and allowing for faster arrival/departure at crossing sections (Landex, Kaas, & Hansen, 2006).
Timetabling is an essential part of strategic planning. It is required to evaluate if chosen design alternatives will have feasible timetables. This can mostly be done on an aggregated level, but requires a higher level of detail on some locations. Mesoscopic modelling is proposed.

With mesoscopic modelling the basic path sequence of a railway service is determined first, followed by path finetuning in greater detail where required (Botte & D'Acierno, 2018). Special attention has to be applied to the begin / end of single track sections (Lindfeldt, 2012). The planning of new stations requires specific attention, as their location is not set in stone. The location of stations can be tested by placing dummy nodes in the model (Sparing, 2016).

3. Methodology

The literature is assembled into general assessment methodology. This is done according to a concise heuristic. The potential for improvement of railway networks starts with identifying the needs of passengers, followed by an analysis of the network, suggesting and creating timetables of changes and evaluating whether the needs of passengers are met (Gasparik, Dedik, Cechovic, & Blaho, 2020). This heuristic can be combined with the accessibility potential operationalization and equity assessment. Then the following methodology for equity evaluation of regional PT networks becomes a six step approach. The following steps are identified:

1. Identify travel motives and distinctions between inhabitants in the region.
2. Assess the range of infrastructure and rolling stock
3. Analyse the potential for travel time reduction
4. Determine timetables for each proposed change
5. Compute the accessibility potential within the region for each alternative
6. Asses equity effects for all inhabitants per alternative and compare change

Travel motives of inhabitants are key activities that are not supplied sufficiently locally and require travel away from the location of origin (Lucas, 2012). There are seven types of key activities, of which place of work is particularly important. The difference between inhabitants are at least location within the region under evaluation and a form of prosperity indicator (Martens, Bastiaanssen, & Lucas, Measuring transport equity: Key components, framings and metrics, 2019). This step is done first to investigate data dependencies.
Assessment of the range of infrastructure and rolling stock is required to obtain data on the infrastructure, current service and dynamic performance of applicable rolling stock. This is required as input for steps 3 and 4, due to path dependence. The current situation is also the base alternative of step 5. The potential of travel time reduction is case dependent. Different scenarios to reduce the minimum travel time are possible. The in vehicle time can be reduced with different rolling stock, reduction of single track infrastructure or both.
Access time can be reduced for some settlements with new stations. Design alternatives are made for these scenarios. Feasible timetables need to be modelled for each design alternative (Landex, Kaas, & Hansen, 2006). This is an iterative process where measures are applied to remove headway conflicts from path sequences of services (Botte & D'Acierno, 2018). Measures are applying holding at a station, delaying the start of a path sequence or computing the length of additional double track required that allows for unrestricted crossing of opposing services. The timetabling process generates a feasible basic hour pattern, time distance diagrams, the location and length of expanded double tracked crossings required and minimum travel times between stations for each design alternative.
The changes to the network reduce travel time, which should improve the activity-space of inhabitants., ideally so that they achieve an equal distribution of opportunity through a region. The accessibility potential is computed by calculating the activity-space for a specific key activity per location of origin. A gravity model with exponential decay is used for this purpose. This model computes the chance of interaction by diminishing the attractiveness to opportunities further away from the location of origin (Geurts & van Wee, 2004). The attractiveness gradually diminishes but never becomes zero. For equity research this continuous function is preferred over a discrete cut-off value. The shortest path between locations is used (Camporeale, Caggiani, Fonzone, & Ottomanelli, 2016). Connecting services out of the region should be included to simulate onward travel opportunities (Sharav, Givoni, & Shiftan, 2019).
The following operationalization is used:

$$A_i = e^{-\beta c_{access}(i)} * e^{-\beta c_{TTL}} * \sum_{j=1}^{y} D_j * e^{-\beta c_{egress}(j)} \qquad (1)$$

The place of origin *i* has a path to station *i* with constant caccess(i). One path exists per station par, see the railway timetable. Resistance is given by cTTL. Parameter cegress(j) is the same as for place *i* in area A. Equation (1) requires equition (2), which is the resitance function that represents Dutch commuting. (Östh, Reggiani, & Nijkamp, 2018).

$$f(C_{ij}) = e^{-\beta c_{ij}} \qquad (2)$$

Time *ij* is the cost Cij of concern, which is multiplied with parameter -β.
Equity assessment is done by commuting the distribution of opportunity between inhabitants in a case area for each design alternative. Application of the Theil index is proposed for this research. The Theil index is preferred over the more common Gini coefficient because the Theil index allows for arbitrary assignment of inhabitants into groups, without becoming biased (Souche, Mercier, & Ovtracht, 2015). The Theil index compares the accessibility contribution of a group to with the mean of the population (van Wee & Mouter, 2021).

Equation 3 contains a refined version of the Theil-index. Here the index is decomposed into subgroups (Hamidia, Camporeale, & Caggiani, 2019). This allows inhabitants to be divided for location and income. Equity is calculated within and between the groups.

$$T = \text{within} + \text{between} = \sum_{l=1}^{M}\sum_{k=1}^{N_k}\frac{1}{P_T}\frac{A_{lk}}{A_l}ln\left(\frac{A_{lk}}{A_l}\right) + \sum_{l=1}^{M}\frac{P_l}{P_T}\frac{A_l}{\bar{A}}ln\left(\frac{A_l}{\bar{A}}\right) \quad (3)$$

Eq. 3 contains M population groups *l*, with N inhabitants *k*. Population P_T gets divided in *l* people that belong to subgroup P*l*. Inhabitant l has the accessibility A_{lk} and accessibility A*l* is the group per capita average accessibility. This allows for distinctions to be made on income and location of inhabitants, so for multiple factors that have an influence on equity. The index becomes ln (N) when equity is 0% and zero when equity is 100%. The equity between inhabitants is computed by dividing the T value with ln (N). This results in the ability of the Theil-index to yield a value that expresses the level of equality within the population. This can be compared between the identified design alternatives.

4. Case

The methodology is tested with a case evaluation. This is executed in the Kop van Noord-Holland region. Specifically in the Alkmaar – Den Helder corridor, without the inhabitants of the municipalities of Alkmaar, Bergen, Opmeer and Wieringermeer area of Hollands-Kroon. This case area is partly rural and subject to population decline (de Voogd & Cuperus, 2021). This justifies evaluating this corridor.
Employment is identified to be a key activity of interest, as workplaces fall below the average in the Province and wider Randstad region (CBS, 2021). Supply of other key activities did not prove to deviate substantially. Inhabitants are divided based on their location and income group, with income in two groups: inhabitants with any or none susceptibility to transport poverty (CBS, 2019). Privacy results in the socio economic data to be of the lowest detail level. The current range of infrastructure is the present railway, which is single track North of Schagen, passing loops are present at intermediate stations. VIRM and SLT are used in the Province. Dynamic performance data is sourced publically. Scenarios for travel time reduction are evaluated with design alternatives. These are;

0. Current situation
1. VIRM with current infrastructure
2. SLT with current infrastructure
3. VIRM with expanded infrastructure
4. SLT with expanded infrastructure
5. SLT with Waarland station
6. SLT with Breezand station
7. SLT with Waarland & Breezand station
8. VIRM and SLT with Waarland & Breezand station

The design alternatives are timetabled with applicable standards for a frequency of 4 trains per hour. This is a policy goal and an improvement from the current frequency of 2 trains per hour (Provincie Noord-Holland, 2019). It is expected that an increased number of headway conflicts will occur as a result. The location and distance of additional double track required is computed as part of this process. The accessibility is computed for every design alternative, with the assumption that each inhabitant in a location has the same decay function and uses the railway. In reality this may differ, but this cannot be evaluated with the available data. This limits the generalizability of the equity results to differences between the base and design alternatives of the railway corridor. This will result in an underestimation of inequity in the case area, but this is not considered to be a problem because this still allows to evaluate and rank the equity effects of the design alternatives.
The dynamic performance of rolling stock (Huurman, 2013) (Henning van Steenis, 2010), timetable standards from the infrastructure manager (Prorail, 2017), present situation and design requirements (Openrailwaymap, S.D.) (Prorail, 2016) are used to model train paths first, address headway conflicts and model basic hour pattern timetabled. The accessibility potential is computed with the beta value of β = 0,03 (Muhammad, 2007).
The excel spreadsheet program has been used for this purpose, as with the computation of accessibility potential and equity indicator.

5. Validation

Validation is executed by the conduction of a series of tests that change specific components. The equity assessment model is tested as each of these tests covers a different aspect of the model. The following tests are done:
1.) Reduction of access time: average cycle speed from 16 km/h to 22 km/h
2.) Resistance: stronger decay with β = 0,036.
3.) Railway timetable. 20% shorter travel time
4.) Railway timetable. 20% longer travel time
5.) Inhabitants: 2000 additional in Waarland of low income class
6.) Inhabitants: Den Helder doubled, proportioal income classes
7.) Oppertunity: +25% more workplaces in Alkmaar
8.) Oppertunity: +25% more workplaces in Haarlem
These tests have expectations. Test 1,3,6 improve equity. Test 2,4, 5 (conditional) reduce equity. Test 5 improves equity, only for SLT Waarland alternative. Test 7,8 no major change in equity, but test 7 is expected to cause stronger reaction than test 8.

Validation:	Equity							
Test	1 Access	2 Resistance	3 Railway	4 Railway	5 Inhabitants	6 Inhabitants	7 Oppertunity	8 Oppertunity
Alternative			timetable -20%	timetable +20%	Waarland +2000	Den helder x2	Alkmaar +25%	Haarlem +25%
Current	0,173%	-0,260%	0,113%	-0,123%	-0,003%	0,117%	-0,003%	-0,002%
VIRM	0,171%	-0,269%	0,120%	-0,131%	-0,002%	0,113%	-0,007%	-0,002%
SLT	0,167%	-0,264%	0,110%	-0,127%	-0,003%	0,111%	-0,006%	-0,001%
VIRM expand.	0,173%	-0,264%	0,111%	-0,121%	-0,003%	0,118%	-0,006%	-0,001%
SLT expanded	0,170%	-0,256%	0,095%	-0,111%	-0,004%	0,117%	-0,005%	-0,001%
SLT Waarland	0,135%	-0,234%	0,114%	-0,129%	0,003%	0,097%	-0,007%	-0,002%
SLT Breezand	0,149%	-0,244%	0,097%	-0,116%	-0,005%	0,095%	-0,005%	-0,001%
SLT Wl. & Br.	0,114%	-0,222%	0,118%	-0,135%	0,003%	0,073%	-0,007%	-0,002%
Mixed	0,114%	-0,200%	0,097%	-0,106%	-0,001%	0,071%	-0,006%	-0,001%

Table 1: validation

The validation did not give any unexpected results the methodology is proved to work and results can be accepted.

6. Results

Timetable results are presented first, followed by accessibility potential and equity.

Railway timetabling

Timetable modeling yields feasible basic hour patterns for all design alternatives for the frequency of 4 trains per hour. This does come with side effects. The design alternatives with present infrastructure have to use holding, which is expected to reduce the accessibility potential, which is in turn detrimental to equity. The alternatives with expanded infrastructure or stations require investments in the infrastructure however.

The alternatives with present infrastructure achieve limited travel time reduction VIRM is 2,0 and SLT 3,4 minutes faster, compared to the 37,0 minutes over the entire corridor for the present situation. Their capabilities are reduced when their respective train paths have to wait out headway conflicts.

Travel times decrease significantly when infrastructure is expanded where required, a 3,8 minute reduction is possible for VIRM and 6,2 for SLT. This requires the 1,7km single tracked section between Den Helder and Den Helder Zuid, plus a 1,1km section North Of Anna Paulowna to be double tracked. Calling at one of the new stations comes with a time penalty of 1,9 minute, per additional station.

The design alternatives SLT Waarland, SLT Breezand require the same track to be doubled as the prior alternatives.

The SLT Waarland & Breezand alternative needs 3,0 km of trach to be doubled between Anna Paulowa and Breezand, plus 1,1 km north of Den Helder Zuid. The train path of the SLT Waarland & Breezand alternative takes 34,6 minutes over the entire corridor.

The mixed alternative, which alternates between a SLT calling at all stations and a VIRM skipping Waarland and Breezand, is able to retrieve some travel time. While the SLT takes 34.6 minutes to reach Alkmaar from Den Helder it also includes a VIRM train path to Alkmaar that skips Waarland and Breezand station. The VIRM requires 33,6 minutes. This mixed alternative does require the most additional double tracking however; 10,7 km in total. A time distance diagram with an overlay of train paths is given in figure 1, timetables are included in the appendix.

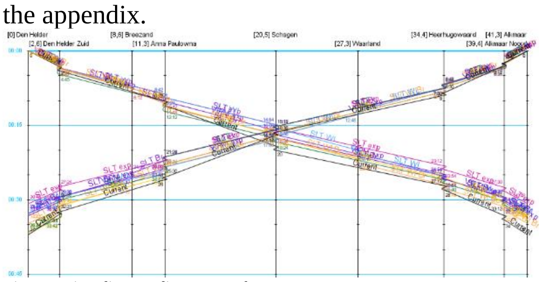

Figure 1: time distance diagram overlay

Accessibility potential

The accessibility potential is reported in an appendix as it mainly has an internal purpose. It is used to provide accessibility data that is distributed between groups of inhabitants with the equity evaluation. Some interesting observations are made, which follow. The average per capita accessibility potential reveals that any design alternative is better than the present situation. The increased potential ranges from 9,8 to 15,7% between design alternatives. It is very interesting that the accessibility potential differs significant between the current, SLT, VIRM, VIRM expanded and SLT alternatives, but does not change substantially between the SLT expanded alternative and any of the alternative that considers new stations. This indicates a tradeoff between inhabitants and stresses the need for an equity evaluation.

Alternative	Equity: location and income equity (%)	improvement over current (%)	Equity: location equity (%)	improvement over current (%)	Equity type Improvement difference (%)
Current	99,15%	0,00%	99,57%	0,00%	0,00%
VIRM	99,16%	1,06%	99,58%	0,57%	47,60%
SLT	99,19%	3,78%	99,59%	1,94%	52,60%
VIRM expanded	99,19%	3,39%	99,59%	1,70%	49,50%
SLT expanded	99,23%	7,32%	99,61%	3,67%	49,90%
SLT Waarland	99,27%	12,12%	99,63%	6,13%	50,70%
SLT Breezand	99,27%	11,43%	99,63%	6,03%	53,20%
SLT Wl. & Br.	99,32%	16,26%	99,66%	8,53%	52,80%
Mixed	99,39%	23,65%	99,69%	12,23%	51,90%

Table 2: equity results

Equity assessment

Given the results of the alternatives it is concluded that reduction of access travel times has a greater effect on equity than reduction of in vehicle travel time. Alternatives that include new stations have at least double the equity improvement over the alternative that just includes expanded infrastructure. This does not mean that in vehicle travel time should be ignored. A tradeoff between passengers does occur, this is indicated by the substantial difference in equity between the mixed and SLT Waarland & Breezand alternatives. The 7,3% equity difference is attributed to the limited stop IC train path. Furthermore it is observed that vertical equity, evaluating for location and income group, reveals approximately 50% more equity between inhabitants compared to horizontal equity (using location only). It is advisable to always include groups divided by income or other welfare indicators.

The results of the equity case evaluation are interesting. A clear distinction in equity scores of design alternatives is observed. VIRM, SLT with present infrastructure and VIRM with expanded infrastructure did not yield an significant equity improvement. Discussed equity improvements are relatively minor compared to the SLT with expanded infrastructure alternative and alternatives that include additional stations.

Alternative	Improvement (%)	Infrastructure cost (x1000)	Marginal cost of equity improvement (x1000)
Current	0,00%	n/a	n/a
VIRM	1,06%	n/a	n/a
SLT	3,78%	n/a	n/a
VIRM expanded	3,39%	€ 12.471	€ 3.676
SLT expanded	7,32%	€ 18.990	€ 2.594
SLT Waarland	12,12%	€ 22.378	€ 1.847
SLT Breezand	11,43%	€ 22.378	€ 1.958
SLT Wl. & Br.	16,26%	€ 34.387	€ 2.115
Mixed	23,65%	€ 67.159	€ 2.840

Table 3: marginal infrastructure investment cost

As the design alternatives with additional stations have substantially higher equity improvement than the SLT with only expanded infrastructure alternative, it can be concluded that the effect of access time reductions is of a higher magnitude than the reduction of in vehicle travel time. This claim needs some nuance however.

The higher equity improvement of the mixed alternative over the alterative with both stations is an indication that travel time tradeoffs between inhabitants are present within the corridor. The 7,4% can be attributed to the shortest path from Den Helder, Anna Paulowna and Schagen using the limited stop VIRM service, which has a shorter travel time than the SLT service that also calls at Waarland and Breezand. So, new stations will cause inequity, unless these effects are mitigated with a heterogeneous service.

The alternatives that change infrastructure require investment. The cost of these investments is computed using key figures and included in an appendix. The costs can be set off against the equity gained. Table 3 contains the marginal cost of equity improvement. The SLT Breezand alternative has the lowest marginal cost. The equity improvement of the SLT Waarland & Breezand alternative are substantially higher however, with only a 10% increase in marginal cost of equity improvement. Therefore the SLT Waarland & Breezand alternative is endorsed.

7. Discussion
The equity differences between the design alternatives and current situation point out that welfare gains can be made by changing the PT service. Extending double track is considered to be worthwhile, as most design alternatives have overlap in where they require the doubling of single track alignment.

Not all effects and consequences could be measured however. This is due to the unavailability of data. A cost benefit analysis of the outcome is not possible due to passenger and vehicle operation data not being disclosed to the public.
Another effect that could not be addressed is the influence of transport poverty. Including transport poverty requires a different parameter that considers the susceptibility of inhabitants to transport poverty. This parameter requires data, which is not available. Additionally; private motor vehicles do provide shorter travel times than PT, but computation of affiliated travel times requires detailed traffic models, which do currently not exist for the area. Private motor vehicles are not included for this reason. Despite the two shortcomings the results of this research can be used, with the notion that the equity assessment is done between railway alternatives only.

8. Conclusion
This research combined transport equity as an social indicator with PT planning and railway timetabling. It connects the distribution of accessibility between groups of inhabitants with travel time consequences of PT planning. Equity of public transport networks in rural areas can be assessed by doing an equity evaluation on accessibility effects PT network changes, preferably for multiple network alternatives. This can be done with the outlined assessment methodology.

The first step is to evaluate the needs and differences between groups of inhabitants. The composition of these groups has to be relevant; so targeted to groups that may be at disadvantage. This research identified location and income to be distinctive for the region assessed.
There are multiple ways to improve equity of a PT service. Improvement measures have to be incremental in rural areas. Access / egress time can be changed with providing new stations and supporting infrastructure. Travel times between stations can be shortened with faster accelerating rolling stock and / or removing time lost due headway conflicts with doubling sections of single track. This should happen at locations where disadvantaged inhabitants benefit the most.
This is determined by obtaining travel times for the regional PT network, for every alternative assessed. The resulting timetables are used to construct shortest paths with minimal travel times between locations, which is used to compute the activity-space of inhabitants for the previously identified key activities that require travel. The accessibility potential is required, which is the cumulative number of relevant key activities within the activity-space of inhabitants. Equity gets determined by computing the distribution of accessibility potential between inhabitants.

This methodology got applied to the Alkmaar – Den Helder railway corridor. By comparing the differences between alternatives and identifying root causes the following general conclusion is drawn;

Shortening travel times by changing to rolling stock with faster acceleration has a minor effect; an equity increase of 3,8%. This is the result of train services being hindered by opposing traffic. Eliminating time loss of single tracked sections has a greater effect on equity than changing rolling stock, equity between inhabitants gets improved with 7,3%. The equity effect of in reduced access / egress time by providing new stations at underserved settlements is substantially larger than the effect of vehicle time reductions. Improvements between 11,4% and 16,3% are possible. The new stations are not beneficial to all however. This is revealed by the 7,4% equity gain that is realized when a heterogeneous service with limited stop service is introduced. So some inhabitants become disadvantaged when new stations are opened. There is no easy solution, which proves the necessity of transport equity assessments.

Recommendations
It is recommended to do follow up research. The influence of the factor transport poverty on the resistance function should be defined. Additionally it is advisable to improve traffic models NRM-West and / or VENOM with zones of a higher detail for the researched area. The Alkmaar – Den Helder area is currently covered as exogenous zones only, has a large mesh size, which has a low precision. This is not accurate enough for private motor vehicles to be included into the model.
This research should be redone once the above is known, more equity differences between inhabitants are expected with these additional components.

Furthermore it is recommended to include equity and societal implications of PT network design decisions into objective functions of TNDSP models.

Appendix B: Specification of current timetable

Currently a service with a basic 30 minute headway is offered. This rail service generally consists of NS intercity series 3000. This is expanded with intercity series 800 during rush hour. Most of these additional rush hour services terminate at Schagen station. Some services of train series 800 begin or end at Den Helder. The extension of series 800 to Den Helder is currently limited to 2 trains per rush hour period and directional. The directionality of this service is to Alkmaar in the morning rush hour and to Den Helder in the afternoon (NS, 2022). Both series 3000 and 800 are worked with VIRM type rolling stock. VIRM rolling stock has subseries of 4 and 6 carriages. This type of electrical multiple unit rolling stock can be coupled together. Composition varies throughout the day. Both single VIRM4, VIRM6 and combinations of VIRM4 plus VIRM6 are used (Treinpostities, 2022). A combination of VIRM4 and 6 is the maximum that the train platforms can accommodate (Prorail, 2017).

Analysis of the current timetable serves multiple purposes. It provides travel times for a 'do nothing' scenario and defines the timing of arrival and departure at Alkmaar station. Timing of arrivals and at Alkmaar is important, because Alkmaar is at the edge of the evaluated network. Timing between arrival and departure at network edge should be kept constant, in order for trains to continue towards Amsterdam. The current timetable is included in table 17, formatted as a service pattern from Den Helder station. This is an adaptation of the published timetable, sourced from NS (2022). One train sequence in the corridor is given, starting from Den Helder station. The arrival and departure times are in minutes after the start event at Den Helder. IC3045 and IC3032 are used, which have a 8 minute arrival-departure headway at Alkmaar. The published timetable of NS does not specify arrival times, with the exception of Alkmaar and Den Helder station. This is fixed by assuming that the minimum prescribed station dwell time is used and factored into the running times between stations. Adding another sequence at 30 minute headway will yield a basic hour pattern.

