Transit Oriented Development: a study into the relation between spatial developments and public transport use

Case study: StedenbaanPlus

Final report MSc. Thesis project
June 11, 2014

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Transit Oriented Development: a study into the relation between spatial developments and public transport use
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PREFACE

This thesis is presented in partial fulfillment of the requirements for the degree of MSc. in Civil Engineering, track Transport & Planning, and has been completed at the Delft University of Technology. This report covers the analysis of the transit oriented development theory for land use and passenger transportation development, based on the case study StedenbaanPlus in the Randstad south wing. With use of the Dutch transportation model NRM the robustness of future developments is assessed.

First, I would thank my graduation committee. Foremost I would thank Rob van Nes for his assistance and detailed feedback during the 10 months I worked on this thesis. Also, I would like to thank the rest of the committee, Bart van Arem, John Baggen and Paul Wiggenraad for their guidance and comments. A special thanks goes to Marcel Bus from Panteia, Freek Hofker from ProRail and Rob Clement from Rijkswaterstaat for giving me the opportunity to use their software and datasets during my thesis and for offering me all the necessary help.

At the university I would like to thank the room-mates of the 'Afstudeerhok' for all their help, feedback and the perfect ambiance during the whole graduation process. My appreciation also goes out to my colleagues at Spoorzone Delft, who have offered me, despite my limited availability, a part-time job at this fantastic project throughout my entire graduation process (and afterwards!).

At last I would like to thank my girlfriend, family and friends for their interest in my study and for the feedback on the report and their useful advises on performing a research study.

Marc Schouwenaars
Delft, June 2014

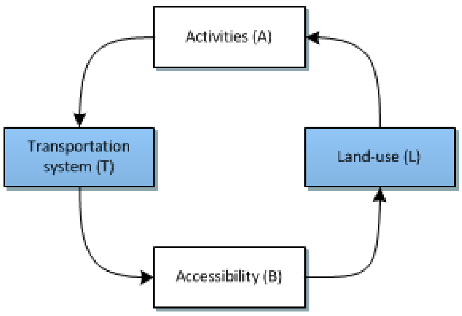
SUMMARY

EXECUTIVE SUMMARY (EN)

The development of cities and villages has always been dependent of accessibility factors. Many of the cities were raised along river banks and after the industrial revolution along the newly constructed railroads. When the private car became more affordable the new residential areas were built close to the highways. They seem to be natural developments, but during the last years this process is more and more guided. The best known example is the Vierde Nota Extra (fourth additional memorandum), commonly known as VINEX. In this memorandum places outside the cities were given a residential destination and soon after complete new residential areas arose.

Coordinating spatial growth experiences some problems during the last years. Building towards the highways stimulates car use, while the infrastructure in the cities cannot handle this increase in demand. Consequently accessibility problems and air pollution starts to occur. In order to stop this process, governments are studying worldwide on methods which can coordinate this growth in such a way, that liveability of the cities increases again. One of the methods which seems to achieve this is Transit Oriented Development. This method is focused on using existing and new infrastructure for public transport instead of roads for cars. The current Dutch public transport network still has some rest capacity left in order to absorb a shift from car to public transport.

The principle of Transit Oriented development is based on the land use and transport feedback cycle of Wegener. In this circle it is assumed that land use gets influenced by transport use via accessibility. Since, the better the accessibility of a location, the more interesting this location is to live at. The other way around transport is influenced by land use via activities. At a certain location activities are undertaken (e.g. working, shopping or recreating) and to come there transport is needed. In the case of Transit Oriented Development accessibility is enhanced by constructing new stations and stops, new lines ore new connections. The number of activities undertaken is stimulated by choosing the locations for living and working in such a way, that there is hardly any resistance if one wants to get from one location to the other. The land use and transport feedback cycle of Weneger is shown below:



Spatial developments and transport use are not only influenced by each other. There are also numerous other factors which influence location choice and transport use in one way or another. The main research question of this project is thus:

What is the relation between spatial developments and public transport use in case of application of TOD for StedenbaanPlus and can this relation be generalized for other projects as well?

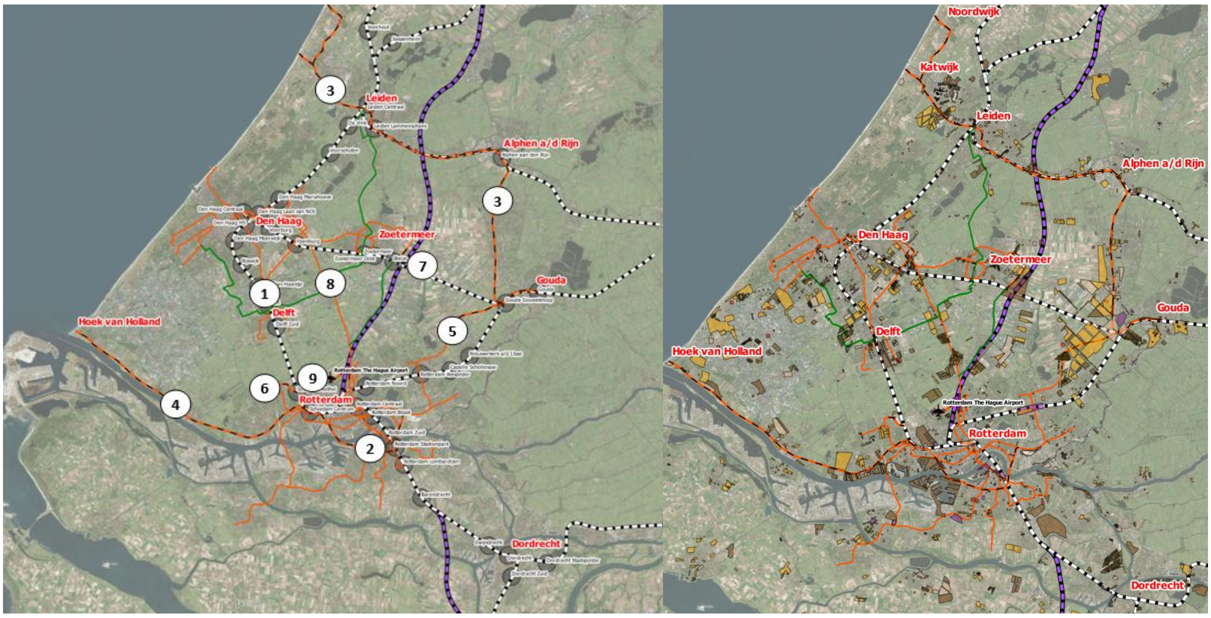
The main research question already shows that this project focuses on one TOD-project in particular, StedenbaanPlus. StedenbaanPlus is the name of a collection of smaller TOD-projects in the south wing of the Randstad. The project StedenbaanPlus was initiated between Leiden and Dordrecht in order to enhance the current public transport network and to stimulate the use of it. In that way the accessibility within the cities in this area, Rotterdam and Den Haag, is kept at level.

As mentioned before there are some other factors besides land use and transport use which influence the demand for public transport. These variables can be divided over external (outside the mobility system) and internal (inside the mobility system) variables. Besides spatial developments other external factors like demographic details and economic situation can be found. The quality, costs and travel time of modes like car, public transport and slow modes are identified as internal variables. Based on effects and elasticity's these factors have been assessed on the influence size. This study led to the conclusion that especially the economic situation, the spatial developments and the abolishment of the student PT travel card have the largest influence. The effects of demographic details, the introduction of road pricing and other pricing policy are assumed to be a little bit lower. The effects of road quality, car costs, parking costs and bicycle facilities are assumed to be negligible and thus will not be taken into account in this study.

The actual effects of these variables on the demand for public transport cannot be measured until in the future. So if one wants to make an estimation on the effects in most cases the use of a transport model is proposed. A transport model tries to predict the future as best as possible and based on about 12 available models the NRM appeared to be the best model for simulation public transport use in the Randstad south wing. Even though the NRM has numerous changeable variables, it is unable to simulate the abolishment of the student PT-travel card.

The public transport network of the Randstad south wing knows numerous adaptations for the next 20 years, but not all of these adaptations contribution to forming the StedenbaanPlus network. Based on selection criteria eventually 9 projects have been selected as part of the StedenbaanPlus network:

1. Capacity increase heavy railroad Rotterdam – Den Haag
2. Zuidtangent metro Rotterdam
3. Conversion RijnGouweLijn from heavy rail into light rail
4. Conversion Hoekse Lijn from heave rail into light rail
5. Extension of the Nesselande metro to Gouda
6. Extension of the Schiedam tram to Schiedam Kethel
7. Extention of the Zoetrmeer light rail line to Zoetermeer Bleizo
8. Construction of a BRP system between Den Haag – Delft – Zoetermeer – Leiden
9. Construction of a tram line between Rotterdam Central Station and Rotterdam Airport.



The spatial developments in the south wing of the Randstad have been established by the different municipalities in the area. The right map above shows which location the municipalities have chosen for the developments and their relation to the public transport network. Main projects are Valkenburg near Leiden, Zuidplaspolder near Gouda, Spoorzone Delft, Rijswijk Zuid and Harnaschpolder near Delft and the Rotterdam city harbours. Based on Hansen's potential model the total number of inhabitants planned to live in the new areas have distributed over the same areas again, but now with respect to their accessibility by public transport. This introduced a shift between residential projects, but simulations must show whether these shift imply an increase in public transport as well.

After processing the network adjustment in the NRM using the programs of CUBE and TRANS, the spatial programs have been merged into the NRM, just like the other influence factors identified earlier. The scenario's which will eventually be used in this study are:

- Introduction of road pricing
- Pricing policy for public transport
- Economic situation (WLO scenarios Regional Community and Global Ecnonomy)
- Spatial developments (as proposed, like in Hansen's distribution and after cancelling the projects)
- Enhanced public transport (with and without the projects)

Model calculations then showed these results:

Project	Subproject		Assessment summary
Project 1	Program high frequent train services Rotterdam – Den Haag	✓	Feasible; enough demand for train travelers seems to be generated.
	Station of Delft Sion		Feasible, only if the residential area of Rijswijk Zuid will be fully constructed. It is advised to realize this station already in the early phase, in order to avoid irreversible trends on car use.
Project 2	Metro Rotterdam Kralingse Zoom – Rotterdam Stadion – Zuidplein – Schiedam	✓	Feasible; enough demand for BTM travelers seems to be generated.

Project	Subproject		Assessment summary
	Station of Rotterdam Stadionpark	✓	Feasible; the amount of daily passengers expected to use this station is far more than the average guideline of 1,000 passengers per day NS uses.
Project 3	Conversion RijnGouwLijn	?	Doubtful; large decrease in the number of public transport users is computed by the NRM. This decrease can be explained by the unfairly low preference for the light rail mode. Further research is suggested (e.g. with use of a local model).
Project 4	Conversion Hoekse Lijn	?	Doubtful; a large decrease in the number of public transport users is computed by the NRM. This decrease can be explained by the unfairly low preference for the light rail mode. Further research is suggested (e.g. with use of a local model).
Project 5	Metro Nesselande - Gouda	✗	Infeasible; the amount of expected passengers on the line is assessed as to low. A bus rapid transit system between Nesselande and Gouda Gouweknoop will be more appropriate.
	Station of Gouda Gouweknoop	✓	Feasible; the train station of Gouda Gouweknoop is supposed to attract enough daily passengers, even without a connecting BTM service.
Project 6	Tram line Schiedam Kethel	?	Doubtful; the amount of passengers expected on this tramline extension are about equal to the average occupancy rate of the Rotterdam trams. Since the (operation) costs of a tram extension are expected to be lower than the costs for a new tram connection, the project is assessed as probably feasible. Further research is suggested (e.g. with use of a local model).
	Station of Schiedam Kethel	✓	Feasible; due to low uncertainties in spatial developments (the residential area of Schiedam Kethel has already been built); this train station is assessed as feasible.
Project 7	Light rail line Zoetermeer Bleizo	?	Doubtful; the light rail line extension to Bleizo will be most probably used by visitors to the recreational facilities planned nearby. Since the NRM generates too little trip attraction to such facilities, this might be the explanation for the low demand. Further research is suggested (e.g. with use of a model which simulates recreational facilities in better way).
	Station of Bleizo	?	Doubtful; the trip production and attraction to the station of Bleizo is about equal to the minimum number of passengers required by NS to operate the station. This might as well be the explained by the limited attraction to the recreational facilities nearby. Further research is suggested (e.g. with use of a model which simulates recreational facilities in better way).
Project 8	BRT Den Haag – Delft – Zoetermeer – Leiden	✓	Feasible; the BRT system between Den Haag and Leiden will attract enough passengers per day in order to reach an occupancy equal to the average bus occupancy for the Den Haag region.
Project 9	Tram line Rotterdam Airport	✗	Infeasible; the occupancy of the tram line between Rotterdam central station and Rotterdam The Hague Airport simulated by the NRM is assessed as too low.

Since StedenbaanPlus implies a large diversity in projects, the results can be used for other TOD-projects as well. Based on the demand for public transport all new residential area can be compared with high density areas elsewhere. The average number of trips undertaken per household is 0.24 in this case. The effect of the enhanced public transport is recognizable as well; the extra number of PT-trips per household in the new residential areas is 0.16, which means in increase of about 66% in case of introduction of TOD. In general the number of PT trips increases with about 6.000 trips to 29.000 (+20%).

The effect of the introduction of road pricing is smaller than expected; only 0% till 0.45% extra public transport trips. The effect of the higher public transport rates are larger. In the case of 10% higher rates, the decrease in the number of trips is only 2.5% for train trips and 1.7% for BTM trips.

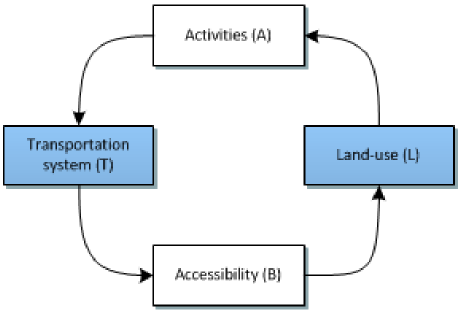
The economic situation has the largest influence. The GE-scenario shows about 19% more train trips and 17% more BTM trips than in the case of the RC-scenario.

Some remarks should be mentioned. The NRM is a model which tries to predict the future en therefore knows some limitations. For an example the NRM make a very large distinction between train and BTM, while in reality there is hardly any difference at all. Calculation results for conversion projects from heavy rail into light rail might show different trends than in reality would occur. It is also important to realize that the NRM is actually a car model and that public transport has a much smaller role. Therefore the elasticity's and trips have been checked limitedly or not at all. The results give thus a good trend prognosis, but no exacts prediction at all.

BEKNOPTE SAMENVATTING (NL)
De ontwikkeling van steden en dorpen is tot nu toe altijd al afhankelijk geweest van bereikbaarheidsfactoren. Veel van deze steden zijn ontstaan langs waterwegen en na de opkomst van de stoomtrein langs de nieuw aangelegde spoorlijnen. Toen de personenwagens voor meer en meer mensen beschikbaar kwamen, werd er vooral richting de snelwegen gebouwd. Het lijken natuurlijke ontwikkelingen te zijn, maar de laatste jaren wordt dit proces steeds meer gestuurd. Het bekendste voorbeeld hiervan is de Vierde Nota Extra, ook wel bekend als de VINEX. In deze nota worden er voor het eerst locaties aangewezen van welke de bestemming volledig wordt gewijzigd naar wonen en al snel ontstonden hier dan ook de eerste grote VINEX woonwijken.

Het coördineren van deze ruimtelijke groei stuit de laatste jaren echter op een aantal problemen. Het bouwen richting de autosnelwegen stimuleert juist het autogebruik, terwijl de infrastructuur (vooral in de grote steden) deze groei van het autoverkeer niet aan kan. Het gevolg zijn een hoop verkeersinfarcten en een teruglopende luchtkwaliteit in de steden. Om dit proces een halte toe te roepen wordt er wereldwijd gestudeerd op methoden om deze ruimtelijke groei zo te coördineren, dat de leefbaarheid van de steden er juist op vooruit gaat. Eén van de methoden die dit weet te bereiken is Transit Oriented Development. Deze methode is juist niet gericht op het autogebruik, maar op het benutten van bestaande infrastructuur voor openbaar vervoer en het aanleggen van nieuwe infrastructuur voor dit doel. Het huidige openbaar vervoer netwerk heeft namelijk op de meeste plaatsen in Nederland nog voldoende restcapaciteit om een verschuiving van auto naar openbaar vervoer op te vangen.

Het principe van Transit Oriented Development is gebaseerd op de land-use and transport feedback cycle van Wegener. In deze cirkel wordt verondersteld dat ruimtegebruik wordt beïnvloed door transport via bereikbaarheid. Immers, des te beter een locatie bereikbaar is, des te interessanter deze locatie is om te gaan wonen. Andersom wordt transport beïnvloed door ruimtegebruik via activiteiten. Op een bepaalde locatie worden activiteiten ondernomen (bijvoorbeeld gaan werken, winkelen of recreëren) en om daar te komen is vervoer nodig. In het geval van Transit Oriented Development worden de variabelen bereikbaarheid activiteiten tegelijkertijd verbeterd, zodat zij elkaar op een positieve manier gaan beïnvloeden. De bereikbaarheid wordt verbeterd door het aanleggen van nieuwe stations, nieuwe lijnen of verbindingen en het ondernemen van activiteiten wordt gestimuleerd door de locaties voor wonen en werken zodanig te kiezen dat er zo min mogelijk weerstand is om van de ene locatie naar de andere te gaan. De land-use en transport feedback cycle van Wegener is hieronder weergegeven.



Ruimte- en transportgebruik worden echter niet alleen beïnvloed door elkaar. Er zijn ook nog tal van andere factoren te noemen die op de een of andere manier invloed uitoefenen op enerzijds locatiekeuze en anderzijds transport gebruik. De hoofdvraag van dit onderzoek luidt dan ook:

Wat is de relatie tussen ruimtegebruik en openbaar vervoer gebruik in het geval van Transit Oriented Development voor het project StedenbaanPlus en kan deze relatie worden gegeneraliseerd voor andere projecten?

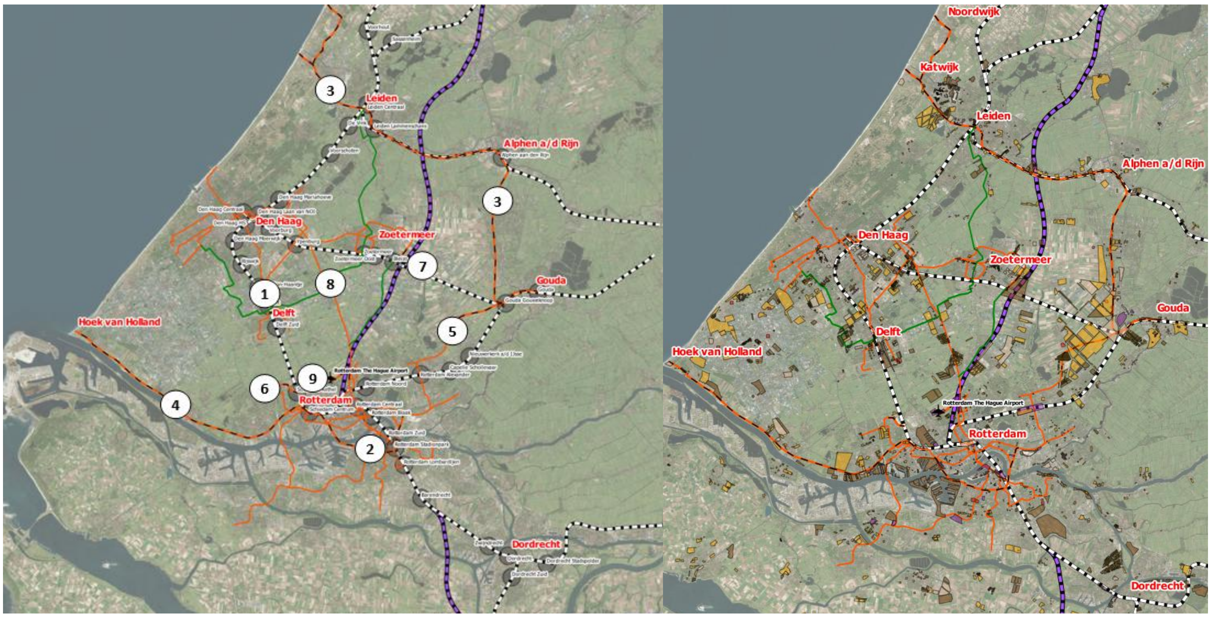
Zoals de hoofdvraag al een beetje laat zien wordt dit onderzoek toegespitst op een specifiek TOD-project in Nederland, te weten StedenbaanPlus. StedenbaanPlus is de verzamelnaam voor allemaal kleine TOD-projecten in de zuidvleugel van de Randstad. Tussen grofweg Leiden en Dordrecht is het project StedenbaanPlus opgestart om het bestaande openbaar vervoer netwerk beter te benutten en het gebruik ervan te stimuleren. Op die manier wordt dan de bereikbaarheid van de grote steden in dit gebied, Rotterdam en Den Haag, op peil gehouden.

Zoals gezegd zijn er naast ruimtegebruik en transportgebruik ook nog andere factoren die invloed uitoefenen op de vraag naar openbaar vervoer. Deze variabelen kunnen worden opgesplitst in externe variabelen (buiten het mobiliteitssysteem) en interne variabelen. Als externe variabelen kunnen naast ruimtelijke ontwikkelingen ook nog invloeden worden gevonden door demografische ontwikkelingen (bevolkingssamenstelling en kenmerken) en de economische situatie. Bij interne variabelen worden zowel voor het vervoermiddel auto als trein en fiets invloeden gevonden voor de kosten, reistijden en kwaliteiten van het betreffende vervoermiddel. Op basis van effecten en elasticiteiten is voor al deze factoren gekeken wat hoe groot deze invloeden zijn. Hieruit bleek dat vooral de economische situatie, de ruimtelijke ontwikkelingen en de afschaffing van de OV-studentenkaart verreweg de grootste gevolgen zullen hebben voor de vraag naar openbaar vervoer. Een iets kleiner effect hebben de demografische kenmerken, de invoering van rekeningrijden en het prijsbeleid voor openbaar vervoer. Het effect van de wegkwaliteit, autokosten, parkeerkosten en fietsfaciliteiten is bijna te verwaarlozen en zal in deze studie dus niet worden meegenomen.

De exacte effecten van deze variabelen op de vraag naar openbaar vervoer in het geval van TOD kan pas in de toekomst gemeten worden. Om toch een inschatting van de effecten te kunnen maken wordt in zulke gevallen vaak gewerkt met een transportmodel, dat de werkelijkheid zo goed mogelijk voorspelt. Op basis van een beschouwing van een 10-tal transport modellen is gebleken dat het NRM van Rijkswaterstaat (Nederlands Regionaal Model) het best in staat is om deze effecten te modelleren en te simuleren. Ondanks de vele mogelijkheden van het model, bleek het helaas door de ingewikkelde prijsverwevenheid niet mogelijk om de effecten van de afschaffing van de OV-studentenkaart te simuleren met het NRM.

In het openbaar vervoer netwerk van de zuidelijke Randstand worden de komende jaren veel wijziging doorgevoerd, maar niet al deze wijzigingen kunnen aangewezen worden als een bijdrage tot StedenbaanPlus. Op basis van selectiecriteria zijn er uiteindelijk 9 projecten aan te wijzen als onderdeel van het StedenbaanPlus netwerk:

1. Capaciteitsverhoging spoor Rotterdam – Den Haag
2. Zuidtangent metro Rotterdam
3. Ombouw RijnGouweLijn van spoor naar light rail
4. Ombouw Hoekse Lijn van spoor naar light rail
5. Verlenging metro Nesselande naar Gouda
6. Verlenging tram Schiedam naar Schiedam Kethel
7. Verlenging light rail Zoetermeer naar Zoetermeer Bleizo
8. Aanleg van een snelle busverbinding Den Haag – Delft – Zoetermeer – Leiden
9. Aanleg van tramverbinding van Rotterdam Centraal naar Rotterdam Airport



De ruimtelijke ontwikkelingen in de zuidvleugel van de Randstad zijn vastgesteld in de gemeentelijke programma's. De rechter kaart hierboven laat zien welke locaties de gemeenten in beeld hebben voor de ontwikkelingen en hun nabijheid tot openbaar vervoer. De grootste projecten voor de komende jaren zijn Valkenburg bij Leiden, Zuidplaspolder bij Gouda, Spoorzone Delft, Rijswijk Zuid en Harnaschpolder bij Delft en de Rotterdamse Stadshavens. Op basis van het Hansen's Potential Model is met behoud van totalen de nieuwe toe te voegen bevolkingsomvang opnieuw toegedeeld tot de projecten met het oog op de verbeterde bereikbaarheid per OV. Hierbij trad een verschuiving op tussen projecten. De simulaties moeten uitsluitsel geven of deze verschuiving ook leidt tot een hoger OV-gebruik.

Nadat met behulp van de programma's TRANS en CUBE de netwerkwijzigingen zijn doorgevoerd in het NRM, de ruimtelijke programma's zijn ingevoerd en ook de andere factoren zijn toegevoegd aan de variabelen was het NRM geschikt voor het uitvoeren van de simulaties. De scenario's die hier uiteindelijk bij gebruik zijn:

- Invoering rekening rijden
- Hoger prijsbeleid openbaar verover
- Economische situatie (WLO scenario's Regional Community and Global Economy)
- Ruimtelijke ontwikkelingen (als voorzien, als in Hansen's toedeling en annulering van de projecten)
- Verbeterd OV (met en zonder doorvoering projecten)

Uit de modelresultaten kwam het volgende naar voren:

Project	Subproject		Resultaat
Project 1	PHS Rotterdam – Den Haag	✓	Haalbaar, genoeg vraag voor verhoogde capaciteit.
	Station Delft Sion		Haalbaar, genoeg vraag voor nieuw station
Project 2	Metro Rotterdam Kralingse Zoom – Rotterdam Stadion – Zuidplein – Schiedam	✓	Haalbaar, genoeg vraag voor nieuwe lijn
	Station Rotterdam Stadionpark	✓	Haalbaar, genoeg vraag voor nieuw station
Project 3	Ombouw RijnGouwLijn	?	Twijfelachtig, kan komen door de manier waarop NRM spoor naar light rail ombouwt. Aanvullend onderzoek nodig.
Project 4	Ombouw Hoekse Lijn	?	Twijfelachtig, kan komen door de manier waarop NRM spoor naar light rail ombouwt. Aanvullend onderzoek nodig.
Project 5	Metro Nesselande - Gouda	✗	Niet haalbaar, onvoldoende vraag voor nieuwe lijn
	Station Gouda Gouweknoop	✓	Haalbaar, genoeg vraag voor nieuw station
Project 6	Tramlijn Schiedam Kethel	?	Twijfelachtig, genoeg vraag om aan te sluiten om huidige bezettingsgraad van andere trams in Rotterdam (21%)
	Station Schiedam Kethel	✓	Haalbaar, genoeg vraag voor nieuw station
Project 7	Light rail lijn Zoetermeer Bleizo	?	Twijfelachtig gezien de onzekere bestemming van het gebied. Alleen haalbaar bij volledige ontwikkeling conform plannen.
	Station Bleizo	?	Twijfelachtig gezien de onzekere bestemming van het gebied. Alleen haalbaar bij volledige ontwikkeling conform plannen.
Project 8	Bus Den Haag – Delft – Zoetermeer – Leiden	✓	Haalbaar, genoeg vraag voor een hoogfrequente lijn
Project 9	Tramlijn Rotterdam Airport	✗	Niet haalbaar, onvoldoende vraag voor nieuwe lijn

Aangezien StedenbaanPlus een zeer grote diversiteit aan projecten omvat, kunnen de resultaten ook van toepassing worden verklaard op TOD-projecten elders in het land. Op basis van de vraag naar OV kunnen alle nieuwe wijken worden vergeleken met dicht bebouwde gebieden elders in de randstad. Het gemiddelde aantal ondernomen reizen per huishouden is in dit geval zo'n 0,24. Het effect van de verbeterde bereikbaarheid per OV is aanzienlijk. In het geval van verbeterd OV worden er per huishouden zo'n 0,16 méér reizen per dag gemaakt dan in het geval van geen verbeterd OV. Dit houdt in dat wanneer TOD wordt uitgevoerd er 66% extra reizen per openbaar vervoer worden gemaakt vanuit de nieuwe woonwijken dan zonder TOD. In het aantal autoreizen zit een kleine daling, wat betekent dat alle reizen vanuit de nieuwe woonwijken per OV gemaakt worden en tevens nog een klein aandeel van de bestaande autorijders overstappen naar het OV. In totaal gaat het dan om zo'n 29.000 extra OV reizen per dag in de zuidvleugel (+20%).