Train series Station	IC3045	IC3032
Den Helder	0,00	82,00
Den Helder Zuid	4,00	78,00
Den Helder Zuid	4,00	78,00
Anna Paulowna	10,00	71,00
Anna Paulowna	11,00	69,00
Schagen	18,00	62,00
Schagen	18,00	62,00
Heerhugowaard	27,00	54,00
Heerhugowaard	27,00	54,00
Alkmaar Noord	33,00	48,00
Alkmaar Noord	33,00	48,00
Alkmaar	37,00	45,00

Table 17: service timetable. Adapted from NS (2022)

The railway corridor is also used by series 4800 between Alkmaar and Heerhugowaard. This is a local service between Hoorn and Amsterdam, via Haarlem. Series 4800 has a 30 minute headway. It is not included in the evaluation, because it is assumed that the desired 15 minute headway of intercity series 3000 will leave sufficient train paths for series 4800 to continue. Series 4800 uses 4 or 6 car SLT rolling stock both single and combinations of two units (Treinpostities, 2022). This service has a 2 minute arrive-depart headway of opposing services in Alkmaar station.

Appendix C: Rolling stock run time specification

Rolling stock selection

VIRM and SLT rolling stock are chosen for evaluation because they are already used in the area and data on their dynamic performance is available. Usage of current rolling stock is practical, because these are available in depots in Den Helder and Alkmaar. Other homologated rolling stock could be used as well, but this requires transfers of rolling stock and retraining of staff. It is observed in table 18 that other common recent rolling stock has higher power to weight ratios. It is assumed that using SNG or FLIRT3 will result in faster acceleration than VIRM and SLT, provided that this is feasible within the infrastructure.

Type	Subtype	Power (kW)	Weight (ton)	Power to weight ratio (kW/ton)
VIRM	4 car	1608	236	6,81
VIRM	6 car	2312	349	6,62
SLT	4 car	1500	129	11,63
SLT	6 car	2000	175	11,43
SNG	3 car	1600	110	14,55
SNG	4 car	2400	138	17,39
FLIRT3	3 car	2000	116	17,24
FLIRT3	4 car	2000	137	14,60

Table 18: rolling stock. Adapted from NS (s.d.)

Acceleration data for FLIRT3 and SNG is not publicly available however. Therefore it is assumed that SNG and FLIRT3 are able to at least match the acceleration of SLT rolling stock. SLT rolling stock is therefore also a proxy for modern rolling stock in general. Under normal circumstances the assumed quicker acceleration of these types is not needed, but it might prove useful when making up for delay. Usage of SLT acceleration as a proxy could also prove to be useful for evaluating opportunities for recently ordered intercity rolling stock. Manufacturer CAF has been selected to supply a new generation of double deck intercity rolling stock, which might feature quicker acceleration than the currently deployed VIRM. If this is indeed the case the modelled SLT design alternatives may become feasible. Timetabling for the newer types of rolling stock should be done if data becomes available, and when results of this research indicates that swapping rolling stock is advantageous.

Acceleration data

Acceleration data in this research is sourced from other research. The dataset used by Huurman (2013) uses acceleration constants, which are discretised per speed step. These constants defined per speed steps, with each step spanning a difference of 20 km/h. The total range of these steps steps spans from zero to 140 km/h in 20 km/h increments, with one exception. 130 km/h is added, since this is a specific maximum speed for some line sections. The dataset of Huurman (2013) is assumed to be correct, since the author validated its data with Xandra, which is a proprietary application courtesy of Arcadis. Table 19 contains the acceleration and braking times and distance for speeds that are common in the railway corridor.

	VIRM				SLT			
	Accelerate		Brake		Accelerate		Brake	
	t(min)	dst (m)	t(min)	dst (m)	t(min)	dst (m)	t(min)	dst (m)
0-40	0,4	137	0,3	94	0,3	88	0,3	88
0-80	1,0	792	0,6	374	0,7	533	0,5	353
40-80	0,6	654,8	0,3	280,6	0,4	444,7	0,3	264,6
0-100	1,5	1545	0,7	585	1,0	1051	0,7	551
40-100	1,1	1408	0,4	491	0,8	962	0,4	463
0-130	2,6	3567	0,9	988	1,8	2457	0,9	931
130-140	0,5	1013	0,1	158	0,3	714	0,1	149
0-140	3,0	4580	1,0	1146	2,1	3172	0,9	1080

Table 19: Acceleration and braking time / distance for common corridor speeds*, without supplement*

One property of the acceleration data is that it only applies to a single set of 6 car VIRM and SLT rolling stock. These have different power to weight ratios than their 4 car counterparts. It is assumed that this leads to different acceleration behaviour. Even though VIRM4 and SLT4 have a slightly higher power to weight ratio is advisable to raise the timetable supplement factor. This will also compensate for coupled operation of rolling stock, which will have roughly equal acceleration, but have longer signal release times of block sections. For this a one percent increase of the timetabled run time supplement is advised.
Another property of the used acceleration data is the absence of specification on incline. The study where data originates from does not specify incline. It is assumed that this is somewhat included in the acceleration constants, on the basis that the case application covers the SAAL corridor South-East of Amsterdam. The SAAL corridor area is assumed to be similar to Den Helder – Alkmaar corridor, both are situated in relatively level terrain. This assumption cannot be tested, because detailed data on the location and angle of inclination of the railway embankment is not publicly available. In order to compensate for this the run time supplement should be increased with 1 percent. So; the minimum of 5 percent run time supplement should be raised to 7 percent, in order to compensate for variations in rolling stock and inclination.

Furthermore it is assumed for this research that trains try to achieve the shortest possible travel time between stations by using the maximum acceleration available and cruising at constant speed until they are required to brake in order to come to a stop. Short travel times between stations enlarge activity-spaces, which might contribute to a higher equity score. Using the maximum acceleration available for run time computations has downsides, which is discussed later.

Run time computation

The station to station run time is calculated by sum of acceleration, cruising at constant speed and braking between each station for each type of rolling stock. First it is calculated which distance the rolling stock travels at the maximum speed of the line section. Then the time of this phase is calculated and time for acceleration and braking added. When the distance to accelerate to and brake from line speed exceeds the distance between station the line speed is unachievable. A lower target speed is selected in these cases. It is assumed that trains receive an order for the highest speed step that permits any distance at constant speed. Any enroute speed reduction should be achieved before entering the section in question. Inversely; trains are only allowed to accelerate after entering a section with a higher line speed. Infrastructure data is obtained from sections 4.2 and table 25. The preceding section contains relevant acceleration data and supplement parameter values. These are used to compute the distance and time at the maximum permitted line speed.

Table 20 contains the distance and time at constant speed for the current set of stations and table 21 the differences when Waarland and Breezand are included.

Station	Length (km)	Rolling stock achieves (km/h)		Distance constant speed (km)		Time constant speed (min)		Distance constant speed (km)		Time constant speed (min)	
		VIRM	SLT	VIRM	SLT	VIRM	SLT	VIRM	SLT	VIRM	SLT
Den Helder				Departure				Arrival			
	2,60	80	80	1,43	1,71	1,08	1,29	1,43	1,71	1,08	1,29
Den Helder Zuid											
	3,80	130	130	0,22	1,34	0,10	0,62	2,81	2,87	1,30	1,32
	4,90	140	140	2,77	3,12	1,19	1,34	0,18	1,59	0,08	0,68
Anna Paulowna											
	9,20	140	140	3,49	4,96	1,49	2,12	3,49	4,96	1,49	2,12
Schagen											
	13,90	140	140	8,19	9,66	3,51	4,14	8,19	9,66	3,51	4,14
Heerhugowaard											
	5,00	130	130	0,43	1,61	0,20	0,74	0,43	1,61	0,20	0,74
Alkmaar Noord											
	1,30	80	80	0,23	0,50	0,17	0,38	0,27	0,50	0,20	0,38
	0,60	40	40	0,51	0,51	0,76	0,77	0,46	0,51	0,69	0,77
Alkmaar				Arrival				Departure			

Table 20: Run time at maximum line speed (current stations)

Station	Length (km)	Rolling stock achieves (km/h)		Distance constant speed (km)		Time constant speed (min)		Rolling stock achieves (km/h)		Distance constant speed (km)	Distance constant speed (km)		Time constant speed (min)
		VIRM	SLT	VIRM	SLT	VIRM	SLT	VIRM	SLT	VIRM	SLT	VIRM	SLT
Den Helder Zuid		Departure						Arrival					
	3,8	130	130	0,22	1,34	1,43	2,61	130	130	1,43	2,61	0,66	1,20
	2,2	140	140	0,07	0,42	0,03	0,18	130	130	0	0	0	0
Breezand													
	2,7	100	120	0,59	0,03	0,36	0,01	100	120	0,59	0,03	0,36	0,01
Anna Paulowna													
Schagen													
	6,8	140	140	1,09	2,56	0,47	1,10	140	140	1,09	2,56	0,47	1,10
Waarland													
	7,1	140	140	1,39	2,86	0,59	1,22	140	140	1,39	2,86	0,59	1,22
Heerhugowaard		Arrival						Departure					

Table 21: Run time at maximum line speed (new stations)

The time at constant speed of table 20 and 21 is summed up with respective acceleration and braking times from Table 19. A time supplement of 7% is added to these times. This results in table 22 and 23 below.

Run time between stations (in minutes)				
Station	VIRM	SLT	VIRM	SLT
Den Helder (departure)			Den Helder (arrival)	
	2,85	2,68	2,85	2,68
Den Helder Zuid				
	5,66	5,31	5,75	5,36
Anna Paulowna				
	5,88	5,49	5,88	5,49
Schagen				
	8,04	7,64	8,04	7,64
Heerhugowaard				
	3,95	3,60	3,95	3,60
Alkmaar Noord				
	2,70	2,53	2,66	2,53
Alkmaar (arrival)			Alkmaar (departure)	

Table 22: Run time between (current) stations

Run time between stations (in minutes)				
Station	VIRM	SLT	VIRM	SLT
Den Helder (departure)			Den Helder (arrival)	
	2,85	2,68	2,85	2,68
Den Helder Zuid				
	4,42	4,07	4,45	4,10
Breezand				
	2,75	2,45	2,75	2,45
Anna Paulowna				
	5,88	5,49	5,88	5,49
Schagen				
	4,78	4,39	4,78	4,39
Waarland				
	4,92	4,52	4,92	4,52
Heerhugowaard				
	4,92	4,52	4,92	4,52
Alkmaar Noord				
	2,70	2,53	2,66	2,53
Alkmaar (arrival)			Alkmaar (departure)	

Table 23: Run time between stations (with new)

The main purpose of the applied 7% time supplement is to prevent the spread of delay. This creates slack under normal conditions, when train services do not have to recover from delay for example. This slack time could be used for energy efficient driving under normal conditions. Slower acceleration and coasting reduces energy demand. Energy efficient driving is not considered to be part of the strategic scope of this research, but it should be considered as a part of macroscopic simulation, if a more detailed study gets conducted later.

Appendix D: preliminary station selection

Site selection

Multiple populated places in the corridor area are currently not served by the railway. It is assumed that inhabitants of these places have a smaller activity space because of the longer access/egress times to railway stations. Opening a new station on the railway near these places reduces the access time and is assumed to enlarge the activity space for these inhabitants.

Location and potential travel time effects of the station are the main subjects of evaluation. The required (railway) infrastructure is another, but this has to be evaluated once the station site is selected and equity evaluation results in a positive outcome. Stations cannot be built everywhere, have side effects for railway passengers when built and evaluating all potential locations would require excessive effort.

The number of potential station sites is reduced by formulating a set of requirements. There requirements are based on the literature review.

- The station site must be built on the current alignment and not require new right of way.
- The location must be connected with the underlying infrastructure network.
- The station should be located in or near a populated place with substantial inhabitants.
- The location should reduce travel time substantially when compared to a no station scenario.

With these requirements the number of potential locations is reduced. Initially Breezand, Oudesluis, Waarland, de Weel, t' Veld, Noord- and Zuid Scharwoude are nearby the railway line. Connection with the underlying road network is best achieved by selecting sites near level crossings, overpasses or tunnels. Locations that meet this requirement are included in table 24. For these locations an evaluation is done. It is tested if these locations are nearby sufficient inhabitants and if these inhabitants will have substantial travel time benefits. For nearbyness it is assumed that inhabitants within 10 minute cycling distance are likely to use the station. When applying an average cycling speed of 16 km/h (Decisio, 2018) this equates to 2,7 km cycling distance. The number of inhabitants within range is calculated by plotting isochrone maps of the website openroute service, which includes inhabitant data (Openroute service, 2022). The 10 minute cycling distance isochrones from Openroute service are displayed in figure 11 to figure 13.Time saving potential of the location is computed by calculating the travel time difference with and without a station. This is based on the data of appendix E and F.

Location	Street	Inhabitants within 2,7km	Travel time reduction (min)
Breezand	Burg. Lovinkstraat	2719	9,8
Breezand	Zandvaart	2219	9,2
Oudesluis	Sportlaan	631	21,6
Waarland	Weelweg	5635	22,7
Zuid-Scharwoude / Heerhugowaard	Hasselaarsweg	17529	1,9

Table 24: station site evaluation

On the basis of the results of table 24 Oudesluis and Zuid-Scharwoude are excluded from further evaluation. Oudesluis has too few inhabitants. The travel time reduction potential of Zuid-Scharwoude is considered to be too little to justify an station. The travel time reduction at Zuid-Scharwoude is likely to be offset by a time increase of passengers on board the train. The time reduction of 1,9 is less than 2 minutes, which is the time trains usually loose by calling at a station. Furthermore it is assumed that the time reduction will decrease as a result of planned improvement projects at the wider Heerhugowaard station area.

The Weelweg at Waarland is a feasible location sufficient inhabitants nearby, in part because it serves de Weel and t' Veld. The potential of this location could furter be improved by reorganization of the bus network, which is addressed in appendix H.

Breezand has two potential locations. The Burgemeester Lovinkstraat is chosen in this research, because it has a slightly better reach. The distance between these locations is 600 metres, with another street being in partial in proximity. So there is some variation possible in location of the platforms. The railway alignment is in a curve in this area, which is measured to be 1400m. This is assumed to be not a problem because this curve is wider than the minimum 300m of EU directive 1299/2014 article 4.2.9.4 (EC, 2014).
The attractiveness of Breezand station can be raised substantially by improving the road connection with Julianadorp. Inhabitants of Julianadorp have to take a lengthy detour or take a ferry to cross the Noord Hollansch kanaal currently. It is assumed that a bridge can be built over the canal. This will reduce access times for the inhabitants of Julianadorp substantially. The distance between Julianadorp and the projected station location at Breezand is the shortest when the bridge is built at the former Blauwe Keet hamlet. The access times with this bridge are included in appendix G.

Only stations at Weelweg, Waarland and Burgemeester Lovinkstraat, Breezand are included in further evaluation. Providing stations at one or both of these locations is included in the scenario's. Timetables incorporating these stations are made and the equity evaluation will conclude if provision of one or both of the stations is better from a system perspective, or that inhabitants are better off with the stations of the current situation.

Figure 11: 10 minute cycling isochrone Breezand

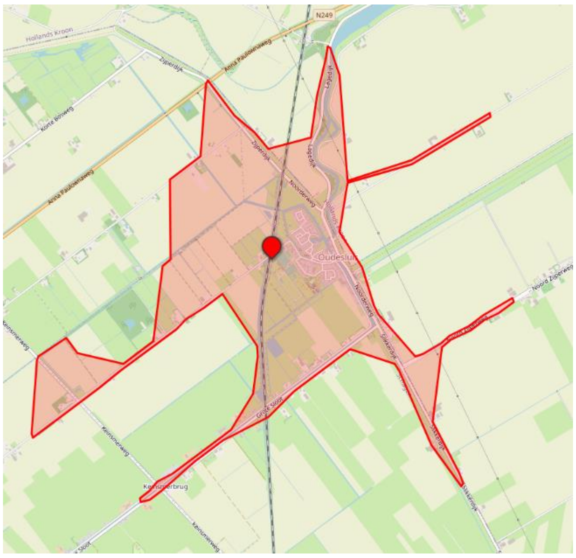

Figure 10: 10 minute cycling isochrone Oudesluis

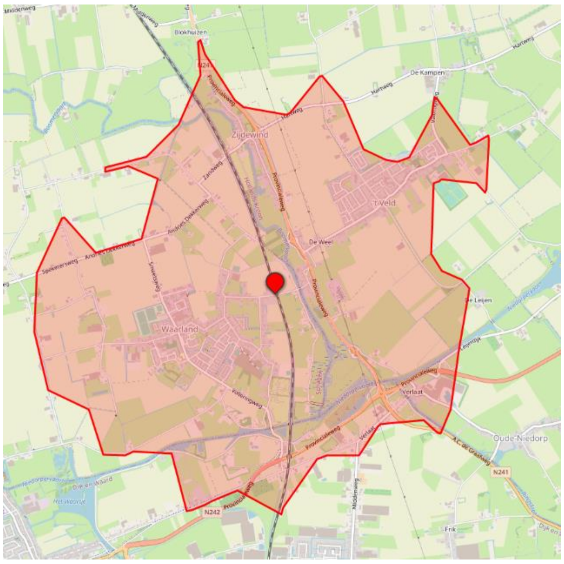

Figure 13: 10 minute cycling isochrone Waarland

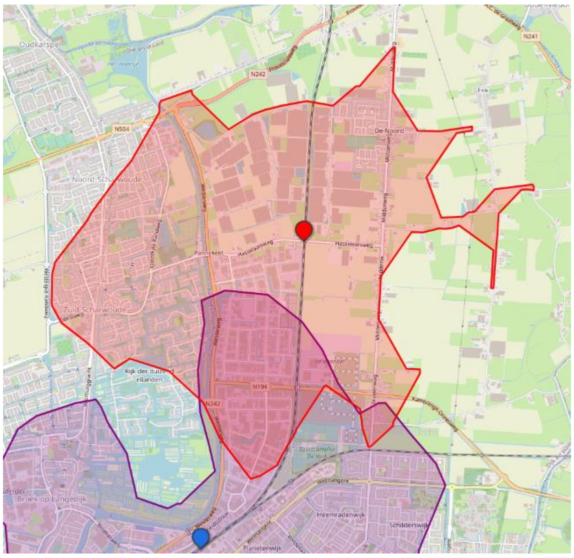

Figure 12: 10 minute cycling isochrone Zuid-Scharwoude, Heerhugowaard

Lineside location

The location on the railway of the projected Waarland and Breezand stations has to be determined. The distance from the projected location to the nearest existing station is calculated. This is done with the measure distance feature of google maps (Google, S.D.). The distance from Waarland and Breezand to their neighbouring stations is included in table 25.

Station	Length (km)	Track number (#)	Permitted speed (km/h)
Den Helder			
	2,60	single	80
Den Helder Zuid			
	3,80	single	130
	2,20	single	140
Breezand			
	2,70	single	140
Anna Paulowna			
	9,20	single	140
Schagen			
	6,80	double	140
Waarland			
	7,10	double	140
Heerhugowaard			
	5,00	double	130
Alkmaar Noord			
	1,30	double	100
	0,60	double	40
Alkmaar			

Table 25: distance to projected stations. Sourced from Prorail (2020), Openrailwaymap (S.D.), (Google, S.D.).

Appendix E: railway timetabling

The process of modelling a basic path sequence into a feasible timetable is described for every railway scenario. The data of section 4.4.1 and 4.4.2 is used to model the timetables. The path sequence process of section 4.4.3 and heuristic of 4.4.4 is executed for all scenarios in the Excel spreadsheet program. Excel is chosen for being readily available and requiring little programming. Path sequences are computed at a tenths of a minute level of detail. This is prescribed as best practice by infrastructure manager Prorail (2016) in their design rules for railway infrastructure.
Using Excel for timetable modelling has some drawbacks. It lacks some sophisticated features of advanced railway planning software. Time distance (TD) diagrams are a hassle to create in Excel and conflict identification plus assessment has to be done manually. TD diagrams are created by importing the train paths into jTrainGraph (Scherzinger, 2021).

For all design alternatives the initial path sequences are given first, plus the method expand this sequence into a basic hour pattern. Time is reported in minutes from the start event. The pattern is analysed for headway conflicts. These conflicts, their duration and resolution are reported, for the current or any required follow-up iterations till a feasible timetable is achieved.

VIRM without changed infrastructure

The initial path sequence of the VIRM rolling stock without any changes in the infrastructure is given table 26. An basic hour pattern is obtained by copying the first path with an 15 minutes added to the path.

Station	IC3001	IC3002	IC3003	IC3004	IC3005	IC3006	IC3007	IC3008	IC3009
Den Helder	0,0	59,4	15,0	74,4	30,0	89,4	45,0	104,4	60,0
Den Helder Zuid	2,9	56,5	17,9	71,5	32,9	86,5	47,9	101,5	62,9
Den Helder Zuid	3,7	55,7	18,7	70,7	33,7	85,7	48,7	100,7	63,7
Anna Paulowna	9,3	50,0	24,3	65,0	39,3	80,0	54,3	95,0	69,3
Anna Paulowna	10,2	49,2	25,2	64,2	40,2	79,2	55,2	94,2	70,2
Schagen	16,0	43,3	31,0	58,3	46,0	73,3	61,0	88,3	76,0
Schagen	16,9	42,5	31,9	57,5	46,9	72,5	61,9	87,5	76,9
Heerhugowaard	24,9	34,4	39,9	49,4	54,9	64,4	69,9	79,4	84,9
Heerhugowaard	25,7	33,6	40,7	48,6	55,7	63,6	70,7	78,6	85,7
Alkmaar Noord	29,7	29,7	44,7	44,7	59,7	59,7	74,7	74,7	89,7
Alkmaar Noord	30,5	28,8	45,5	43,8	60,5	58,8	75,5	73,8	90,5
Alkmaar	33,2	26,2	48,2	41,2	63,2	56,2	78,2	71,2	93,2

Table 26: VIRM wihout changed infrastructure initial

This timetable has conflicts. IC3002 and IC3005 have a 3,76 minute conflict at Schagen station towards Anna Paulowna, IC3002 and IC3007 have a 5,36 minute conflict at Anna Paulowna station towards Den Helder Zuid and IC3002 and IC3009 have a 0,39 minute conflict at Den Helder station towards Den Helder Zuid.
The 3,76 minute conflict of IC3002 and IC3005 is solved first by delaying the start of IC3002 at Alkmaar. This delays the timing of all other events of this train path. The conflict of IC3002 and IC3007 at Anna Paulowna station is reduced to 1,56 minute, therefore IC3007 is held by 1,56 minute Anna Paulowna station. The conflict of IC3002 and IC3009 got increased to 5,79 minutes as a result of the previous measures. The conflict at Den Helder Zuid station

towards Den Helder.becomes 1,91 minute when evaluated from Den Helder Zuid station, therefore IC3002 is held by 1,91 minute at Den Helder Zuid.

3 measures were required, with a delayed start of 3,76 minutes and a total of 3,47 minutes of holding at stations. The resulting feasible path sequence is given in table 27 and time distance diagram of the basic hour pattern in figure 14.

	IC3001	IC3002	IC3003	IC3004	IC3005	IC3006	IC3007	IC3008	IC3009
Den Helder	0,0	66,7	15,0	81,7	30,0	96,7	45,0	111,7	60,0
Den Helder Zuid	2,9	63,8	17,9	78,8	32,9	93,8	47,9	108,8	62,9
Den Helder Zuid	3,7	61,1	18,7	76,1	33,7	91,1	48,7	106,1	63,7
Anna Paulowna	9,3	55,4	24,3	70,4	39,3	85,4	54,3	100,4	69,3
Anna Paulowna	10,1	53,0	25,1	68,0	40,1	83,0	55,1	98,0	70,1
Schagen	16,0	47,1	31,0	62,1	46,0	77,1	61,0	92,1	76,0
Schagen	16,8	46,3	31,8	61,3	46,8	76,3	61,8	91,3	76,8
Heerhugowaard	24,9	38,2	39,9	53,2	54,9	68,2	69,9	83,2	84,9
Heerhugowaard	25,7	37,4	40,7	52,4	55,7	67,4	70,7	82,4	85,7
Alkmaar Noord	29,7	33,4	44,7	48,4	59,7	63,4	74,7	78,4	89,7
Alkmaar Noord	30,5	32,6	45,5	47,6	60,5	62,6	75,5	77,6	90,5
Alkmaar	33,2	30,0	48,2	45,0	63,2	60,0	78,2	75,0	93,2

Table 27:feasible path VIRM without changed infrastructure

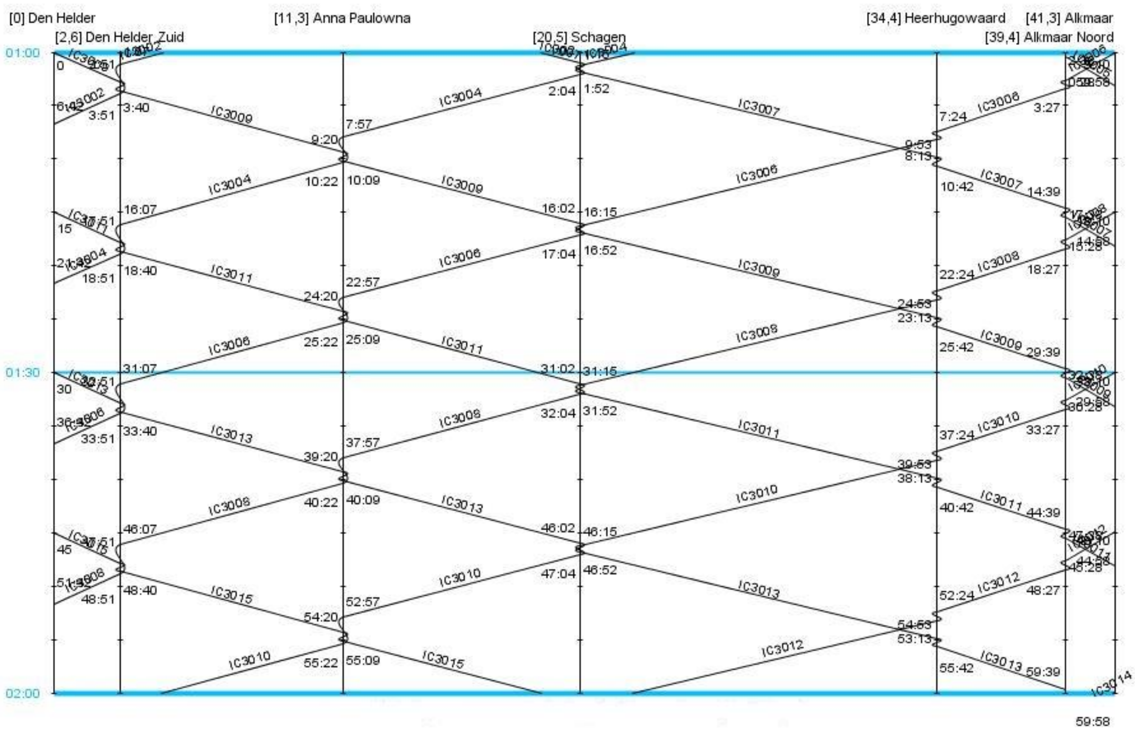

Figure 14:TD diagram VIRM without changed infrastructure

SLT without changed infrastructure

The initial path sequence of the SLT rolling stock without any changes to the infrastructure is given in table 28. The basic hour pattern for this sprinter service is obtained by copying this first path with an 15 minutes added to the path.

Station	SPR4801	SPR4802	SPR4803	SPR4804	SPR4805	SPR4806	SPR4807	SPR4808
Den Helder	0,0	54,6	15,0	69,6	30,0	84,6	45,0	99,6
Den Helder Zuid	2,7	51,9	17,7	66,9	32,7	81,9	47,7	96,9
Den Helder Zuid	3,4	51,2	18,4	66,2	33,4	81,2	48,4	96,2
Anna Paulowna	8,7	45,8	23,7	60,8	38,7	75,8	53,7	90,8
Anna Paulowna	9,4	45,1	24,4	60,1	39,4	75,1	54,4	90,1
Schagen	14,9	39,6	29,9	54,6	44,9	69,6	59,9	84,6
Schagen	15,6	38,9	30,6	53,9	45,6	68,9	60,6	83,9
Heerhugowaard	23,2	31,3	38,2	46,3	53,2	61,3	68,2	76,3
Heerhugowaard	23,9	30,6	38,9	45,6	53,9	60,6	68,9	75,6
Alkmaar Noord	27,5	27,0	42,5	42,0	57,5	57,0	72,5	72,0
Alkmaar Noord	28,2	26,3	43,2	41,3	58,2	56,3	73,2	71,3
Alkmaar	30,8	23,8	45,8	38,8	60,8	53,8	75,8	68,8

Table 28: SLT current infrastructure initial

This timetable has two conflicts initially. SPR4802 and SPR4805 have a 6,24 minute conflict at Schagen station towards Anna Paulowna, SPR4802 and SPR4807 have a 8,87 minute conflict at Anna Paulowna station towards Den Helder Zuid.
The 6,25 minute conflict of SPR4802 and SPR4805 is solved first by delaying the start of SPR4802 at Alkmaar. This delays the timing of all other events of this train path. The conflict of SPR4802 and SPR4807 at Anna Paulowna station is reduced to 2,63 minute by the previous intervention, therefore SPR4807 is held by 2,6 minute Anna Paulowna station.
The pitfall of the previous interventions is the creation of a new headway conflict at Den Helder Zuid station towards Den Helder. SPR4802 and SPR4809 have a headway conflict of 2,93 minutes as a result of the previous measures. Therefore SPR4802 is held by 2,93 minute at Den Helder Zuid.

3 measures were required, with a delayed start of 6,24 minutes and a total of 5,5 minutes of holding at stations. The resulting feasible path sequence is given in table 29 and time distance diagram of the basic hour pattern in figure 15.

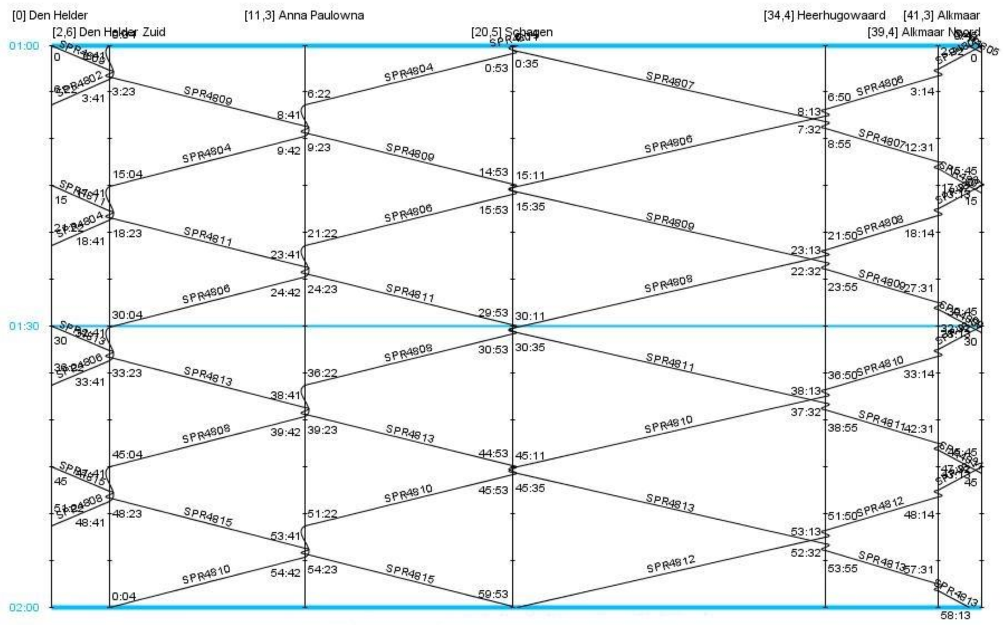

Figure 15: TD diagram SLT without changed infrastructure

Station	SPR4801	SPR4802	SPR4803	SPR4804	SPR4805	SPR4806	SPR4807	SPR4808	SPR4809
Den Helder	0,0	66,4	15,0	81,4	30,0	96,4	45,0	111,4	60,0
Den Helder Zuid	2,7	63,7	17,7	78,7	32,7	93,7	47,7	108,7	62,7
Den Helder Zuid	3,4	60,1	18,4	75,1	33,4	90,1	48,4	105,1	63,4
Anna Paulowna	8,7	54,7	23,7	69,7	38,7	84,7	53,7	99,7	68,7
Anna Paulowna	9,4	51,4	24,4	66,4	39,4	81,4	54,4	96,4	69,4
Schagen	14,9	45,9	29,9	60,9	44,9	75,9	59,9	90,9	74,9
Schagen	15,6	45,2	30,6	60,2	45,6	75,2	60,6	90,2	75,6
Heerhugowaard	23,2	37,5	38,2	52,5	53,2	67,5	68,2	82,5	83,2
Heerhugowaard	23,9	36,8	38,9	51,8	53,9	66,8	68,9	81,8	83,9
Alkmaar Noord	27,5	33,2	42,5	48,2	57,5	63,2	72,5	78,2	87,5
Alkmaar Noord	28,2	32,5	43,2	47,5	58,2	62,5	73,2	77,5	88,2
Alkmaar	30,8	30,0	45,8	45,0	60,8	60,0	75,8	75,0	90,8

Table 29: SLT current infrastructure feasible

VIRM with expanded infrastructure

The initial path sequence of the VIRM rolling stock is given in table 30.The basic hour pattern for this intercity service is obtained by copying this first path with an 15 minutes added to the path. This alternative permits change to the infrastructure, therefore the initial path sequences can be assumed to be possible. Opposing headway conflicts occur however, which has the consequence that double tracking part of the alignment is required. The conflicts have to be minimized without applying holding in order to achieve a short travel time with minimal double tracking of single tracked sections.

Station	IC3001	IC3002	IC3003	IC3004	IC3005	IC3006	IC3007	IC3008	IC3009
Den Helder	0,0	64,8	15,0	79,8	30,0	94,8	45,0	109,8	60,0
Den Helder Zuid	2,9	61,9	17,9	76,9	32,9	91,9	47,9	106,9	62,9
Den Helder Zuid	3,7	61,1	18,7	76,1	33,7	91,1	48,7	106,1	63,7
Anna Paulowna	9,3	55,3	24,3	70,3	39,3	85,3	54,3	100,3	69,3
Anna Paulowna	10,2	54,5	25,2	69,5	40,2	84,5	55,2	99,5	70,2
Schagen	16,0	48,6	31,0	63,6	46,0	78,6	61,0	93,6	76,0
Schagen	16,9	47,8	31,9	62,8	46,9	77,8	61,9	92,8	76,9
Heerhugowaard	24,9	39,8	39,9	54,8	54,9	69,8	69,9	84,8	84,9
Heerhugowaard	25,7	39,0	40,7	54,0	55,7	69,0	70,7	84,0	85,7
Alkmaar Noord	29,7	35,0	44,7	50,0	59,7	65,0	74,7	80,0	89,7
Alkmaar Noord	30,5	34,2	45,5	49,2	60,5	64,2	75,5	79,2	90,5
Alkmaar	33,2	31,5	48,2	46,5	63,2	61,5	78,2	76,5	93,2

Table 30: VIRM expanded infrastructure initial

This timetable has three conflicts initially. IC3002 and IC3005 have a 3,76 minute conflict at Schagen station towards Anna Paulowna, IC3002 and IC3007 have a 5,36 minute conflict at Anna Paulowna station towards Den Helder Zuid and IC3002 and IC3009 have a short conflict at Den Helder station for now.
Addressing these conflicts would require lengthy double tracking. This is reduced by delaying the start of IC3002 at Alkmaar with 3,76 minutes. This measure reduces the conflict of IC3002 and IC3007 at Anna Paulowna station to a 1,60 minutes and introduces a conflict between of IC3002 and IC3009 at Den Helder station.

The conflict of IC3002 and IC3009 at Anna Paulowna towards Den Helder Zuid is removed by increasing the delayed start of IC3002 at Alkmaar with 1,60 minute. This does create a conflict of 0,37 minute at Anna Paulowna towards Schagen, which is addressed by installing double track.
The conflict of IC3002 and IC3009 at Den Helder Zuid station towards Den Helder becomes 1,95 minute due to the delayed start sequence. This is addressed by installing double track.

The resulting feasible path sequence is given in table 31 and time distance diagram of the basic hour pattern in figure 16.Four measures are required, a delayed start of 5,36 minutes and two locations where double tracked passing loops need to be extended.

Station	IC3001	IC3002	IC3003	IC3004	IC3005	IC3006	IC3007	IC3008	IC3009
Den Helder	0,0	64,7	15,0	79,7	30,0	94,7	45,0	109,7	60,0
Den Helder Zuid	2,9	61,9	17,9	76,9	32,9	91,9	47,9	106,9	62,9
Den Helder Zuid	3,7	61,1	18,7	76,1	33,7	91,1	48,7	106,1	63,7
Anna Paulowna	9,3	55,3	24,3	70,3	39,3	85,3	54,3	100,3	69,3
Anna Paulowna	10,1	54,5	25,1	69,5	40,1	84,5	55,1	99,5	70,1
Schagen	16,0	48,6	31,0	63,6	46,0	78,6	61,0	93,6	76,0
Schagen	16,8	47,8	31,8	62,8	46,8	77,8	61,8	92,8	76,8
Heerhugowaard	24,9	39,7	39,9	54,7	54,9	69,7	69,9	84,7	84,9
Heerhugowaard	25,7	38,9	40,7	53,9	55,7	68,9	70,7	83,9	85,7
Alkmaar Noord	29,7	35,0	44,7	50,0	59,7	65,0	74,7	80,0	89,7
Alkmaar Noord	30,5	34,2	45,5	49,2	60,5	64,2	75,5	79,2	90,5
Alkmaar	33,1	31,5	48,1	46,5	63,1	61,5	78,1	76,5	93,1

Table 31: VIRM expanded infrastructure feasible

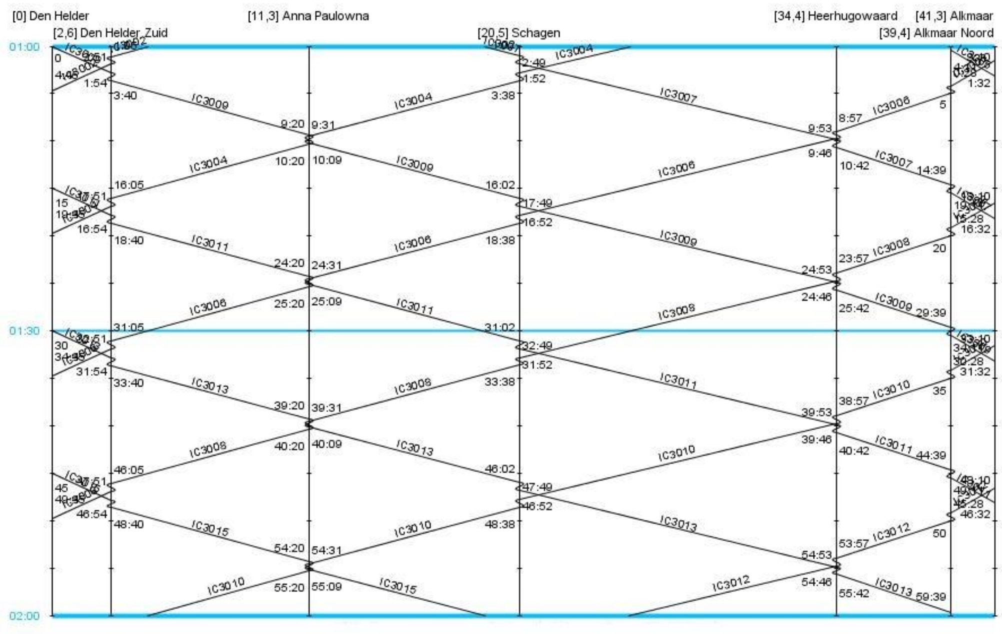

Figure 16: TD diagram VIRM expanded infrastructure

For Anna Paulowna this can be handled by incorporating an unused siding into the main track. Trains cross at the station, IC3007 could accelerate up to 40 km/h during the conflict requiring 0,14 km, sight and reaction time requiring 0,1 km and 0,09 km for braking to a stop. This totals 0,33km, which is less than the currently not utilised siding.

The crossing of trains IC3002 and IC3009 does take place North of Den Helder Zuid station, approximately 0,48 minutes after departure of IC3002 ((62,85-61,90)/2=0,48). One minute for signal release is added, so the acceleration phase needs to cover 1,5 minute. IC3002 could accelerate up to 100 km/h during the conflict requiring 1,55 km, sight and reaction time requiring 0,3 km and 0,55 km for braking to a stop. This totals 2,34 km, which is longer than the distance of the remaining single tracked section. The shunting tracks of Den Helder station could be rebuilt as part of a double tracked alignment. It is assumed that the depot tracks of Den Helder station can be rearranged for this purpose. This is expected not to be a problem as double track and the stub track to the former port area can still be used for headshunting. The remaining single track is 1,7 km, which needs to be doubled.

SLT with expanded infrastructure

The initial path sequence when using SLT rolling stock is given in table 32. The basic hour pattern for the service is obtained adding 15 minutes to successive path sequences. This scenario allows expansions to the infrastructure, therefore these path sequences can be assumed to be feasible. This is not efficient as opposing headway conflicts do occur. This would require two new passing loops of 4,4 km length each. One would be midway between Schagen and Anna Paulowna, the other between Den Helder Zuid and Breezand. The latter has the presence of the Koegrasbrug bridge as a complicating factor, doubling a moveable bridge is considered to be cost restrictive.

Reduction of headway conflicts remains useful because it minimises the need for extending double tracked parts of the alignment. Again application of holding at intermediate stations is avoided, as this is essentially time lost when activity-spaces are computed.

Station	SPR4801	SPR4802	SPR4803	SPR4804	SPR4805	SPR4806	SPR4807	SPR4808	SPR4809
Den Helder	0,0	54,6	15,0	69,6	30,0	84,6	45,0	99,6	60,0
Den Helder Zuid	2,7	51,9	17,7	66,9	32,7	81,9	47,7	96,9	62,7
Den Helder Zuid	3,4	51,2	18,4	66,2	33,4	81,2	48,4	96,2	63,4
Anna Paulowna	8,7	45,8	23,7	60,8	38,7	75,8	53,7	90,8	68,7
Anna Paulowna	9,4	45,1	24,4	60,1	39,4	75,1	54,4	90,1	69,4
Schagen	14,9	39,6	29,9	54,6	44,9	69,6	59,9	84,6	74,9
Schagen	15,6	38,9	30,6	53,9	45,6	68,9	60,6	83,9	75,6
Heerhugowaard	23,2	31,3	38,2	46,3	53,2	61,3	68,2	76,3	83,2
Heerhugowaard	23,9	30,6	38,9	45,6	53,9	60,6	68,9	75,6	83,9
Alkmaar Noord	27,5	27,0	42,5	42,0	57,5	57,0	72,5	72,0	87,5
Alkmaar Noord	28,2	26,3	43,2	41,3	58,2	56,3	73,2	71,3	88,2
Alkmaar	30,8	23,8	45,8	38,8	60,8	53,8	75,8	68,8	90,8

Table 32: SLT expanded infrastructure initial

The timetable has two headway conflicts initially. First to address is the conflict of 6,73 minutes between SPR4802 and SPR4805 at Anna Paulowna station towards Schagen station. This is done by delaying the start of SPR4801 with 8,3 minutes at Alkmaar station. This reduces the conflict of SPR4802 and SPR4807 at Anna Paulowna station to 0,57 minute. The delayed start intervention creates a new headway conflict at Den Helder station however. SPR4802 and SPR4809 have a headway conflict of 3,86 minutes and cross each other approximately midway between stations. These conflicts are addressed by installing double track.