Het effect van de invoering van rekeningrijden heeft een klein effect op het OV gebruik; invoering leidt tot slechts 0% tot 0,45% meer reizen. Het effect van verhoogd OV tarief is iets groter. Een verhoging van de tarieven met 10% zorgt voor een daling in het aantal treinreizen van 2,5% en 1,7% voor het aantal bus, tram en metroreizen.

De economische situatie lijkt het grootste effect van allemaal te hebben. In het GE scenario worden er tot 19% meer treinreizen gemaakt en tot 17% meer bus, tram en metroreizen dan in het RC scenario.

Enige opmerkingen dienen er nog wel bij de resultaten geplaatst te worden. Het NRM is een model dat de toekomst probeert te voorspellen en daardoor ook zijn beperkingen kent. Zo maakt het model een groot onderscheid tussen trein en BTM, terwijl in werkelijk deze grens een stuk vager is. Ombouw van bepaalde projecten lijkt dus niet haalbaar, terwijl er in werkelijkheid hele andere resultaten op kunnen treden. Daarnaast is het belangrijk om te realiseren van het NRM van oorsprong een automodel is en het OV altijd een ondergeschikte rol heeft gehad. Toetsing van elasticiteiten en aantallen reizen gebeurt daarom ook maar in beperkte mate. De resultaten geven dus een goede richting aan, maar geen exacte voorspelling.

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PART I PROJECT DESCRIPTION

1 INTRODUCTION

1.1 PROBLEM STATEMENT

1.1.1 The history of transport and land use

Already in the early medieval ages transport determined the spatial developments for a strong part. Cities were as large as a man could walk, because walking was the only mode available. People worked and lived at almost the same location. In the early 19th century transport by horse and barge became the most common way of travelling over long distances (Zondag, 2007). Therefore it was no wonder the villages around the waterways grew much stronger than the ones inland, since travelling over roads was much more expensive than travelling over water (Filarsky, 2004). Up to the 2nd World War spatial settlement (population and industry) adapted itself to the mobility offered by the railway network. After the 2nd World War the private car became affordable for most of the people and became the most popular mode of transport. The growing availability of the private car was the main cause for spatial fragmentation, sub-urbanization and urban sprawl. Other factors causing sub-urbanization are the increasing income, smaller household size and consequential changes in lifestyle (Zondag, 2007). The most popular places for people to live were nearby the amenities, but not to close: in the suburbs. It became clear that the ongoing process of suburbanization led to other problems, such as congestion and environmental externalities. In order to keep the cities livable and to prevent a worsening accessibility, all different levels of governments agreed to coordinate land-use in a more active way.

1.1.2 Transit oriented development

One of the available strategies for coordination of spatial growth is transit oriented development (TOD). In TOD the enhancement of the public transport network is done simultaneously with the spatial developments in order to strengthen each other. An enhanced accessibility is supposed to lead to increased attractiveness and an increasing number of inhabitants is supposed to lead to a higher demand for public transport. This higher demand then justifies the costs for an enhanced public transport network. This relation is explained by the land use and transport feedback cycle (Wegener, 1986).

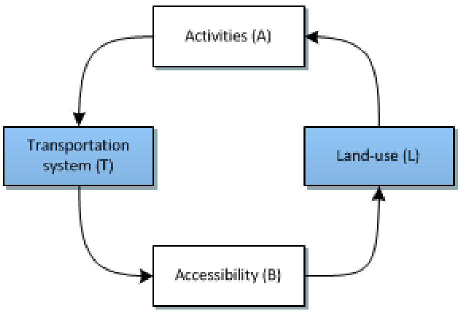

Figure 1-1 Land-use and transport feedback cycle (Wegener, 1986)

The cycle shown above is often used as a theory behind policy making on new residential areas and public transport network adjustments. In reality it seems that the cycle does not always works as expected. The increased demand for public transport does not occur, or the spatial developments stay out, although the network is already enhanced.

1.2 CASE STUDY: THE RANDSTAD SOUTH WING

The principles of TOD are often applied to the Randstad south wing. At least 40% of new spatial programs have to be built within the direct influence area of public transit stops, in order to enhance their relation. But will there be success, or will it only lead to a lot of costs for society, without anyone actually benefitting from it? For that reason the Randstad south wing has been chosen as a case study.

1.2.1 About the Randstad south wing

The south wing of the Randstad is collection of urban districts, cities and villages and counts over 3.5 million inhabitants, nearly 1.5 million work places and a regional gross product of €128 billion (Zuidvleugel, 2014). Because of this combination the area has a large economic potential and therefore the ambition exists to develop this region into a coherent metropolitan area in order to enhance the international competition position with other metropolitan areas. This ambition is translated into actions by the different city councils, urban districts and the province of South-Holland, which together form the project office “Projectbureau Zuidvleugel” (Zuidvleugel, 2013).

With use of different policy tools the development of the south wing area is guided into the right direction. One of the spatial trends, urbanization, is an important element which needs to be coordinated on a regional scale. In order to make this possible, the south wing area is included in the MIRT (Meerjarenprogramma Infrastructuur, Ruimte en Transport)-publication of the Dutch government. In this publication it is stated that the conversion of the south wing area into a metropolitan area can only be reached by urban intensifying. The additional demand for houses must mainly concentrate around the cities of Den Haag (55%) and Rotterdam (20%) (Ministerie van Infrastructuur en Milieu, 2013).

1.2.2 “StedenbaanPlus”

The south wing project office states that when the above mentioned change is carried out and no measures are taken to facilitate the growth of the population, the accessibility of the south-wing region will soon decrease. To prevent this, or to even enhance the accessibility, they say it is unavoidable to make major adjustment to the transport network and structure. Hereby the south wing partners specifically aim at strengthening the public transport networks in the region. The function of this network must be especially linking all urban areas together in order to form one large well interconnected metropolitan area. The enhancements made on the train network and the underlying public transport network are seen apart from each other due to the different ownership. The enhanced train network is called the “Stedenbaan” and the networks of metro, light rail, tram and bus are called the “StedenbaanPlus” network (StedenbaanPlus, 2013). One of the aims when strengthening the public transport network is to make many good connections between the train network and the underlying networks (node development).

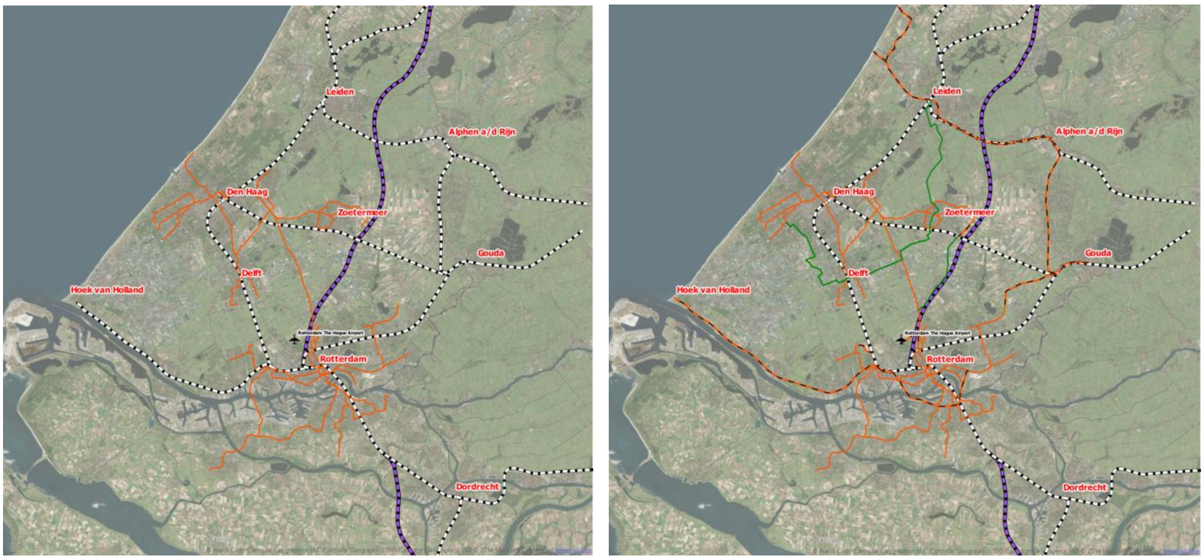

Figure 1-2 Current and proposed PT network (HSL, heavy rail, light rail, metro, tram+ and HOV-bus)

1.2.3 Vision for the future

The development of the Randstad south wing into a metropolitan area is more or less a chicken-and-egg problem. Urban planners state that the enhanced public transport network is necessary in order to provide good conditions for spatial developments (TOD/Transit Oriented Development), but transport planners believe that the network enhancements cannot be made before the increase in transport demand is generated.
Besides, it is not said that the demand for public transport will only grow. Other influence factors like pricing, population trends and national policy measures may have a larger negative influence on the demand for public transport then the extra demand created by spatial developments.

Therefore it is necessary to investigate what the relation between spatial growth and the demand for public transport is, and what other influence factors on public transport demand yield next to the influence of the spatial developments. Based on the results, a general relationship is derived and a policy guideline is set up per infrastructural adjustment in order to make smart choices for future developments.

1.3 SOCIAL AND SCIENTIFIC RELEVANCE

Every year a large amount of the governments revenues are invested in infrastructural projects. About 1/3rd (€2,5 bln.) of the expenditures on the infrastructure fund is dedicated to public transport adjustments. Logically it must be checked very well that the money will not go to projects which later turn out to be very unprofitable. By providing a policy guideline for making investments the distribution of the available budget can be made in the most optimal way.

On the other hand the results of this research project can be used for scientific purposes as well. The new knowledge about the relation between spatial developments and public transport demand may be useful for other projects as well. Also an evaluation of the application of the transport demand prediction model will be made, especially related to the application of transit oriented development.

1.4 RESEARCH OBJECTIVE

The final aim of the research project is to look into the land-use and transport process, especially in the case of application of transit oriented development. By using a case study (StedenbaanPlus), project-specific and general conclusions will be drawn which apply to other TOD cases besides StedenbaanPlus as well. The result will be a policy guideline for StedenbaanPlus and a general advice for other TOD proposals.

1.5 STAKEHOLDERS AND PROBLEM OWNERS

The research objective is to provide a policy guideline for policy makers, but who are these policy makers anyway?

1.5.1 Current organization

The public transport services in the Netherlands are not operated by one single authority. There is a very complex system of concession grantors and concessionaires. The set-up of this system is shown below.

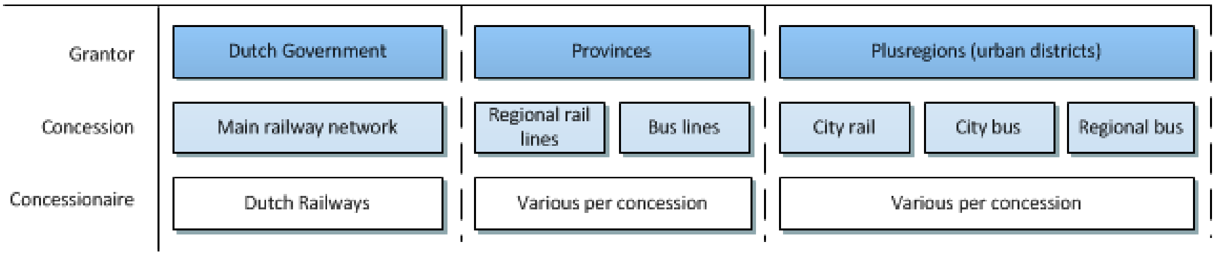

Figure 1-3 Organization diagram of the public transport system

On a national level there is only the main railway network concession, which is currently granted to the Dutch Railways. On a more regional level the different concessions are granted by the provinces. Regional rail lines, which do not belong to the main railway network, are granted by the provinces as well. In densely populated areas, such as around the cities of Amsterdam, Den Haag, Rotterdam, Utrecht, Eindhoven and Arnhem-Nijmegen, the concessions for public transport are granted by so-called plusregions. These regions, often called urban districts, manage the different concessions for city rail (like tram and metro), city buses and regional buses.

The infrastructure owners are thus not the concessionaires (operators), but the grantors of the concessions. In the case of TOD the problem owner is therefore the policy maker. In the case of StedenbaanPlus there are 4 problem owners:

- The Dutch government, represented by ProRail (for main railway network adjustments)
- The province of South-Holland (for adjustments to regional rail lines)
- The urban district of Rotterdam (for adjustments to bus/tram lines in the Rotterdam area)
- The urban district of Den Haag (for adjustments to bus/tram lines in the Den Haag area)

In Figure 1-4 all regional concessions (2013) owned by the provinces and plusregions are shown. The concessions owned by the plusregions are delineated and labeled.

Figure 1-4 Public transport concessions in the Netherlands (Kennisplatform Verkeer en Vervoer, 2013)

1.5.2 Future developments

In 2012 the Dutch Government stated that in the future there will only be three levels of government (country, province and municipality). This means that the plusregions are no longer maintained and its tasks are shifted towards the provinces. Since voluntary cooperation is still possible, the urban districts of Rotterdam and Den Haag decided to organize the public transport concessions as one transport authority starting in January 2015 (Metropoolregio Rotterdam Den Haag, 2013).

1.6 RESEARCH QUESTIONS

1.6.1 Main research question

What is the relation between spatial developments and public transport use in case of application of TOD for StedenbaanPlus and can this relation be generalized for other projects as well?

1.6.2 Sub questions

Transit Oriented Development (TOD):

- What is the relation between spatial developments and public transport use?
- What is TOD?
- What other factors than spatial developments have influence on the demand for public transport and in what way do they effect the demand for public transport?

Case study StedenbaanPlus:

- What is Stedenbaan, StedenbaanPlus and what is the relation with TOD?
- What is the current set-up of the StedenbaanPlus network?
- Which infrastructural or transport service adjustments are planned/prepared for the StedenbaanPlus network?
- Which spatial developments are planned for the Randstad south wing and what is their relation with StedenbaanPlus?

Predicting future transport demand:

- How can future transport demand be predicted?
- In what way can the influence factors be modeled?
- In what way can the infrastructural and transport service adjustment be modeled?

Syntheses (specific for case study StedenbaanPlus):

- What happens if the future transport demand is projected on the future proposed public transport network?
- Which infrastructural or transport service adjustments are inevitable and which are not?

Syntheses (general):

- Are the findings in the case study applicable for other cases as well?
- In what way can the results of the case study contribute to more solid transport policy?

1.7 SCOPE

The research project is split up into a general part (looking into the land-use and transport relation) and a case study (StedenbaanPlus).

General demarcation:

1.7.1 Type of transport

De choice is between:

- <u>Passenger transport</u>
- Cargo transport
- Both types of transport

Since the Transit Oriented development aims at enhancing the accessibility of live and work places, increasing the radius of action of inhabitants and providing a better external accessibility the aim is at passenger transport only, even though both passenger and cargo transport interact with land-use developments. For this purpose there will only be looked into passenger transport in order to limit the scope of the project.

1.7.2 Type of transport system

De choice is between:

- Train
- All regional public transport (StedenbaanPlus: train, light rail/metro, regional tram- and bus lines)
- All public transport (train, light rail, metro, tram and bus)

Transit Oriented Development includes forming one coherent public transport network. Therefore in this analysis not all forms of public transport are represented, but only the ones contributing to the regional network.

Case study demarcation:

1.7.3 Area

De choice is between:

- International
- National
- Provincial (Zuid-Holland)
- Regional (Zuidvleugel)
- Urban

Only the area which has the ambition to form a metropolitan area is investigated. This is the south wing of the Randstad, roughly from Leiden to Dordrecht (see image below).

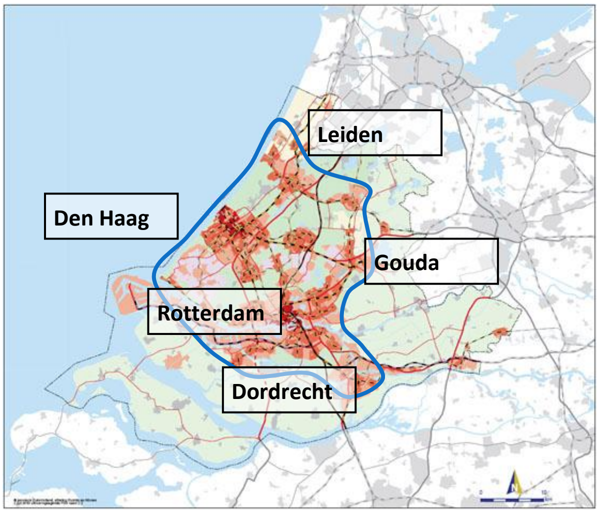

Figure 1-5 Area under investigation: Randstad south wing

1.7.4 Time horizon

De choice is between:

- 2020
- 2030
- 2040

Planning infrastructure projects takes a long time. Therefore it is not convenient to choose 2020 as the time horizon. But, the further in time (2040), the bigger the uncertainty in social and economic predictions become, and thus the bigger the uncertainty in predictions on transport use. Choosing 2030 as the time horizon is therefore the best option.

1.8 METHOD AND TOOLS

In order to make solid guidelines for decision making on infrastructural and network service adjustments it is important to identify all dependencies first. In fact, there are only a few choices people make when planning a trip: location choice (where do people live?), destination choice (where do they want to go to?), mode choice (with which mode do they want to go?), route choice (which route do they choose?) and time choice (when do they want to go?).

Each result of the choices above is influenced by one or multiple factors. In chapter 4 these factors are identified and based on literature study the impact size of the factors is assessed. The factors with the highest impact size are then set as the variables during the rest of the project which influence the demand for public transport.

A second step in this project is the identification of the planned or prepared infrastructural and transport service adjustments. Since the infrastructural networks in the south wing of the Randstad have different owners, the plans are investigated per network owner: ProRail for Stedenbaan and the Rotterdam urban district and the Haaglanden urban district for the underlying public transport networks (StedenbaanPlus).

Future traffic demands cannot be count; they can only be modeled. The choice for the model depends strongly on the criteria set for what the model should be able to do. These criteria follow directly from the variables to model. By comparing the different available models, a choice can be made. After the model is chosen, it can be prepared for the case study.

The fourth step in the process is the actual analysis of the future transport demand; which is followed by running the model for the different scenarios.

The fifth and last step is the syntheses. The results of the model runs will be analyzed for the different infrastructural projects. At last general conclusions are drawn and recommendations are made.

The process above is drawn schematically in Figure 1-6.

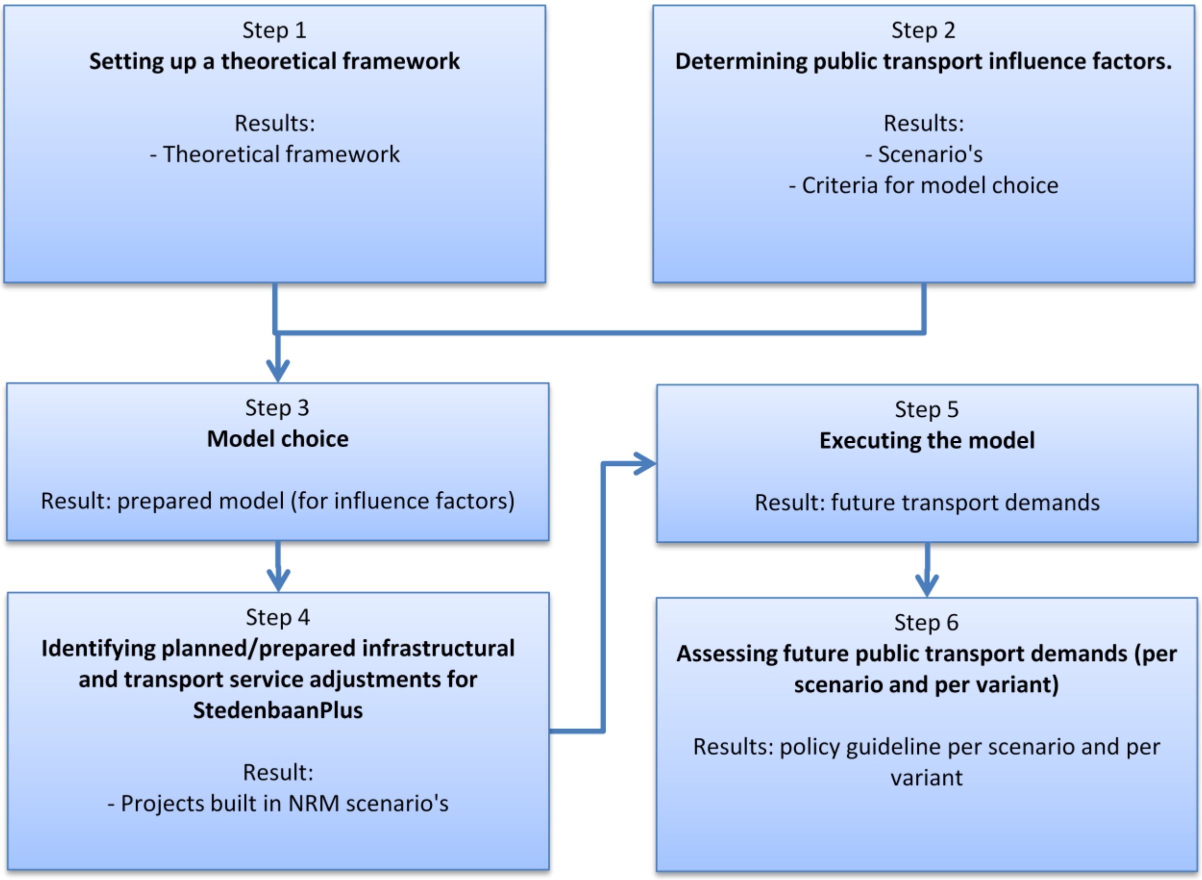

Figure 1-6 Schematic process of the project

1.9 READING GUIDE

This report is split up into three parts. The first part of the report covers project properties and the theory behind transit oriented development. It also discusses the effects which influence public transport demand and the model choice and preparation.

The second part of the report comprises the case study preparation and execution. The general background of StedenbaanPlus is discussed and the proposed future infrastructural network adjustments are identified. After execution of the case study, the project specific results are discussed and conclusions are drawn.

The third and last part of the report contains the general conclusions and recommendations.

2 THEORETICAL FRAMEWORK

2.1 INTRODUCTION

This chapter will discuss the theoretical framework of this study. In the first paragraph the history of land-use policy making will be reviewed. After that the principles of transit oriented development will be explained, followed by an explanation of the two most important elements of the TOD; the processes of land-use and transportation. At last the possibilities of enhancing these processes are discussed.

2.2 LAND-USE AND TRANSPORT POLICY MAKING

In the last decades it became clear that the ongoing process of suburbanization led to problems, such as congestion and environmental externalities. In order to keep the cities livable and to prevent a worsening accessibility, all different levels of governments agreed to coordinate land-use in a more active way. In the Netherlands this is carried out in many different spatial memoranda (Nota's Ruimtelijke Ordening), of which the renewed fourth (Vierde Nota Ruimtelijke Ordening Extra) is the most radical one (BIJN, 2011). It introduces several locations, close to major cities, which are designated to be used for large-scale residential construction. Since 2007 the memoranda are merged into the MIRT (Meerjarenprogramma Infrastructuur, Ruimte en Transport)(Ministerie van Infrastructuur en Milieu, 2007).

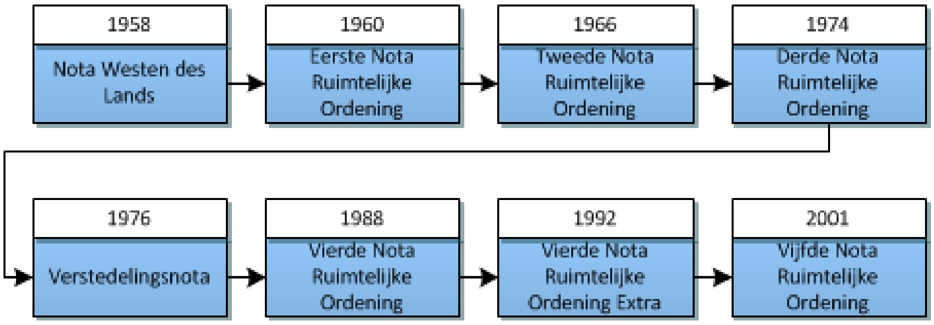

Figure 2-1 Spatial memoranda throughout the years (Ministerie van Infrastructuur en Milieu, 2014)

When formulating policy which is supposed to influence the demand and supply elements in both the transportation and land-use market, it is hard to predict the effects in a detailed way. For that reason models have been developed which predict the behavior of the national or regional system. Based on these model results, policy can either be implemented or revised when the results are unsatisfactory. The diagram below shows the position of such a model in the policy making process.

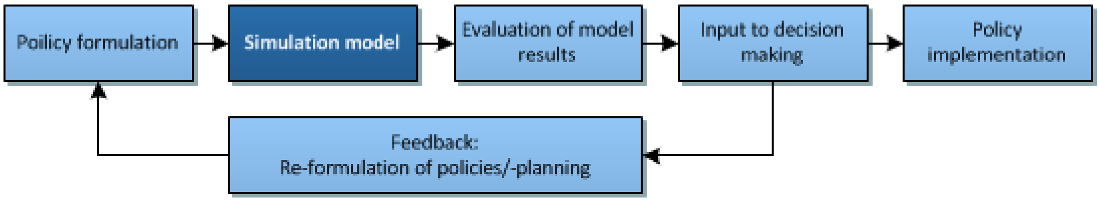

Figure 2-2 The policy making process (Zondag, 2007)

2.3 TOD

2.3.1 Introduction of Transit-oriented development

When in the last decades it became clear that the coordination of urban growth should be tighter, it was not yet decided how this could be done. Multiple spatial planning strategies were available nationally and abroad, all with their different pros and con's. One of these strategies was Transit Oriented Development (TOD). In TOD the local accessibility is kept at level by looking at public transport as the most important way of transport.

The term transit-oriented development was first used in the United States in 1993 where it was seen as a concept to prevent urban sprawl (Dittmar & Ohland, 2004).

The definition of TOD:

> *"Transit Oriented Development (TOD) is a walkable, mixed-use form of development typically focused within a 600m radius of a Transit Station – a Light Rail Transit (LRT) station or Bus Rapid Transit (BRT) stop prior to the arrival of LRT. Higher density development is concentrated near the station to* ***make transit convenient for more people and encourage ridership****. This form of development utilizes existing infrastructure, optimizes use of the transit network and creates mobility options for transit riders and the local community. Successful TOD provides a mix of land uses and densities that create a convenient, interesting and vibrant community for local residents and visitors alike.*
> *City-wide destinations served by frequent service and multiple bus routes should also be included as areas that are appropriate for locating transit oriented development. This includes the general commercial nodes, employment concentrations and institutional nodes."* (City of Calgary, 2005)

2.3.2 TOD in the Netherlands

In the fifties of the past century the importance of the car grows and transit use decreases significantly. The coupling between spatial developments and transit seems to be gone forever. Most of the transit infrastructure is removed (in particular regional tram systems), but most of the train lines are kept intact. In the early seventies, the program "Spoorslag 70" is presented. The timetable is renewed and new train stations are built in the suburbs; the couplings between spatial structure and transport networks are made again. Subsequently the tram networks in the larger cities are extended into the suburbs as well. Plans for new spatial developments were based on the ABC-method, where A-locations were assumed nearby the train stations. The method did not work out very well, since most of the developments took place at the C-locations, which were nearby the highways.

A first form of what could now be called TOD happened when urban growth centers were identified in the third memorandum of spatial planning. Major example is the completely new built city of Zoetermeer, which was connected with a rail link to Den Haag. Within the city, the rail linked served almost all neighborhoods with multiple train stations. In Rotterdam a metro is built which connected the city centre with new residential neighborhoods and towns outside the city. The term TOD was not yet mentioned, but the policy at that time shows very large similarities. Not all towns were happy with the policy turnaround, since connections to the regional transit networks could not be made very easily. For an example the city of Nieuwegein was planned far away from any form of public transport, so the local authorities decided to create their own local network and a light rail connection with the city of Utrecht was born. This was the first example in the Netherlands where spatial developments and transit network construction took place at the same time.

In retrospect the revival of public transport in the seventies of the last century can be seen as the prologue of the past thirty years (1983-2013) in which high-quality public transport is greatly expanded and substantial opportunities were raised for TOD (Tan, Koster, & Hoogerbrugge, 2013).