Table 33 contains the feasible path sequence,figure 17 the TD diagram of the basic hour pattern. Three measures are required; two locations where double tracked passing loops need to be extended and 8,3 minutes of delaying the start of trains to Den Helder.

Station	SPR4801	SPR4802	SPR4803	SPR4804	SPR4805	SPR4806	SPR4807	SPR4808	SPR4809
Den Helder	0,0	62,9	15,0	77,9	30,0	92,9	45,0	107,9	60,0
Den Helder Zuid	2,7	60,2	17,7	75,2	32,7	90,2	47,7	105,2	62,7
Den Helder Zuid	3,4	59,5	18,4	74,5	33,4	89,5	48,4	104,5	63,4
Anna Paulowna	8,7	54,1	23,7	69,1	38,7	84,1	53,7	99,1	68,7
Anna Paulowna	9,4	53,4	24,4	68,4	39,4	83,4	54,4	98,4	69,4
Schagen	14,9	47,9	29,9	62,9	44,9	77,9	59,9	92,9	74,9
Schagen	15,6	47,2	30,6	62,2	45,6	77,2	60,6	92,2	75,6
Heerhugowaard	23,2	39,6	38,2	54,6	53,2	69,6	68,2	84,6	83,2
Heerhugowaard	23,9	38,9	38,9	53,9	53,9	68,9	68,9	83,9	83,9
Alkmaar Noord	27,5	35,3	42,5	50,3	57,5	65,3	72,5	80,3	87,5
Alkmaar Noord	28,2	34,6	43,2	49,6	58,2	64,6	73,2	79,6	88,2
Alkmaar	30,8	32,1	45,8	47,1	60,8	62,1	75,8	77,1	90,8

Table 33: SLT expanded infrastructure feasible

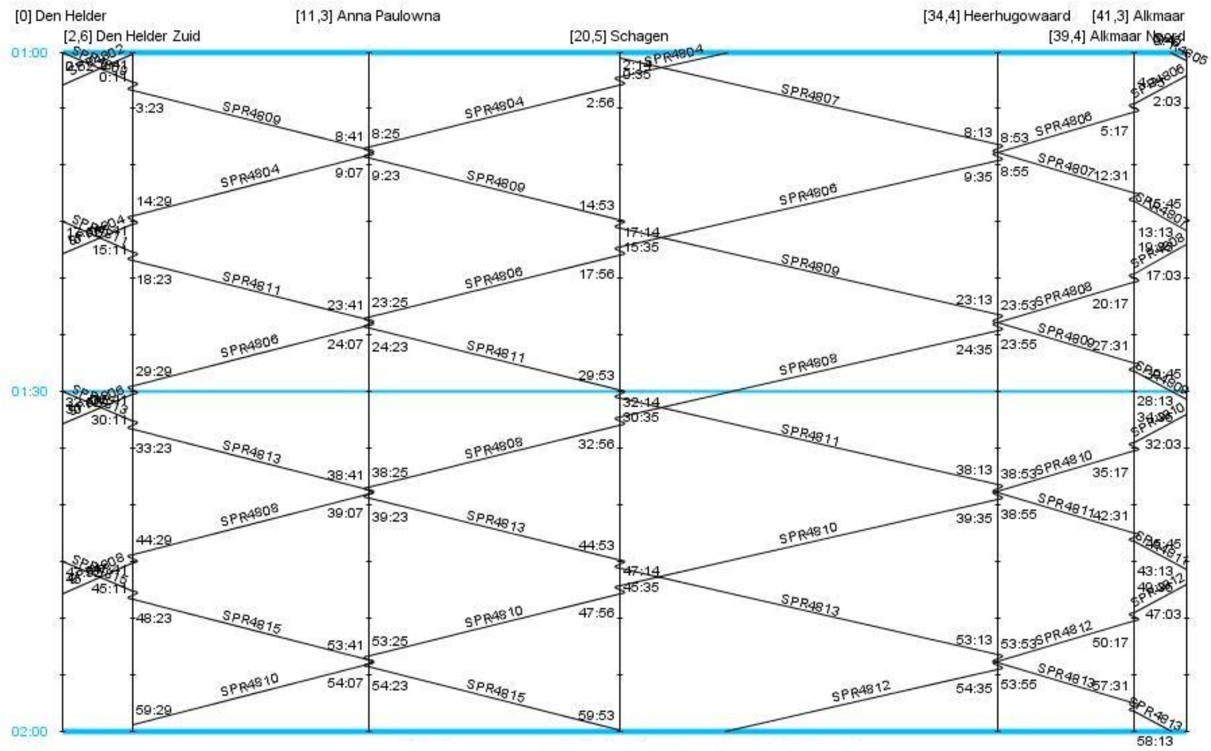

Figure 17: TD diagram SLT expanded infrastructure

SPR4802 and SPR4807 cross each other at the station. SPR4802 may accelerate over 60 hm/h (up to 80 km/h) during the conflict, this requires 0,54 km of track. Sight / reaction time and braking to a stop requires 0,55 km. Therefore the passing loop at Anna Paulowna needs an to be extended with 1,1 km to the North.
The crossing of SPR4802 and SPR4809 does take place in the middle between Den Helder and Den Helder Zuid station, which requires doubling the 1,7km single tracked section between stations.

SLT with expanded infrastructure and Waarland station

The station site for this design alternative is assessed in appendix D. The required run times of rolling stock are given in table 8 of section 4.4.2. The initial path sequence is displayed in table 34.

Station	SPR4801	SPR4802	SPR4803	SPR4804	SPR4805	SPR4806	SPR4807	SPR4808	SPR4809
Den Helder	0,0	58,5	15,0	73,5	30,0	88,5	45,0	103,5	60,0
Den Helder Zuid	2,7	55,8	17,7	70,8	32,7	85,8	47,7	100,8	62,7
Den Helder Zuid	3,4	55,1	18,4	70,1	33,4	85,1	48,4	100,1	63,4
Anna Paulowna	8,7	49,8	23,7	64,8	38,7	79,8	53,7	94,8	68,7
Anna Paulowna	9,4	49,1	24,4	64,1	39,4	79,1	54,4	94,1	69,4
Schagen	14,9	43,6	29,9	58,6	44,9	73,6	59,9	88,6	74,9
Schagen	15,6	42,9	30,6	57,9	45,6	72,9	60,6	87,9	75,6
Waarland	20,0	38,5	35,0	53,5	50,0	68,5	65,0	83,5	80,0
Waarland	20,7	37,8	35,7	52,8	50,7	67,8	65,7	82,8	80,7
Heerhugowaard	25,2	33,3	40,2	48,3	55,2	63,3	70,2	78,3	85,2
Heerhugowaard	25,9	32,6	40,9	47,6	55,9	62,6	70,9	77,6	85,9
Alkmaar Noord	29,5	29,0	44,5	44,0	59,5	59,0	74,5	74,0	89,5
Alkmaar Noord	30,2	28,3	45,2	43,3	60,2	58,3	75,2	73,3	90,2
Alkmaar	32,7	25,7	47,7	40,7	62,7	55,7	77,7	70,7	92,7

Table 34: SLT Waarland initial

The initial path sequence yields a 2,3 minute conflict North of Schagen and 4,3 minute conflict between Anna Paulowna and Den Helder Zuid, requiring 2,1 km and 4,4 km of double track respectively. In order to reduce the distance of single track to be doubled an optimization to reduce headway conflicts is carried out. This is achieved by delaying the start of SPR4802 and subsequent services to Den Helder with 4,3 minutes. The consequences of this measure are pictured in table 35 and figure 18. The conflict at Schagen vanishes and the conflict between SPR4802 and SPR4807 North of Anna Paulowna is reduced to 0,6 minute, requiring 0,8 km of single track. A new conflict is introduced between SPR4801 and SPR4808 however, whom require the remaining 1,7 km of single track between Den Helder and the South station to be doubled.

Crossing between services SPR4802 and SPR4807 takes place at Anna Paulowna station. SPR4802 may accelerate to 80 km/h during this conflict, for which it needs 0,54 of track in order to bridge signal release. Sight / reaction and braking to a stop needs requires 0,55 km. Therefore an extension of the passing loop at Anna Paulowna with 1,1 km is required. Services SPR4801 and SPR4808 cross paths midway between Den Helder Zuid and main station, requiring doubling of the remaining single tracked section between these stations.

Station	SPR4801	SPR4802	SPR4803	SPR4804	SPR4805	SPR4806	SPR4807	SPR4808	SPR4809
Den Helder	0,0	62,8	15,0	77,8	30,0	92,8	45,0	107,8	60,0
Den Helder Zuid	2,7	60,1	17,7	75,1	32,7	90,1	47,7	105,1	62,7
Den Helder Zuid	3,4	59,4	18,4	74,4	33,4	89,4	48,4	104,4	63,4
Anna Paulowna	8,7	54,1	23,7	69,1	38,7	84,1	53,7	99,1	68,7
Anna Paulowna	9,4	53,4	24,4	68,4	39,4	83,4	54,4	98,4	69,4
Schagen	14,9	47,9	29,9	62,9	44,9	77,9	59,9	92,9	74,9
Schagen	15,6	47,2	30,6	62,2	45,6	77,2	60,6	92,2	75,6
Waarland	20,0	42,8	35,0	57,8	50,0	72,8	65,0	87,8	80,0
Waarland	20,7	42,1	35,7	57,1	50,7	72,1	65,7	87,1	80,7
Heerhugowaard	25,2	37,6	40,2	52,6	55,2	67,6	70,2	82,6	85,2
Heerhugowaard	25,9	36,9	40,9	51,9	55,9	66,9	70,9	81,9	85,9
Alkmaar Noord	29,5	33,3	44,5	48,3	59,5	63,3	74,5	78,3	89,5
Alkmaar Noord	30,2	32,6	45,2	47,6	60,2	62,6	75,2	77,6	90,2
Alkmaar	32,7	30,0	47,7	45,0	62,7	60,0	77,7	75,0	92,7

Table 35: SLT Waarland feasible

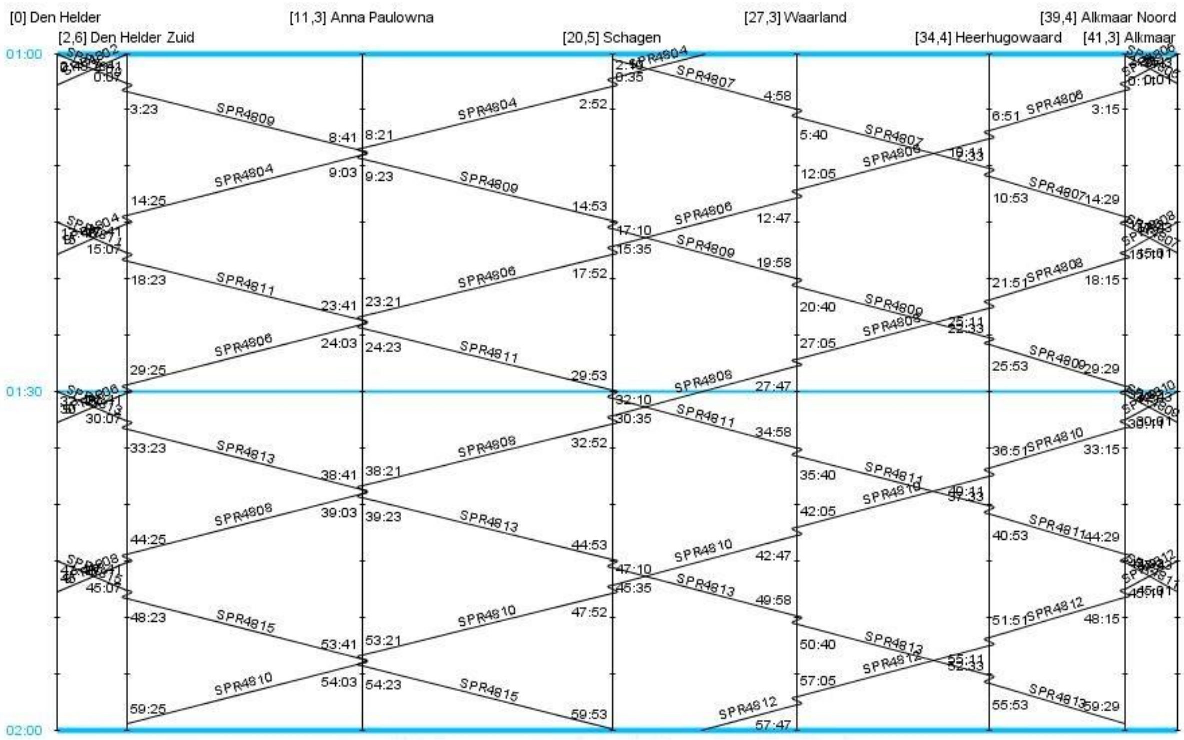

Figure 18: TD diagram SLT Waarland

SLT with expanded infrastructure and Breezand station

As with the previous the site of Breezand station is selected in appendix D and rolling stock run times are given in table 8 of section 4.4.2 for this station. The initial path sequence of the SLT with Breezand station alternative is displayed in table 36.

Station	SPR4801	SPR4802	SPR4803	SPR4804	SPR4805	SPR4806	SPR4807	SPR4808	SPR4809
Den Helder	0,0	58,4	15,0	73,4	30,0	88,4	45,0	103,4	60,0
Den Helder Zuid	2,7	55,7	17,7	70,7	32,7	85,7	47,7	100,7	62,7
Den Helder Zuid	3,4	55,0	18,4	70,0	33,4	85,0	48,4	100,0	63,4
Breezand	7,5	50,9	22,5	65,9	37,5	80,9	52,5	95,9	67,5
Breezand	8,2	50,2	23,2	65,2	38,2	80,2	53,2	95,2	68,2
Anna Paulowna	10,6	47,7	25,6	62,7	40,6	77,7	55,6	92,7	70,6
Anna Paulowna	11,3	47,0	26,3	62,0	41,3	77,0	56,3	92,0	71,3
Schagen	16,8	41,5	31,8	56,5	46,8	71,5	61,8	86,5	76,8
Schagen	17,5	40,8	32,5	55,8	47,5	70,8	62,5	85,8	77,5
Heerhugowaard	25,1	33,2	40,1	48,2	55,1	63,2	70,1	78,2	85,1
Heerhugowaard	25,8	32,5	40,8	47,5	55,8	62,5	70,8	77,5	85,8
Alkmaar Noord	29,4	28,9	44,4	43,9	59,4	58,9	74,4	73,9	89,4
Alkmaar Noord	30,1	28,2	45,1	43,2	60,1	58,2	75,1	73,2	90,1
Alkmaar	32,7	25,7	47,7	40,7	62,7	55,7	77,7	70,7	92,7

Table 36: SLT Breezand inital

Table 36 yields a path conflict of 2,6 minute at Breezand station towards Den Helder Zuid and a major conflict between Schagen and Anna Paulowna, where trains have to cross in the midst of the single tracked section. These conflicts are minimized by holding the return services at Alkmaar for an additional 7,4 minutes. Application of this measure is given in table 37, TD diagram in figure 19. The conflict SPR4802 and SPR4807 is reduced to 1,5 minute, the conflict between Schagen and Anna Paulowna is removed, but a conflict of 0,6 minute between is introduced between SPR4802 and SPR4809 at Den Helder Zuid.

Services SPR4802 and SPR4807 cross paths 0,6 minute following departure from Anna Paulowna station.SPR4802 may accelerate to 80 km/h during this conflict, for which 0,54 km of track is required. Sight / reaction time and braking to a stop requires 0,55 km. Therefore an Northward extension of the passing loop with 1,1 km is required.
SPR4802 and SPR4809 cross paths at Den Helder Zuid station. SPR4802 could accelerate over 60 hm/h, so 80 km/h is assumed during the conflict. 0,54 km of track is required to allow for acceleration, sight / reaction time and braking to a stop requires 0,55 km. Therefore an Northward extension of the passing loop at Den Helder Zuid with 1,1 km is required. As this extended passing loop would end 0,6 km short of the main Den Helder yard it is advised to double the entire single tracked section.

Station	SPR4801	SPR4802	SPR4803	SPR4804	SPR4805	SPR4806	SPR4807	SPR4808	SPR4809
Den Helder	0,0	65,8	15,0	80,8	30,0	95,8	45,0	110,8	60,0
Den Helder Zuid	2,7	63,1	17,7	78,1	32,7	93,1	47,7	108,1	62,7
Den Helder Zuid	3,4	62,4	18,4	77,4	33,4	92,4	48,4	107,4	63,4
Breezand	7,5	58,3	22,5	73,3	37,5	88,3	52,5	103,3	67,5
Breezand	8,2	57,6	23,2	72,6	38,2	87,6	53,2	102,6	68,2
Anna Paulowna	10,6	55,1	25,6	70,1	40,6	85,1	55,6	100,1	70,6
Anna Paulowna	11,3	54,4	26,3	69,4	41,3	84,4	56,3	99,4	71,3
Schagen	16,8	48,9	31,8	63,9	46,8	78,9	61,8	93,9	76,8
Schagen	17,5	48,2	32,5	63,2	47,5	78,2	62,5	93,2	77,5
Heerhugowaard	25,1	40,6	40,1	55,6	55,1	70,6	70,1	85,6	85,1
Heerhugowaard	25,8	39,9	40,8	54,9	55,8	69,9	70,8	84,9	85,8
Alkmaar Noord	29,4	36,3	44,4	51,3	59,4	66,3	74,4	81,3	89,4
Alkmaar Noord	30,1	35,6	45,1	50,6	60,1	65,6	75,1	80,6	90,1
Alkmaar	32,7	33,1	47,7	48,1	62,7	63,1	77,7	78,1	92,7

Table 37: SLT Breezand feasible

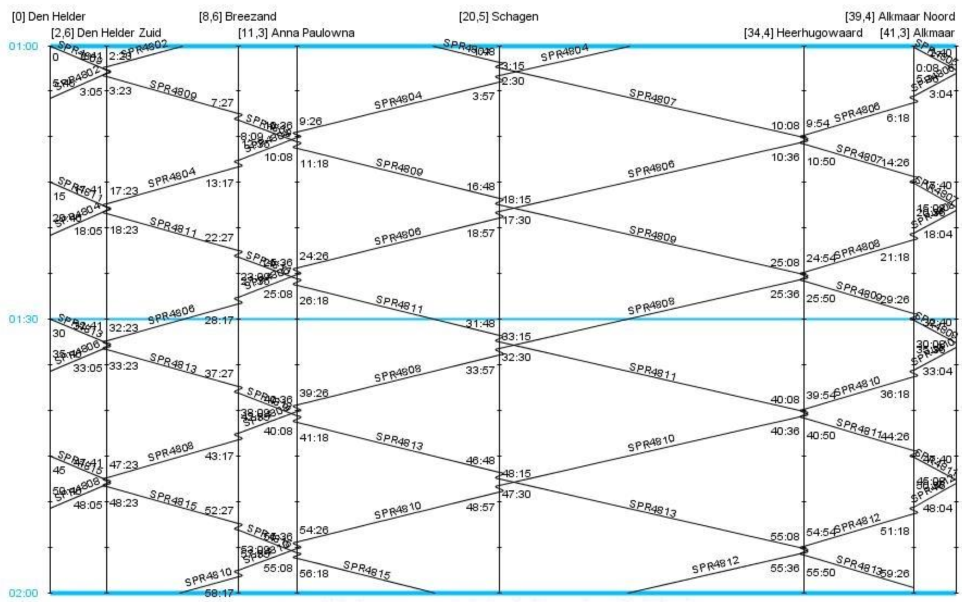

Figure 19: TD diagram SLT Breezand

SLT with expanded infrastructure and Waarland, Breezand station

This alternative builds on the station sites and run times between stations identified in previous alternatives. Table 38 contains the initial path sequences, which contains opposing headway conflicts.

Station	SPR4801	SPR4802	SPR4803	SPR4804	SPR4805	SPR4806	SPR4807	SPR4808	SPR4809
Den Helder	0,0	47,3	15,0	62,3	30,0	77,3	45,0	92,3	60,0
Den Helder Zuid	2,7	44,6	17,7	59,6	32,7	74,6	47,7	89,6	62,7
Den Helder Zuid	3,4	43,9	18,4	58,9	33,4	73,9	48,4	88,9	63,4
Breezand	7,5	39,8	22,5	54,8	37,5	69,8	52,5	84,8	67,5
Breezand	8,2	39,1	23,2	54,1	38,2	69,1	53,2	84,1	68,2
Anna Paulowna	10,6	36,7	25,6	51,7	40,6	66,7	55,6	81,7	70,6
Anna Paulowna	11,3	36,0	26,3	51,0	41,3	66,0	56,3	81,0	71,3
Schagen	16,8	30,5	31,8	45,5	46,8	60,5	61,8	75,5	76,8
Schagen	17,5	29,8	32,5	44,8	47,5	59,8	62,5	74,8	77,5
Waarland	21,9	25,4	36,9	40,4	51,9	55,4	66,9	70,4	81,9
Waarland	22,6	24,7	37,6	39,7	52,6	54,7	67,6	69,7	82,6
Heerhugowaard	27,1	20,2	42,1	35,2	57,1	50,2	72,1	65,2	87,1
Heerhugowaard	27,8	19,5	42,8	34,5	57,8	49,5	72,8	64,5	87,8
Alkmaar Noord	31,4	15,9	46,4	30,9	61,4	45,9	76,4	60,9	91,4
Alkmaar Noord	32,1	15,2	47,1	30,2	62,1	45,2	77,1	60,2	92,1
Alkmaar	34,6	12,6	49,6	27,6	64,6	42,6	79,6	57,6	94,6

Table 38: SLT Waarland & Breezand initial

SPR4805 and 4805 have a conflict of 2,3 minutes at Schagen towards Anna Paulowna. 4802 & 4805 conflict for 0,9 minute at Breezand also towards Anna Paulowna. Lastly 4802 and 4807 conflict between Den Helder main and Zuid station. The conflict at Schagen is removed by delaying SPR4802 with 2,3 minutes. This measure moves the conflict of 4802 & 4805 towards the North of Anna Paulowna and 4802 & 4807 to the vicinity of Den Helder Zuid station. By delaying the start of SPR4802 at Alkmaar with an additional 1,1 minute the conflict at Den Helder Zuid station is reduced to 0,6 minute, while the departure of 4807 is timed exactly 1,0 minute after the arrival of 4802.