TOD projects (with and without success) in the Netherlands are (Tan, Koster, & Hoogerbrugge, 2013):

Table 2-1 TOD projects in the Netherlands

Location	Type	Scale level	Comments
Utrecht - Nieuwegein	Light rail	Local	With the construction of the city of Nieuwegein, the light rail connection with Utrecht is made simultaneously. Although the line is connected to

			Utrecht central station, the connection with the city center of Utrecht and the east (Uithof) has still not been created.
Achterhoek	Heavy rail	Regional	In the Achterhoek the heavy railway line is redesigned as a light transit connection, very well connected to local bus services. Although the transit systems functions above all expectations, almost no spatial developments took place.
Maastricht – Kerkrade/Heerlen	Heavy rail	Regional	The reconstruction of the heavy railway line Heerlen – Kerkrade – Maastricht into light rail would have been the perfect candidate for a TOD-case. Although the reconstruction was not done, two new train stations were opened and spatial developments did took place around these stops.
Arnhem - Nijmegen	Heavy rail	Regional	The region of Arnhem and Nijmegen have tried to use the heavy rail systems for TOD and identified several nodes which can be developed. This process is still ongoing.
Gouda – Alphen a/d Rijn - Leiden	Heavy rail	Regional	The heavy rail connection between Gouda and Leiden was operated by light rail several years as a test. After this test, the line should be reconstructed into a light rail systems with multiple new stops. Governmental disagreements over the proposed route and costs and lack of public support prevented construction works to start.
Utrecht area	Heavy rail	Regional	Randstadspoor is a project which works with new trainstations and an enhanced local train network. Because of the absence of local transit systems, the range of the transport network is limited.
Den Haag – Rotterdam/Zoetermeer	Heavy rail	Regional	The heavy rail systems of the Zoetermeer Stadslijn and the Hofpleinlijn have been reconstructed into light rail. New stations have been added and spatial developments took place at the proposed location around the stops. The number of passengers is higher than expected and still increasing. Randstadrail is definitely the TOD-project with the biggest success.
Den Haag/Rotterdam area	Heavy rail	Regional	The TOD-principle was introduced for the entire Randstad south wing in 2000. Ambitions about spatial developments and transit system enhancements were formulated and translated into agreements between local authorities and carriers. The entire StedenbaanPlus program is not yet realized, but the initial results seem promising for the future.

2.3.3 The mechanism of TOD

Transit-oriented development is a strategy in which the access to public transport and the mixed use of land (living, working, recreating) are planned nearby each other or the relation between these two is strengthened. A common used model to explain this mechanism is the transport- and land-use feedback cycle from Wegener and Fürst. This model shows the interaction between land-use (L) and transport systems (T) and especially the self-influencing cycle it contains. It assumes that investing in a public transport network will influence the accessibility and therefore the attractiveness of that place. Subsequently an increasing attractiveness will influence the land-use potential of that place and the related activities (working, living, shopping etc.). The enhanced transportation network is then used to undertake these activities. This loop is shown in Figure 1-1.

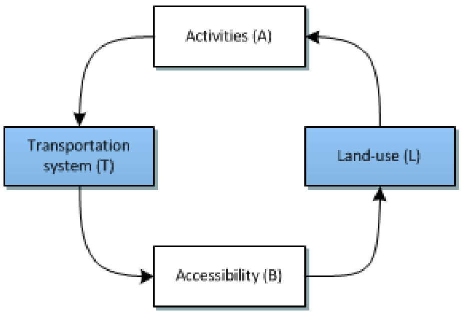

Figure 2-3 Land-use and transport feedback cycle (Wegener, 1986)

Problem with this model is that it assumes a continuously self-improving system, which is in reality not exactly the case. As Hansen already mentioned in 1959 "the accessibility of a region defined as the potential of opportunities for interaction" (Hansen W. , 1959). It is often seen that increasing accessibility (B) does not lead to increasing demand for spatial developments (L). This can be explained by a lack of good policy or insufficient demand for spatial expansion. Too often the link between increased accessibility and land use is expected by definition (van der Krabben, 2013).

By looking deeper into the land use and transport feedback cycle, the following sub-elements can be identified.

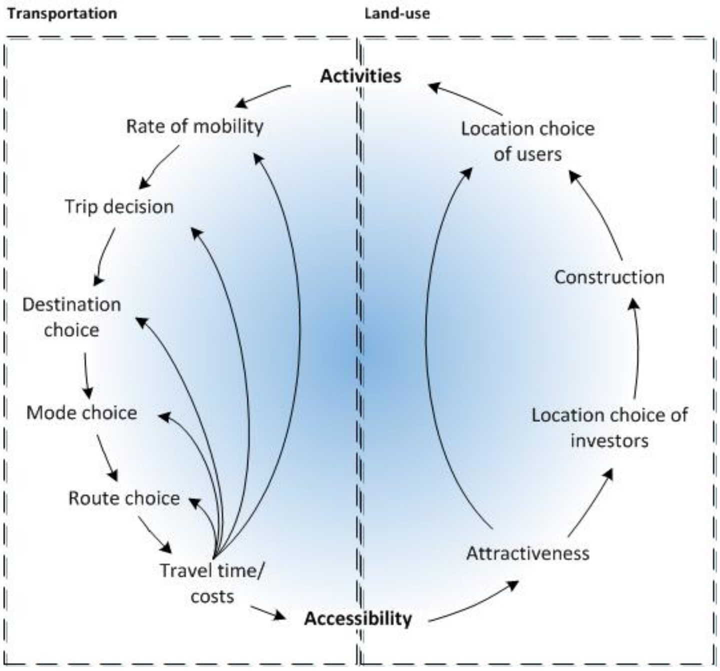

Figure 2-4 Circle of Wegener (Wegener, 1986)

The land use process
The **accessibility** of a certain area determines for a large part the **attractiveness** of it. When an area is attractive, **investors** are likely to choose this location for investing in **constructions** over there. The location of constructions (houses, factories, offices, leisure) determines the **location choice** of its users. In order to come to and leave that location, trips are generated to **activities**.

The transport process
The **rate of mobility** (e.g. car possession) determines if and what **activities** can be undertaken. The next choice is whereto, to which **destination** the trip is made. Based on the origin and destination of the trip, the **mode** is chosen for how to travel to the destination. The mode determines for a large part the **route**. The mode and route together determine the **travel time and costs**. The travel time and costs can be seen as how 'easy or cheap' it is to go to the destination. This level, the **accessibility**, makes the circle of Wegener complete (Figure 2-4 Circle of Wegener).

Overall it can be said that the attractiveness of a location is determined by the accessibility (travel time, quality and costs of the transport modes to it and the demand for transport is determined by the attractiveness of the location itself.

2.4 THE TRANSPORT PROCESS

2.4.1 The trip chain

Most activities people want to undertake, are not located at the origin. For an example, most of the time people work and live at different places. Shopping happens at yet another location, just like education. To go from the origin location to the location where the activity is situated, people make movements. In some cases, these movements are made using more than one type of transport. Each movement then consists out of multiple trips. If during a trip a transfer is made, then the trip consists out of multiple rides.

An example of a trip by public transport is shown below:

- Walking from origin to access transport (bus stop)
- Travelling with access transport (bus)
- Walking from access to main transport (train station)
- Travelling with main transport (train)
- Walking from main transport to destination

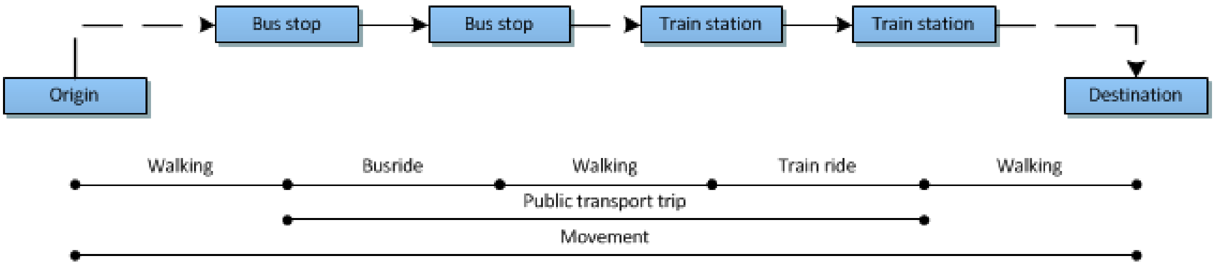

Figure 2-5 Trip chain for public transport movement

2.4.2 Micro-economic utility theory

Once there is a certain demand for movements, it is not yet determined how this movement is performed and whether there is enough utility on making this movement at all. These choices are commonly modeled with the micro-economic utility theory.

The micro-economic utility theory is based on market mechanisms between different destinations. Each destination is suggested to have a certain gaining, a utility, based on the activities located at the that destination. The effort people have to make to reach that destination, is called the disutility. By maximizing the total utility for all possible destinations, it becomes clear which destination will be chosen. In other words, when deciding to make a trip, multiple utility components play a role.

- The utility U_i of staying at the origin i.
- The utility U_j of going to the destination j.
- The disutility Z_{ij} of making the trip from i to j.

The trip will only be made if the utility at the destination minus the disutility of making the trip is larger than the utility at the origin, thus if:

$$\{U_j - Z_{ij} > U_i\} \qquad \text{(Equation 1)}$$

If we say that the utility of staying at the origin is 0 ($N_i = 0$) , then the trip is made when:

$$\{U_j > Z_{ij}\} \qquad \text{(Equation 2)}$$

The total disutility of the trip is determined by the individual elements of each trip.

The utility of going to the destination (U_j) is different for each individual and activity. The total utility is determined by summarizing partial utilities u at destination j for activities g. The partial utility is explained by a weighting factor β times the characteristics X of the activity:

$$U_j = \sum u_{jg} = \sum(\beta_g \cdot X_{jg}) \qquad \text{(Equation 3)}$$

For each trip the total disutility can also be calculated. It contains out of the disutility's per ride z, which can be expressed by the weighting factor of the ride α_h times the characteristics of the ride from i to j (Y).

$$Z_{ij} = \sum z_{ijh} = \sum(\alpha_h \cdot Y_{jg}) \qquad \text{(Equation 4)}$$

In most cases a traveler has multiple alternatives to reach destination j. In that case, the alternative with the highest utility will be chosen (alternative c):

$$U_c = \max(U_j - Z_{ij})\ (for\ each\ j) \qquad \text{(Equation 5)}$$

The micro-economic utility theory assumes individual, rational choice behavior. That means that it is assumed that all criteria to decide are known and can be reproduced in models, all alternatives are known including their utilities and that they can be weighted. In reality a slightly different thing might happen, but overall the model results should be in line with reality (Sanders & van Nes, 2004).

2.5 THE LAND USE PROCESS

2.5.1 Introduction to the land use process

The circle of Wegener shows a direct relation between the accessibility, attractiveness and the investors and users location choice of certain area. Since not all people can live at same, best accessible spot, inhabitants distribute themselves over the available locations. By choosing these locations, different influence factors play a role. In 1973 Hansen developed a simple model which takes into account the most important influence factors on location choice (Lee, 1973).

2.5.2 Hansen's Potential Model

Hansen assumes the most important motive for movements (working) determines the location choice. Hereby the relation between the location of inhabitants and the available work places is called the accessibility index A_i. This index explains for each geographical zone the accessibility to the work places E_{ij}.

$$A_i = \sum_j \frac{E_j}{d_{ij}^b} \qquad \text{(Equation 6)}$$

Since space is not unlimited, the capacity for housing people in a certain zone is called H_i. If then the accessibility index for a zones is multiplied with the zone capacity, the development potential of zone D_i is calculated.

$$D_i = A_i \cdot H_i \qquad \text{(Equation 7)}$$

By comparing the development potential for each zone, the total residential growth G_t can be distributed over the competitive zones.

$$G_i = G_t \cdot \frac{A_i \cdot H_i}{\sum_i A_i \cdot H_i} \qquad \text{(Equation 8)}$$

Where:

G_i Number of households distributed to zone i
G_t Total number of households (per region) which needs to be distributed over the zones
E_j Number of work places in zone j
d_{ij} Minimum travel time by public transport (either train or BTM) between zone i and j.
H_i Amount of available space (equal to project volume)

The factor b is used to simulate exponential dependency. The value of this factor is dependent of the motive of the trip and the travel time. Research has shown that for work purposes the value varies between 0.7 and 1.2 and for shopping purposes between 2.0 and 2.6. When the travel time exceeds 40 minutes, the value tends to 2 for all motives. (Hansen W. G., 1959).

2.6 ENHANCING THE RELATION BETWEEN LAND USE AND TRANSPORT

From the transport and land use process above, it can be derived what the factors are which need to be influenced when picking a certain location for transit oriented development:

Transport process factors

The transit system must have a higher utility compared with other modes ($U_{PT,i} > U_{rest,i}$) .
$U_{PT,i}$ can be improved in three different ways:

- Shorten the trip travel distance (e.g. realization of missing links and stops)
- Shorten the trip travel time (e.g. higher speed and frequencies)
- Increase the pleasantness of the ride (e.g. higher comfort level)

Land use process factors

The origin zone i must have a higher potential compared to other zones, so people will prefer zone i when choosing their location ($D_i > D_{rest}$) .
D_i can be improved by improving A_i. Subsequently A_i is improved by minimizing d_{ij}:

- Shorten the distance (e.g. build close to transit access points)
- Shorten the travel time (e.g. efficient spatial structure around transit access point)
- Increase the pleasantness (e.g. realizing a high quality public space around transit access point)

Examples

In the table below some examples are shown of possible enhancements which can increase the trips utility.

Table 2-2 Land use and transport process enhancement methods

	Decreasing distance	Decreasing travel time	Increasing pleasantness
Land use	▪ Spatial developments close to the transit system (decreasing access and egress distance)	▪ Efficient spatial structure around transit stop (e.g. direct walk routes to station)	▪ Enhancing the comfort of the transit surroundings
Access point	▪ Compact node development (short walking distances within the transit node)	▪ Efficient travel information technologies (e.g. real-time information) ▪ E.g. escalators and elevators	▪ Enhancing the comfort of the transit node ▪ Bicycle parking facilities ▪ Park & Ride facilities ▪ Amenities and shops

Transport system	▪ Construction of missing links (more direct links between transit nodes) ▪ Connection new nodes to the network	▪ Increasing frequencies ▪ Increasing speeds	▪ Enhancing the comfort level of the transit system (e.g. better seats, waiting facilities)

2.7 CONCLUSIONS

The paragraphs above have showed to the most important elements of the TOD-process and how the influence each other. The first element is land-use, which produces activities. To get to these activities, trips will be made. The demand for trips results in the construction of infrastructure and new infrastructure leads to improved accessibility. This improved accessibility then influences the location choice of people and thus land-use.

In general the influence cycle mentioned above can be aggregated into only two processes: the transport process and the land-use process.

In the transport process the production of trips is explained by looking into the trip chain and the micro-economic utility process. The land-use process is explained by Hansen's Potential Model, which states that the better a home location's accessibility, the higher the location's potential is. And the higher this potential, the more likely it is that people will choose this location for undertaking activities.

3 PUBLIC TRANSPORT USE INFLUENCE FACTORS

3.1 INTRODUCTION

In chapter 2 the relation between public transport use and land use was discussed. It was shown that the demand for transport is influenced by land use and the quality of the transport mode. But how is this transport quality defined and which elements contribute to it? This chapter identifies all of these factors, while rating their influence size. The factors with the highest influence rate will then be used as scenario variables during the rest of this study.

3.2 CATEGORIZATION OF INFLUENCE FACTORS

We can divide the influence factors into two categories: external factors (outside the transport system) and internal factors (inside the transport system).

Figure 3-1 shows examples of these factors. Internal factors can be divided over the subcategories car mode, public transport and slow modes.

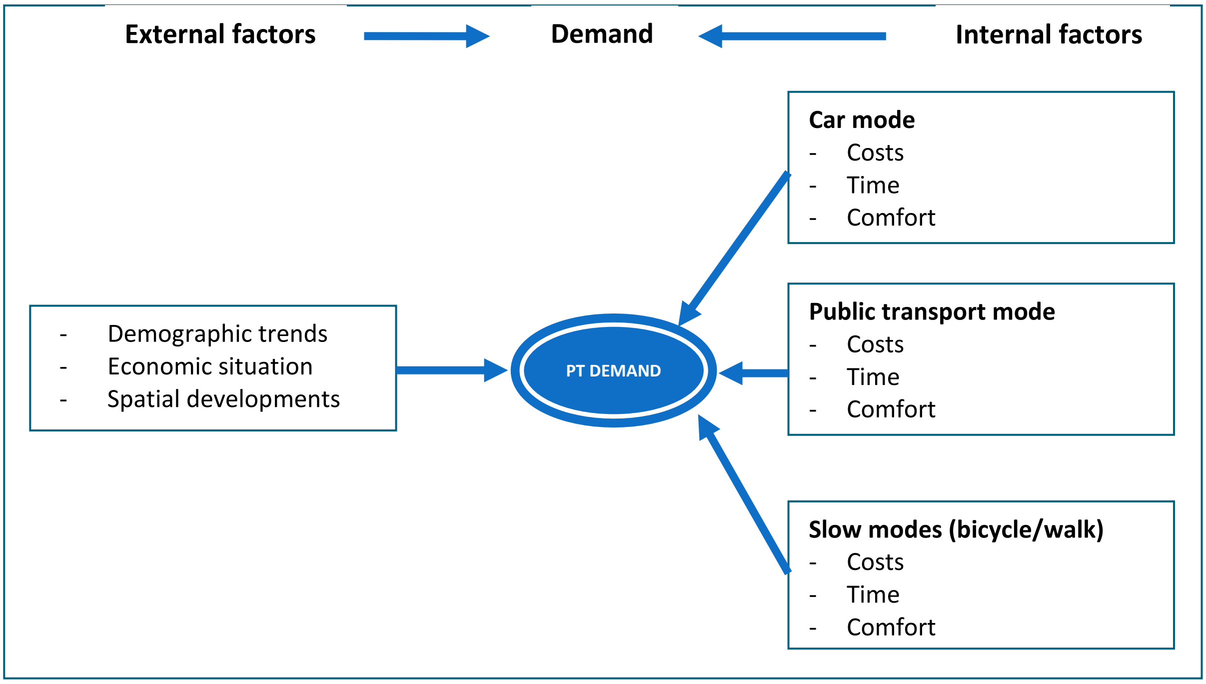

Figure 3-1 Factors influencing the demand for public transport

In the paragraphs below, all influence factors will be judged on their size and impact whether to be a small or a large influence factor for public transport demand. All impacts will be based on literature study. After this, the factors with the largest influence will be taken into account during the rest of the research project and are used in scenarios.

3.3 EXTERNAL FACTORS

3.3.1 Demographic data/trends

Population trends have a large influence on public transport demand. Different trends like growth, discoloration, individualization, intensification and urbanization may have influence on the demand for public transport (Bakker, Derriks, & Savelberk, 2011).

- Research has shown that the process of aging will not lead to differences in PT-demand.
- Immigrants are more focused on public transport than on cycling. It is expected that once their incomes will rise, immigrants are going to move outside the cities to area's with a less dense PT-network and the surplus for public transport use will disappear.
- Individualization and intensification will lead to less PT-use on the countryside and more PT-use in the urban areas.
- The trends of people moving from the countryside to the cities (urbanization) will lead to more PT-use, since the network is denser in the city centers (availability of modes).

Table 3-1 shows the relation between income category and trip production per mode. It can be observed that especially for low-income households the share of public transport is higher than car (and for high-income households the private car is a more common way of transport).

Table 3-1 Relation between trip production per person, per day, per mode and income category (Centraal Bureau voor de Statistiek, 2012)

	Car (driver)	Car (passenger)	Train	BTM	Bicycle	Walk
Income €0 - €10.000	0,57	0,39	0,12	0,12	0,9	0,59
Income €10.000 - €20.000	0,63	0,36	0,04	0,08	0,75	0,57
Income €20.000 - €30.000	0,98	0,4	0,05	0,05	0,74	0,46
Income €30.000 - €40.000	1,14	0,37	0,06	0,04	0,74	0,41
Income €40.000 - €50.000	1,28	0,35	0,06	0,05	0,68	0,38
Income €50.000+	1,24	0,38	0,05	0,03	0,66	0,32

Impact assessment:

Impact size	Remark
2	Demographic details have a large influence on the number of trips produced.

3.3.2 Economic situation

The economic situation of a country is an important influence factor for public transport demand. Since it is hard to predict what the future economic and financial situation will be, the CPB (Centraal Planbureau Netherlands) developed four different scenarios for future economic trends. These four scenarios are applicable for all European countries (Lejour, 2003).

Table 3-2 Four different future trends for economic development (Lejour, 2003)

	Public responsibility	Private responsibility
National sovereignty	Regional Communities	Transatlantic Market
International cooperation	Strong Europe	Global Economy

Each scenario has a different impact on the demand for public transport. The modal split for train traffic decreases or stays the same for all four scenario. In absolute kilometers the demand for trains increases in all four scenarios. The market share as well as the absolute kilometers for BTM will descend in all scenarios.

In the scenarios Global Economy and Transatlantic Market the market share of trains increases during peak hours and descents during off-peak hours. This means that in the market-driven economies the difference in demand between peak and off-peak grows. The same analysis yields for BTM (Besseling & Groot, 2006).

Table 3-3 Modal split in passenger mileage per scenario on work days (Besseling & Groot, 2006)

	Car driver	Car passenger	Train	BTM	Cycling/Walking
% passenger mileage					
2002	50.7	18.5	9.9	5.7	15.1
Global Economy (2040)	61.3	15.5	7.8	3.7	11.7
Strong Europe (2040)	57.2	16.7	9.0	4.5	12.6
Transatlantic Market (2040)	59.3	15.8	8.7	4.3	12.0
Regional Communities (2040)	54.7	17.2	9.8	5.1	13.2

Table 3-4 Travelers kilometers per scenario on work days (Besseling & Groot, 2006)

	Car driver	Car passenger	Train	BTM	Cycling/Walking
In billion travelers kilometers					
2000	114.0	44.9	17.9	6.5	20.5
Global Economy (2040)	193.4	52.1	19.0	5.9	13.1
Strong Europe (2040)	169.5	52.7	20.4	6.6	15.9
Transatlantic Market (2040)	162.2	46.0	18.3	5.8	12.9
Regional Communities (2040)	130.8	43.9	18.3	6.1	15.4

Impact assessment:

Impact size	Remark
3	The economic situation has a large influence on public transport use (especially train).

3.3.3 Spatial developments

The spatial structure around public transport access nodes is often very determinative for the services offered at that node. The number of citizens, work places, learning places and amenities is strongly related to the potential of a PT-node. For an example in a densely populated area (lots of high-rise buildings) and numerous shopping facilities it is obvious that there is a big potential for a large public transport hub where different modes come together. On the other hand, on the countryside, with only a few houses around, the best achievable node is just a bus stop.
Transit oriented development is a method which works the other way around. First locations are chosen to be developed into for an example a residential area or a shopping area. In that area the accessibility is first enhanced (access roads, public transport stops), after which the climate for settlements is improved and developers and companies want to built at that location. In that way city planners can steer the developments into certain areas.

The main spatial target for the south wing of the Randstad is urban intensifying. In order to coordinate the new need for settlement of inhabitants on a regional scale, the south wing is included in the MIRT (Meerjarenprogramma Infrastructuur, Ruimte en Transport)-publication of the Dutch government. In this publication it is stated that the growth in de south wing can only be reached by urban intensifying. The additional demand for dwellings must concentrate around Den Haag (55%), Rotterdam (20%) and Leiden (10%). The Randstad South Wing has an ambitious policy goal to build 80% of the newly added dwellings within the existing built-up area. The Stedenbaan agreement stated that for the period 2010-2020 40% (about 40.000 dwellings) is to be located within the catchment area of the 36 Stedenbaan railway stations. In the period 2006-2010, 45% of the new dwellings in the South Wing area was actually built near StedenbaanPlus railway stations; this was more than the ambition of 40%. The current forecast is that 27.000 new dwellings will be built near Stedenbaan stations in the period 2010-2020 (Geurts, Maat, Rietveld, & De Visser, 2012).

The large number of new citizens close to the Stedenbaan stations will have a strong effect on the demand for public transport in these catchment areas.

Table 3-5 Number of trips per day per person per motive and per mode (Centraal Bureau voor de Statistiek, 2012)

		Trips per day per person				
	Motives	**Work**	**Business**	**Recreational**	**Education**	**Other**
Population density	**Modes**					
Very dense	**Car (driver)**	0,2	0,02	0,12	0,01	0,09
	Car (passenger)	0,02	.	0,06	0,03	0,03
	Train	0,04	.	.	0,01	.
	Bus/tram/metro	0,04	.	0,03	0,02	0,01
	Bike	0,14	.	0,18	0,11	0,06
	Walk	0,03	.	0,22	0,06	0,04
Dense	**Car (driver)**	0,25	0,03	0,17	0,02	0,11
	Car (passenger)	0,02	.	0,08	0,04	0,03
	Train	0,03	.	.	0,01	.
	Bus/tram/metro	0,01	.	0,01	0,01	.
	Bike	0,12	.	0,18	0,14	0,06
	Walk	0,03	.	0,14	0,06	0,04
Normal	**Car (driver)**	0,26	0,03	0,21	0,02	0,11
	Car (passenger)	0,02	.	0,08	0,04	0,03
	Train	0,01	.	.	0,01	.
	Bus/tram/metro	0,01	.	.	0,01	.
	Bike	0,12	.	0,18	0,15	0,06
	Walk	0,02	.	0,11	0,06	0,04

Based on Table 3-5 Number of trips per day per person per motive and per mode it can be observed that public transport use increases the denser the area is populated.

Impact assessment:

Impact size	Remark
3	The densification of areas (spatial developments) has a large influence on public transport use (both train and BTM).

3.4 CAR MODE FACTORS

3.4.1 Car costs

It is often assumed that the car system and the public transport system form sort of communicating vessels. Unfortunately this assumption is wrong. There are many differences between car and public transport which makes the two markets overlap for only a small part of the users (Baanders, Bovy, Van der Hoorn, & Van der Waard, 1991).
First, there is the time-factor; a car is available 24/7, while public transport mostly functions only parts of the day. Second factor is location; in cities the public transport network is very dense, but often on the countryside public transport is not even an option. Third difference is the motive; people travelling with lots of luggage are not having an easy trip in public transport. Fourth factor is the personal properties of a traveler. If you have not got a driver license, driving a car is not an option. At last travel conditions prevent a switch. If you'd like to read while travelling, you cannot take your car, but if you'd like to listen to loud music without ear plugs, using public transport is not advised.
All those differences prevent people from switching between public transport and car unhindered. Besides the differences mentioned above, public transport and car are not the only two 'barrels' which communicate (think about other modes like walking, cycling, car-pooling and taking a taxi).

The effect of car costs on public transport demand appears to be relatively low (Van der Waard, 1990). The average cross elasticity of the PT mileage for the fuel price is 0.14. This means that if the fuel price increases with 1%, the use of public transport increases with 0.14%. This is an average over all motives. If we look on the long-range relations, where the train is a good competitor with car traffic, this value is a little bit higher: 0.22. For commuting traffic this value is even higher: 0.26. The low elasticity can be explained by the availability of alternatives.

Impact assessment:

Impact size	Remark
1	Almost no relation between car costs and public transport use is expected.

3.4.2 Road pricing

On the 13th of November 2009 the Dutch government decided to implement "anders betalen voor mobiliteit". This plan, which will be implemented in phases, introduces a different paying method for car drivers. Not the possession of a car will be charged, but only the kilometers travelled. At first a base tariff will be introduces, but later on the tariffs for traveling during peak and off-peak hours will be different. In March 2010 the implementation of the plan was cancelled by a lack of support for the plan in the Dutch parliament.

Before March 2010 the Dutch government performed research on the plan and estimated that the demand for public transport would increase with 4% to 6% after full implementation (Bakker, Gille, Mijjer, & Van Mourik, 2005).

Table 3-6 Effects of introducing 'ander betalen voor mobiliteit' (Bakker, Gille, Mijjer, & Van Mourik, 2005)

		Netherlands	Randstad	Rest Netherlands
Mobility per transport mode (kilometers traveled)	Car driver	-15%	-16%	-15%
	Car passenger	-8%	-9%	-8%
	Train	5%	6%	5%
	Bus/Tram/Metro	5%	5%	4%
	Cycling/Walking	8%	7%	8%

An analyses from Goudappel Coffeng shows that the introduction of road pricing (and thus the abolition of motor vehicle tax and taxes on the purchase of a car) causes a bigger car fleet. The increasing availability of a car means a decrease in the number of so-called PT-captives.
The introduction of the peak-charge might not result in a shift from car to public transport, but in a shift from car during peak to car during off-peak (Baas, Bouwknegt, & Brands, 2010).