This results in two conflicts that have to be solved with local doubling of single track; the aforementioned conflict of 0,6 minute at Den Helder Zuid to the North and between 4802 & 4805 for 1,5 minute at Anna Paulowna for direction Breezand. For the conflict at Den Helder Zuid; SPR4802 is could accelerate over 60 km/h in this conflict time, for which 0,53 is required to advance during signal release. Sight / reaction plus and braking is 0,55 km, so an expansion of the passing loop with 1,1 km is required at Den Helder Zuid. SPR4802 & 4805 cross approximately 0,26 minute after departure of SPR4802 from Anna Paulowna, to which one minute for signal release is added. SPR4802 accelerates to just under 120 km/h, requiring 1,9 km of track, plus 1,1 km for sight reaction and braking. So 3,0 km of double track is required, which in practice means that the entire track section between Anna Paulowna and Breezand needs to be double tracked. The end result is displayed in figure 20 and table 39.

Station	SPR4801	SPR4802	SPR4803	SPR4804	SPR4805	SPR4806	SPR4807	SPR4808	SPR4809
Den Helder	0,0	50,7	15,0	65,7	30,0	80,7	45,0	95,7	60,0
Den Helder Zuid	2,7	48,0	17,7	63,0	32,7	78,0	47,7	93,0	62,7
Den Helder Zuid	3,4	47,3	18,4	62,3	33,4	77,3	48,4	92,3	63,4
Breezand	7,5	43,2	22,5	58,2	37,5	73,2	52,5	88,2	67,5
Breezand	8,2	42,5	23,2	57,5	38,2	72,5	53,2	87,5	68,2
Anna Paulowna	10,6	40,1	25,6	55,1	40,6	70,1	55,6	85,1	70,6
Anna Paulowna	11,3	39,4	26,3	54,4	41,3	69,4	56,3	84,4	71,3
Schagen	16,8	33,9	31,8	48,9	46,8	63,9	61,8	78,9	76,8
Schagen	17,5	33,2	32,5	48,2	47,5	63,2	62,5	78,2	77,5
Waarland	21,9	28,8	36,9	43,8	51,9	58,8	66,9	73,8	81,9
Waarland	22,6	28,1	37,6	43,1	52,6	58,1	67,6	73,1	82,6
Heerhugowaard	27,1	23,6	42,1	38,6	57,1	53,6	72,1	68,6	87,1
Heerhugowaard	27,8	22,9	42,8	37,9	57,8	52,9	72,8	67,9	87,8
Alkmaar Noord	31,4	19,3	46,4	34,3	61,4	49,3	76,4	64,3	91,4
Alkmaar Noord	32,1	18,6	47,1	33,6	62,1	48,6	77,1	63,6	92,1
Alkmaar	34,6	16,0	49,6	31,0	64,6	46,0	79,6	61,0	94,6

Table 39: SLT Waarland & Breezand feasible

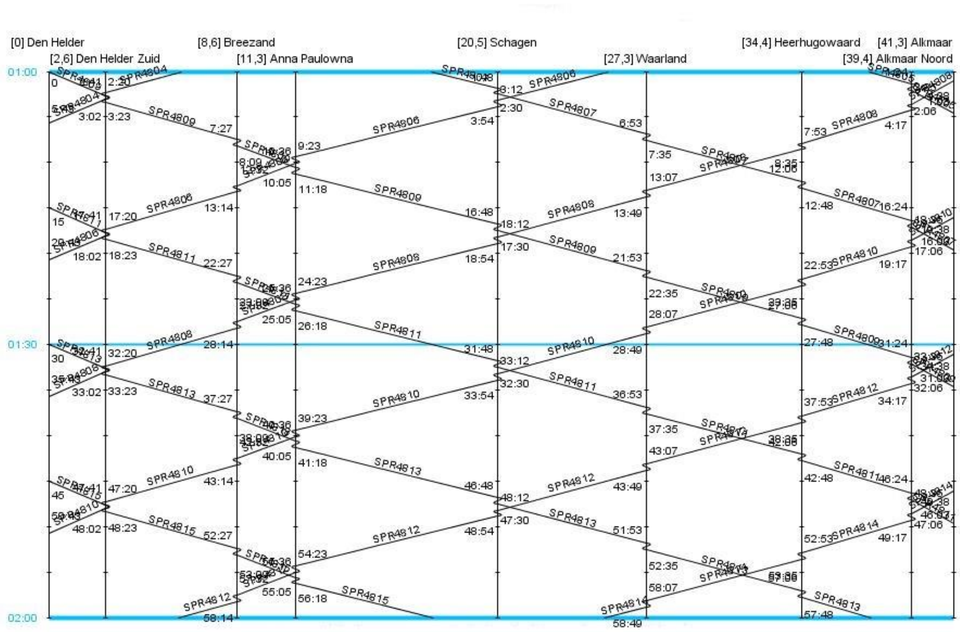

Figure 20: TD diagram SLT Waarland & Breezand

SLT & IC with expanded infrastructure and Waarland, Breezand station

This design alternative consists of an alternating IC and SPR service. This alternative builds on the station sites and run times between stations identified in previous alternatives. Table 38 contains the in initial path sequence of this alternative.

Station	SPR4801	IC3002	IC3003	SPR4802	SPR4803	IC3004	IC3005	SPR4804	SPR4805
Den Helder	0,0	90,2	15,0	77,3	30,0	120,2	45,0	107,3	60,0
Den Helder Zuid	2,7	87,4	17,9	74,6	32,7	117,4	47,9	104,6	62,7
Den Helder Zuid	3,4	86,6	18,7	73,9	33,4	116,6	48,7	103,9	63,4
Breezand	7,5			69,8	37,5			99,8	67,5
Breezand	8,2			69,1	38,2			99,1	68,2
Anna Paulowna	10,6	80,8	24,3	66,7	40,6	110,8	54,3	96,7	70,6
Anna Paulowna	11,3	79,0	25,1	66,0	41,3	109,0	55,1	96,0	71,3
Schagen	16,8	73,1	31,0	60,5	46,8	103,1	61,0	90,5	76,8
Schagen	17,5	72,3	31,8	59,8	47,5	102,3	61,8	89,8	77,5
Waarland	21,9			55,4	51,9			85,4	81,9
Waarland	22,6			54,7	52,6			84,7	82,6
Heerhugowaard	27,1	64,3	39,8	50,2	57,1	94,3	69,8	80,2	87,1
Heerhugowaard	27,8	63,5	40,6	49,5	57,8	93,5	70,6	79,5	87,8
Alkmaar Noord	31,4	59,5	44,6	45,9	61,4	89,5	74,6	75,9	91,4
Alkmaar Noord	32,1	58,7	45,4	45,2	62,1	88,7	75,4	75,2	92,1
Alkmaar	34,6	56,1	48,1	42,6	64,6	86,1	78,1	72,6	94,6

Table 40: Mixed initial

The basic hour pattern for the service is obtained by adding 30 minutes to successive train paths copies of the initial service. The initial path of a SLT service that calls at all stations is followed by a limited stop service with a headway of 15 minutes. This service is operated with VIRM rolling stock and skips Waarland and Breezand stations.
This alternative allows expansions to the infrastructure, therefore these path sequences can be assumed to be feasible. This is not efficient as opposing headway conflicts do occur. This would require two new passing loops of 4,4 km length each. One would be midway between Schagen and Anna Paulowna, the other between Den Helder Zuid and Breezand. The latter has the presence of the Koegrasbrug bridge as a complicating factor, doubling a moveable bridge is considered to be cost restrictive. Therefore it is decided to allow a little bit of holding at Anna Paulowna, if required to avoid doubling the Koegrasbrug.

The initial path sequence of table 40 contains multiple conflicts. Solving any conflict creates or increases headway conflicts elsewhere. So most can only be solved by proposing the doubling of single track.
Crossing between IC3003 and IC3004 is computed to take place 1,8 minute after leaving Schagen station, this equates to 2,4 km from the station. At this location an 4,4 km long midway passing loop could be assumed. As such a passing loop would end just short of Schagen station it is better to extend the double track with 4,4 km from Schagen station.
Two crossings are scheduled to take place between Breezand and Anna Paulowna. SPR48001 and SPR48004 are scheduled to cross between Breezand and Anna Paulowna, IC3001 and IC3006 are scheduled to cross just West of Breezand station. The crossing of IC3001 and IC3006 is considered to be the most restrictive, since they cross at speed and

require the Koegrasbrug to be double tracked. This is avoided by holding IC3001 for 1,0 minute at Anna Paulowna station, which moves the crossing away from the bridge, allowing for an double tracked extension with 4,4 km from Anna Paulowna station to just before the bridge.
The railway section between Den Helder main and Zuid section is subject to two opposing headway conflicts as well. SPR4808 has a departure conflict of 1,2 minute with IC3003 and IC3006 and SPR4803 cross midway. The spatial location of the latter conflict could be moved towards Den Helder Zuid by delaying SPR4803 with 3,1 minute at Alkmaar, but this is no panacea, as the conflict cannot be totally removed. Therefore double tracking Den Helder - Den Helder Zuid is proposed. This results in table 39 and figure 21.

Station	SPR4801	IC3002	IC3003	SPR4802	SPR4803	IC3004	IC3005	SPR4804	SPR4805
Den Helder	0,0	90,2	15,0	77,3	30,0	120,2	45,0	107,3	60,0
Den Helder Zuid	2,7	87,4	17,9	74,6	32,7	117,4	47,9	104,6	62,7
Den Helder Zuid	3,4	86,6	18,7	73,9	33,4	116,6	48,7	103,9	63,4
Breezand	7,5			69,8	37,5			99,8	67,5
Breezand	8,2			69,1	38,2			99,1	68,2
Anna Paulowna	10,6	80,8	24,3	66,7	40,6	110,8	54,3	96,7	70,6
Anna Paulowna	11,3	79,0	25,1	66,0	41,3	109,0	55,1	96,0	71,3
Schagen	16,8	73,1	31,0	60,5	46,8	103,1	61,0	90,5	76,8
Schagen	17,5	72,3	31,8	59,8	47,5	102,3	61,8	89,8	77,5
Waarland	21,9			55,4	51,9			85,4	81,9
Waarland	22,6			54,7	52,6			84,7	82,6
Heerhugowaard	27,1	64,3	39,8	50,2	57,1	94,3	69,8	80,2	87,1
Heerhugowaard	27,8	63,5	40,6	49,5	57,8	93,5	70,6	79,5	87,8
Alkmaar Noord	31,4	59,5	44,6	45,9	61,4	89,5	74,6	75,9	91,4
Alkmaar Noord	32,1	58,7	45,4	45,2	62,1	88,7	75,4	75,2	92,1
Alkmaar	34,6	56,1	48,1	42,6	64,6	86,1	78,1	72,6	94,6

Table 41: Mixed feasible

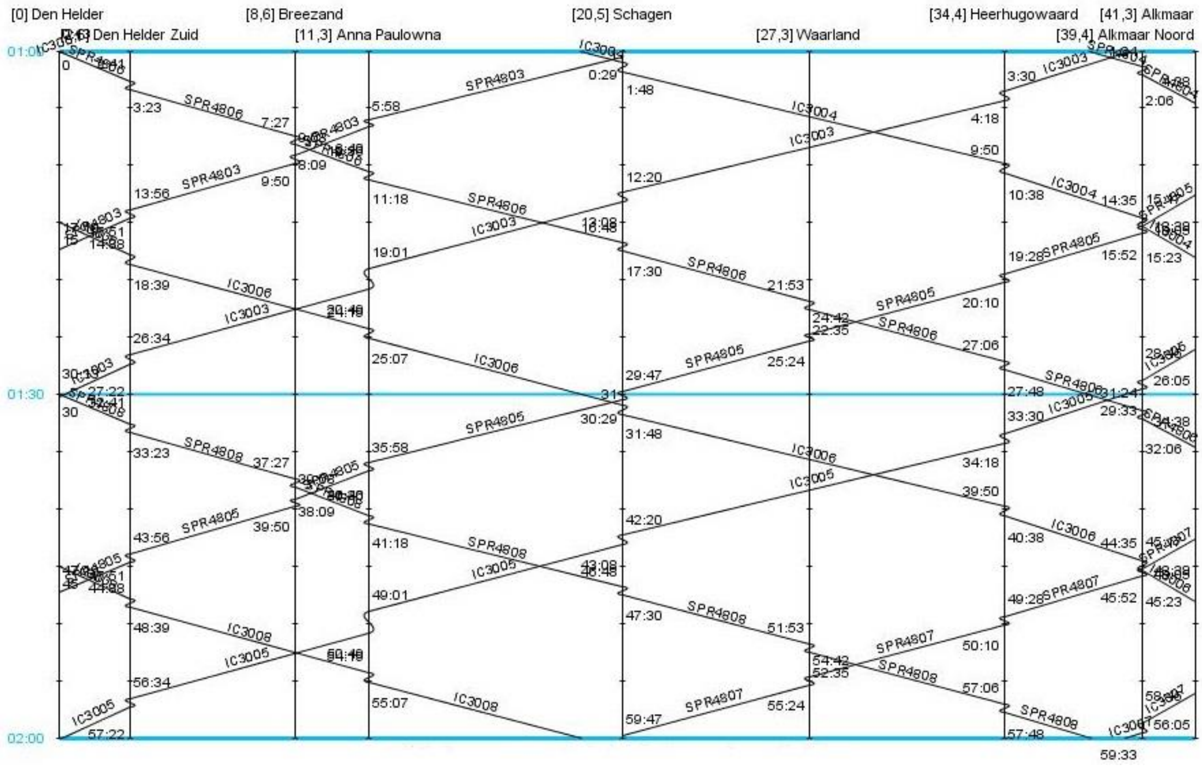

Figure 21: TD diagram mixed

Transition to travel times

The train paths of the feasible timetables are used to compute travel times between stations. These are required for the c_{TTL} travel cost function of the accessibility potential computation. Travel times between the stations are computed from the departure at $station_i$ of origin and arrival at $station_j$ of destination. This varies per design alternative. In Excel it is implemented by inserting train paths in a specific section of the travel time computation sheet. The travel times between stations between the Alkmaar and Den Helder bound itineraries are averaged when they differ. The construction of these sheets is specific to if / which additional station is provided. This is done because any new station changes some shortest paths from a number of postalcodes, which is given in appendix G.

Doubling of track

Table 42 contains an overview of which design alternatives require track doubling at which location. This is sourced from the timetabling process of the respective design alternatives.

Doubling of single track: alternative	Schagen	Anna Paulowna		Breezand		Den Helder Zuid		Den Helder
	North (km)	South (km)	North (km)	South (km)	North (km)	South (km)	North (km)	South (km)
VIRM expanded		0,4						1,7
SLT expanded			1,1					1,7
SLT Waarland			1,1					1,7
SLT Breezand			1,1				1,1	
SLT Wl. & Br.				2,7	0,3		1,1	
mixed	4,4			2,7	1,7			1,7

Table 42: Single track sections to be doubled

Appendix F: Socio economic data

Level of detail

The case area consists of the Kop van Noord-Holland region, excluding Alkmaar, Bergen, Opmeer and the Wieringermeer area. The reason for this selection is that analysis is only relevant for inhabitants that are likely to use the railway corridor. Areas whose inhabitants are likely to use the railway corridor are considered internal zones. Anything else is external.

The level of detail is dictated by CBS (Statistics Netherlands), their data is released at the first four digits of postal code level only. The income class specification is the least detailed dataset. Here; postal code 1769 (Haringhuizen) and 1786 (Den Helder) are excluded. These probably contain too few inhabitants to demarcate income class without sacrificing the privacy of the inhabitants in question.

Inhabitants and income

From CBS (Statistics Netherlands) the inhabitant (CBS, 2021) and income distribution (CBS, 2019) datasets are used. The income dataset only yields the number of households and their income quintile, so the inhabitant dataset is used to obtain the number of inhabitants per household. Section 4.1.2 outlines that the lowest two quintiles are susceptible to transport poverty. Therefore the lower two income quintiles are grouped in resulting table 43, which contains the number of inhabitants that are susceptible to transport poverty.

Location	Postcode	Inhabitants total	Inhabitants at risk	inabitants not at risk
Heerhugowaard	1701	8895	2713	6182
Heerhugowaard	1702	8600	3191	5409
Heerhugowaard	1703	12535	4914	7621
Heerhugowaard	1704	8680	2318	6362
Heerhugowaard	1705	16845	4329	12516
Heerhugowaard	1706	2015	230	1785
Broek op Langedijk	1721	6135	1742	4393
Zuid-Scharwoude	1722	6085	1643	4442
Noord-Scharwoude	1723	5750	2007	3743
Oudkarspel	1724	3925	1099	2826
Winkel	1731	3400	1061	2339
Lutjewinkel	1732	775	257	518
Nieuwe Niedorp	1733	3330	1022	2308
Oude Niedorp	1734	400	80	320
't Veld	1735	2165	714	1451
Zijdewind	1736	395	82	313
Waarland	1738	2665	749	1916
Schagen	1741	12430	4574	7856
Schagen	1742	6530	2031	4499
Sint Maarten	1744	1875	493	1382
Dirkshorn	1746	1640	553	1087
Tuitjenhorn	1747	3775	1261	2514
Warmenhuizen	1749	6100	1635	4465
Schagerbrug	1751	2080	560	1520

Sint Maartensbrug	1752	735	156	579
Sint Maartensvlotbrug	1753	620	237	383
Burgerbrug	1754	835	247	588
Petten	1755	1655	540	1115
't Zand	1756	2425	858	1567
Oudesluis	1757	710	212	498
Callantsoog	1759	2380	859	1521
Anna Paulowna	1761	8355	3058	5297
Breezand	1764	3775	1057	2718
Wieringerwaard	1766	2270	783	1487
Kolhorn	1767	1030	361	670
Barsingerhorn	1768	920	239	681
Den Helder	1781	9050	4362	4688
Den Helder	1782	10680	4678	6002
Den Helder	1783	2630	1447	1184
Den Helder	1784	9380	5037	4343
Den Helder	1785	9180	4544	4636
Julianadorp	1787	2665	922	1743
Julianadorp	1788	11970	2837	9133
Huisduinen	1789	580	118	462

Table 43: Inhabitant and income data

Employment

Employment data is sources internally at the Provincie Noord-Holland. This data can also be sourced via Lisa, a organisation in which the Provincie Noord-Holland participates. Data of January 2020 was available at the time of writing. Companies with one employee are excluded first. It is assumed that these will not generate substantial commuting. Then the data was formatted into jobs per location. For the internal zones and Alkmaar this is done into the number of jobs per postal code in table 44. Alkmaar is included as quasi internal here, as the jobs need to be allocated to one of the two railway stations within the corridor. All locations featured in appendix F are included as external locations, at municipal level. The employment data for these external locations is included in table 45.

Location	Postal code	Jobs available
Heerhugowaard	1701	2257
Heerhugowaard	1702	2693
Heerhugowaard	1703	5993
Heerhugowaard	1704	7498
Heerhugowaard	1705	892
Heerhugowaard	1706	69
Broek op Langedijk	1721	3201
Zuid-Scharwoude	1722	631
Noord-Scharwoude	1723	1121
Oudkarspel	1724	990
Winkel	1731	834
Lutjewinkel	1732	117
Nieuwe Niedorp	1733	661

Oude Niedorp	1734	122
't Veld	1735	430
Zijdewind	1736	50
Waarland	1738	442
Schagen	1741	4574
Schagen	1742	2748
Sint Maarten	1744	195
Dirkshorn	1746	388
Tuitjenhorn	1747	895
Warmenhuizen	1749	3759
Schagerbrug	1751	255
Sint Maartensbrug	1752	56
Sint Maartensvlotbrug	1753	213
Burgerbrug	1754	186
Petten	1755	1355
't Zand	1756	676
Oudesluis	1757	38
Callantsoog	1759	655
Anna Paulowna	1761	1727
Breezand	1764	1040
Wieringerwaard	1766	162
Kolhorn	1767	60
Barsingerhorn	1768	117
Haringhuizen	1769	4
Den Helder	1781	9930
Den Helder	1782	2322
Den Helder	1783	99
Den Helder	1784	3030
Den Helder	1785	2399
Den Helder	1786	2750
Julianadorp	1787	1670
Julianadorp	1788	634
Huisduinen	1789	77
Alkmaar	1811	3574
Alkmaar	1812	7750
Alkmaar	1813	1127
Alkmaar	1814	2629
Alkmaar	1815	5964
Alkmaar	1816	2550
Alkmaar	1817	9015
Alkmaar	1821	1512
Alkmaar	1822	3060
Alkmaar	1823	4009
Alkmaar	1824	905

Alkmaar	1825	1613
Alkmaar	1826	292
Alkmaar	1827	453
Langedijk	1832	13
Langedijk	1834	568

Table 44: Jobs per postal code

Municpality	Jobs available
Heiloo	5365
Castricum	7936
Uitgeest	3059
Zaanstad	51835
Amsterdam	551290
Heemskerk	7924
Beverwijk	15832
Velsen	30986
Bloemendaal	4325
Haarlem	55785

Table 45: employment out of the case area

Appendix G: access egress

This appendix Bddresses the spatial allocation of postal codes, agress time from the postal code to railway stations and egress time out of the corridor area.
The PC4 postal code division outlined in appendix E is used. This has to be spatially allocated to the case area. It is assumed that this can be done as the mesh size of PC4 areas are fairly detailed and are designed unbiassed. Spatial allocation is done with the google maps website. It is assumed that search engine google spatially assignes postal codes to the weighted population centre of the area. This enables the spatial postal code location to be used for the inhabitants of the postal code area. This method is not often used in scientific literature, but has some acclaim (Hu, Wang, Li, & Wang, 2020).