Impact assessment:

Impact size	Remark
2	A small relation between road pricing and public transport use is expected.

3.4.3 Car parking costs

Parking fees affect trip destinations as well as vehicle use. An increase in parking prices can reduce use of parking facilities at a particular location, but this may simply shift vehicle travel to other locations. However, if parking prices increase throughout an area, there is effective enforcement of parking regulations, and there are good travel alternatives, parking price increases can reduce total vehicle travel (Litman, 2013).

Table 3-7 Parking price elasticity's (TRACE, 1999)

Motive	Car driver	Car passenger	Public Transport	Bike/walk
Commuting	-0.04	+0.01	+0.01	+0.02
Business	-0.03	+0.01	+0.00	+0.01
Education	-0.02	+0.00	+0.00	+0.00
Other	-0.15	+0.03	+0.02	+0.05
Total	-0.07	+0.02	+0.01	+0.03

As one can see in Table 3-7 the elasticity for public transport use is very low for all motives.

Impact assessment:

Impact size	Remark
1	Almost no relation between parking costs and public transport use is expected.

3.4.4 Road quality (travel time)

As said before, the modes car and public transport are no communicating vessels (Baanders, Bovy, Van der Hoorn, & Van der Waard, 1991). The influence of enhanced road quality (as in enhanced travel time), causes only a small shift from public transport to car. On some trajectories where the average travel time is very high due to congestion, this might be a opportunity for public transport. On the other hand, if the travel time via road is enhanced due to new connections or upgraded roads, travelers might prefer the car mode.

Impact assessment:

Impact size	Remark
1	Almost no relation between road quality and public transport use is expected.

3.5 PUBLIC TRANSPORT MODE FACTORS

3.5.1 Public transport costs

The effects of PT-rates on the demand for public transport itself are often investigated. Table 3-8 shows the effect of prices changes on the short and long term for train and BTM.

Table 3-8 Price elasticity's for public transport (Geilenkirchen & Geurts, 2010)

	Short term	Long term
Train	-0.3 till -0.7	-0.6 till -1.1
BTM	-0.1 till -0.5	-0.3 till -1.0

Impact assessment:

Impact size	Remark
2	A small relation between public transport pricing and public transport use is expected.

3.5.2 Student travel product

In 1991 a public transport travel document for students was introduced. With this document, students have the right to travel for free during certain periods (weekdays or weekend) and to travel with discount during the other period. The coalition agreement of cabinet Rutte II states that the government intends to abolish the card or convert the student travel product into a discount card, without periods of free travelling. Since the exact measures are not known yet, the following effects are expected with the complete abolishment of the card (In 't Veld & Kouwenhoven, 2013):

- Increasing costs for students
- Less travelled kilometers per student
- Transfer from public transport to car/bike
- More students living away from home
- Decreasing level of facilities

Table 3-9 Effects on travelled kilometers (x1.000.000) by students after complete abolishment of student PT-document (In 't Veld & Kouwenhoven, 2013)

	Effect	
	Train	BTM
Km's travelled by students in 2012	7382	2683
Less travelled kilometers	-1260	-334
Transfer from PT to car/bike	-1793	-753
More students living away from home	-291	-94
Decreasing level of facilities	-77	-16
Km's travelled by students after complete abolishment of student PT-document	3961	1487
Decrease in % km's travelled by students	-46%	-45%
Passenger kilometers 2012	17100	6500
Decrease in % km's travelled totally	-20%	-18%

The consequences mentioned above, will also affect the revenues of public transport. Without additional measures public transport companies cannot maintain the current quality levels of public transport. The expected effects are a decreasing public transport supply (lines/frequencies, 8% for train and 5% for BTM) and/or increasing rates for travelers (average 10%). Since there is little room for raising the rates any further within the current contracts, it is likely that the solution will be to decrease the supply.

Impact assessment:

Impact size	Remark
3	A strong relation between abolishment of the student travel card and public transport use is expected.

3.5.3 Public transport quality

Improvements in the quality of public transport influence the demand for transport. But in the context of this investigation, they are not identified as a risk or an opportunity itself.

3.6 SLOW MODE FACTORS

3.6.1 Bicycle facilities

In the Netherlands cycling is a very important mode of transport and also an important feeder for other modes. As shown in Table 3-10 20-37% of all train passengers travel to the train station by bike. Therefore it is obvious that the accessibility of train stations by bike and quality of the bike storage facilities at train stations might influence the demand for trains.

Research into the use of bicycles as a access and egress transport mode to train stations has shown that enhancing the accessibility of train stations by bike and the quality of bicycle storage facilities caused a shift from access/egress-BTM to bike, but did not led to a larger demand for train services itself. It is assumed that other developments in the influence area of train stations have a bigger influence on the demand for trains than the quality of bicycle facilities (Fietsberaad, 2007).

Table 3-10 Modal split access and egress transport to train in 2005 (Fietsberaad, 2007)

Access and egress transport train 2005	Small station on countryside	Small station in town centre	Large station in suburb	Large station in city centre
Walk/car passenger/taxi	36%	44%	51%	45%
Bicycle	37%	36%	20%	23%
BTM	9%	10%	23%	30%
Car driver	18%	10%	6%	2%
Total	100%	100%	100%	100%

Impact assessment:

Impact size	Remark
1	Almost no relation between the availability of bicycle facilities and public transport use is expected.

3.7 CONCLUSIONS

When the influence factors of the analysis above are gathered together and ordered based on their impact size, the following table can be composed.

Table 3-11 Result impact analysis PT use influence factors

Impact size	Top opportunity factors
3	*Economic situation*
	Spatial developments
	Student travel product
2	*Demographic data*
	Road pricing
	Public transport pricing
1	Road quality
	Car costs
	Car parking costs
	Bicycle facilities

All influence factors with impact size 2 and 3 will be taken into account into the study. Road quality will only be taken into account for large travel time improvements in the south wing of the Randstad. Below the influence factors for the project are listed. All six factors have two possible values and therefore form the base of 64 combinations (2^6).

- Economic situation (regional community versus global economy)
- Spatial developments (as planned versus postponed/cancelled)
- Student travel product (as current versus complete abolishment)
- Demographic data (change of population composition is coupled to economic situation)
- Road pricing (as current versus kilometer charge)
- Public transport pricing (as current versus current + 10%)

These 64 combinations form the different scenarios.

4 MODEL PREPARATION

4.1 INTRODUCTION

Predicting future travel demands on a large scale is a very complicated matter. As seen in chapter 3, there are many different influence factors for location, destination, mode, route and time choice. To make models which predict as good as possible, as many influence factors (scenario's) as possible must be built in the models. At first this chapter discusses all the criteria for the model, derived from the previous chapter and the project plan. In appendix A the eleven most used transport models are discussed and based on the type of model, the application and the other properties, these models are compared with the criteria set. A multi criteria analysis will then lead to the model choice and finally this model is prepared for the model study.

4.2 MODEL CRITERIA

4.2.1 General criteria

- Availability (free/cheap)
- Time horizon (2030)

4.2.2 Scenario criteria

As seen in paragraph 3.7 the following variables must be available in the model:

- Spatial developments (as planned versus postponed/cancelled)
- Student travel product (as current versus complete abolishment)
- Public transport pricing (as current versus current + 10%)
- Road pricing (as current versus kilometer charge)
- Economic situation (regional community versus global economy)

4.2.3 Network criteria

Different types of infrastructural and service level adjustments must be made in the public transport network. This comprises:

- Adjustments in route/stops/frequencies of train services
- Adjustments in route/stops/frequencies of metro services
- Adjustments in route/stops/frequencies of light rail services
- Adjustments in route/stops/frequencies of tram services

4.2.4 Assessment criteria

Next to the variables and network adjustments, the form of the output is also a criteria for the model choice.

- Level of detail of zoning (PC4)
- Distinction between different modes (car, public transport, bike, walk)
- Distinction in time (peak, off-peak, weekend)
- Distinction in motive

4.3 MODEL EVALUATION AND CHOICE

In the table below all criteria are summarized and each model is rated based on whether the model can be applied for that criteria.

Table 4-1 Criteria table model choice

	Prefered property	TIGRIS	SMILE	TEM	Mobilec	MOVE	Scenarioverkenner	FACTS	NRM	LMS	NVM	RVMK	Haaglandenmodel
General criteria													
Type	Passenger	1	0	0	1	1	1	1	1	1	1	1	1
Costs	€ 0.00	0	0	0	0	1	0	0	1	1	0	0	0
Time horizon	2030	1	1	1	1	1	1	1	1	1	1	1	1
Simulation type	Dynamic (land-use - transport)	1	0	0	0	0	0	0	0	0	0	0	0
Simulation level	Macroscopic	1	0	0	1	1	1	1	1	1	1	1	1
Area	Randstad south wing	1	1	1	1	1	1	1	1	1	1	0	0
Scenario criteria													
Spatial developments	Adjust zonal properties	1	1	1	0	1	1	0	1	1	1	1	1
Student travel card abolishment	Simulation with and without	0	0	0	1	1	1	0	0	0	1	1	1
Public transport pricing	Possibility to adjust PT-prices	1	1	1	1	1	1	1	1	1	1	1	1
Road pricing	Possibility to simulate road pricing	1	1	1	1	1	1	1	1	1	1	1	1
Economic scenario's	Multiple, preferable RC and GE (bandwidth)	1	1	1	1	1	1	1	1	1	1	1	1
Network criteria													
Level of detail PT network	Network on link and node level	1	0	0	0	0	0	0	1	1	1	1	1
Manage train services	Manage network and services	1	0	0	0	0	0	0	1	1	1	1	1
Manage metro services	Manage network and services	1	0	0	0	0	0	0	1	1	1	1	1
Manage light rail services	Manage network and services	1	0	0	0	0	0	0	1	1	1	1	1
Manage tram services	Manage network and services	1	0	0	0	0	0	0	1	1	1	1	1
Manage bus services	Manage network and services	1	0	0	0	0	0	0	1	1	1	1	1
Assessment criteria													
Zone detail	PC4	0	0	0	0	0	0	0	1	0	1	1	1
Different modes	Car, train, metro, light rail, tram, bus	1	0	0	1	1	0	1	1	1	1	1	1
Different time periods	Morning peak, rest day, evening peak	0	1	1	1	1	0	0	1	1	1	1	1
Different motives	Live, work, recreational	1	0	0	0	1	0	0	1	1	1	1	1
Level of detail produced trips	Number of PT trips per link and node	0	0	0	0	0	0	0	0	0	1	1	1
		17	7	7	10	13	9	8	19	18	20	19	19
Availability	Third party, with support	0	1	1	0	1	1	0	1	1	0	0	0
Final score (score * availability)		0	7	7	0	13	9	0	19	18	0	0	0

Based on the final score the NRM is the best model to apply in this project. For all model descriptions see appendix A.

4.4 DETAILED MODEL DESCRIPTION

The NRM is a very complex model which predicts future traffic demand in numerous steps. The flow chart diagram below shows the schematic set-up of the NRM. The blue rectangles represent the 5 different modules, the continuously outlined blocks the input data and the dashed outlined blocks the intermediate results.

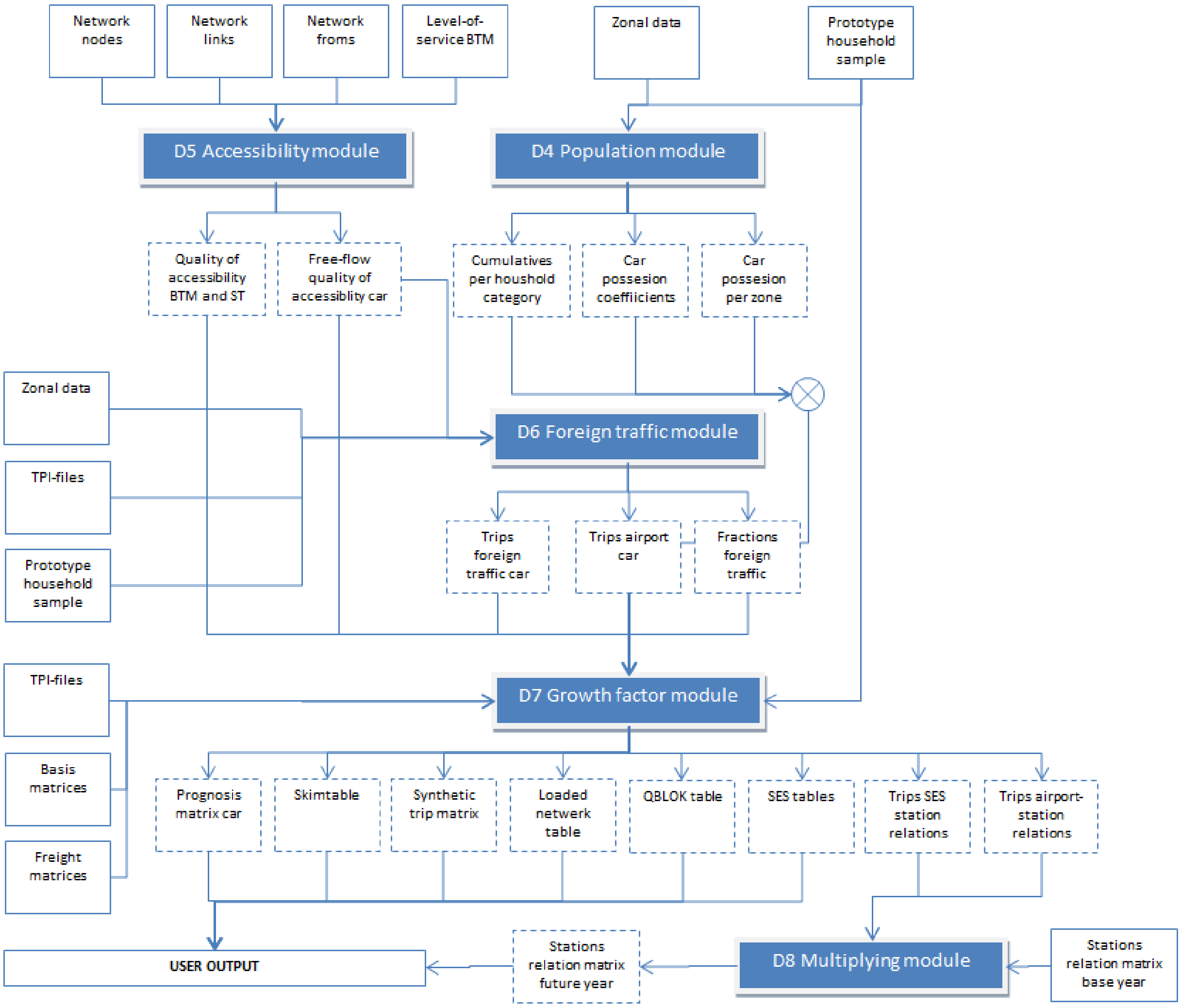

Figure 4-1 Schematic set-up of the NRM (Rijkswaterstaat, 2011)

4.5 MODEL PREPERATION

4.5.1 Economic situation

The economic situation is expressed in the so-called WLO-scenario's (see paragraph 3.3.2). Two of these scenarios, regional community and global economy are predefined scenario options in the NRM. Running the model in either RC or GE mode implies different economic growth, population growth and welfare (Rijkswaterstaat, 2011).

4.5.2 Spatial developments

The details about the population's place of residence, characteristics and composition are stored in zonal data file. The entire Netherlands (and even the border regions) are divided into 3608 zones (the zones are coherent with 4-digit postal codes). For each zone details about size and distances, number of inhabitants, number of work places, education places, population composition, car ownership and income are specified (Rijkswaterstaat, 2011).

The prediction of some of these values comes from the new map of Holland, the so-called "Nieuwe kaart van Nederland". This is a map, which shows all future planned spatial developments in the categories of agriculture, public green, recreation, amenities, mixed use, working, living, infrastructure and water (Nirov, 2008). Changes in spatial settlement can be processed by adjusting the related zonal data. The zonal data is exogenous, which implies that there is no feed-back loop between mobility and land use (Rijkswaterstaat, 2011).

4.5.3 Student travel product

The student travel card is not specifically modeled in the NRM. Transport costs for public transport, which determine for a certain part the utility of a trip, are determined based on input files.
Train tariff: tariff index * costs derived from TPI-files
BTM tariff: tariff index * number of tariff zones (per HB-pair) * costs per zone (data from LOS4____.BIN) (Rijkswaterstaat, 2011).

Since there is made no distinction in transport costs per motive or user group, it is very hard to adjust the transport costs specifically for students with a travel card. Rijkswaterstaat has investigated the possibilities to modify the NRM so that the effects of abolishing the student travel card can be calculated. Unfortunately the conclusion of this research is that it is not possible to evaluate the effects with the growth model version 2004 (Hoffman, 2013). In a new version (built 2013-2014) this option is planned to be implemented.

Overall it can be concluded that the effects of abolishing the student travel card cannot be determined directly with the NRM.

4.5.4 Demographic data

The demographic data is specified in the zonal data file (see paragraph 4.5.2). This data is exogenous, but different for the RC and GE scenario (Rijkswaterstaat, 2011).

4.5.5 Road pricing

The introduction of road pricing ('Anders betalen voor mobiliteit') means that the fixed costs for car possession are abolished and replaced by variable costs based on car use. Although the introduction of road pricing is currently set on hold, the Dutch politicians in the second chamber did agree on the new price per kilometer. The rate for passenger cars will be 6,7 cent/km in 2018. When applying an inflation correction of 1,022% per year, the price will be 8,6 cent/km in 2030 (Baas, Bouwknegt, & Brands, 2010).

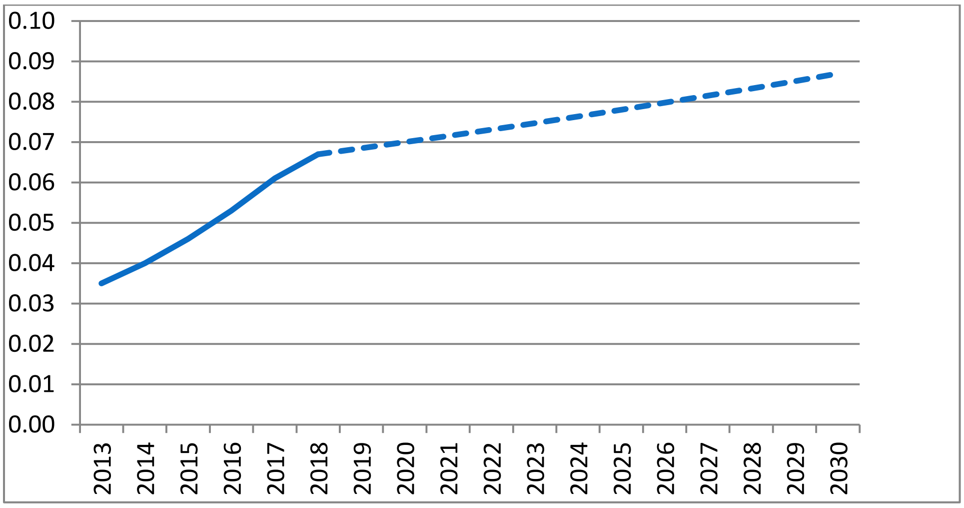

Figure 4-2 Variable costs road pricing

The fixed car costs will be set to 0%.

4.5.6 Public transport pricing

The public transport rates are easy to set in the policy settings in the NRM, but a distinction between train and BTM rates is made. The future rates for both modes are defined in the NRM principles report by Rijkswaterstaat (Rijkswaterstaat, 2011).

Table 4-2 Train and BTM tariff rates NRM

Train rates per motive			
Index 2004 = 100			
	2004	**2030 RC**	**2030 GE**
Live-work	100	111	111
Other motives	100	108	108

BTM rates per motive			
Index 2004 = 100			
	2004	**2030 RC**	**2030 GE**
All motives	100	116	116

4.6 SET-UP OF THE ANALYSIS

During the set-up of the analysis five influences are defined that have to be modeled, with each two options:

- Road pricing:	Pay For carPosession	Pay For Mobility
- Public transport pricing	Normal rates	Normal rates +10%
- WLO scenario	Regional community	Global economy
- Spatial downgrading	Spatial plans 2008	Without spatial plans 2008
- Public transport enhancements system	Current PT-system	Enhanced StedenbaanPlus

With all these influences, $2^5 = 32$ different scenario's can be identified:

The effect of an influence can be measured by comparing two scenarios with exactly the same properties, except the influence which needs to be assessed. By doing this for all influences, to table below is the result. The number of scenario's needed to run is now limited from 32 to only 6.

Table 4-3 Scenario set-up

0	Scenario						
PFP	Road pricing (PayForPossession vs. PayForMobility)	PFP	PFP	PFP	PFP	PFP	PFM
P0%	PT Pricing (0% vs. 10% additional rate incease)	P0%	P0%	P0%	P0%	P10%	P0%
	WLO (Regional Community vs. Global Economy)	RC	RC	RC	GE	RC	GE
SP	Spatial (All spatial vs. No spatial)	SP	SP	SP-	SP	SP-	SP
PT	Public Transport (Proposed vs. Enhanced)	PT	PT+	PT	PT+	PT	PT+
	Influence PT enhancement						
	Influence spatial downsize						
	Bandwidth						
	Influence PT pricing						
	Influence Road pricing						
	Influence WLO-scenario						
		1	2	3	4	5	6

The lines indicate which influence can be assessed by comparing the two scenarios' it is linked to. The base year scenario is called scenario 0.

4.7 CONCLUSIONS

Predicting future public transport use is often done by using transport models. There are numerous models available, all with different properties and characteristics, but most of all: different aims. By comparing some of these models with the criteria derived from the set-up of this study, the model which fits these criteria as best can be derived. For this study the best model to use appeared to be the NRM (Nederlands Regionaal Model).

The NRM is a model with a very large number of input variables and a very detailed output. By performing the study with different input variable values (based on the derived scenario's), the future public transport use can be calculated. Unfortunately the NRM is incapable of simulating the abolishment of the student travel card, which means that the total number of scenario's dropped from 64 to 32. Since the NRM has a calculation time of about 5 days, simulating 32 different scenario's takes a lot of time. Therefore another way of limiting the number of runs needed has been found. By comparing two scenario's which only differ at one variable only 6 runs are needed instead of 32.

PART II CASE STUDY STEDENBAANPLUS

5 STEDENBAANPLUS NETWORK AND SERVICE ENHANCEMENTS

5.1 INTRODUCTION

The last step in the case study preparation is determining the infrastructural adjustments for the StedenbaanPlus area. At first the current public transport network is discussed. After that the plans for future network adjustments from the network owners are explored. These projects are then classified based on their relevance to transit oriented development and the StedenbaanPlus ambitions. At last these projects are discussed in detail, including the way of implementing them into the NRM.

5.2 RANDSTAD SOUTH WING PUBLIC TRANSPORT SERVICE SCALES

If we take a look at the south wing public transport network, we can observe four different scale levels; international, national, regional/interurban and urban/local. There are multiple different transport modes which serve not all of these levels. The table below indicates which mode operates at which scale level.

Table 5-1 Service scales and transport modes

Mode ↓ scale →	International	National	Regional/interurban	Urban/local
High speed trains	X	X		
Intercity trains		X	X	
Local trains		X	X	X
Metro/light rail			X	X
Regional tram/bus			X	X
City tram/bus				X

Based on the size of the Randstad south wing area, it is located in the national/interurban scale level.

Table 5-2 Service scales and transport modes (including demarcation of Randstad south wing)

Mode ↓ scale →	International	National	Regional/interurban	Urban/local
High speed trains	X	X		
Intercity trains		X	X	
Local trains		X	X	X
Metro			X	X
Light rail			X	X
Regional tram			X	X
Regional bus			X	X
City tram				X
City bus				X

RANDSTAD SOUTH WING

5.3 NETWORK OWNERS

In the Randstad south wing the public transport network is divided over three responsible owners:

- ProRail (for the main railway network)
- The urban district of Rotterdam (for the regional and urban transport in the Rotterdam area)
- The urban district of Haaglanden (for the regional and urban transport in the Den Haag area)

5.4 CURRENT PUBLIC TRANSPORT NETWORK AND SERVICES

The map below shows the set-up of the current public transport network for the Randstad south wing. Only the high quality services with a national or regional scale are shown. Regional bus services are not shown.

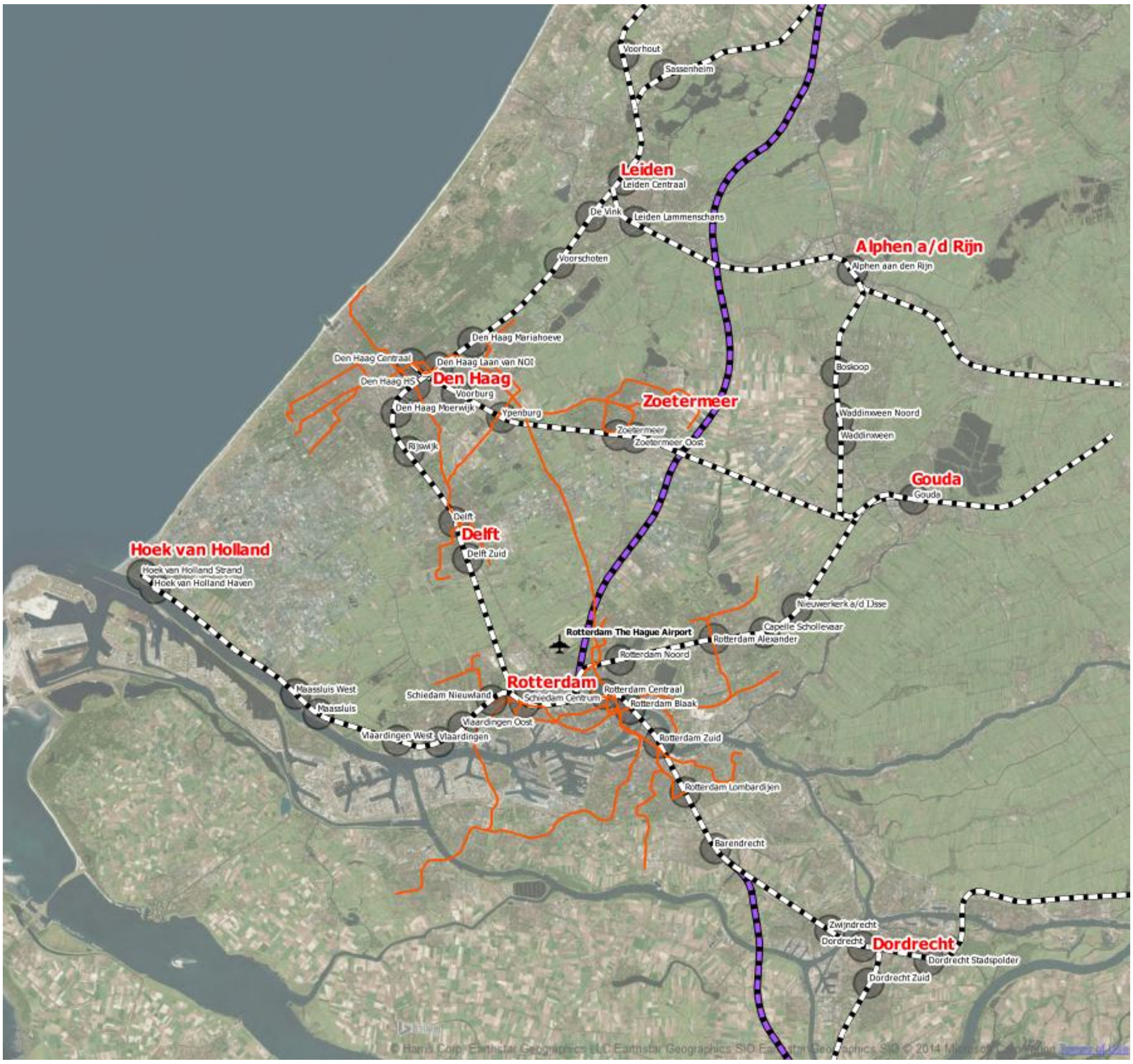

Figure 5-1 Current public transport network Randstad south wing

Main international feeder is the high speed line from Belgium (black/purple line). National feeders are the heavy rail lines coming from Roosendaal/Breda, from Gorinchem, Utrecht, Haarlem and Schiphol (black/white lines).