Access

Based on section 4.1.1 it is assumed that most inhabitants commute to jobs, which are predominantly located in the Alkmaar region or further to the South. Therefore the shortest path is determined for inhabitants to travel South. Each PC4 location is allocated to a station offering the shortest trip option to the South. This is done for both cycling and bus modes. Google maps is used to retrieve the shortest cycling distance and shortest travel time by bus. Data is obtained on weekdays, early in the afternoon. In this manner realistic travel times for commuting are expected. Bus travel times consist of walking to the stop, in vehicle time and transfer time at the station. Cycling travel times are computed by multiplying the given distance with the determined average cycling speed of 16 km/h. Some locations are favourable for either Waarland or Breezand station. The shortest path to one of these projected stations is included if so.
The access times are given in table 46.

Location	Postal code	Nearby station for cycles	cycle travel time (min)	Alternative	travel time (min)	Nearby station using bus	bus travel time (min)
Heerhugowaard	1701	Heerhugowaard	14,6			Alkmaar	38,0
Heerhugowaard	1702	Heerhugowaard	13,5			Alkmaar	43,0
Heerhugowaard	1703	Heerhugowaard	6,0			Heerhugowaard	10,0
Heerhugowaard	1704	Heerhugowaard	7,5			Heerhugowaard	8,0
Heerhugowaard	1705	Heerhugowaard	15,4			Alkmaar	22,0
Heerhugowaard	1706	Heerhugowaard	13,1			Alkmaar	33,0
Broek op Langedijk	1721	Heerhugowaard	11,3			Alkmaar	35,0
Zuid-Scharwoude	1722	Heerhugowaard	15,8			Alkmaar	27,0
Noord-Scharwoude	1723	Heerhugowaard	22,5			Alkmaar	39,0
Oudkarspel	1724	Heerhugowaard	21,8	Waarland	19,9	Alkmaar	42,0
Winkel	1731	Schagen	46,9	Waarland	34,9	Heerhugowaard	61,0
Lutjewinkel	1732	Schagen	30,0	Waarland	29,6	Heerhugowaard	44,0
Nieuwe Niedorp	1733	Heerhugowaard	40,1	Waarland	20,3	Alkmaar	33,0
Oude Niedorp	1734	Heerhugowaard	34,9	Waarland	15,4	Alkmaar	48,0
't Veld	1735	Heerhugowaard	44,3	Waarland	15,0	Schagen	22,0
Zijdewind	1736	Schagen	18,0	Waarland	12,8	Schagen	54,0
Waarland	1738	Heerhugowaard	33,0	Waarland	7,5	Schagen	27,0
Schagen	1741	Schagen	6,0			Schagen	17,0
Schagen	1742	Schagen	8,6			Schagen	37,0
Sint Maarten	1744	Schagen	23,3			Alkmaar	60,0

Dirkshorn	1746	Schagen	24,8			Alkmaar	62,0
Tuitjenhorn	1747	Schagen	33,0	Waarland	24,4	Alkmaar	37,0
Warmenhuizen	1749	Heerhugowaard	43,9	Waarland	33,4	Alkmaar	26,0
Schagerbrug	1751	Schagen	18,0			Schagen	24,0
Sint Maartensbrug	1752	Schagen	23,6			Schagen	15,0
Sint Maartensvlotbrug	1753	Schagen	32,6			Schagen	32,0
Burgerbrug	1754	Schagen	35,6			Alkmaar	55,0
Petten	1755	Schagen	47,3			Alkmaar	41,0
't Zand	1756	Anna Paulowna	28,9			Schagen	25,0
Oudesluis	1757	Anna Paulowna	20,3			Schagen	25,0
Callantsoog	1759	Anna Paulowna	42,0			Schagen	50,0
Anna Paulowna	1761	Anna Paulowna	10,1			Anna Paulowna	10,0
Breezand	1764	Anna Paulowna	16,5	Breezand	3,8	Anna Paulowna	23,0
Wieringerwaard	1766	Anna Paulowna	21,8			Anna Paulowna	14,0
Kolhorn	1767	Schagen	30,4			Schagen	23,0
Barsingerhorn	1768	Schagen	18,8			Schagen	10,0
Haringhuizen	1769	Schagen	11,3			Schagen	17,0
Den Helder	1781	Den Helder	6,4			Den Helder	23,0
Den Helder	1782	Den Helder	3,8			Den Helder	9,0
Den Helder	1783	Den Helder Zuid	15,8			Den Helder	28,0
Den Helder	1784	Den Helder Zuid	8,3			Den Helder Zuid	9,0
Den Helder	1785	Den Helder Zuid	4,5			Den Helder Zuid	14,0
Den Helder	1786	Den Helder Zuid	11,3			Den Helder	20,0
Julianadorp	1787	Den Helder Zuid	26,6	Breezand	25,1	Den Helder Zuid	31,0
Julianadorp	1788	Den Helder Zuid	25,1	Breezand	21,8	Den Helder Zuid	20,0
Huisduinen	1789	Den Helder	10,9			Den Helder Zuid	25,0
Alkmaar	1811	Alkmaar	5,6				
Alkmaar	1812	Alkmaar	16,9				
Alkmaar	1813	Alkmaar	5,3				
Alkmaar	1814	Alkmaar	9,4				
Alkmaar	1815	Alkmaar	6,8				
Alkmaar	1816	Alkmaar	8,3				
Alkmaar	1817	Alkmaar	10,1				
Alkmaar	1821	Alkmaar	9,0				
Alkmaar	1822	Alkmaar Noord	7,5				
Alkmaar	1823	Alkmaar Noord	4,5				
Alkmaar	1824	Alkmaar Noord	3,8				
Alkmaar	1825	Alkmaar Noord	9,8				
Alkmaar	1826	Alkmaar Noord	7,9				
Alkmaar	1827	Alkmaar Noord	14,6				

Table 46: Access time to station

Egress out of corridor

Two connecting rail services lead out of the case area. At Alkmaar the intercity service (from Den Helder) continues to Amsterdam and a local service goes to Haarlem and terminates in Amsterdam. Only the part of the route to Haarlem is evaluated of this local service, as it the last part to Amsterdam is expected to offer very little residual opportunity for inhabitants of the case area.

The ferry to Texel does also offer a connexion out of the case area, but this will not be investigated further. It is assumed that the required bus transfer, 25 minutes sailing time and egress trip on the island is a deterrent to most opportunity and prevents most commutes. The travel times of connecting trains from Alkmaar station are sourced from NS (2022) and given in table 47. At these stations it is assumed that people have an average egress time of 10 minutes. Additionally; the employment opportunity of Amsterdam is assumed to be at 10 minutes from Amsterdam Sloterdijk station. This is not very precise, but assumed to be sufficient. In practice; the attractiveness of jobs that are further than half an hour diminishes rapidly due to the exponential decay function.

Station	Travel time (min)
Alkmaar (dwell)	3
Heiloo	8
Castricum	14
Uitgeest	23
Krommenie	41
Zaandam	28
Amsterdam Sloterdijk	34
Heemskerk	28
Beverwijk	31
Driehuis	36
Bloemendaal	42
Haarlem	46

Table 47: travel times of connecting rail services

Appendix H: Investment cost

Some sections of railway require expansion of double track and / or construction of stations to achieve the modelled travel times. These measures require investment. This section estimates the cost of these infrastructure measures.

The distance and location of single tracked sections that have to be doubled is given in table 48, which is recalled from appendix E.

Doubling of single track:	Schagen	Anna Paulowna		Breezand		Den Helder Zuid		Den Helder
alternative	North (km)	South (km)	North (km)	South (km)	North (km)	South (km)	North (km)	South (km)
VIRM expanded		0,4						1,7
SLT expanded			1,1					1,7
SLT Waarland			1,1					1,7
SLT Breezand			1,1				1,1	
SLT Wl. & Br.				2,7	0,3		1,1	
mixed	4,4			2,7	1,7			1,7

Table 48: Single track sections to be doubled

Specification of alternatives

As displayed in table 48; most design alternatives need doubling of single track North of Anna Paulowna and either a substantial or the entire single track section between Den Helder and Den Helder zuid. The mixed service design alternative is an exception, which requires lengthening of the passing loop at Anna Paulowna till the Koegrasbug and extending the double track end from from Schagen 4,4 km Northward, till the proximity of Oudesluis. Additionally stations need to be built at either Waarland, Breezand or both for the respective design alternatives. Figure 22 to figure 24 contain detailed maps.

It is decided that three alignment alternatives are estimated, plus the cost of new stations. This is chosen for multiple reasons. Alternatives do not differ substantially are combined. It is decided to only evaluate a 1,7 km double track expansion at Den Helder, since it only varies 600 metres, which is expected to account for just 10% of the expected project cost. Therefore doubling the remaining single track in Den Helder is considered to be more futureproof. Newer types of rolling stock offer faster acceleration and require longer crossing sections. New rolling stock will become available which offers faster acceleration, this is discussed in chapter 7. It is chosen to facilitate this new rolling stock over reducing the investment cost. This might create excess track under some alternatives, mainly when VIRM type remain to be used. Excess track is assumed to be beneficial to timetable stability, as it prevents the spread of delay to some extent. It should be considered of the 10% cost saving is worth restricting some alternatives. The project cost are considered to be sunk cost, therefore it is not advisable double as little track as possible. Therefore it is chosen to refrain from assessing the investment cost of the VIRM expanded alternative into detail, as this alternative is considered to be outdated. New rolling stock will become available in the future, which is expected to have faster acceleration. It is assumed that the VIRM alternative can be estimated by subtracting the Anna Paulowna section of the SLT alternative.

This results in 3 alignment alternatives evaluated:

1. Doubling of 1,1 km single track North of Anna Paulowna station and doubling of the remaining single track between Den Helder main and Zuid station. (with or without stations according to the design alternative)
2. Doubling of 3,0 km single track between Anna Paulowna and Breezand station, construction of Waarland station and double tracking between Den Helder main and Zuid station.
3. The previous but with 4,4 km of double track between Anna Paulowna and the Koegrasbrug and 4,4 km of double track extension North of Schagen. (for the mixed alternative)

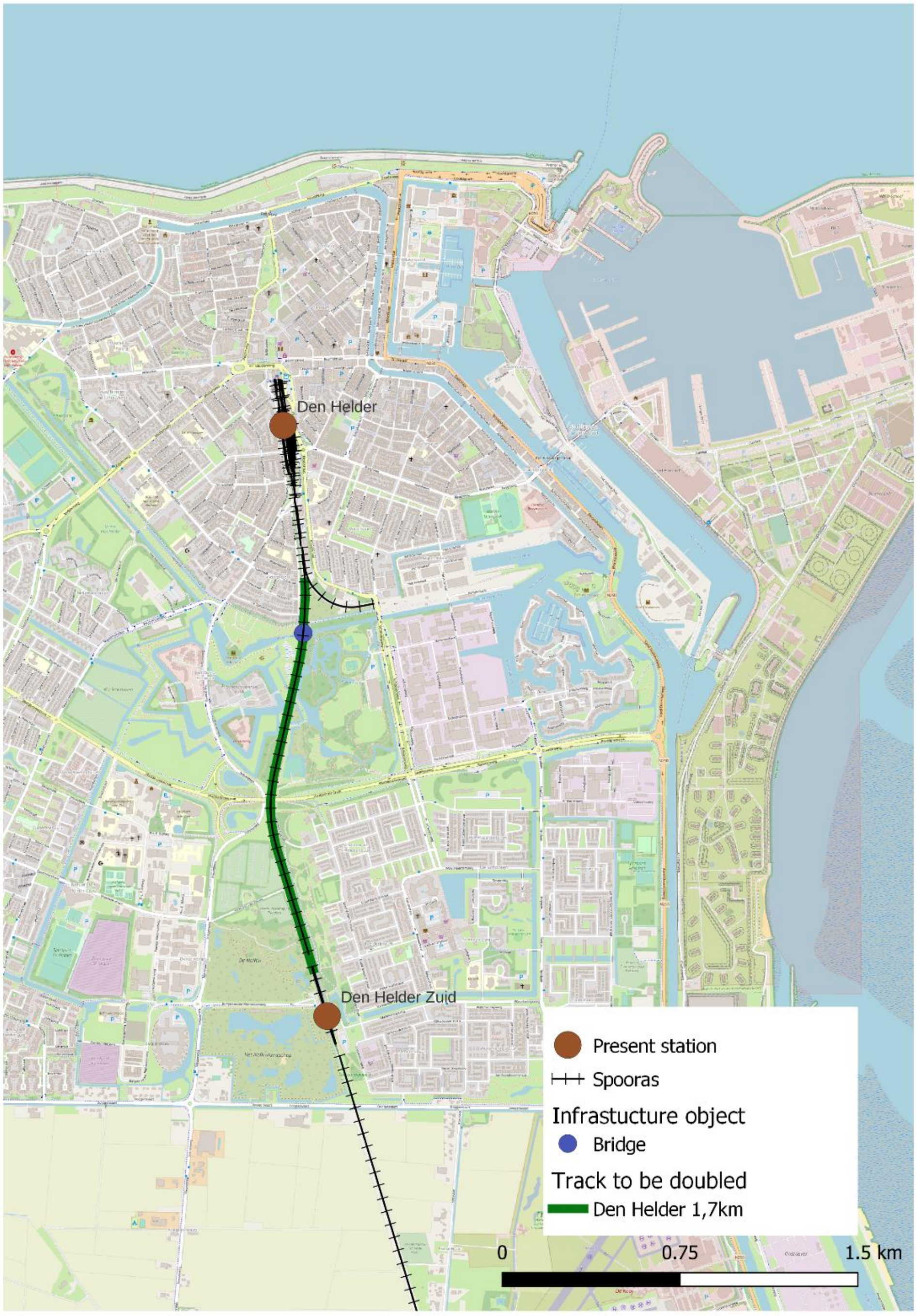

Figure 22: Track doubling Den Helder

Figure 23: Track doubling Anna Paulowna - Breezand

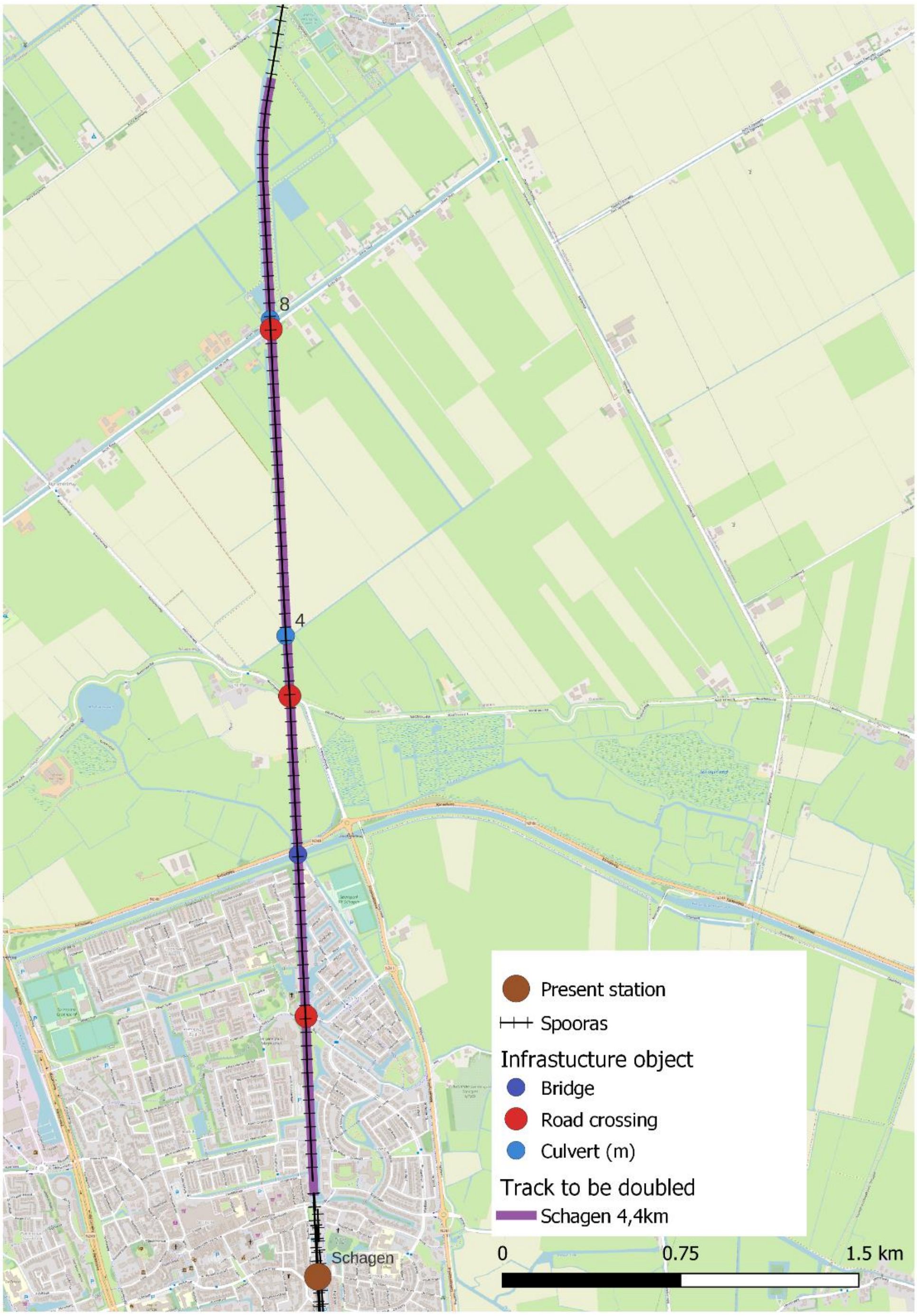

Figure 24: Track doubling Schagen

Cost data

Detailed cost specifications of railway projects are not released usually. This section borrows these mainly from the Nedersaksenlijn project, whom did release detailed estimates. Specifically a student thesis (de Heus, 2016), which got validated later (Movares, 2019). The original thesis report received some criticism on assumptions, but these are mostly related to design choices, not the cost data itself. Additionally the data is for a completely new railway, which is assumed to be of higher cost compared to expanding the existing alignment on the corridor. Therefore it is assumed that the key figures can be applied when adjusted for inflation. Inflation is assumed to be 7,4% in 2022 and 1,8% in the 2016-2021 period (CPB, 2020).
Constructing a basic station is estimated to add 3,0 million euros, when adjusted for inflation (CROW, 2015). A simple underpass is estimated to cost 2,0 million euros (Gemeente Winterswijk, 2022).

The estimation of cost is specified in table 49.

Infrastucture cost		
Category	Component	Valuation
Railway allingment		
	Earthworks (m)	€ 660
	Tracklaying (m)	€ 480
	Catenary (m)	€ 420
	Signalling (m)	€ 300
	Cabling (m)	€ 240
	interlocking (pc)	€ 1.800.000
Railway components		
	Points (pc)	€ 180.000
	level crossing (pc)	€ 600.000
Civil structures		
	Culvert: dive under (m)	€ 120
	Culvert: slope (pc)	€ 600
	Railway bridge (pc)	€ 720.000
	underpass (pc)	€ 2.000.000
	bicycle parking (pc)	€ 50.000
Station		
	basic (pc)	€ 3.000.000
	bicycle parking (pc)	€ 50.000
Overhead		
	Risk surcharge	15%
	To be detailed	20%
	indirect cost	25%
	Engineering cost	20%
	Permits etc.	5%
	Unforeseen	5%

Table 49:infrastructure cost estimation

This specification is applied on the case corridor with some assumptions. Firstly; the right of way corridor is deemed wide enough to allow a second track. The width of the embankment is in excess of 20 metres in nearly all locations, allowing the installation of a second track

after some earthworks.
Lengthening an existing passing loop is expected to require 1 point, superfluous points are removed. When a unused bridge structure is present next to the current alignment 25% of the cost of a new bridge is charged to allow for conservation. 100% is charged when only abutments are present.

Estimation of investment cost

Alignment

Double track is required in a number of locations. This section considers the doubling of 1,7 km between Den Helder and Den helder Zuid in table 50, 1,1 km North of Anna Paulowna in table 51, a 1,9 km extension of the latter towards Breezand in table 52, another 1,4 extension towards the Koegrasbrug in table 53 and the doubling 4,4 km North of Schagen in table 54. Alignment cost for these sections is calculated by measuring the alignment on satellite imagery and counting / measuring the relevant objects encountered. Fixed cost are assigned to the Den Helder and Den helder Zuid section, as this section is used by all alternatives.