The two main cities, Rotterdam and Den Haag, are connected by a heavy rail link (served by local and intercity trains) and a light rail line. The region of Rotterdam has a metro network with 5 lines and multiple tram+ services (high quality tram). The region of Den Haag has many tram lines of which 5 lines have a regional function (to Zoetermeer and Delft). High quality regional services are shown in orange.

5.5 PROPOSED STEDENBAANPLUS PUBLIC TRANSPORT NETWORK AND SERVICES

5.5.1 Proposed project per network owner

Now that the network owners have been identified, their plans for future adjustments can be examined. The table below shows per network owner these projects. Given the properties of these projects, they have been rated based on their relation to StedenbaanPlus, the investment size (under or over €5mln euro) and the whether they contribute to large quality improvements (e.g. travel time or accessibility).

Table 5-3 Randstad south wing public transport projects

Network owner	Project	Relation with StedenbaanPlus (in influence area)	Estimated investment(> €5 mln)	Change in transport quality	**Take into account**
Min I&M	Frequency increase Rotterdam - Den Haag	1	1	1	**1**
Min I&M	Schiedam Kethel (IVV 467 Spaland [SPL])	1	1	1	**1**
Min I&M	Rotterdam Stadionpark (IVV 618 Rotterdam Stadion [RTST])	1	1	1	**1**
Min I&M	Gouda Gouweknoop (IVV 657 Gouda West [GDWE])	1	1	1	**1**
Min I&M	Bleizo (IVV 326 Bleiswijk-Zoetermeer [BLZO])	1	1	1	**1**
Min I&M	Sion/'t Haantje (IVV 909 Dekft Sion-Haantje [DTS])	1	1	1	**1**
SRR	Zuidtangent metro Kralingse Zoom - Zuidplein	1	1	1	**1**
SRR	Zuidtangent metro Zuidplein - Schiedam Centrum	1	1	1	**1**
SRR	Tram Rotterdam Airport	1	1	1	**1**
SRR	Metro Nesselande - Gouda Gouweknoop	1	1	1	**1**
SRR	Tram naar Schiedam Kethel	1	1	1	**1**
SRR	Inkorten uiteinden tram (Woudhoek en Spangen)	0	0	0	**0**
SRR	Keerlus tram Langenhorst	0	0	0	**0**
SRR	Ridderkerklijn	0	1	1	**0**
SRR	Tramstructuur Hillegersberg - Schiebroek	0	0	0	**0**
SRR	ZORO-rail	1	1	0	**0**
SGH	Light rail Oosterheemlijn - Bleizo	1	1	1	**1**
SGH	HOV Leyenburg - Delft - Zoetermeer	1	1	1	**1**
SGH	HOV Den Haag CS - Valkenburg	0	1	1	**0**
SGH	HOV Leyenburg - Westland	0	1	1	**0**
SGH	HOV Zoetermeer - Leiden	1	1	1	**1**
SGH	HOV Den Haag - Maassluis	0	1	1	**0**
SGH	Capaciteitsverhoging tramlijnen 2 en 9	0	0	0	**0**
SGH	Aanpassingen Stationsplein HS	0	0	0	**0**
SGH	Ontkoppeling tram- en autoverkeer Koningskade door het aanleggen van een tunnel voor tramlijn 9	0	1	0	**0**
SGH	Tramlijn 1 via nieuwe Binckhorst	1	1	0	**0**
SGH	Tramlijn 11 naar Norfolk	0	1	1	**0**
PZH	RijnGouweLijn Oost	1	1	1	**1**
PZH	RijnGouweLijn West	1	1	1	**1**

All projects which contribute to all of these three criteria are taken into account. These are the projects which scored a 1 in the right blue column. Since some projects interfere with each other, they can be combined. This leads to the final 9 projects. These projects are shown in the map below and are discussed in the next paragraphs.

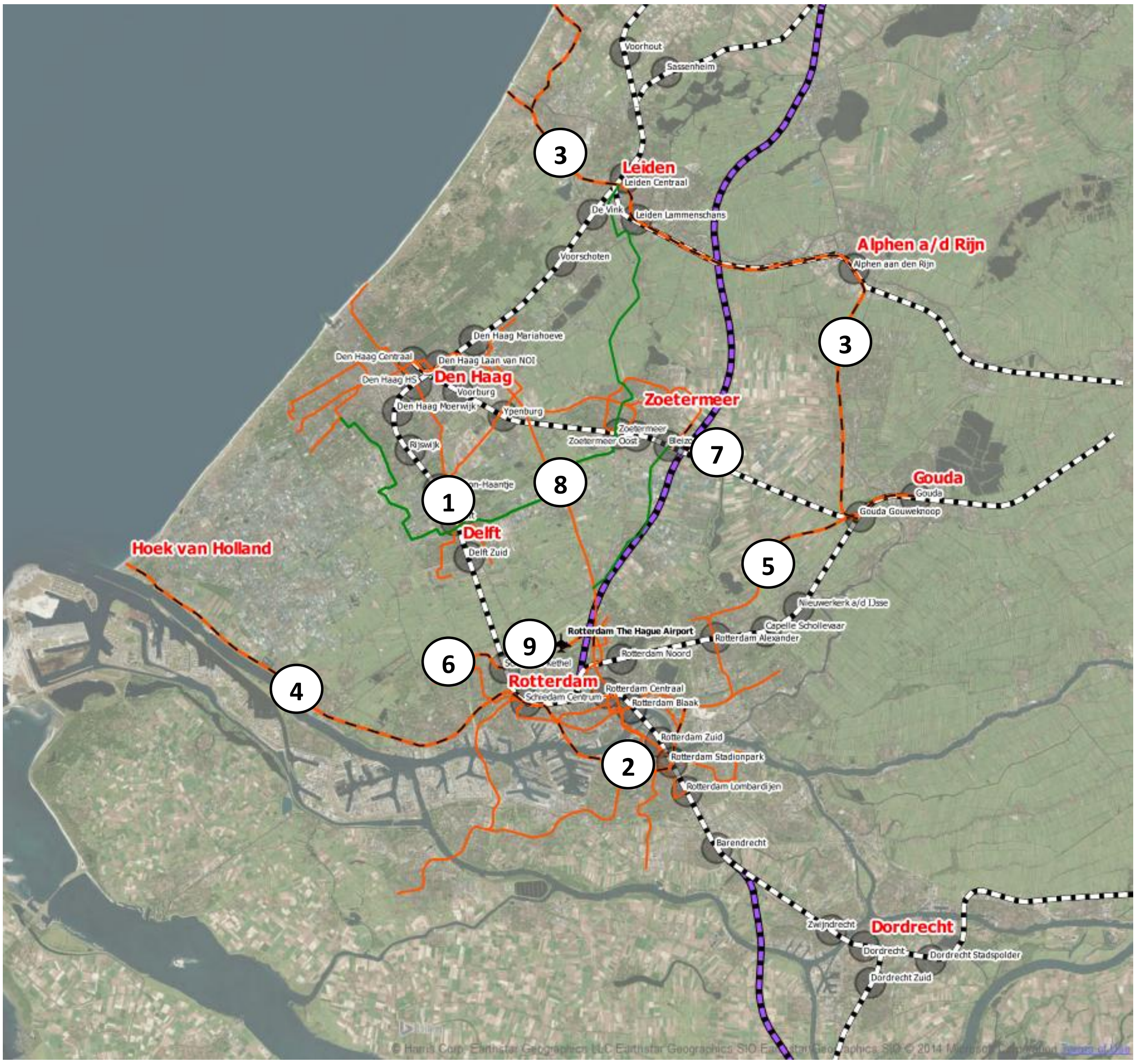

Figure 5-2 Proposed future public transport network Randstad south wing

5.5.2 Project 1: Frequency increase Den Haag – Rotterdam (including one new train station)

Introduction

The Dutch government ambitions for public transport (specifically heavy rail) are high. The coalition of Balkenende IV agreed to a short-term growth for public transport of at least 5%, which led to the plan “Groei op het spoor”. On the long term the ambition is high frequency train traffic, in combination with a growth of cargo transport per train. In order to formulate the long-term perspective, the plan “Programma Hoogfrequent Spoor” (PHS) was written. The high frequency train traffic will not be implemented on every corridor, but only on the ones with high perspectives. These corridors are:

- Alkmaar – Amsterdam - Utrecht - Eindhoven
- Utrecht - Arnhem - Nijmegen
- Amsterdam - Schiphol - Den Haag - Rotterdam – Eindhoven

New infrastructure

For the case of StedenbaanPlus the corridor of Amsterdam – Eindhoven is the most interesting one. It runs right through the study area and has major relations with the underlying public transport network. Based on the chosen lining, bottlenecks have been identified which prevent PHS from being implemented. In the StedenbaanPlus area this bottleneck is the narrowing track between Rijswijk and Schiedam. By reconstructing the part Rijswijk – Delft Zuid from 2 to 4 tracks, PHS can be implemented. In this case it is assumed that the tracks between Schiedam and Rotterdam are then fully available for trains between Den Haag and Rotterdam and that the Hoekse Lijn (Rotterdam – Schiedam – Hoek van Holland) is then reconstructed into a metro line (see project 4).

Another point of discussion related to this line is the construction of two new train stops. The first one is located at Delft Sion. Local authorities lobby for this new station because of the spatial developments taking place there, but the station is explicitly left out of the PHS program. In a later phase it might be constructed along the line, but at first this is not the case. In this research project the train station of Delft Sion will be taken into account, since it is very interesting in relation to the principle of TOD. The second train station, Schiedam Kethel, is discussed in project 6.

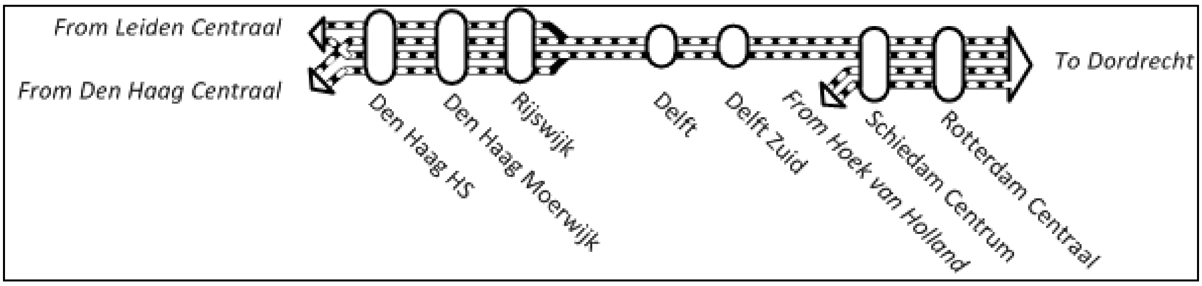

Figure 5-3 Project 1 track scheme (current)

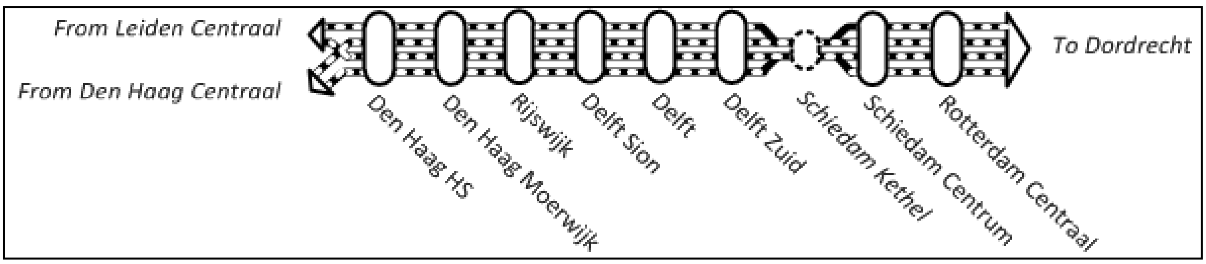

Figure 5-4 Project 1 track scheme (proposed)

Lining

The table below shows the current and proposed PHS lining.

Table 5-4 Lining Den Haag - Rotterdam

	Current lining (2014)		Proposed PHS lining (2020/2030)	
	Route	**Frequency**	**Route**	**Frequency**
International/high speed trains	Amsterdam – Brussels (BeNeLux)	1x per hour	Den Haag – Brussels (Fyra/Intercity Direct)	1x per hour
Intercity's	Amsterdam - Vlissingen	2x per hour	Amsterdam - Vlissingen	2x per hour
	Amsterdam - Dordrecht	2x per hour	Amsterdam - Breda	2x per hour
	Den Haag - Venlo	2x per hour	Den Haag - Venlo	2x per hour
Local trains	Den Haag - Roosendaal	2x per hour	Den Haag - Roosendaal	2x per hour
	Den Haag - Breda	2x per hour	Den Haag - Dordrecht	4x per hour
Total number of trains per hour		11		13

From the table above it can be observed that the number trains running between Den Haag and Rotterdam increases from 11 to 13 per hour (ProRail, 2010).

Previous studies

Implementing the PHS program is a very large and complex operation. The costs of infrastructural adaptations are very high, so before the preparations and construction works started, the Dutch government has carried out several social cost-benefit analyses. In the final report the conclusion is drawn that the forecast on the total transport value increases from 19,3 to 21,5 billion travelers' kilometers per year (Spit, Scholten, & van Dijk, 2010) for the entire Netherlands, which makes the implementation financially feasible.

For the corridor Den Haag – Rotterdam the implementation of PHS should lead to an increase in the number of trips made from 15.300 to approximately 18.000 in 2020 (18% growth). Compared with 2004 the growth will be about 30% (this includes other factors such as economic situation, car possession and demographic data) (ProRail, 2010).

5.5.3 Project 2: Metro line 6 Rotterdam (including 1 new train station)

Introduction

The south of Rotterdam has a relatively large disadvantaged position, compared to other districts of the city. More than 50% of the inhabitants in the south (200.000 people) live in so-called "krachtwijken". That means that the participation into education is low and unemployment is high. The bad accessibility plays a major role in this. The south is less attractive to live in, due to the fact that is has a bad accessibility by public transport. Therefore it is also a less attractive environment for companies to settle in.

The "city vision 2030" introduced several measures to enhance the accessibility and stimulate the housing environment. One of the enhancements is creating spatial developments around Stadionpark and to connect this area with other ones in the city by high quality public transport. The current public transport system is namely assumed to not be able to facilitate the urban growth in the next 15 years.

New infrastructure

The proposed enhancement of the network is the construction of the 6th metro line in the Rotterdam area. For this expansion new infrastructure is needed between the existing metro stations of Kralingse Zoom, Zuidplein and Marconiplein. In the map below the existing metro stations are shown in yellow. 8 new stations (shown in green) are planned to be constructed on the line. Halfway the first part of the new line a transfer point is created onto the railway network. At this point, the train station of Rotterdam Stadionpark has to be built as well (Stadsregio Rotterdam, 2012).

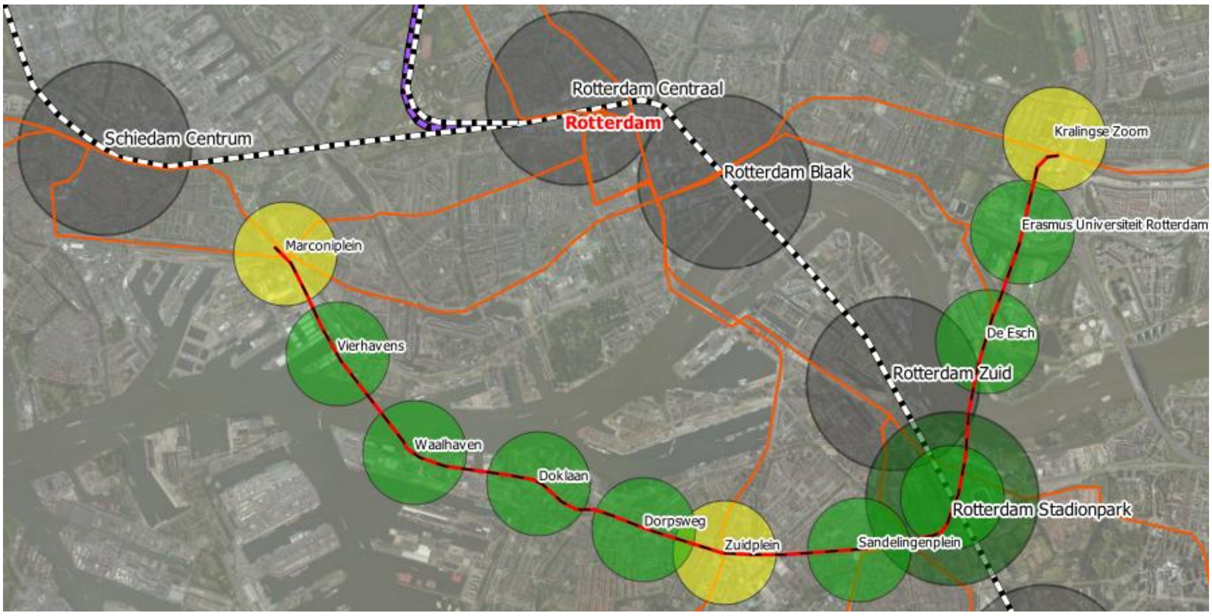

Figure 5-5 Project 2 map

Lining

Metro lines running over the new infrastructure are planned to start at Vlaardingen West and end at Binnenhof (replacing the existing metro line A from Schiedam Centrum to Binnenhof). See the figure below for the proposed lining and connections with other public transport services.

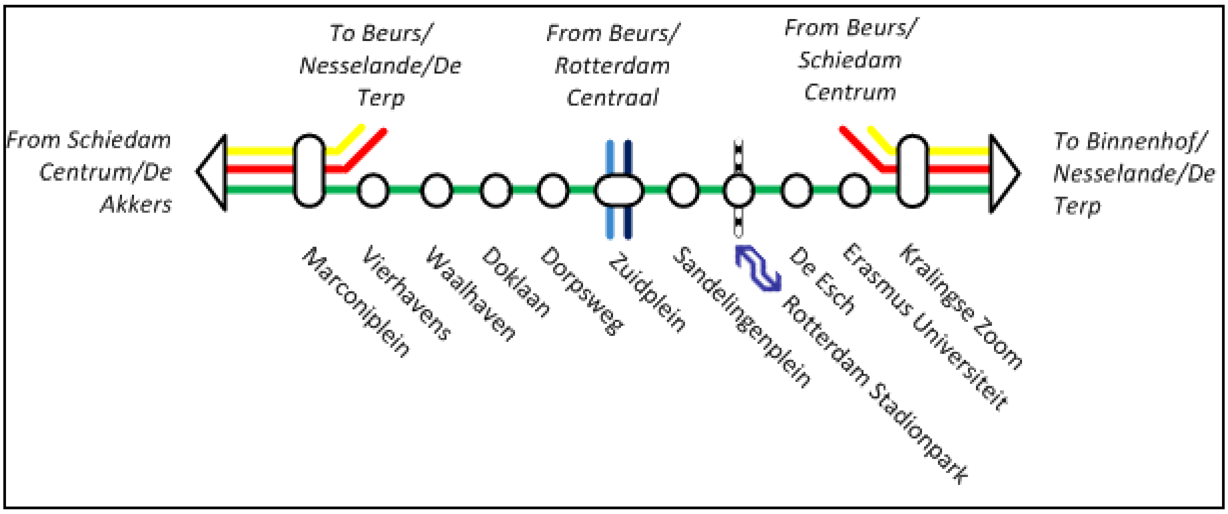

Figure 5-6 Project 2 lining scheme

The new metro line is supposed to have a frequency of 6 times per hour, all day from 6h till 24h. The maximum capacity is therefore with 3 trains (with each a 104 seats and 166 pitches) 87.480 passengers per day between each stop (Stadsregio Rotterdam, 2012).

Previous studies
Limited studies have been carried out so far on this project, but the most detailed one is “OV op Zuid” from the consultancy company Goudappel Coffeng. Different service levels have been simulated in order to predict future use of the new connection and influences on other lines. The most important conclusion is that the plan mentioned above is the most promising one. It attracts the most new public transport trips compared to other scenarios (+7%). Together with the new intercity stop Stadionpark, it enhances the accessibility of the south of Rotterdam significantly (31.000 passengers per day at Stadionpark) (Goudappel Coffeng, 2010).

5.5.4 Project 3: Conversion heavy rail Gouda – Leiden to light rail (including several new stops)

Introduction
Long before the plans were made to build a light rail line between Gouda, Leiden en Katwijk/Noordwijk, local tram ways were running over parts of the routes as proposed for the RijnGouweLijn nowadays. Around 1960, when the private car was emerging, the local tram way network around Leiden disappeared. In the late 80's, plans for a regional public transport connection around Leiden were raised again, as a possible solution for the bus congestion in the Breestraat in Leiden. When it became clear that the existing heavy railway line from Gouda to Alphen a/d Rijn threatened to be closed, plans arose for rebuilding it into a light rail or tram line and to connect it to the new part in Leiden and to extend it towards the coast of Katwijk. The plans became even bigger, when light rail branches towards Leiderdorp and Schiphol were suggested. A possible connection to the light rail network of Den Haag via Zoetermeer was neither ruled out (Leeuwenburgh, 2010).

The first objections against the new public transport network came when presumptions were made that the tram would be dangerous for slow traffic, the investments costs raised from 450 million guilders in 1990 to 470 million euros in 2006. In 2009 the government agreed of co-financing the new line till Katwijk for an amount of 45 million euro's. In 2011 an agreement was signed to initially implement the line as a rapid bus system, with the possibility of reconstructing it into tram. It was also agreed that the part from Gouda to Leiden would be realized on the existing railway network, including higher train frequencies (thus without a tram through the city centre of Leiden) (Provincie Zuid-Holland, 2012).

Although the plans for a direct light rail connection between Gouda, Leiden and Katwijk/Noordwijk are set aside, it might still be interesting to see what the effects of the line are in relation to TOD (especially on the part Gouda – Alphen a/d Rijn and the part Leiden – Valkenburg).

New infrastructure
As mentioned before, the light rail connection was supposed to run over former heavy rail from Gouda to Alphen a/d Rijn. Between Alphen a/d Rijn and Leiden Lammenschans the light rail vehicles would run over heavy rail, combined with train services between Utrecht and Leiden. After Leiden Lammenschans the line would run via the city centre of Leiden towards the coast on new infrastructure. From Valkenburg a branch was supposed to run to Katwijk and a branch to Noordwijk.

In Figure 5-7 the green stations are new light rail stations which have to be built. The yellow ones are existing heavy rail stations which have to be redesigned.

Previous studies
Already since the RijnGouweLijn has been a serious plan, investigations into the possible transport potential of this line have taken place. One of these reports is from AGV, a consultancy company. It performed research into the RijnGouweLijn and concluded that between Gouda en Leiden the average number of passengers per hour is 600 (during peak hours). Between Leiden and Katwijk/Noordwijk this is about 1.000. Based on the proposed route and frequencies, the total number of passengers on an average workday will then be 50.000 (Verweijen, 2007).

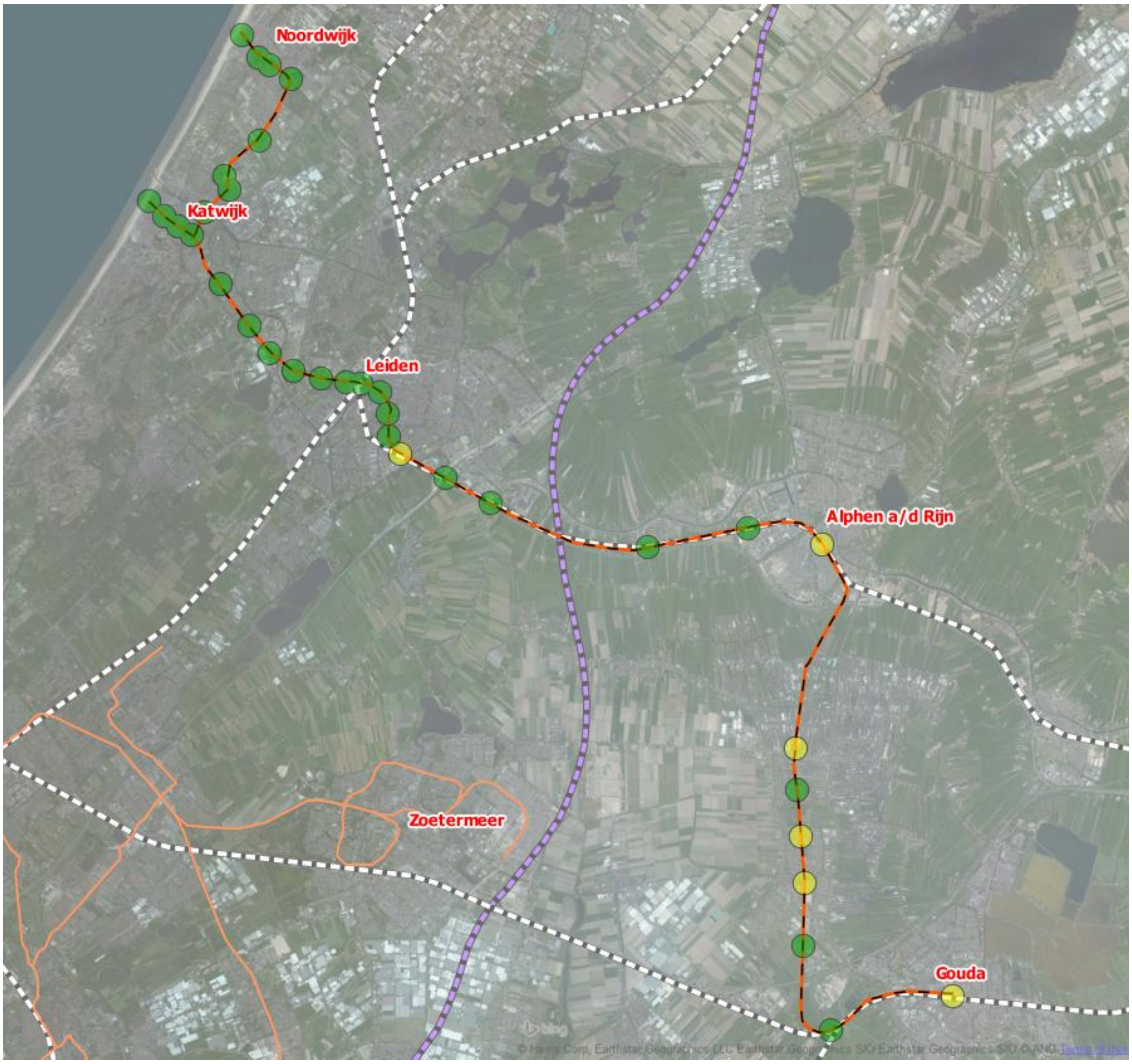

Figure 5-7 Project 3 map

Lining

Two different service lines are planned to run over the RijnGouwLijn. The first one runs from Gouda to Katwijk and has a frequency of 4 times per hour. The second line runs from the A4-transferium to Noordwijk and has a frequency of 4 times per hour all day as well. Combining these two services, vehicles operate with a 7,5 minute interval between the A4-transferium and Katwijk Raadhuis.

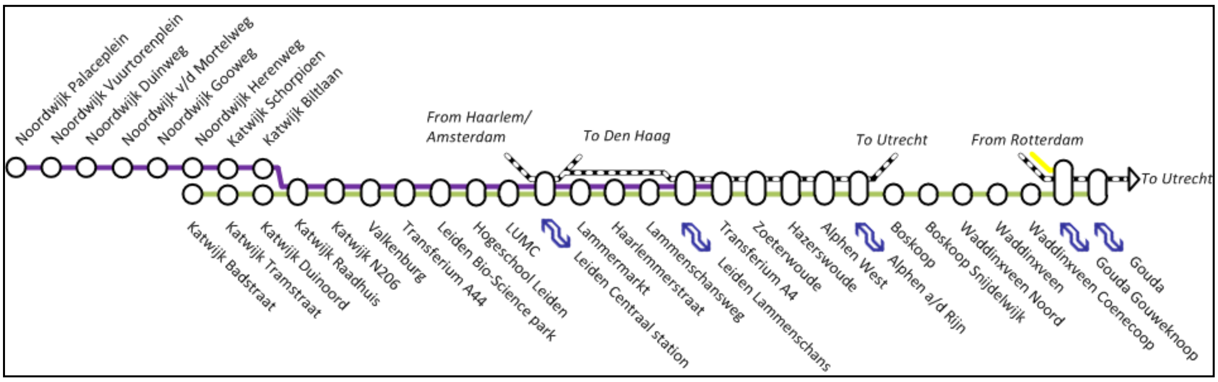

Figure 5-8 Project 3 lining scheme

5.5.5 Project 4: Conversion Rotterdam – Hoek van Holland to light rail (including two new stops)

Introduction

The railway track Rotterdam – Maassluis was constructed in 1891 and in 1893 the tracks were extended to Hoek van Holland. After the privatization of the Dutch Railways in 1995 the minister of transport wrote a list of 30 regional railway lines which no longer had to be part of the main railway network. One of these lines was the Hoekse Lijn (Rotterdam – Hoek van Holland).

In 2006 the urban district of Rotterdam signed an agreement with the minister concerning the transfer of the Hoekse Lijn from ProRail to the urban district. After several studies into the future exploitation of the line, the plan of integration into the Rotterdam metro network was proposed. Until the actual reconstruction of the line in 2017, Dutch Railways operates the line on behalf of the urban district of Rotterdam.

New infrastructure

Although the fact that about 95% of the future metro tracks run over the exact same route as the current heavy railway line, costs of reconstruction are still relatively high: 312 million euro's. At Schiedam Centrum a new fly-over has to be built to make the connection between existing metro tracks and future routing, all platforms are redesigned, the route is extended at the beach, the catenary is adjusted and the existing cargo trains must still be able to run over about half of the line. The stop of Maassluis Steendijkspolder is an extra stop added to the metro line and the stop of Hoek van Holland strand is moved 900m towards the beach (Stadsregio Rotterdam, 2014).

Figure 5-9 Project 4 map

The stations in the image above colored yellow are existing heavy rail station that need to be redesigned. The stations colored green are new stops.

Lining

As mentioned in project 2, the green metro line in Rotterdam (running from Binnenhof to Schiedam Centrum) is planned to be extended till Maassluis Steendijkspolder with a frequency of 3 times per hour. The yellow line (running from Nesselande to Schiedam Centrum) is planned to be extended till Hoek van Holland strand with a frequency of 3 times per hour as well. Combining these two between

Schiedam and Maassluis a frequency of every 10 minutes is offered. During peak hours the frequency of the green line increases to 6 times per hour, offering 9 trains per hour between Schiedam and Maassluis (Stadsregio Rotterdam, 2014).

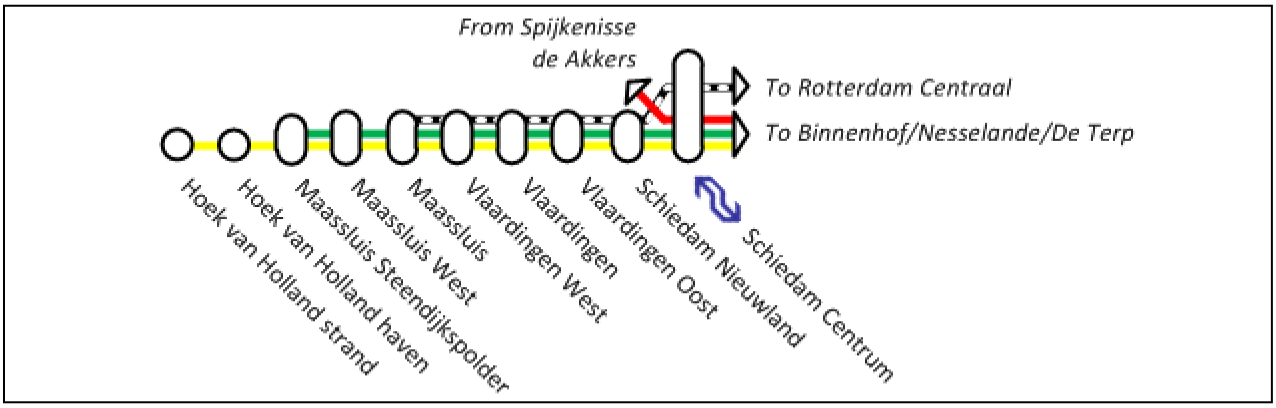

Figure 5-10 Project 4 lining scheme

Previous studies

In 2012 Goudappel Coffeng performed a study into the future demand for public transport on the Hoekse Lijn using the regional model RVMK. This model shows that the Hoekse Lijn carried out as a metro lines attracts about 40% more passengers in 2020 than it would do in case of a heavy rail line. After 2020 a growth of about 5-10% can be expected (Stadsregio Rotterdam, 2014) (van Oort, 2012).

5.5.6 Project 5: Metro line extension Nesselande (including one new train station)

Introduction

The rural area north-east of the city of Rotterdam is planned to be reconstructed into built-up area, called Zuidplaspolder. The policy framework for this spatial development, the ISP (Inter Gemeentelijk Structuurplan), contains information about different public transport network scenarios for the new residential area (Projectorganisatie Zuidplaspolder, 2006).

New infrastructure

The main structure of the public transport network is supposed to develop synchronic with the spatial developments in the area. At first the new train station of Gouda Gouweknoop can be opened at the merging points of the three railway lines (Gouda – Rotterdam, Gouda – Den Haag and Gouda – Alphen a/d Rijn). In the second phase the current metro line at Rotterdam Nesselande is supposed to be extended with one station, right in the middle of the new area. In a third phase the line is planned to be further extended towards a new metro stop and the new railway stop of Gouda Gouweknoop (Projectorganisatie Zuidplaspolder, 2006).

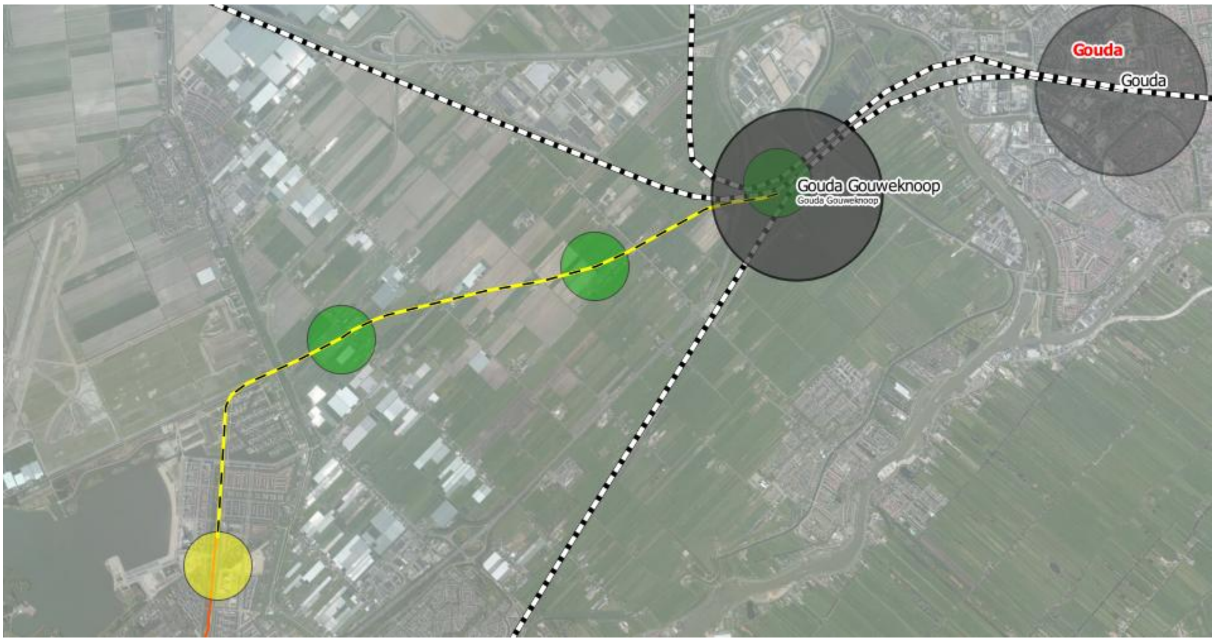

Figure 5-11 Project 5 map

Lining

The current line ending at Rotterdam Nesselande (yellow line) has a frequency of 6 times per hour on work days and a frequency of 4 times per hour on weekend days. When this line is extended towards Gouda Gouweknoop, frequencies are not changed.

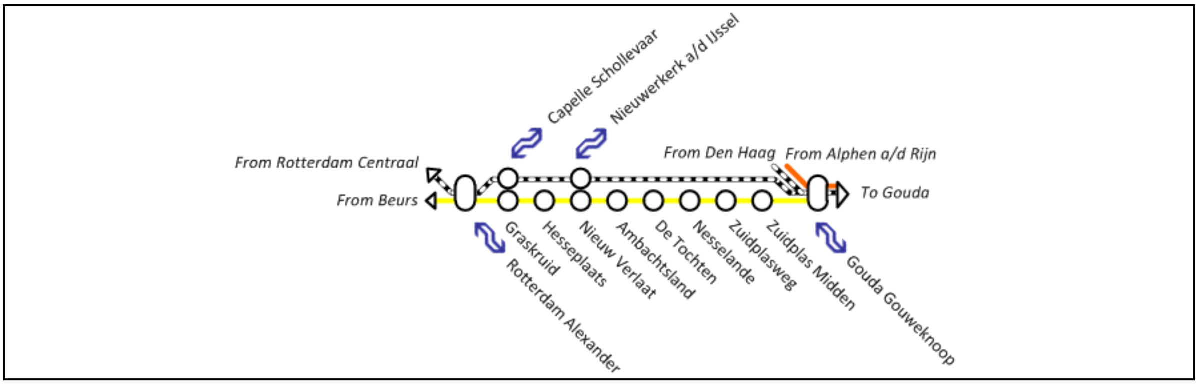

Figure 5-12 Project 5 lining scheme

Previous studies
Not many studies have been done yet into the extension of the Rotterdam metro to Zuidplaspolder and Gouda Gouweknoop. Although the construction of a transfer station on both railway lines (Gouda – Rotterdam/Den Haag) and light rail line towards Alphen a/d Rijn is quite expensive due to the tracks layout and therefore labeled as undesirable, the expectation is that the transport potential is quite high. The future service level is also very high: it will be served by four local trains per hour between Gouda and Den Haag, 2 local trains per hour between Gouda and Rotterdam, 4 light rail trains per hour between Gouda and Alphen a/d Rijn/Leiden and 6 metro trains per hour between Gouda Gouweknoop and Rotterdam city centre/Hoek van Holland.

In the reports for the MIRT (Meerjarenprogramma Infrastructuur, Ruimte en Transport) for the Rotterdam region, selections have been made on which project should be taken into account for the calculations of passengers in 2020 and 2030. The project of the Zuidplas metro extension has been explicitly left out, due to the fact that the spatial developments are assumed to take place within urban areas and the Stadshavens near Schiedam. That means that no calculations on passenger potential have been made yet (Stadsregio Rotterdam, 2009).

5.5.7 Project 6: Extension tram line Schiedam Kethel (including one new train station)

Introduction

The train station of Schiedam Kethel-Kerklaan is a former stop on the line Rotterdam – Den Haag from 1892 till 1938. In the early 90's plans arose for developing a new spatial area in between the centre of Schiedam, the railway tracks and the Woudhoek neighborhood. Already during the development of this new neighborhood plans were made to reopen the station of Schiedam Kethel (Spaland) in order to connect to new residential are to the public transport network. During the construction preparations are made for this. The current tram line is supposed to be extended till the new train station(Gemeente Schiedam, 2001).

New infrastructure

A new train station is supposed to be built around the existing tracks (double track). The extension of the tram line is shown below in blue. It covers two new tram stops as well (Kerkweg and Schiedam Kethel).

Figure 5-13 Project 6 map

Lining

The new railway stop of Schiedam Kethel is supposed to be operated by local trains only. Based on The future frequency increase in project 1, the current frequency of 4 local trains per hour will be further increased to 6 in 2020. The connected tramway (with its current frequency of 4 times per hour) will be extended towards the train station.

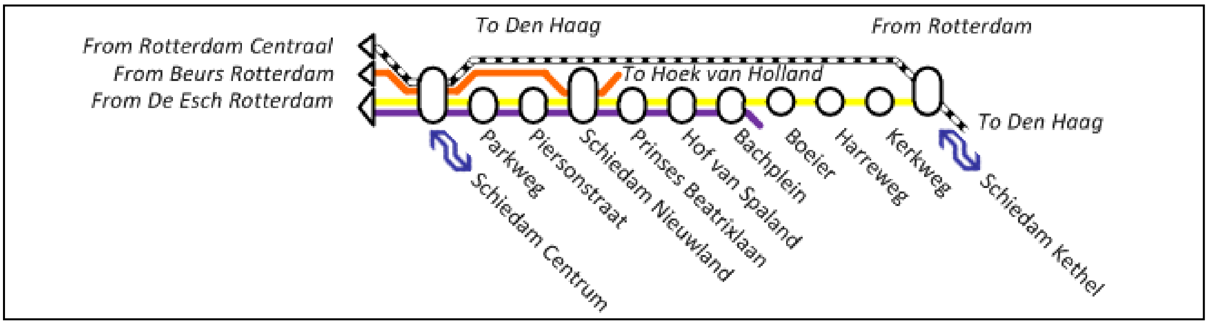

Figure 5-14 Project 6 lining scheme

Previous studies
In 2004 the station of Schiedam Kethel was part of study into potential new train station in relation to the implementation of Stedenbaan. During that research the station was considered to have enough passengers per day using it and the station could be integrated into the current timetable. Later studies showed that although the station could be integrated into the current timetable, a combination of PHS and a new train station would only be possible if the tracks between Delft Zuid and Schiedam Centrum are doubled.

Since the implementation of PHS has preference over the realization of a new train station, the costs of the station increased significantly (€3,5 million to €165 million). After intensive discussions it was decided in 2011 that the train station of Schiedam Kethel will not be built until at least 2020 due to a lack of financing (Schultz van Haegen, 2011).

5.5.8 Project 7: Extension light rail line Zoetermeer (including one new train station)

Introduction

The Oosterheemline is an extension of the Zoetermeer city line, which was built in 2007 with the purpose of coupling the new residential area of Oosterheem. In 2009 it was decided to extent the Oosterheemline to the new planned location of Bleizo, although the actual realization of the train station is still uncertain (Bleizo, 2014).

New infrastructure

The substructure of the future extension (shown below in blue) has already been made. Today the tracks end at the stop of Javalaan. The extension comprises the realization of two new light rail stops (Van Tuyllpark and Bleizo). The new train stop of Bleizo will be built on the current double track stretch between Den Haag and Gouda.

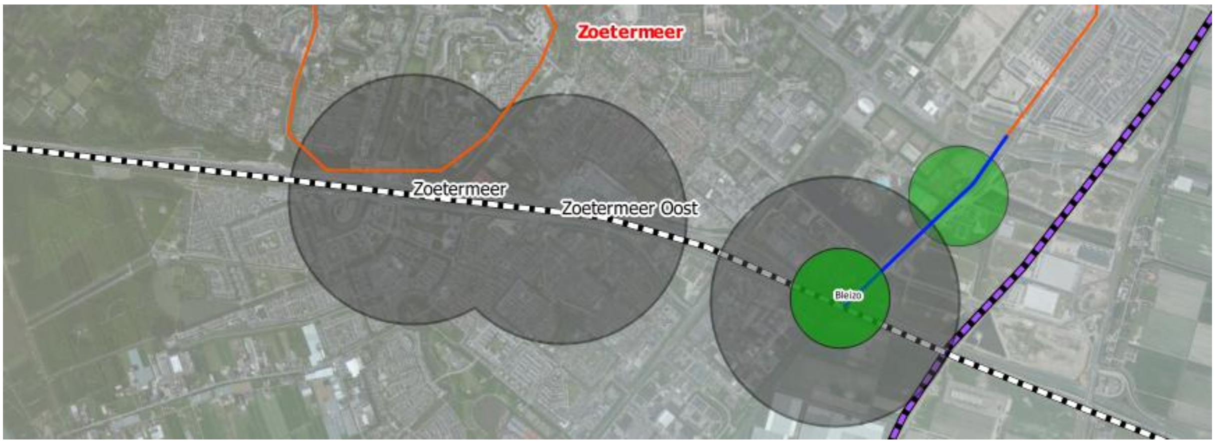

Figure 5-15 Project 7 map

Lining

The line which is supposed to be extended, Randstadrail line 4, runs with a frequency of 6 times per hour on work days and 4 times per hour during the evening and in the weekends.

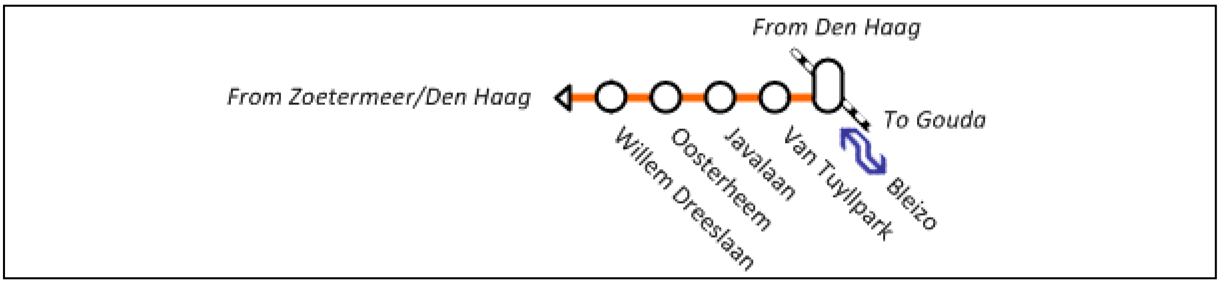

Figure 5-16 Project 7 lining scheme

Previous studies

Multiple studies have been carried out, especially for the number of passengers boarding at the stop of Bleizo each day. Research by the municipalities of Zoetermeer and Lansingerland shows an average of 4.400 passengers per day (Gemeente Lansingerland, 2013).

5.5.9 Project 8: Bus rapid transit line Den Haag – Delft – Zoetermeer - Leiden

Introduction

In the multiannual program for infrastructure of the urban district of Haaglanden a light rail link has been proposed, which connects Den Haag and Leiden, through Delft, Pijnacker and Zoetermeer. Already during early studies into the potential for such a line, it became clear that the demand for public transport is below the minimum required for a tram connection, especially at the part Delft – Zoetermeer.

New infrastructure

Although a bus does not need new infrastructure at first (since it can run over existing roads), free bus lanes might be wishful in order to speed up travel times and to limit the possibilities for delay due to congestion. During the construction of these new bus lanes, the possibility of reconstructing it to light rail in a later phase has been taken into account (MOVIN, 2009). The route of the line is shown below in green:

Figure 5-17 Project 8 map

Lining

In Figure 5-18 the proposed route for the new BRT-line is shown. Since not all stops are known yet, the neighborhoods and towns it passes are dotted. Important transfer point between other StedenbaanPlus services are also shown (Stadsgewest Haaglanden, 2009). The proposed frequency is 6 times per hour on work days and 4 times per hour during the evenings and in the weekends.

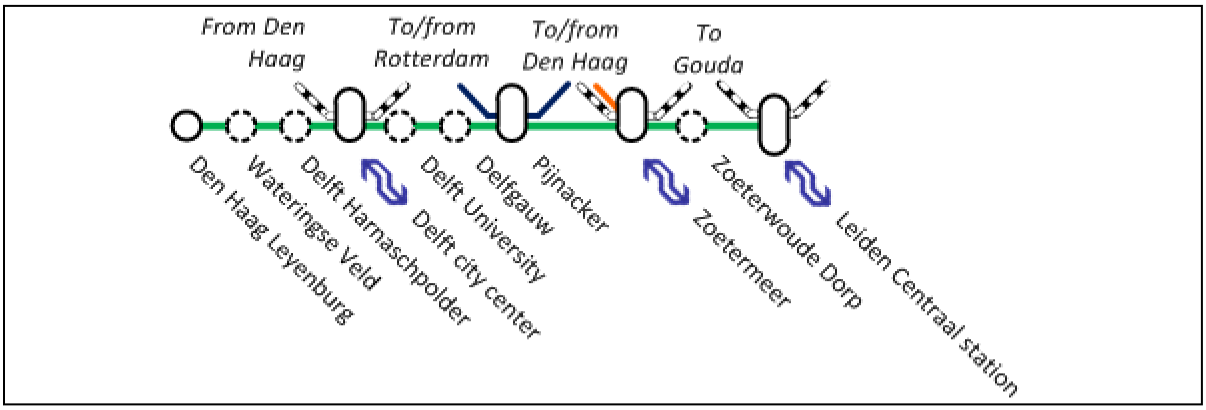

Figure 5-18 Project 8 lining scheme

Previous studies

MOVIN performed research into the demand for a BRT-service between Den Haag, Delft, Zoetermeer and Leiden, in order to investigate whether a light rail or a bus service should be implemented. Exact figures on the demand are not published.

5.5.10 Project 9: Tram line extension Rotterdam The Hague Airport

Introduction

The airport of Rotterdam The Hague started as a regional airport (Zestienhoven) in 1955 as a replacement for the during the 2nd World War demolished airport of Rotterdam Waalhaven. Several large international airlines such as Swissair, Lufthansa and Air France were soon operating from Rotterdam. However, in the 1970s plans were made to either close or move the airport to make room for houses and the uncertain future caused stagnation in the airport's growth and many operators left. For almost thirty years the airport faced closure, but the economic growth of the 1990s caused an increase in passengers again and in 2001 it was decided that the airport's current location would be maintained for at least a century. In 2003 726 thousand and in 2012 1,270 million passengers used the airport of Rotterdam. This growth is planned to continue up to between 1,6 and 2,9 million passengers per year in 2030. Besides growth, one of the other main goals that Rotterdam/The Hague airport has set, is to increase the number of flight of especially ones with a business purpose (60% in 2030).

The name of the airport was changed from Zestienhoven to Rotterdam The Hague Airport on February 10, 2010, mostly for promotional and brand-marketing reasons for the metropolitan region of Rotterdam – The Hague.

Table 5-5 Rotterdam/The Hague airport access and egress numbers

	Dutch citizens (access)		**Foreigners (egress)**	
	Business	Rest	Business	Rest
2004	641	1,496	733	183
2030 RC	1,087	1,874	1,242	230
2030 GE	2,167	3,034	2,477	371

New infrastructure

In order to keep up with the growing stream of passengers coming to the airport every day, the organization aims at strengthening the share of people coming by public transport. Currently the airport is served by a local bus services to the Rotterdam central station and a shuttle service to the metro stop of Meijersplein (especially for passengers to Den Haag). Plans arose to extent the current tram line to Schiebroek further to the Airport. The extension (orange-black in the map below), comprises three new tram stops as well (Meijersplein, Airport business park and Airport terminal).

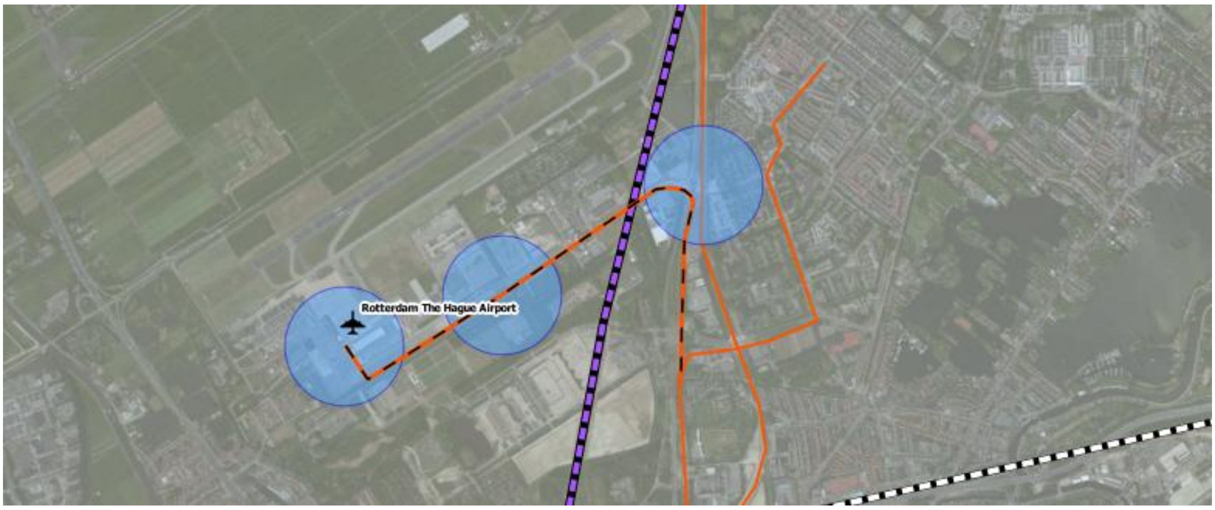

Figure 5-19 Project 9 map

In 2014 the urban districts of Rotterdam and Den Haag announced the wish of constructing a tram not only to the airport, bus even until Delft (connecting it to tram line 19). In that case the airport is well accessible throughout the entire south wing region (from the Rotterdam, form Den and also from Delft).

Lining

The new tram line has a proposed frequency of 3 times per hour.

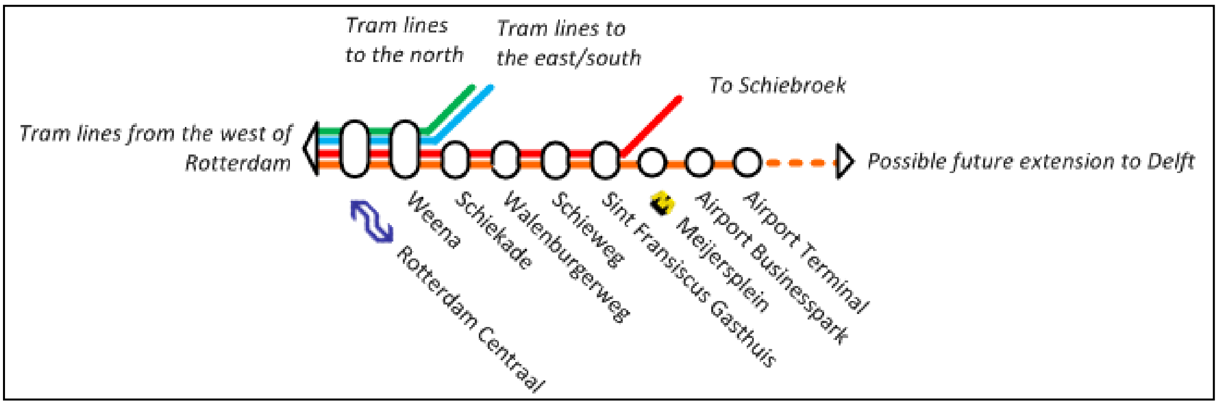

Figure 5-20 Project 9 lining scheme

Previous studies

Now that the wish for a tram connection has been announced, studies are being done into the number of passengers which will use it. These studies are not yet finished and thus not published.

5.6 IMPLEMENTATION IN THE NRM

Paragraph 4.5 discussed in what way the influence factors can be modeled within the NRM, but did not mention the actual StedenbaanPlus projects. This paragraph discusses the way of implementing new or adjusting existing public transport networks in the NRM.

The NRM distinguishes two types of public transport networks: train and BTM. Both types are discussed below.

5.6.1 Railway lines and stops

Railway lines, stops and timetables are built in the NRM in so-called TPI-files. There are four TPI-files:

- Node file (containing the stations)
- Lining file (containing the timetable)
- Frequency file (containing train frequencies)
- Connection file (containing a connection for each OD-pair).

TPI-files cannot be edited in the NRM, since the files are produced by ProRail. Editing TPI-files is only allowed after getting permission from ProRail.

The TPI-files for StedenbaanPlus are edited in TRANS. TRANS allows users to reconstruct the train network of lines and stops and to adjust the overlying timetable.