Category	Component	Den Helder – Den Helder Zuid		
Railway right of way		required	sum	
	Earthworks (m)	1700	€	1.122.000
	Tracklaying (m)	1700	€	816.000
	Catenary (m)	1700	€	714.000
	Signalling (m)	1700	€	510.000
	Cabling (m)	1700	€	408.000
	interlocking (pc)	1	€	1.800.000
Railway components				
	Points (pc)	2	€	360.000
	level crossing (pc)			
Civil structures				
	Railway bridge (pc)	0,25	€	180.000
Subtotal			€	5.910.000
Overhead				
	Risk surcharge		€	886.500
	To be detailed		€	1.182.000
	indirect cost		€	1.477.500
	Engineering cost		€	1.182.000
	Permits etc.		€	295.500
	Unforeseen		€	295.500
	Vat		€	1.241.100
	Sub total		€	12.470.100

Table 50: Alingment cost Den Helder – Den Helder zuid

Category	Component	Anna Paulowna	
Railway right of way		required	sum
	Earthworks (m)	1100	€ 726.000
	Tracklaying (m)	1100	€ 528.000
	Catenary (m)	1100	€ 462.000
	Signalling (m)	1100	€ 330.000
	Cabling (m)	1100	€ 264.000
Railway components			
	Points (pc)	1	€ 180.000
	level crossing (pc)	1	€ 600.000
Subtotal			€ 3.090.000
Overhead			
	Risk surcharge		€ 463.500
	To be detailed		€ 618.000
	indirect cost		€ 772.500
	Engineering cost		€ 618.000
	Permits etc.		€ 154.500
	Unforeseen		€ 154.500
	Vat		€ 648.900
	Sub total		€ 6.519.900

Table 51: Alignment cost Anna Paulowna

Category	Component	Breezand	
Railway right of way		required	sum
	Earthworks (m)	1900	€ 1.254.000
	Tracklaying (m)	1900	€ 912.000
	Catenary (m)	1900	€ 798.000
	Signalling (m)	1900	€ 570.000
	Cabling (m)	1900	€ 456.000
Railway components			
	level crossing (pc)	2	€ 1.200.000
Civil structures			
	Culvert: dive under (m)	9	€ 1.080
	Culvert: slope (pc)	4	€ 2.400
	underpass	1	€ 2.000.000
Subtotal			€ 5.191.080
Overhead			
	Risk surcharge		€ 463.500
	To be detailed		€ 618.000
	indirect cost		€ 772.500
	Engineering cost		€ 618.000
	Permits etc.		€ 154.500
	Unforeseen		€ 154.500
	Vat		€ 648.900
	Sub total		€ 8.620.980

Table 52: Alingment cost Anna Paulowna – Breezand

Category	Component	Koegrasbrug	
Railway right of way		required	sum
	Earthworks (m)	1400	€ 924.000
	Tracklaying (m)	1400	€ 672.000
	Catenary (m)	1400	€ 588.000
	Signalling (m)	1400	€ 420.000
	Cabling (m)	1400	€ 336.000
Railway components			
	level crossing (pc)	2	€ 1.200.000
Subtotal			€ 4.140.000
Overhead			
	Risk surcharge		€ 463.500
	To be detailed		€ 618.000
	indirect cost		€ 772.500
	Engineering cost		€ 618.000
	Permits etc.		€ 154.500
	Unforseen		€ 154.500
	Vat		€ 648.900
	Sub total		€ 7.569.900

Table 53: Alingment cost Breezand – Koegrasbrug

Category	Component	Schagen – Oudesluis	
Railway right of way		required	sum
	Earthworks (m)	4400	€ 2.904.000
	Tracklaying (m)	4400	€ 2.112.000
	Catenary (m)	4400	€ 1.848.000
	Signalling (m)	4400	€ 1.320.000
	Cabling (m)	4400	€ 1.056.000
	interlocking (pc)		
Railway components			
	Points (pc)	1	€ 180.000
	level crossing (pc)	3	€ 1.800.000
Civil structures			
	Culvert: dive under (m)	12	€ 1.440
	Culvert: slope (pc)	4	€ 2.400
	Railway bridge (pc)	1	€ 720.000
Subtotal			€ 11.944.000
Overhead			
	Risk surcharge		€ 1.792.000
	To be detailed		€ 2.389.000
	indirect cost		€ 2.936.000
	Engineering cost		€ 2.389.000
	Permits etc.		€ 597.000
	Unforseen		€ 597.000
	Vat		€ 2.508.000
	Sub total		€ 25.202.000

Table 54: Alingment cost Schagen – Oudesluis

Stations

For stations a general estimate is given by CROW (2015). A station, when adjusted for inflation, is expected to cost between 3 and 12 million EUR. The exact cost within this range depends on multiple factors. Substantial aspects are the number of tracks / platforms and underpasses, lifts, bus stops, parking and other amenities if required.
An exact estimation cannot be given for either Waarland or Breezand station. This depends on design choices. Waarland has to be built with two side platforms. Building the station nearby the level crossing saves investment in an underpass, but this is not the most appealing from a passenger journey perspective, as the railway crossing has to be shared with road traffic.

The cost estimation for Breezand station is less straightforward. Not all the design alternatives require the same number of platforms. For the SLT Breezand and SLT Waarland & Breezand alternatives the station can be built with a single platform, because there is no double track required in the station. The mixed alternatives requires two platforms because double track is required at and near the station. Secondly; the level crossings at Zandvaart and Burgemeester Lovinkstraat in relative close proximity. They are 640 metres apart, therefore special safety circuits are expected to be required when a station is built. Level crossing elimination could be considered, which drives up cost.
Additionally; an over- or underpass is expected to be required in the mixed alternative. Either at Anna Paulowna or Breezand, for passenger safety reasons. The double tracked passing loop at Anna Paulowna currently has left hand traffic. This is in contrast with normal operating procedures, but assumed to be done for safety reasons at Anna Paulowna station. This station has level crossings between platforms. Southbound trains call at the village side platform of the station with left hand traffic. The level crossing between platforms will become a barrier during the morning peak when switched to right hand traffic. Right hand traffic will benefit Breezand station however, as left hand traffic will mean that all passengers at Breezand will have to cross the railway during the morning peak. Therefore an over- or underpass is required at either Anna Paulowna or Breezand if a service with two limited stop intercity and two sprinter trains per hour is offered. This will increase cost, the extent of which is unknown as it depends on specifications and local conditions. This is best evaluated in follow up research.

Given the simple station requirements it is assumed that the a station with two platforms will cost is 3,0 million euro. No discount is applied when one platform is required. This is chosen to account for uncertainties. Bicycle parking and other amenities are required and assumed to cost €50.000. Overhead cost apply. Table 55 results in a total sum of 3,4 million EUR per station.

Station		
Civil structures		
	station	€ 3.000.000
	bike parking	€ 50.000
Subtotal		€ 3.050.000
Overhead		
	Risk surcharge	€ 458.000
	To be detailed	€ 610.000
	indirect cost	€ 763.000
	Engineering cost	€ 610.000
	Permits etc.	€ 153.000
	Unforseen	€ 153.000
	Vat	€ 641.000
	Total	€ 3.388.000

Table 55: Station cost

Total infrastructure cost

The expected total cost of infrastructure investment is given in table 56:

Investment cost					
Alternative	SLT Expanded infrastructure	SLT Waarland	SLT Breezand	SLT Waarland & Breezand	Mixed
Alignment	€ 18.990.000	€ 18.990.000	€ 18.990.000	€ 27.611.000	€ 60.383.000
Stations	€ 0	€ 3.388.000	€ 3.388.000	€ 6.776.000	€ 6.776.000
Total cost	€ 18.990.000	€ 22.378.000	€ 22.378.000	€ 34.387.000	€ 67.159.000

Table 56: Infrastructure investment cost

Reservations apply; it should be considered that this is a rough estimate and not a precise calculation. It should be mentioned that while infrastructure investment is a very important, but not only part of the equation. Other costs apply as well, such as the cost of operating rolling stock. It could not be included because applicable data was not available to the author. Follow up research is required in this field.

Appendix I: Accessibility potential

The accessibility potential of each place is given in table 57. This table is the result of applying section 3.5 and 4.5.2 on appendix E, F and G. Appendix E is used for the travel times between stations and appendix G for the access time to places from each station. Appendix F contains the number of jobs available and inhabitants of each place. The travel times and number of jobs are an input for the accessibility potential computation. For each design alternative under evaluation the accessibility potential is computed from each postcode place of origin to all places of work accessible through the PT network. The total number of workplaces accessible is reported per location of origin per design alternative.

The number of inhabitants is used to compote the average number of jobs accessible per capita. The average number of jobs accessible per capita is used as a derivate. It weighs the accessibility potential for each location and expresses the accessibility potential in a concise and understandable manner. This allows a quick interpretation of the results.

Accessibility potential										
Alternative		Current	VIRM	SLT	VIRM expanded	SLT expanded	SLT Waarland	SLT Breezand	SLT Wl. & Br.	Mixed
Average workplace accessible per capita (#)		91279	100250	104143	101036	105469	105218	105659	105413	105647
Place name	Postcode	Workplaces accessible per location (#)								
Heerhugowaard	1701	111685	122061	125686	122283	126051	125947	125890	125796	122819
Heerhugowaard	1702	115519	126251	130000	126480	130377	130270	130211	130114	127035
Heerhugowaard	1703	144667	158107	162802	158394	163275	163140	163067	162945	159089
Heerhugowaard	1704	138301	151150	155638	151425	156090	155962	155891	155775	152089
Heerhugowaard	1705	109200	119345	122889	119562	123246	123145	123089	122997	120087
Heerhugowaard	1706	116826	127679	131471	127911	131852	131744	131685	131586	128472
Broek op Langedijk	1721	123585	135067	139078	135313	139482	139367	139304	139200	135906
Zuid-Scharwoude	1722	107978	118010	121515	118225	121867	121767	121712	121621	118743
Noord-Scharwoude	1723	88185	96377	99239	96553	99527	99446	99401	99326	96976
Oudkarspel	1724	90191	98570	101498	98750	101792	95388	101663	95237	98623
Winkel	1731	33784	37730	39262	37840	39440	60822	39362	60726	62885
Lutjewinkel	1732	56049	62596	65138	62779	65434	71197	65304	71084	73612
Nieuwe Niedorp	1733	64356	70335	72424	70463	72634	94321	72542	94171	97520
Oude Niedorp	1734	60836	66488	68462	66609	68661	109175	68574	109002	112878
't Veld	1735	89517	97834	100739	98012	101032	110410	100903	110235	114155
Zijdewind	1736	80337	89721	93365	89983	93788	118120	93602	117933	122126
Waarland	1738	64356	70335	72424	70463	72634	138269	72542	138050	142959
Schagen	1741	115149	128600	133823	128975	134430	128686	134163	128419	130170
Schagen	1742	106429	118861	123688	119208	124249	118941	124003	118694	120313
Sint Maarten	1744	68630	76647	79759	76870	80121	76698	79962	76539	77583
Dirkshorn	1746	65610	73274	76250	73488	76596	73323	76444	73171	74169
Tuitjenhorn	1747	45432	50740	52800	50887	53040	83342	52934	83210	86169
Warmenhuizen	1749	79395	86771	89348	86929	89607	79376	89493	79251	82069
Schagerbrug	1751	80337	89721	93365	89983	93788	89781	93602	89595	90817
Sint Maartensbrug	1752	67862	75789	102157	76010	102621	75840	102417	75683	76715

Sint Maartensvlotbrug	1753	51804	57856	60206	58025	60479	57895	60359	57775	58563
Burgerbrug	1754	47346	52876	55024	53030	55273	52912	55164	52802	53522
Petten	1755	40295	45002	46830	45133	47042	45032	46949	44939	45552
't Zand	1756	49332	55378	58310	55470	58452	56046	58296	55890	56035
Oudesluis	1757	63900	71732	75529	71851	75714	72597	75511	72395	72582
Callantsoog	1759	33275	37354	39331	37416	39427	37804	39322	37699	37797
Anna Paulowna	1761	86580	97192	102337	97354	102587	98364	102313	98090	98344
Breezand	1764	71509	80274	84523	80407	84729	81241	114936	110556	114555
Wieringerwaard	1766	61088	68576	72206	68690	72382	69402	72189	69209	69388
Kolhorn	1767	55422	61896	64410	62076	64702	61938	64573	61809	62652
Barsingerhorn	1768	78549	87725	118690	87981	119228	87784	118992	87602	88796
Haringhuizen	1769	98369	109860	114322	110180	114840	109934	114612	109706	111202
Den Helder	1781	76480	82396	85884	86032	91979	88449	87808	84475	86913
Den Helder	1782	82746	89147	92921	93081	99516	95696	95002	91396	94034
Den Helder	1783	63541	69698	73127	71102	75560	72581	72088	69276	71283
Den Helder	1784	79574	87284	91579	89042	94625	90894	90278	86755	89269
Den Helder	1785	89049	97678	102483	99645	105892	101717	101027	97086	99898
Den Helder	1786	72725	79772	83697	81378	86481	83071	82508	79288	81585
Julianadorp	1787	45853	50296	52770	51309	54526	52376	60529	58223	60329
Julianadorp	1788	47963	52611	55199	53670	57035	54787	66979	64426	66757
Huisduinen	1789	66822	71991	75038	75167	80364	77280	76719	73807	75937

Table 57: Accessibility potential of design alternatives

The accessibility potential is computed from locations of origin to places of work elsewhere via the PT network. The workplaces are correspond with one railway station at the respective destination. The destination stations are either in or out of the evaluated Alkmaar – Den Helder railway corridor. Table 58 consists of the average workplace potential per capita of the population, split between the location of destination. Internal locations are within the Alkmaar – Den Helder railway corridor, external locations are out of the case area. Which external locations are included is given in appendix G. The percentage of total indicates how much of the total number of internal or external workplaces are covered by the design alternatives.

	Average accessibility (per capita)					
Alternative	Total	% of total	Internal	% of total	External	% of total
Current	91279	10,75%	36073	31,51%	55206	7,52%
VIRM	100250	11,81%	37179	32,48%	63071	8,59%
SLT	104143	12,27%	37855	33,07%	66288	9,03%
VIRM expanded	101036	11,90%	37542	32,80%	63494	8,65%
SLT expanded	105469	12,43%	38454	33,59%	67015	9,13%
SLT Waarland	105218	12,40%	38878	33,96%	66340	9,03%
SLT Breezand	105659	12,45%	38507	33,64%	67152	9,14%
SLT Wl. & Br.	105413	12,42%	38944	34,02%	66469	9,05%
Mixed	105647	12,45%	39700	34,68%	65947	8,98%

Table 58: Accessibility contribution of locations

Table 58 indicates that there is a substantial difference between the percentage of workplaces covered within and out of the corridor. This difference is in the order of a factor four. There are still a significant number of workplaces accessible, but this caused by the larger number of external workplaces in general. The decay function of the gravity model causes the attractivity of workplaces South from Alkmaar to plumet for inhabitants of the corridor area. It indicates that a substantial group of inhabitants does not commute very far out of the corridor area. The diminishing attractiveness of workplaces South of Alkmaar could be of relevance when considering rolling stock and service design. Transfers are generally not preferred by passengers, but could be acceptable when well-timed and if the number of passengers having to transfer is not too high. This can only be verified with revealed railway passenger data, which could not be obtained for this research.

Appendix J: Equity assessment

The equity values and key results of each alternative are displayed in table 59. The equity assessment is executed with the help of methodology section 3.6 and section 4.6 of the case specification. The Theil index is outlined in section 3.6 of the methodology and elaborated in section 4.6 of the case description. Appendix F, and I are used as input data.

	Equity: location and income		Equity: location		Equity type
Alternative	equity (%)	improvement over current (%)	equity (%)	improvement over current (%)	Improvement diffrence (%)
Current	99,153%	0,00%	99,571%	0,00%	0,0%
VIRM	99,164%	1,06%	99,576%	0,57%	47,6%
SLT	99,191%	3,78%	99,590%	1,94%	52,6%
VIRM expanded	99,187%	3,39%	99,588%	1,70%	49,5%
SLT expanded	99,226%	7,32%	99,607%	3,67%	49,9%
SLT Waarland	99,274%	12,12%	99,632%	6,13%	50,7%
SLT Breezand	99,267%	11,43%	99,631%	6,03%	53,2%
SLT Wl. & Br.	99,316%	16,26%	99,656%	8,53%	52,8%
Mixed	99,390%	23,65%	99,693%	12,23%	51,9%

Table 59: Equity assessment

The specification of Theil 2 values and equity contributions of individual postcodes are given for all alternatives in the tables below. The reported Theil values of each postcode are the sum of the within component of both population group, plus the between component divided by the number of postcodes. By summing this up for all postcodes the Theil value of the case area is obtained for the alternative under evaluation. The Theil value is divided by ln(n=208870) to yield the inequality percentage. The inequality percentage is an expression of unfairness. The inverse of this is inequality percentage is the Equity score of the case region. It is decided to code equity as fairness, so by computing how far the equity indicator is from a 100% equal distribution of accessibility potential.
The Theil 1 values are obtained in the same manner, save for the differences between inhabitant groups, as Theil 1 is an equity assessment for location only. This is coined horizontal equity in scientific literature. Table 59 shows that assessing for location only yields substantially higher equity scores. Substantial equity differences are missed in other words. This is due to income not being distributed equal within the case region. Equity assessment for location only is therefore not used further, other than for comparing between equity types. The detailed equity values tables below allow the conduction of a geographical information system (GIS) analysis. The QGIS software package is used for this purpose. The analysis results are included in appendix H.

Alternative		Current			VIRM			SLT		
Theil2 value		0,1038			0,1024			0,0991		
Equity percentage		99,153%			99,164%			99,191%		
postcode	place	Theil 2	Percentage unequal	Equity contribution (%)	Theil 2	Percentage unequal	Equity contribution (%)	Theil 2	Percentage unequal	Equity contribution (%)
1701	Heerhugowaard	0,0205	0,168%	-0,168%	0,0200	0,163%	-0,163%	0,0189	0,154%	-0,154%
1702	Heerhugowaard	0,0252	0,205%	-0,205%	0,0245	0,200%	-0,200%	0,0234	0,191%	-0,191%
1703	Heerhugowaard	0,0909	0,742%	-0,742%	0,0895	0,731%	-0,731%	0,0870	0,710%	-0,710%
1704	Heerhugowaard	0,0496	0,405%	-0,405%	0,0488	0,398%	-0,398%	0,0473	0,386%	-0,386%
1705	Heerhugowaard	0,0326	0,266%	-0,266%	0,0315	0,257%	-0,257%	0,0297	0,242%	-0,242%
1706	Heerhugowaard	0,0051	0,042%	-0,042%	0,0050	0,041%	-0,041%	0,0047	0,039%	-0,039%
1721	Broek op Langedijk	0,0231	0,189%	-0,189%	0,0227	0,185%	-0,185%	0,0218	0,178%	-0,178%
1722	Zuid-Scharwoude	0,0110	0,090%	-0,090%	0,0106	0,087%	-0,087%	0,0100	0,081%	-0,081%
1723	Noord-Scharwoude	-0,0018	-0,015%	0,015%	-0,0020	-0,017%	0,017%	-0,0025	-0,020%	0,020%
1724	Oudkarspel	-0,0004	-0,003%	0,003%	-0,0006	-0,005%	0,005%	-0,0009	-0,007%	0,007%
1731	Winkel	-0,0117	-0,096%	0,096%	-0,0117	-0,096%	0,096%	-0,0117	-0,096%	0,096%
1732	Lutjewinkel	-0,0022	-0,018%	0,018%	-0,0022	-0,018%	0,018%	-0,0022	-0,018%	0,018%
1733	Nieuwe Niedorp	-0,0076	-0,062%	0,062%	-0,0077	-0,063%	0,063%	-0,0078	-0,064%	0,064%
1734	Oude Niedorp	-0,0009	-0,008%	0,008%	-0,0009	-0,008%	0,008%	-0,0010	-0,008%	0,008%
1735	't Veld	-0,0004	-0,003%	0,003%	-0,0005	-0,004%	0,004%	-0,0006	-0,005%	0,005%
1736	Zijdewind	-0,0004	-0,003%	0,003%	-0,0003	-0,003%	0,003%	-0,0003	-0,003%	0,003%
1738	Waarland	-0,0060	-0,049%	0,049%	-0,0061	-0,049%	0,049%	-0,0062	-0,050%	0,050%
1741	Schagen	0,0357	0,291%	-0,291%	0,0389	0,318%	-0,318%	0,0392	0,320%	-0,320%
1742	Schagen	0,0110	0,090%	-0,090%	0,0124	0,101%	-0,101%	0,0125	0,102%	-0,102%
1744	Sint Maarten	-0,0036	-0,030%	0,030%	-0,0035	-0,028%	0,028%	-0,0035	-0,028%	0,028%
1746	Dirkshorn	-0,0037	-0,030%	0,030%	-0,0036	-0,029%	0,029%	-0,0036	-0,029%	0,029%
1747	Tuitjenhorn	-0,0125	-0,102%	0,102%	-0,0124	-0,101%	0,101%	-0,0124	-0,101%	0,101%
1749	Warmenhuizen	-0,0067	-0,055%	0,055%	-0,0069	-0,056%	0,056%	-0,0073	-0,059%	0,059%
1751	Schagerbrug	-0,0021	-0,017%	0,017%	-0,0019	-0,015%	0,015%	-0,0018	-0,015%	0,015%
1752	St.Maartensbrug	-0,0014	-0,012%	0,012%	-0,0014	-0,011%	0,011%	-0,0001	-0,001%	0,001%
1753	St.Maartensvlotbrug	-0,0020	-0,016%	0,016%	-0,0019	-0,016%	0,016%	-0,0019	-0,016%	0,016%
1754	Burgerbrug	-0,0026	-0,021%	0,021%	-0,0026	-0,021%	0,021%	-0,0026	-0,021%	0,021%
1755	Petten	-0,0056	-0,046%	0,046%	-0,0056	-0,046%	0,046%	-0,0056	-0,046%	0,046%
1756	't Zand	-0,0078	-0,063%	0,063%	-0,0077	-0,063%	0,063%	-0,0076	-0,062%	0,062%
1757	Oudesluis	-0,0016	-0,013%	0,013%	-0,0016	-0,013%	0,013%	-0,0015	-0,013%	0,013%
1759	Callantsoog	-0,0085	-0,069%	0,069%	-0,0085	-0,069%	0,069%	-0,0085	-0,069%	0,069%
1761	Anna Paulowna	-0,0040	-0,033%	0,033%	-0,0023	-0,019%	0,019%	-0,0013	-0,011%	0,011%
1764	Breezand	-0,0066	-0,054%	0,054%	-0,0061	-0,050%	0,050%	-0,0058	-0,048%	0,048%
1766	Wieringerwaard	-0,0058	-0,048%	0,048%	-0,0056	-0,046%	0,046%	-0,0055	-0,045%	0,045%
1767	Kolhorn	-0,0030	-0,024%	0,024%	-0,0029	-0,024%	0,024%	-0,0029	-0,024%	0,024%
1768	Barsingerhorn	-0,0011	-0,009%	0,009%	-0,0010	-0,008%	0,008%	0,0012	0,010%	-0,010%
1781	Den Helder	-0,0140	-0,114%	0,114%	-0,0152	-0,124%	0,124%	-0,0150	-0,122%	0,122%
1782	Den Helder	-0,0096	-0,078%	0,078%	-0,0112	-0,092%	0,092%	-0,0109	-0,089%	0,089%
1783	Den Helder	-0,0072	-0,059%	0,059%	-0,0072	-0,059%	0,059%	-0,0071	-0,058%	0,058%
1784	Den Helder	-0,0120	-0,098%	0,098%	-0,0121	-0,099%	0,099%	-0,0113	-0,093%	0,093%
1785	Den Helder	-0,0022	-0,018%	0,018%	-0,0023	-0,019%	0,019%	-0,0014	-0,011%	0,011%
1787	Julianadorp	-0,0088	-0,072%	0,072%	-0,0088	-0,072%	0,072%	-0,0088	-0,072%	0,072%
1788	Julianadorp	-0,0359	-0,293%	0,293%	-0,0359	-0,293%	0,293%	-0,0357	-0,292%	0,292%
1789	Huisduinen	-0,0011	-0,009%	0,009%	-0,0012	-0,010%	0,010%	-0,0012	-0,010%	0,010%