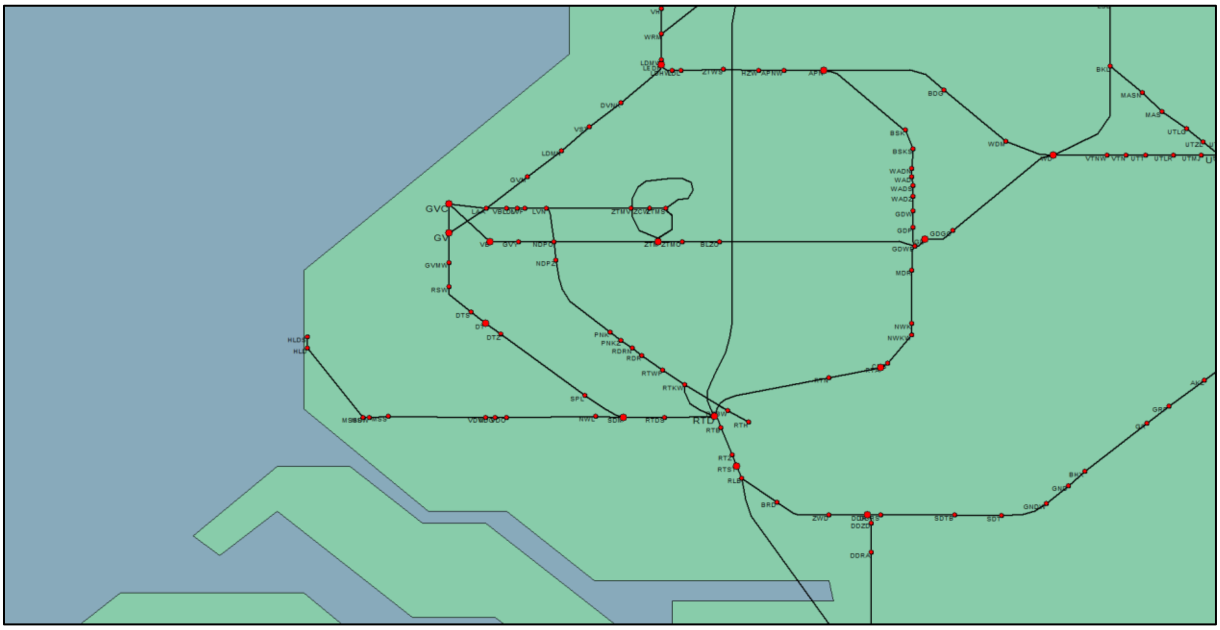

Figure 5-21 StedenbaanPlus in TRANS©

Once networks are adjusted in TRANS, it allows users to export TPI-files which can be used as input for the NRM. The adjustments made in TRANS are:

- Increase in train frequency (Leiden -) Den Haag – Rotterdam (- Dordrecht).
- New stop Delft Sion
- New stop Schiedam Kethel
- New stop Rotterdam Stadion
- New stop Bleizo
- New stop Gouda Gouweknoop
- Removal of Hoekse Lijn from timetable
- Removal of RijnGouweLijn from timetable

5.6.2 Bus, tram and metro lines and stops

The bus, tram and metro lines are processed differently by the NRM. Not the network and timetable are used as input, but the accessibility quality. These file specify for BTM as main, access or egress transport the accessibility quality for each OD-pair. Consequently the allocation of BTM-trips is not done on linings, but on OD-pairs.

The accessibility quality is prepared by Panteia. Based on the routes and timetables received from the operators, the accessibility quality is calculated in CUBE Voyager. CUBE contains all public transit stops and routes on a national level.

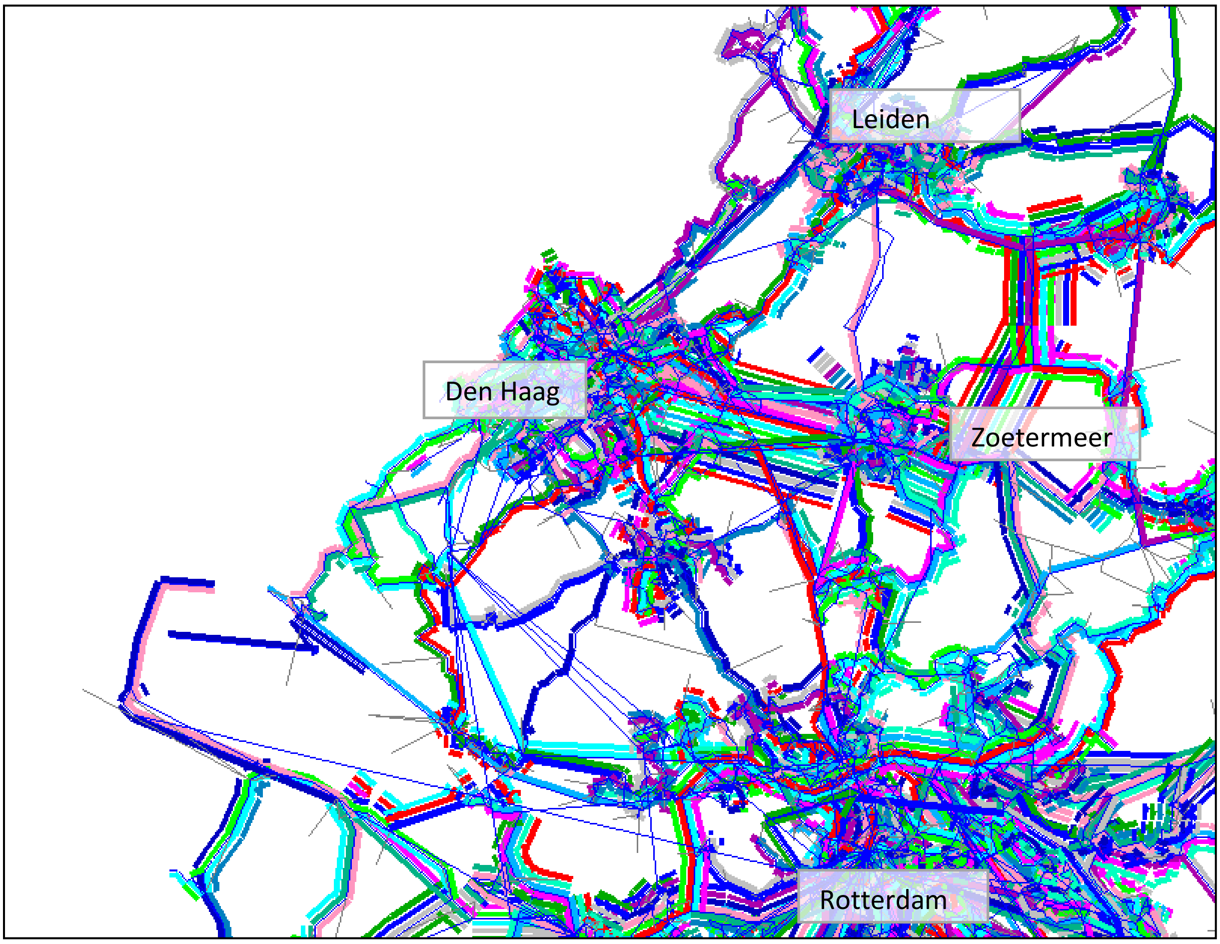

Figure 5-22 StedenbaanPlus in CUBE©

Subsequently the timetable is laid over this BTM network and an algorithm calculates for each OD-pair the total distance, waiting times, walk and travel times, number of transfers, walking distances and travel costs. These values are used by the NRM to determine the utility for a certain relation.

The adjustments made in CUBE:

- New train stops (including connections to underlying BTM-network)
- Extension of existing bus, tram or metro lines
- Integration of reconstruction-stretches (Hoekse Lijn and RijnGouwLijn)
- Implementation of new bus, tram or metro lines

5.7 CONCLUSION

Since the network owners publish their plans for new infrastructure every now and then, all future proposed adjustments have been reviewed. Given the criteria of relevance to StedenbaanPlus, investment size and quality improvements the projects which have to be taken into account have been identified. The following 9 projects will be used during this study:

1. Frequency increase Den Haag – Rotterdam
2. Metro line 6 Rotterdam
3. Conversion heavy rail Gouda – Leiden
4. Conversion heavy rail Hoek van Holland – Rotterdam
5. Metro line extension Nesselande
6. Tram line extension Schiedam Kethel
7. Light rail line extension Zoetermeer Bleizo
8. BRT Den Haag – Zoetermeer – Leiden
9. Tram line Rotterdam The Hague Airport

6 RANDSTAD SOUTH WING SPATIAL DEVELOPMENTS

6.1 INTRODUCTION

As mentioned before, the extra demand for houses must concentrate around the cities of Den Haag (55%) and Rotterdam (20%) (Ministerie van Infrastructuur en Milieu, 2013). This has been defined in the MIRT (Meerjarenprogramma Infrastructuur, Ruimte en Transport)-publication of the Dutch government. The map below shows the location of these spatial programs for the Randstad south wing (Nirov, 2008).

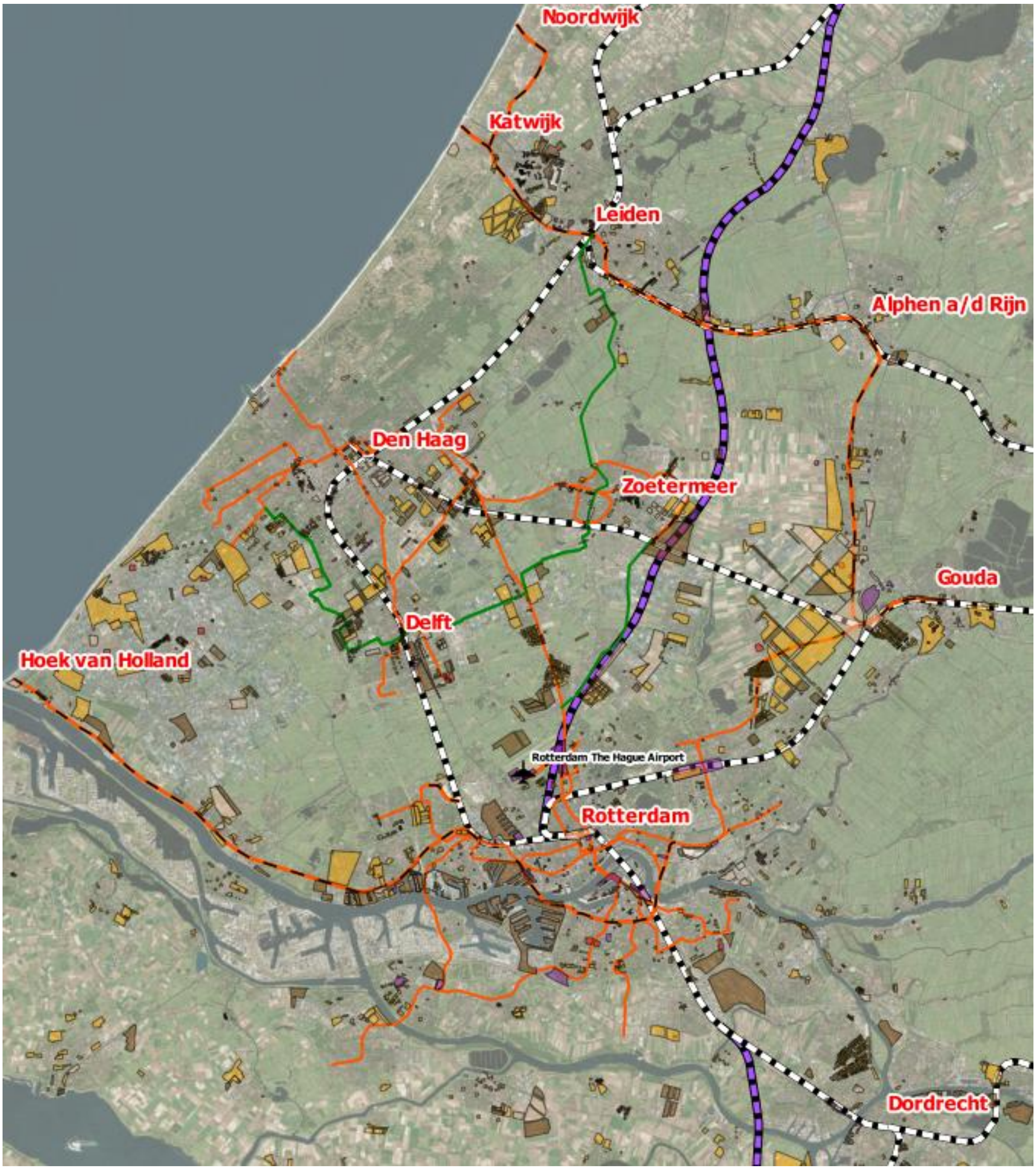

Figure 6-1 Randstad south wing spatial development programs

In the map above housing projects are colored orange, industry projects brown and office projects purple.

6.2 PROJECTS WITHIN PUBLIC TRANSPORT INFLUENCE AREA

Since only the spatial projects situated close to the public transports do actually influence the demand for public transport, it is necessary to determine the influence area of the StedenbaanPlus network. This is done by looking into the catchment area per stop. Based on rules defined within the Stedenbaan ambitions, the areas are formulated as below (StedenbaanPlus projectbureau, 2012):

- Stedenbaan railway stop: all 4-digit zip code area's within a radius of 1200m
- Metro stop: all 4-digit zip code area's within a radius of 800m
- Light rail stop: all 4-digit zip code area's within a radius of 800m
- Tram+ stop: all 4-digit zip code area's within a radius of 600m
- BRT stops: all 4-digit zip code area's within a 600m line offset

This gives the following map.

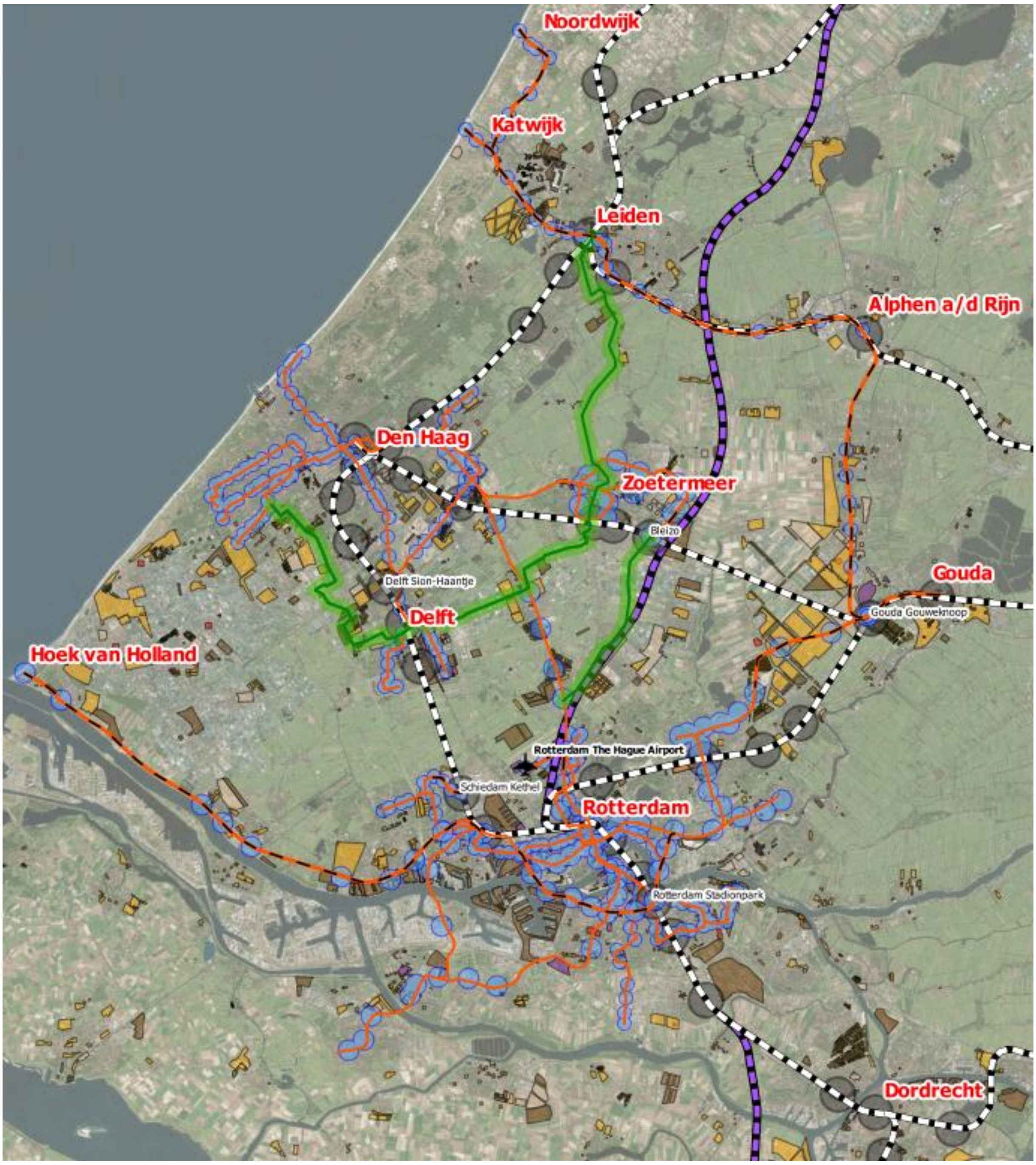

Figure 6-2 Randstad south wing spatial development programs (including influence areas)

By now looking into the influence areas which have an overlap with proposed residential or working projects. This gives the following list of projects which are planned to be completed in 2030 (Nirov, 2008). In some cases projects are mentioned twice or more times in the list. This means that these projects are spread over multiple NRM-zones.

Table 6-1 Spatial project within influence area (including planned properties)

Project	AGRI	INDUSTRY	DETAIL	OTHER	HOUSE-HOLDS
Bleizo Agri (Bleizo, 2013)	2,25	0	0	0	0
Bleizo Prisma (Bleizo, 2013)	0	525	250	525	0
Heron Nootdorp (Gemeente Pijnacker-Nootdorp, 2014)	0	375	0	375	0
Stadshavens Rotterdam 1 (Gemeente Rotterdam, 2013)	0	5000	0	5000	0
Stadshavens Rotterdam 2 (Gemeente Rotterdam, 2013)	0	5000	0	5000	0
Stadshavens Rotterdam 3(Gemeente Rotterdam, 2013)	0	2500	0	2500	0
Technopolis Delft (Science Port Holland, 2013)	0	3925	0	8575	0
Vliet-A4 zone 1 (Gemeente Den Haag, 2013)	0	700	0	700	0
Vliet-A4 zone 2(Gemeente Den Haag, 2013)	0	700	0	700	0
Vliet-A4 zone 3(Gemeente Den Haag, 2013)	0	350	0	350	0
Feijenoord Parkstad 1 (Gemeente Rotterdam, 2013)	0	0	0	2500	0
Feijenoord Parkstad 2 (Gemeente Rotterdam, 2013)	0	0	0	0	800
Feijenoord Parkstad 3(Gemeente Rotterdam, 2013)	0	0	0	0	400
Gouda Gouwepark (Gemeente Gouda, 2013)	0	0	0	3000	0
Noordrand Rotterdam airport (Businesspark Rotterdam The Hague Airport, 2013)	0	3000	250	11000	0
Berkel Westpolder 1	0	1800	0	1800	1200
Berkel Westpolder 2	0	0	0	0	1800
Gouda Westergouwe	0	0	0	0	3800
Harnaschpolder 1	0	0	0	0	433
Harnaschpolder 2	0	0	0	0	433
Klapwijk Noord	0	0	0	0	1250
Nesselande Prins Alexander	0	0	0	0	500
Pijnacker Overgauw	0	0	0	0	4300
Pijnacker West	0	0	0	0	1000
Rijswijk zuid 1	0	0	0	0	833
Rijswijk zuid 2	0	0	0	0	3000
Spoorzone Delft 1	0	0	0	0	180
Spoorzone Delft 2	0	0	0	0	420
Spoorzone Delft 3	0	0	5000	0	600
Valkenburg 1	0	0	0	0	2000
Valkenburg 2	0	0	0	0	3000
Waddinxveen 1	0	0	0	0	200
Waddinxveen 2	0	0	0	0	2500
Zuidplas 1	0	0	0	0	690
Zuidplas 2	0	0	0	0	910
Zuidplas 3	0	0	0	0	600
Zuidplas 4	0	0	0	0	300

The spatial programs from above do not only influence the number of inhabitants, but also the population density of the south wing. The two maps below show this density, expressed as the number of inhabitants per acre for each NRM-zone. The left image is the 2004 situation and the right image is the 2030 RC situation.

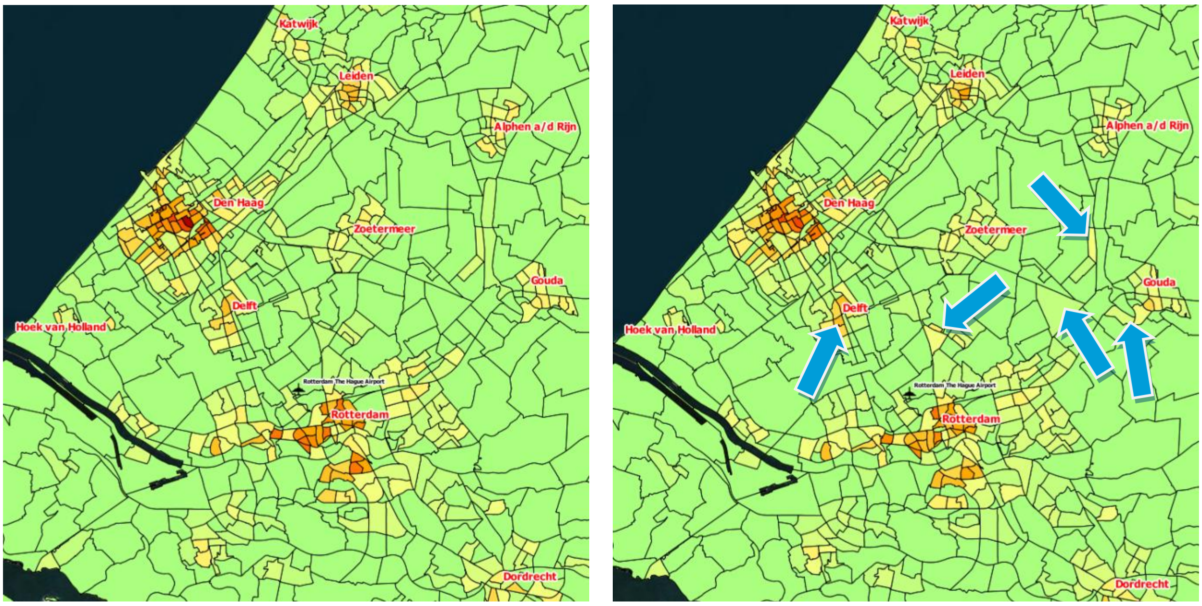

Figure 6-3 South wing population density 2004 (left) and 2030 RC prognosis (right)

It can be clearly observed that especially close to the heavily populated areas the density increases. This so-called ‘urban intensifying’ is one of the goals stated in the MIRT (Ministerie van Infrastructuur en Milieu, 2013).

6.3 DISTRIBUTION OVER SOUTH WING

As mentioned before, the spatial developments are implemented in the NRM by adjusting the zonal data. The size of the spatial programs is predefined within the NRM and derived from the new map of the Netherlands (Nirov, 2008).

6.3.1 Distribution based on Hansen's Potential Model

As seen in paragraph 2.5.2 the distribution of residents over the available locations can be done based on potential. Potential is hereby defined as the capacity times its accessibility. It is doubtful whether the size of the spatial programs is in line with Hansen's model. Therefore in this paragraph the whole south wing spatial development program (residential projects only) will be allocated over the available zones in accordance with Hansen's model. H stands for available amount of space, which is set equal to the size of the spatial project in this case.

$$A_i = \sum_j \frac{E_j}{d_{ij}^b} \qquad \text{(Equation 9)}$$

$$G_i = G_t \cdot \frac{A_i \cdot H_i}{\sum_i A_i \cdot H_i} \qquad \text{(Equation 10)}$$

The total demand for housing is analyzed for three regions: Rotterdam, Den Haag and Gouda. The accessibility is calculated using the NRM for two cases; the standard RC-scenario and the RC-scenario with enhanced public transport (all StedenbaanPlus projects). Since train and BTM are seen as separate modes, but both modes are enhanced, the accessibility of jobs is calculated for both modes. The number of jobs in zone j is divided by the square of the travel time (in minutes) from zone i to j. For each OD-pair the minimum value of the train and BTM travel time is used. Train travel times include access and egress transport (with whatever mode used).

Thus:

$$G_i = G_t \cdot \frac{\sum_j \frac{E_j}{d_{ij}^2} \cdot H_i}{\sum_i \sum_j \frac{E_j}{d_{ij}^2} \cdot H_i} \qquad \text{(Equation 11)}$$

Where:

G_i Number of households distributed to zone i

G_t Total number of households (per region) which needs to be distributed over the zones

E_j Number of work places in zone j

d_{ij} Minimum travel time by public transport (either train or BTM) between zone i and j. Here the factor b is set to the value of 2 to simulate exponential dependency (see paragraph 2.5.2).

H_i Amount of available space (equal to project volume)

In reality a large amount of factors influence the location choice. In this case only the accessibility (expressed as travel time) of workplaces and the planned size of the projects are taken into account, in order assess the effect of the public transport enhancement.

In the next chapter public transport use is calculated based on the Hansen PT+ distribution as well. Below the shifts in distribution are shown for the regions of Rotterdam, Den Haag and Gouda.

6.3.2 Rotterdam area

All spatial programs in the Rotterdam area sum up to a total of 4.700 new households.

Table 6-2 Rotterdam area spatial projects

Project	Zone	Program volume (H)	Hansen distribution PT	Hansen distribution PT+
Feijenoord Parkstad 2	1916	800	1.141	1.407
Feijenoord Parkstad 3	1907	400	628	586
Berkel Westpolder 1	1738	1.200	1.011	943
Berkel Westpolder 2	1739	1.800	1.496	1.360
Nesselande Prins Alexander	1841	500	423	405

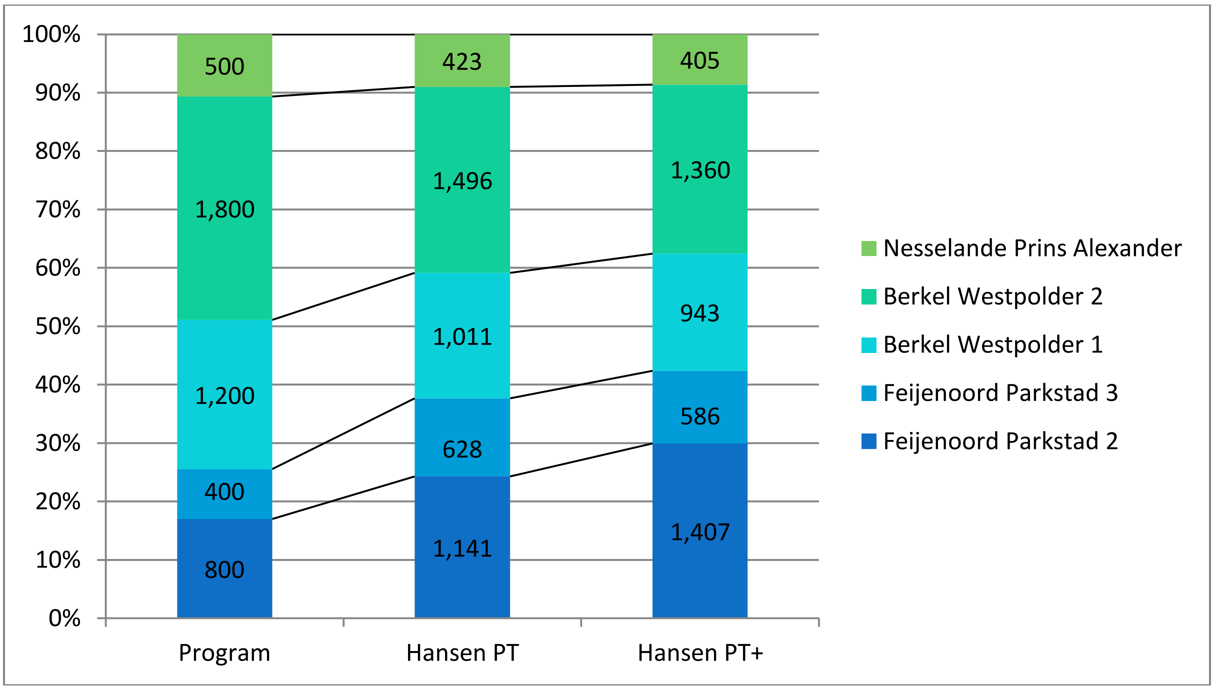

Figure 6-4 Rotterdam area spatial distribution

As one can see from the figures above, the spatial programs distributed based on Hansen shows preference for especially the neighborhood of Feijenoord Parkstad, to the detriment of Berkel Westpolder. In the case of enhanced public transport this shift is even larger.

6.3.3 Den Haag area

All spatial programs in the Rotterdam area sum up to a total of 12.949 new households.