Table 60: Equity values (without infrastructure change)

Alternative		VIRM expanded			SLT expanded		
Theil2 value		0,0996			0,0948		
Equity percentage		99,187%			99,226%		
postcode	place	Theil 2	Percentage unequal	Equity contribution (%)	Theil 2	Percentage unequal	Equity contribution (%)
1701	Heerhugowaard	0,0192	0,157%	-0,157%	0,0177	0,144%	-0,144%
1702	Heerhugowaard	0,0237	0,193%	-0,193%	0,0220	0,180%	-0,180%
1703	Heerhugowaard	0,0877	0,716%	-0,716%	0,0840	0,686%	-0,686%
1704	Heerhugowaard	0,0478	0,390%	-0,390%	0,0457	0,373%	-0,373%
1705	Heerhugowaard	0,0302	0,247%	-0,247%	0,0276	0,225%	-0,225%
1706	Heerhugowaard	0,0048	0,039%	-0,039%	0,0045	0,037%	-0,037%
1721	Broek op Langedijk	0,0221	0,180%	-0,180%	0,0208	0,170%	-0,170%
1722	Zuid-Scharwoude	0,0102	0,083%	-0,083%	0,0092	0,075%	-0,075%
1723	Noord-Scharwoude	-0,0024	-0,019%	0,019%	-0,0030	-0,025%	0,025%
1724	Oudkarspel	-0,0008	-0,006%	0,006%	-0,0012	-0,010%	0,010%
1731	Winkel	-0,0117	-0,096%	0,096%	-0,0117	-0,096%	0,096%
1732	Lutjewinkel	-0,0022	-0,018%	0,018%	-0,0022	-0,018%	0,018%
1733	Nieuwe Niedorp	-0,0078	-0,064%	0,064%	-0,0080	-0,065%	0,065%
1734	Oude Niedorp	-0,0009	-0,008%	0,008%	-0,0010	-0,008%	0,008%
1735	't Veld	-0,0006	-0,005%	0,005%	-0,0008	-0,007%	0,007%
1736	Zijdewind	-0,0004	-0,003%	0,003%	-0,0004	-0,003%	0,003%
1738	Waarland	-0,0061	-0,050%	0,050%	-0,0063	-0,051%	0,051%
1741	Schagen	0,0378	0,309%	-0,309%	0,0375	0,306%	-0,306%
1742	Schagen	0,0120	0,098%	-0,098%	0,0118	0,096%	-0,096%
1744	Sint Maarten	-0,0035	-0,029%	0,029%	-0,0035	-0,029%	0,029%
1746	Dirkshorn	-0,0036	-0,030%	0,030%	-0,0036	-0,030%	0,030%
1747	Tuitjenhorn	-0,0124	-0,101%	0,101%	-0,0124	-0,101%	0,101%
1749	Warmenhuizen	-0,0072	-0,058%	0,058%	-0,0077	-0,063%	0,063%
1751	Schagerbrug	-0,0019	-0,016%	0,016%	-0,0020	-0,016%	0,016%
1752	Sint Maartensbrug	-0,0014	-0,011%	0,011%	-0,0002	-0,001%	0,001%
1753	Sint aartensvlotbrug	-0,0019	-0,016%	0,016%	-0,0019	-0,016%	0,016%
1754	Burgerbrug	-0,0026	-0,021%	0,021%	-0,0026	-0,021%	0,021%
1755	Petten	-0,0056	-0,046%	0,046%	-0,0056	-0,046%	0,046%
1756	't Zand	-0,0077	-0,063%	0,063%	-0,0076	-0,062%	0,062%
1757	Oudesluis	-0,0016	-0,013%	0,013%	-0,0016	-0,013%	0,013%
1759	Callantsoog	-0,0085	-0,069%	0,069%	-0,0085	-0,069%	0,069%
1761	Anna Paulowna	-0,0029	-0,023%	0,023%	-0,0022	-0,018%	0,018%
1764	Breezand	-0,0063	-0,051%	0,051%	-0,0061	-0,050%	0,050%
1766	Wieringerwaard	-0,0057	-0,047%	0,047%	-0,0056	-0,046%	0,046%
1767	Kolhorn	-0,0030	-0,024%	0,024%	-0,0030	-0,024%	0,024%
1768	Barsingerhorn	-0,0010	-0,008%	0,008%	0,0012	0,009%	-0,009%
1781	Den Helder	-0,0129	-0,105%	0,105%	-0,0113	-0,092%	0,092%
1782	Den Helder	-0,0081	-0,066%	0,066%	-0,0059	-0,048%	0,048%
1783	Den Helder	-0,0071	-0,058%	0,058%	-0,0069	-0,056%	0,056%
1784	Den Helder	-0,0112	-0,092%	0,092%	-0,0099	-0,081%	0,081%
1785	Den Helder	-0,0012	-0,010%	0,010%	0,0004	0,004%	-0,004%
1787	Julianadorp	-0,0088	-0,072%	0,072%	-0,0087	-0,071%	0,071%
1788	Julianadorp	-0,0357	-0,291%	0,291%	-0,0353	-0,288%	0,288%
1789	Huisduinen	-0,0011	-0,009%	0,009%	-0,0010	-0,008%	0,008%

Table 61: Equity values (with doubling of track only)

Alternative		SLT WL			SLT BR		
Theil2 value		0,0889			0,0897		
Equity percentage		99,274%			99,267%		
postcode	place	Theil 2	Percentage unequal	Equity contribution (%)	Theil 2	Percentage unequal	Equity contribution (%)
1701	Heerhugowaard	0,0179	0,146%	-0,146%	0,0174	0,142%	-0,142%
1702	Heerhugowaard	0,0223	0,182%	-0,182%	0,0219	0,178%	-0,178%
1703	Heerhugowaard	0,0847	0,692%	-0,692%	0,0837	0,683%	-0,683%
1704	Heerhugowaard	0,0460	0,375%	-0,375%	0,0453	0,370%	-0,370%
1705	Heerhugowaard	0,0280	0,228%	-0,228%	0,0271	0,221%	-0,221%
1706	Heerhugowaard	0,0045	0,037%	-0,037%	0,0044	0,036%	-0,036%
1721	Broek op Langedijk	0,0210	0,172%	-0,172%	0,0206	0,168%	-0,168%
1722	Zuid-Scharwoude	0,0094	0,077%	-0,077%	0,0091	0,074%	-0,074%
1723	Noord-Scharwoude	-0,0029	-0,024%	0,024%	-0,0031	-0,025%	0,025%
1724	Oudkarspel	-0,0032	-0,026%	0,026%	-0,0013	-0,011%	0,011%
1731	Winkel	-0,0101	-0,082%	0,082%	-0,0117	-0,096%	0,096%
1732	Lutjewinkel	-0,0019	-0,016%	0,016%	-0,0022	-0,018%	0,018%
1733	Nieuwe Niedorp	-0,0030	-0,025%	0,025%	-0,0080	-0,065%	0,065%
1734	Oude Niedorp	0,0001	0,001%	-0,001%	-0,0010	-0,008%	0,008%
1735	't Veld	0,0011	0,009%	-0,009%	-0,0009	-0,007%	0,007%
1736	Zijdewind	0,0004	0,004%	-0,004%	-0,0004	-0,003%	0,003%
1738	Waarland	0,0088	0,072%	-0,072%	-0,0063	-0,051%	0,051%
1741	Schagen	0,0300	0,245%	-0,245%	0,0371	0,303%	-0,303%
1742	Schagen	0,0085	0,070%	-0,070%	0,0116	0,095%	-0,095%
1744	Sint Maarten	-0,0039	-0,032%	0,032%	-0,0036	-0,029%	0,029%
1746	Dirkshorn	-0,0039	-0,032%	0,032%	-0,0036	-0,030%	0,030%
1747	Tuitjenhorn	-0,0066	-0,054%	0,054%	-0,0124	-0,101%	0,101%
1749	Warmenhuizen	-0,0118	-0,096%	0,096%	-0,0078	-0,063%	0,063%
1751	Schagerbrug	-0,0026	-0,021%	0,021%	-0,0020	-0,016%	0,016%
1752	Sint Maartensbrug	-0,0015	-0,012%	0,012%	-0,0002	-0,002%	0,002%
1753	Sint Maartensvlotbrug	-0,0020	-0,016%	0,016%	-0,0019	-0,016%	0,016%
1754	Burgerbrug	-0,0027	-0,022%	0,022%	-0,0026	-0,021%	0,021%
1755	Petten	-0,0057	-0,046%	0,046%	-0,0056	-0,046%	0,046%
1756	't Zand	-0,0078	-0,064%	0,064%	-0,0077	-0,063%	0,063%
1757	Oudesluis	-0,0017	-0,014%	0,014%	-0,0016	-0,013%	0,013%
1759	Callantsoog	-0,0085	-0,069%	0,069%	-0,0085	-0,069%	0,069%
1761	Anna Paulowna	-0,0050	-0,041%	0,041%	-0,0024	-0,019%	0,019%
1764	Breezand	-0,0069	-0,056%	0,056%	0,0032	0,026%	-0,026%
1766	Wieringerwaard	-0,0060	-0,049%	0,049%	-0,0056	-0,046%	0,046%
1767	Kolhorn	-0,0031	-0,025%	0,025%	-0,0030	-0,024%	0,024%
1768	Barsingerhorn	-0,0013	-0,010%	0,010%	0,0011	0,009%	-0,009%
1781	Den Helder	-0,0137	-0,112%	0,112%	-0,0144	-0,118%	0,118%
1782	Den Helder	-0,0092	-0,075%	0,075%	-0,0102	-0,083%	0,083%
1783	Den Helder	-0,0073	-0,060%	0,060%	-0,0075	-0,061%	0,061%
1784	Den Helder	-0,0127	-0,104%	0,104%	-0,0134	-0,110%	0,110%
1785	Den Helder	-0,0030	-0,024%	0,024%	-0,0039	-0,032%	0,032%
1787	Julianadorp	-0,0089	-0,072%	0,072%	-0,0081	-0,066%	0,066%
1788	Julianadorp	-0,0361	-0,294%	0,294%	-0,0307	-0,250%	0,250%
1789	Huisduinen	-0,0011	-0,009%	0,009%	-0,0012	-0,010%	0,010%

Table 62: Equity values (alternatives SLT Waarland and SLT Breezand)

Alternative		SLT WL BR			Mixed		
Theil2 value		0,0838			0,0748		
Equity percentage		99,316%			99,390%		
postcode	place	Theil 2	Percentage unequal	Equity contribution (%)	Theil 2	Percentage unequal	Equity contribution (%)
1701	Heerhugowaard	0,0177	0,144%	-0,144%	0,0147	0,120%	-0,120%
1702	Heerhugowaard	0,0222	0,181%	-0,181%	0,0189	0,154%	-0,154%
1703	Heerhugowaard	0,0844	0,689%	-0,689%	0,0772	0,630%	-0,630%
1704	Heerhugowaard	0,0456	0,372%	-0,372%	0,0414	0,338%	-0,338%
1705	Heerhugowaard	0,0275	0,224%	-0,224%	0,0222	0,181%	-0,181%
1706	Heerhugowaard	0,0044	0,036%	-0,036%	0,0038	0,031%	-0,031%
1721	Broek op Langedijk	0,0208	0,170%	-0,170%	0,0183	0,150%	-0,150%
1722	Zuid-Scharwoude	0,0092	0,075%	-0,075%	0,0073	0,060%	-0,060%
1723	Noord-Scharwoude	-0,0030	-0,024%	0,024%	-0,0042	-0,035%	0,035%
1724	Oudkarspel	-0,0033	-0,027%	0,027%	-0,0023	-0,019%	0,019%
1731	Winkel	-0,0101	-0,082%	0,082%	-0,0098	-0,080%	0,080%
1732	Lutjewinkel	-0,0019	-0,016%	0,016%	-0,0018	-0,015%	0,015%
1733	Nieuwe Niedorp	-0,0031	-0,025%	0,025%	-0,0023	-0,018%	0,018%
1734	Oude Niedorp	0,0001	0,001%	-0,001%	0,0002	0,002%	-0,002%
1735	't Veld	0,0010	0,008%	-0,008%	0,0018	0,014%	-0,014%
1736	Zijdewind	0,0004	0,004%	-0,004%	0,0006	0,005%	-0,005%
1738	Waarland	0,0087	0,071%	-0,071%	0,0100	0,082%	-0,082%
1741	Schagen	0,0296	0,242%	-0,242%	0,0315	0,258%	-0,258%
1742	Schagen	0,0083	0,068%	-0,068%	0,0092	0,075%	-0,075%
1744	Sint Maarten	-0,0039	-0,032%	0,032%	-0,0038	-0,031%	0,031%
1746	Dirkshorn	-0,0039	-0,032%	0,032%	-0,0039	-0,032%	0,032%
1747	Tuitjenhorn	-0,0067	-0,054%	0,054%	-0,0059	-0,048%	0,048%
1749	Warmenhuizen	-0,0118	-0,097%	0,097%	-0,0108	-0,088%	0,088%
1751	Schagerbrug	-0,0026	-0,021%	0,021%	-0,0024	-0,020%	0,020%
1752	Sint Maartensbrug	-0,0015	-0,012%	0,012%	-0,0015	-0,012%	0,012%
1753	St.Maartensvlotbrug	-0,0020	-0,016%	0,016%	-0,0020	-0,016%	0,016%
1754	Burgerbrug	-0,0027	-0,022%	0,022%	-0,0027	-0,022%	0,022%
1755	Petten	-0,0057	-0,046%	0,046%	-0,0057	-0,046%	0,046%
1756	't Zand	-0,0079	-0,064%	0,064%	-0,0079	-0,064%	0,064%
1757	Oudesluis	-0,0017	-0,014%	0,014%	-0,0017	-0,014%	0,014%
1759	Callantsoog	-0,0085	-0,069%	0,069%	-0,0085	-0,069%	0,069%
1761	Anna Paulowna	-0,0052	-0,043%	0,043%	-0,0053	-0,043%	0,043%
1764	Breezand	0,0018	0,014%	-0,014%	0,0031	0,025%	-0,025%
1766	Wieringerwaard	-0,0060	-0,049%	0,049%	-0,0060	-0,049%	0,049%
1767	Kolhorn	-0,0031	-0,025%	0,025%	-0,0031	-0,025%	0,025%
1768	Barsingerhorn	-0,0013	-0,010%	0,010%	-0,0012	-0,010%	0,010%
1781	Den Helder	-0,0166	-0,135%	0,135%	-0,0150	-0,122%	0,122%
1782	Den Helder	-0,0131	-0,107%	0,107%	-0,0110	-0,090%	0,090%
1783	Den Helder	-0,0079	-0,064%	0,064%	-0,0076	-0,062%	0,062%
1784	Den Helder	-0,0159	-0,130%	0,130%	-0,0142	-0,116%	0,116%
1785	Den Helder	-0,0070	-0,057%	0,057%	-0,0048	-0,039%	0,039%
1787	Julianadorp	-0,0084	-0,068%	0,068%	-0,0082	-0,067%	0,067%
1788	Julianadorp	-0,0319	-0,261%	0,261%	-0,0308	-0,251%	0,251%
1789	Huisduinen	-0,0013	-0,010%	0,010%	-0,0012	-0,010%	0,010%

Table 63: Equity values (alternatives with both new stations)

Appendix K: GIS analysis

The results from the GIS analysis are included in figure 25, 26 and 27. The 3 comparisons cover the main design considerations. Figure 25 covers the reduction of in vehicle travel time. It is observed that equity gains correlate with the length of in vehicle travel time. The trade-off between in vehicle travel time and access time reduction is displayed in figure 26. Equity gains are local to the vicinity of Waarland and Breezand station. The effect is stronger in Breezand than in Waarland. Other areas do not benefit at all, they are better of with the SLT expanded alternative. Furthermore it is concluded that a cycle bridge does not yield any equity gains, as equity in Julianadorp worsens. The mixed alternative is able to retrieve equity lost in the previous analysis, as displayed in figure 27. Most locations that previously featured equity reductions turned have turned positive again. Heerhugowaard is the outlier for all alternatives evaluated. This is assumed to be caused by two effects. First Heerhugowaard has a relative good accessibility potential to start with, while and the rest of the case area lags behind. Heerhugowaard gets relatively worse as the remainder of the case area catches up. This is assumed to be good as the proportion of disadvantaged inhabitants is higher out of Heerhugowaard. The effect is further explained by considering that Heerhugowaard only uses a short section of the railway corridor, which sees minor change. A relative large proportion of the accessibility potential of Heerhugowaard is out of the case area, compared to other alternatives. This explains why other places gain more than Heerhugowaard does.

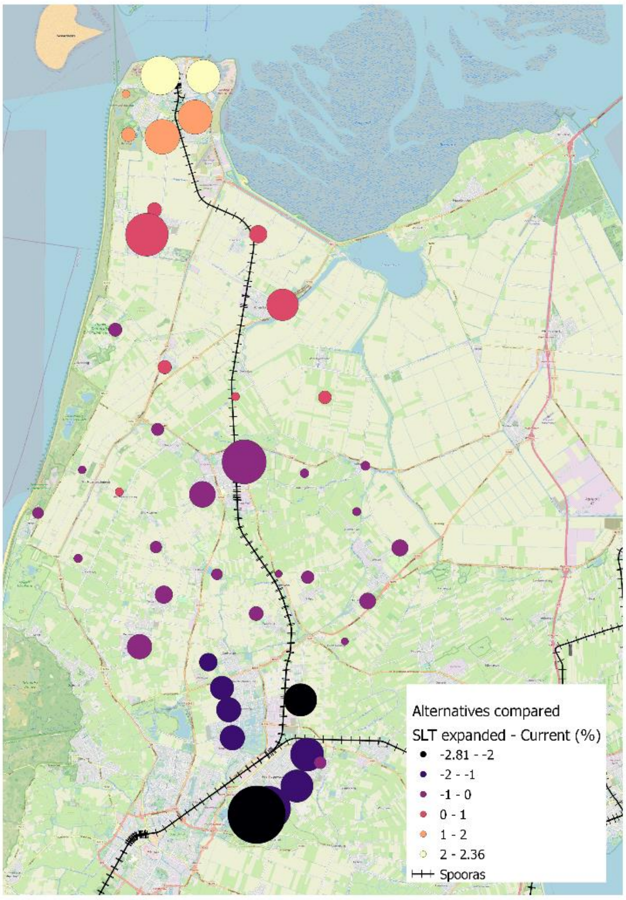

Figure 25

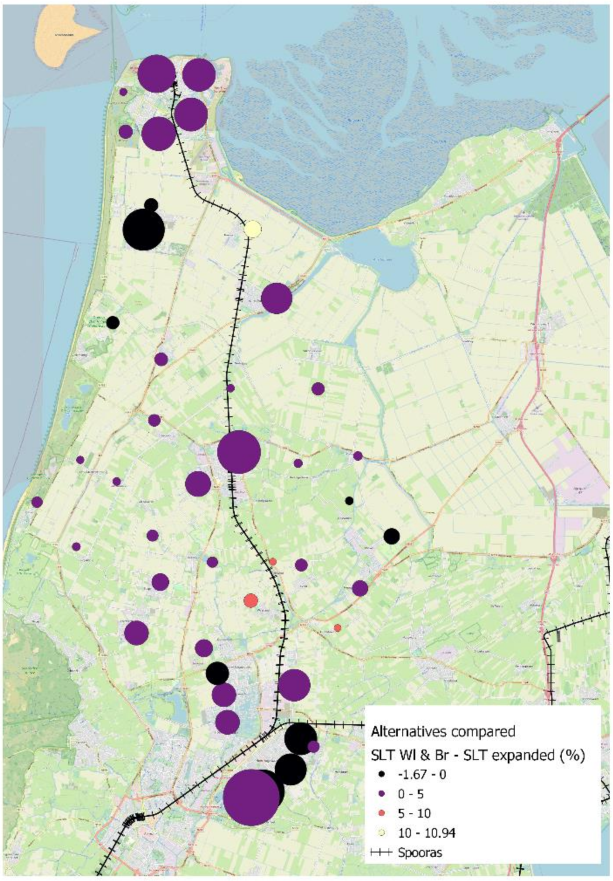

Figure 27

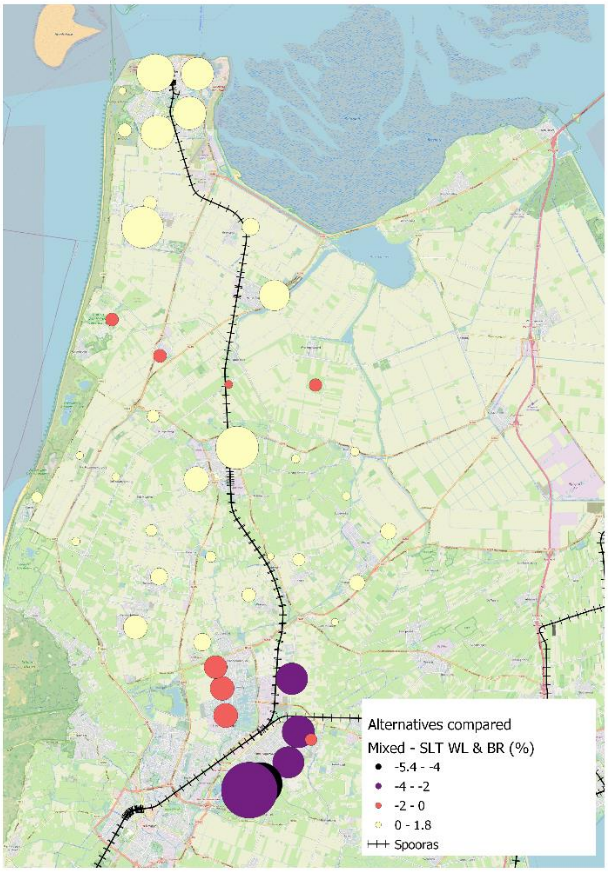

Figure 26