Table 6-3 Den Haag area spatial projects

Project	Zone	Program volume (H)	Hansen distribution PT	Hansen distribution PT+
Harnaschpolder 1	1612	433	405	472
Harnaschpolder 2	1573	433	559	612
Klapwijk Noord	1560	1.250	772	648
Pijnacker Overgauw	1562	4.300	3.203	2.987
Pijnacker West	1561	1.000	723	737
Rijswijk zuid 1	1507	833	962	1070
Rijswijk zuid 2	1509	3.000	3.528	3.529
Spoorzone Delft 1	1568	180	319	326
Spoorzone Delft 2	1571	420	1.044	1.089
Spoorzone Delft 3	1578	600	935	978

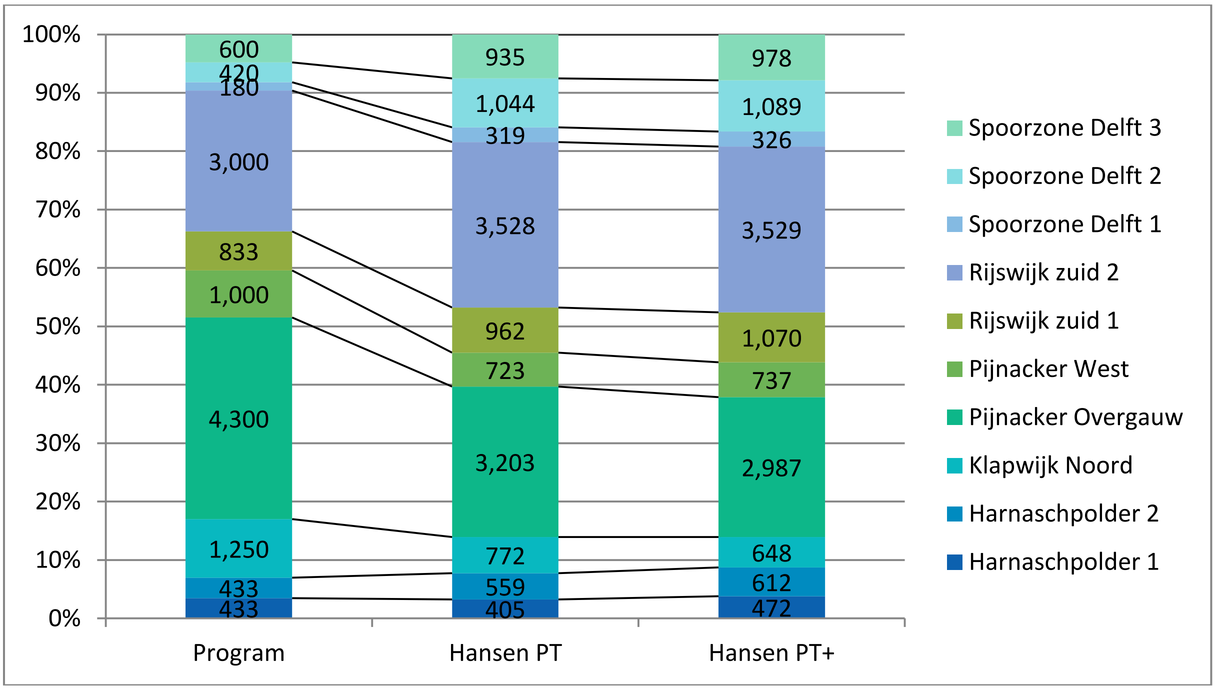

Figure 6-5 Den Haag area spatial distribution

In the Den Haag area the distribution of households based on Hansen shows huge preferences for the Rijswijk Zuid area, at the cost of Pijnacker Overgauw and Klapwijk Noord. In case of enhanced public transport the projects of Rijswijk Zuid profits the most.

6.3.4 Gouda area

All spatial programs in the Rotterdam area sum up to a total of 9.000 new households.

Table 6-4 Gouda area spatial projects

Project	Zone	Program volume (H)	Hansen distribution PT	Hansen distribution PT+
Gouda Westergouwe	1675	3800	4.335	4.213
Waddinxveen 1	1697	200	165	165
Waddinxveen 2	1699	2500	2.976	2.442
Zuidplas 1	1797	690	431	602
Zuidplas 2	1677	910	562	899
Zuidplas 3	1710	600	303	435
Zuidplas 4	1799	300	228	244

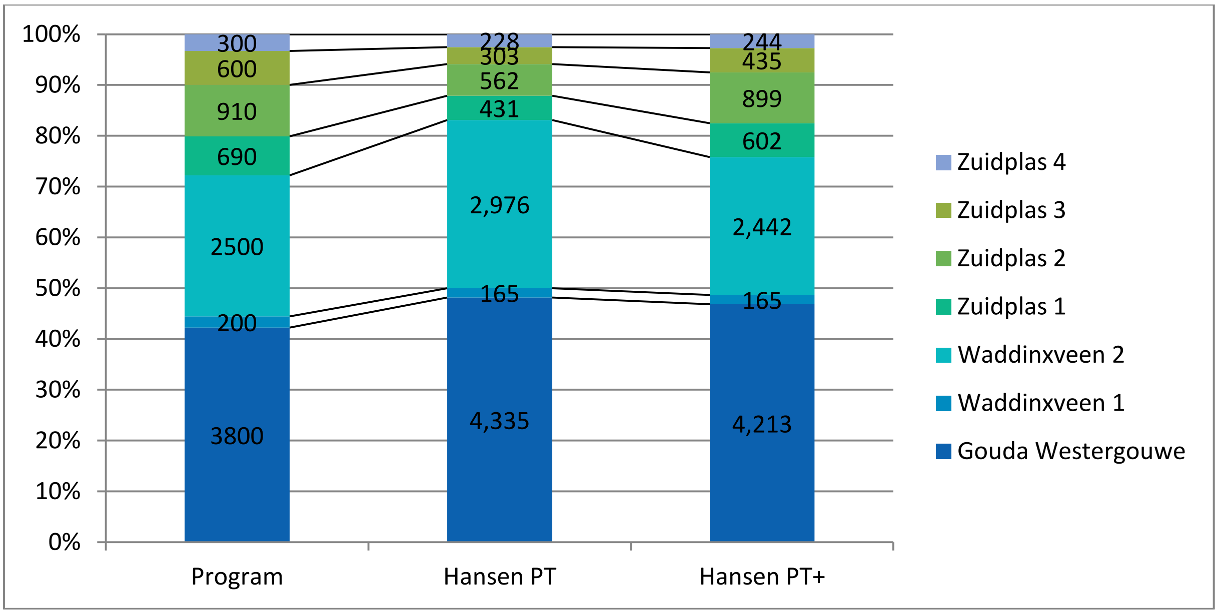

Figure 6-6 Gouda area spatial distribution

In the Gouda area the spatial project of Waddinxveen and Gouda Westergouwe profit the most in case of distribution conform Hansen's model. In case of enhanced public transport there is a large shift from Waddinxveen to Zuidplaspolder. Hansen's distribution in case of PT+ is then almost equal to the actual program volumes.

6.4 CONCLUSION

In this chapter the spatial projects have been identified which are in the direct influence area of the StedenbaanPlus projects defined in chapter 5. Based on Hansen's Potential Model the projects have been redistributed over the areas of Rotterdam, Den Haag and Gouda.

7 MODEL RESULTS CASE STUDY

7.1 INTRODUCTION

The NRM is a very complicated model which has a lot of output. The size of the output files for a base year run is about 6 GB and for a future prognosis run 37 GB. Output is available per year, per scenario, per OD-trip, per mode, per motive and per day part. This means that output is saved in over 11 billion data records. The table below shows for each mode where the data is saved by the NRM. For an example, BTM-trips are produced in SES (BTM as main transport) and in ACC/EGR (BTM as access and egress transport).

Table 7-1 All NRM trip production modules

	TRIPS SES CAR	TRIPS SES TRAIN	TRIPS SES BTM	TRIPS SES BIKE	TRIPS SES WALK	TRIPS ACC/ EGR	Foreign traffic	Airport traffic
Car (DRI&PAX)	X					X	X	X
Train		X						X
Bus/tram/metro			X			X		
Bike				X		X		
Walk					X	X		

To be able to make a good assessment of the feasibility of the various infrastructural measures, the output data must be processed and aggregated in a certain way. The following paragraphs describe these steps and show an assessment of the model results in general and per infrastructural project.

7.2 GENERAL ASSESSMENT

Before the individual results of the infrastructural projects are discussed, it is interesting to take a look at the mobility system of the Randstad south wing at a regional scale level. In order to do this, all NRM zones are joined together into 5 aggregate zones, namely:

1. A- SRR: Stadsregio Rotterdam (city region of Rotterdam);
2. B - SGH: Stadsgewest Haaglanden (city region of Den Haag);
3. C - Rest south wing: The province of south Holland, minus zone A and B;
4. D - Rest Randstad: The Randstad area, minus zone A, B and C;
5. E - Rest Netherlands: The Netherlands, minus all of the zones above.

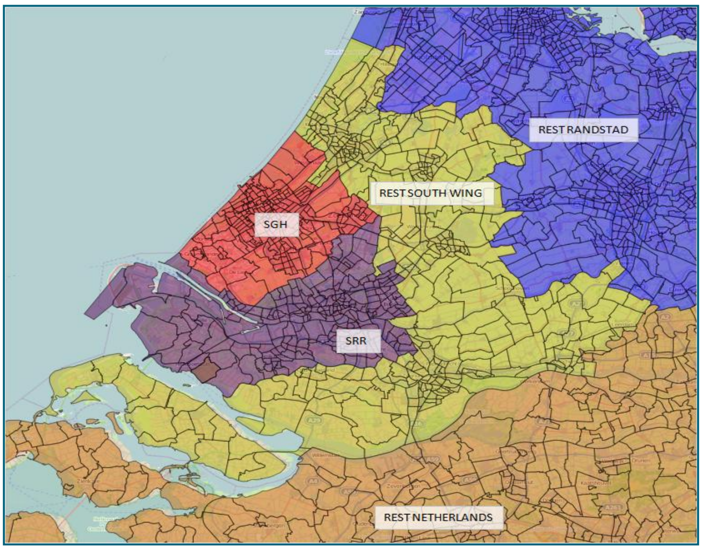

Figure 7-1 Randstad south wing aggregate zones

By looking at the inter- and intrazonal trip distributions, the effects of enhanced public transport may become noticeable.

7.2.1 Randstad south wing accessibility

The first relation to look at is the accessibility of the zones within the metropolitan area. This is done by looking at the number of trips (per mode) from zones A and B to C, D and E.

7.2.1.1 Basic forecast

The basic forecast comprises the forecast from the base year (2004) to the future prognosis year (2030 RC).

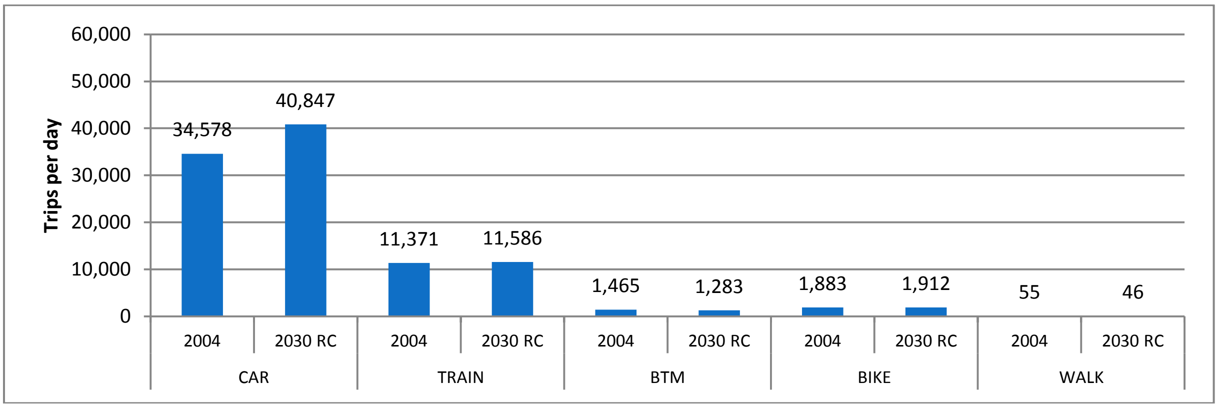

Figure 7-2 Number of trips per mode from zone A+B to zone C+D+E (2004 and 2030 RC)

Based on the diagram above an increase in the number of incoming car trips can be observed from 34.578 to 40.847 per day (+18%). The number of trips made by train increases as well, from 11.371 to 11.586 (+2%). The number of passengers accessing the metropolitan area by BTM decreases significantly (1.465 in 2004 to 1.283 in 2030 RC, -12%). Between the number of cyclists and pedestrians there is hardly any difference between 2004 and 2030 RC.

7.2.1.2 Enhanced public transport

The diagram below shows the difference between a regular 2030 RC prognosis and a 2030 RC PT+ prognosis.

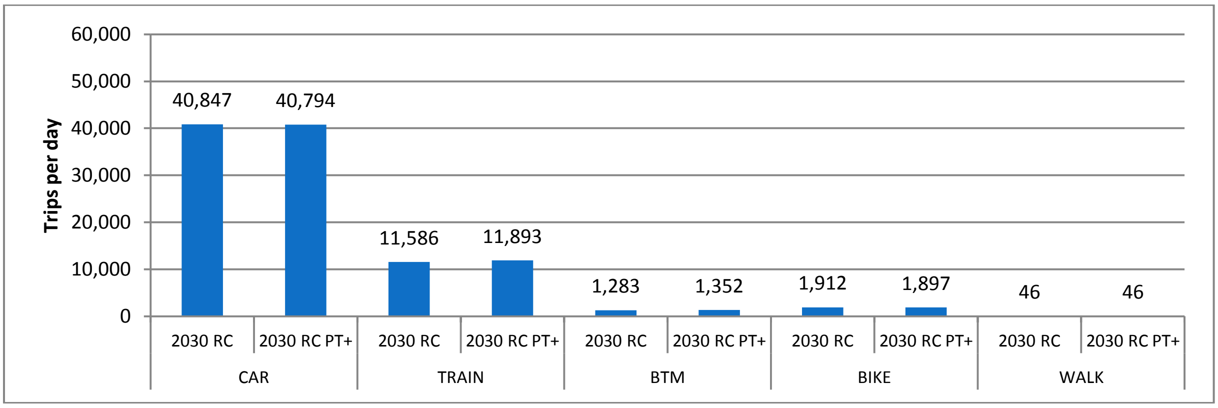

Figure 7-3 Number of trips per mode from zone A+B to zone C+D+E (2030 RC and 2030 RC PT+)

A very small difference can be observed in the number of incoming car trips; it decreases from 40.847 to 40.794 (-0,1%). A larger difference can be seen at the public transport modes. The number of train travelers increases from 11.586 to 11.893 (+2,5%) and the number of BTM traveler's increases from 1.283 to 1.352 (+5,3%). Again the number of interzonal cyclists and pedestrians hardly changes.

7.2.1.3 Spatial downsizing forecast

The third effect that will be analyzed is the spatial downsizing. Multiple projects in the metropolitan area are assumed to have a large influence on the demand for public transport. In this scenario these spatial project are supposed to be cancelled and therefore removed from the zonal input data.

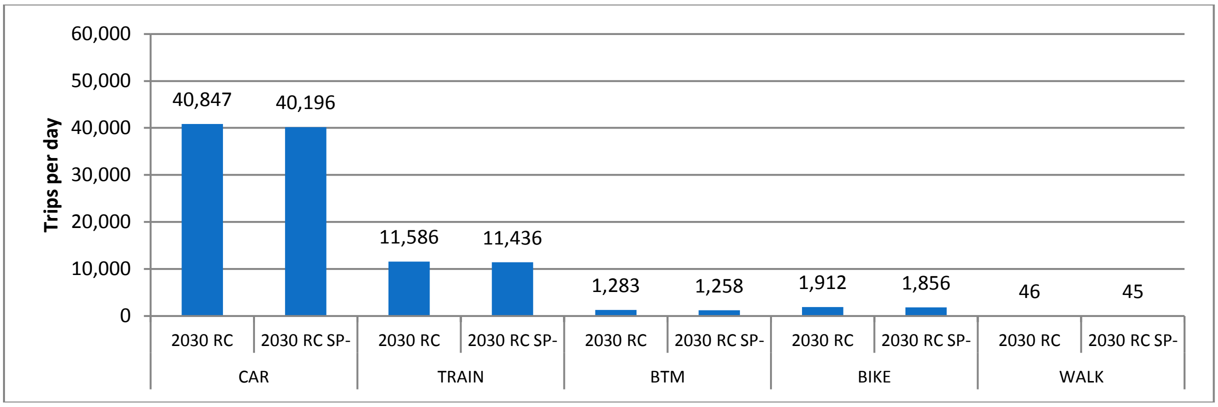

Figure 7-4 Number of trips per mode from zone A+B to zone C+D+E (2030 RC and 2030 RC SP-)

The effect of the spatial downsizing has an equal effect on all modes. The number of car trips decreases with 1,5%. The effect on the train mode is -1,3% and on the BTM-mode -2%. The number of bike and walk trips decrease as well.

7.2.1.4 Influence of the WLO scenario

In order to provide policy makers with figures they can use with enough certainty, the NRM produces forecasts for a RC and a GE-scenario. Together these two scenarios provide a bandwidth between which the actual forecast should be located. This analysis is done based on PT+ for both scenarios.

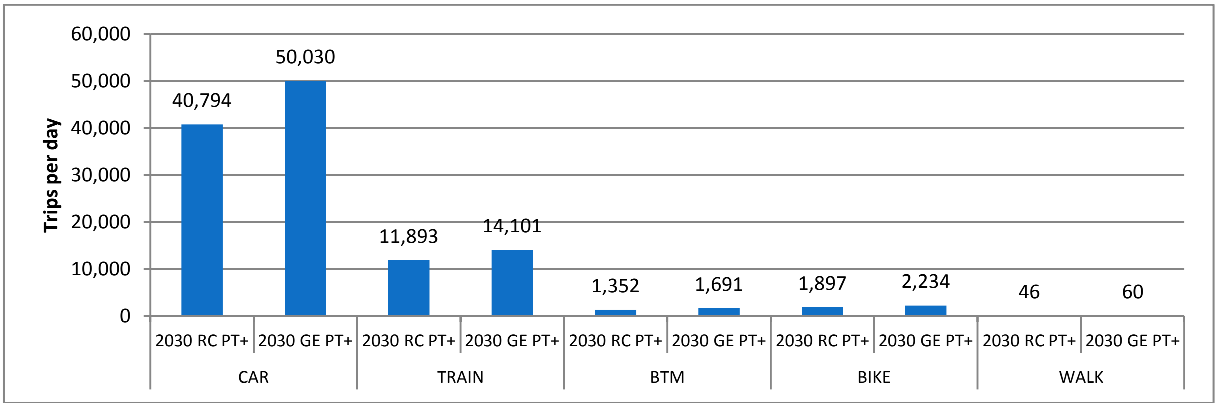

Figure 7-5 Number of trips per mode from zone A+B to zone C+D+E (2030 RC PT+ and 2030 GE PT+)

The effect of GE-forecast is quite large. The effects are +22,5%, +18,6%, +25%, +17,8% and +30,4% for respectively car, train, BTM, bike and walk mode.

7.2.1.5 Public transport pricing forecast

The effects of public transport pricing are visible in the public transport modes. The number of train trips decreases with 2,5% and the number of BTM trips with 1,7%. The effects at car, bike and walk mode are between 0% and +0,1%.

7.2.1.6 Road pricing forecast

The effects of public transport pricing are negligibly small for all modes (between 0% and 0,45%).

7.2.2 Enhancing the connection between Den Haag and Rotterdam

Looking at the number of trips between zone A (Den Haag) and zone B (Rotterdam) for the 2030 RC and the 2030 RC PT+ scenario shows us the effect of the public transport enhancement on the interzonal accessibility of the metropolitan area. Based on these results the assessment can be made whether or not all projects stimulate the ambition to improve the south wing accessibility by enhancing public transport.

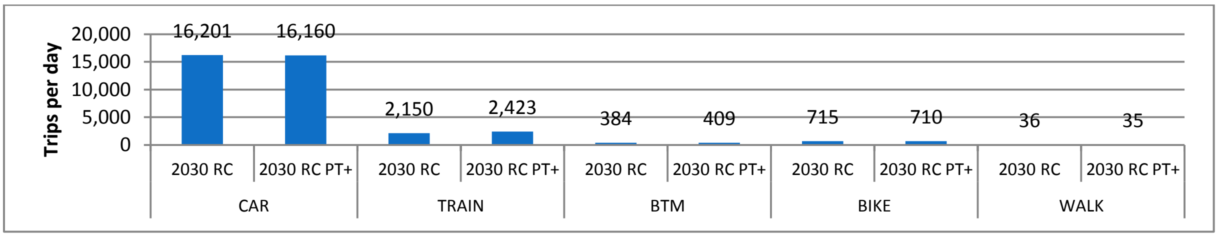

Figure 7-6 Number of trips per mode from zone A to zone B (2030 RC and 2030 RC PT+)

The diagram above shows a small decrease in the number of car trips between Den Haag and Rotterdam, but a significant increase in the number of train trips (+12,7%). The number of BTM trips increases as well (+6,5%). This means that especially train traffic can play large role in enhancing the inter-accessibility of the south wing.

7.2.3 Internal accessibility SGH

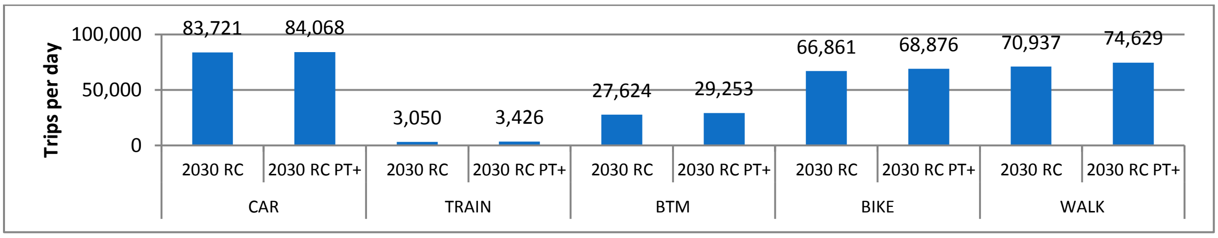

Figure 7-7 Number of trips per mode in zone A (2030 RC and 2030 RC PT+)

The effects of enhanced public transport have effects on all modes. The number of trips increases with 0,4%, 12,3%, 5,9%, 3,0% and 5,2% for respectively car, train, BTM, bike and walk mode.

7.2.4 Internal accessibility SRR

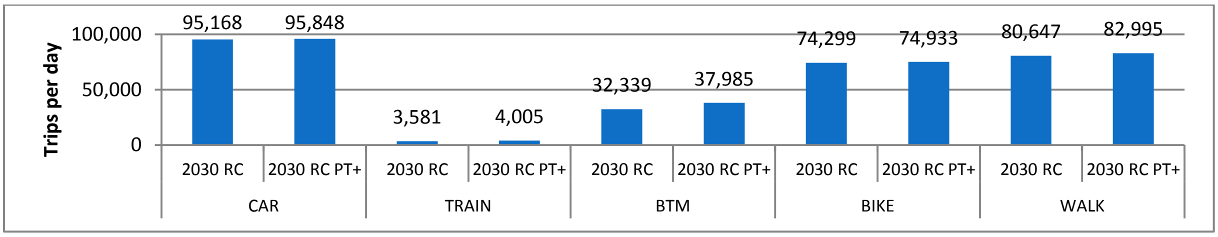

Figure 7-8 Number of trips per mode in zone B (2030 RC and 2030 RC PT+)

The effects of enhanced public transport have effects on all modes. The number of trips increases with 0,7%, 11,8%, 17,4%, 0,8% and 2,9% for respectively car, train, BTM, bike and walk mode.

The increasing number of bike and walk trips can be explained by the enhanced public transport as well. Due to the increasing number of train trips (about +12% in both SGH and SRR region), the number of access and egress trips increases as well. In urban areas the mode share for bike and walk in access and egress transport is relatively high. Therefore increasing number of train trips means increasing number of bike and walk trips as well.

7.2.5 Public transport volumes in case of Hansen's distribution

As seen in paragraph 6.3 the spatial program distributed over the south wing development zones based on Hansen's theory differs from the actual distribution. This paragraph assesses the differences between trip production in case of a spatial program conform the actual developments and a spatial program based on Hansen's distribution.

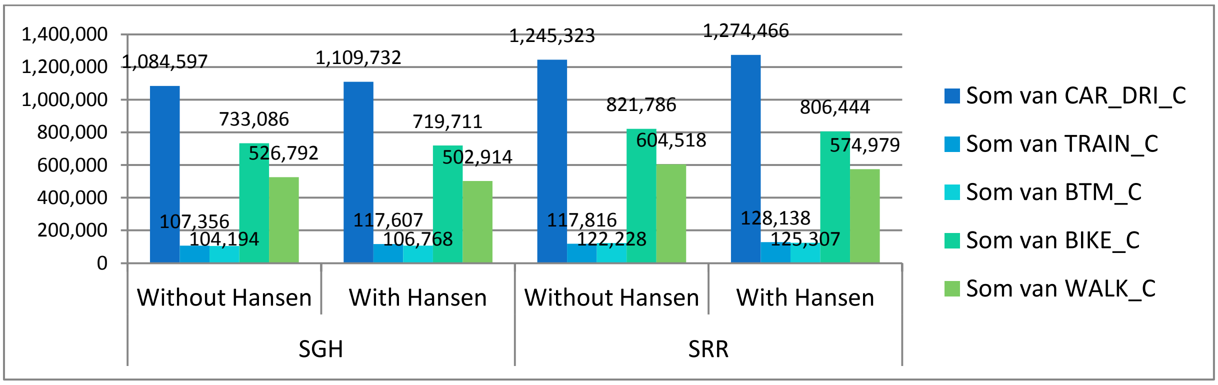

Figure 7-9Public transport volumes in case of Hansen's distribution

In the Den Haag region the number of trips by train increase significantly with 9,3%. In the Rotterdam area this growth is a about equal (9,4%). There is also a growth observable in the BTM mode in SGH (2,4%) and in the Rotterdam area (2,5%). The total number of trips made by car increases as well, but the modes bike and walk decrease. The total number of trips made stays about the same for both areas.

The increasing number of trips made by train can be explained by the fact that especially over the projects with a high public transport accessibility more inhabitants have been distributed and thus more trips are generated. Access and egress transport to the train stations is then likely to be made by BTM.

7.3 PROJECT 1: FREQUENCY INCREASE DEN HAAG – ROTTERDAM (INCLUDING ONE NEW TRAIN STATION)

The first project for which the model results will be analyzed is the frequency increase at the railway line Den Haag – Rotterdam. By looking at the number of boarding passengers on the line Den Haag – Rotterdam, a good guess can be made on the effect of the influence factors on public transport use.

7.3.1 Line use

Below the model results are analyzed for all different influence factors for the entire line.

7.3.1.1 Basic forecast

The table below shows the predicted number of passengers boarding at the stations on the line Den Haag – Rotterdam for the base year (2004) and the future prognosis (2030, regional community scenario). A decrease can be observed at the stations of Den Haag HS, Schiedam Centrum and Rotterdam Centraal. The station of Delft has a significant increase (3.200 new passengers per day).

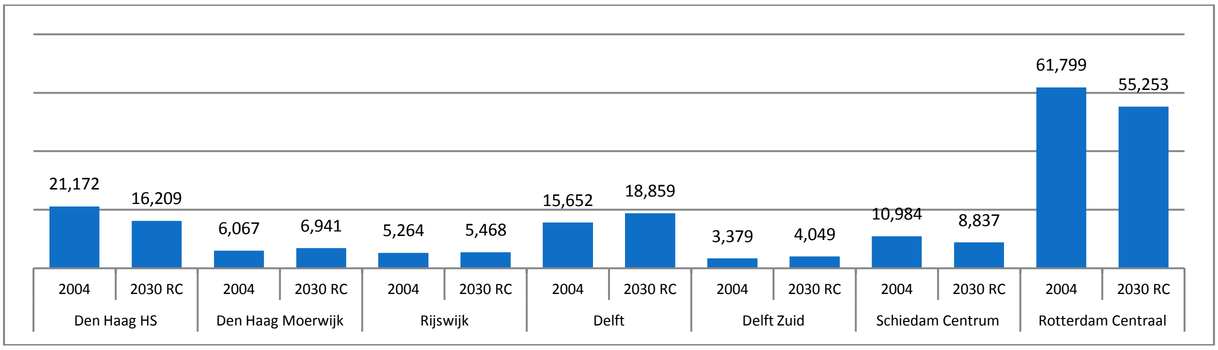

Figure 7-10 Project 1 Boarding passengers line Den Haag – Rotterdam (2004 and 2030 RC)

7.3.1.2 Enhanced public transport forecast

The second scenario is the one with the enhanced public transport. For the line Den Haag – Rotterdam this means increased train frequencies, two new train stations and new cross links with the underlying public transport network at Delft (BRT), Schiedam Kethel (tram extension) and Schiedam Centrum (new metro).

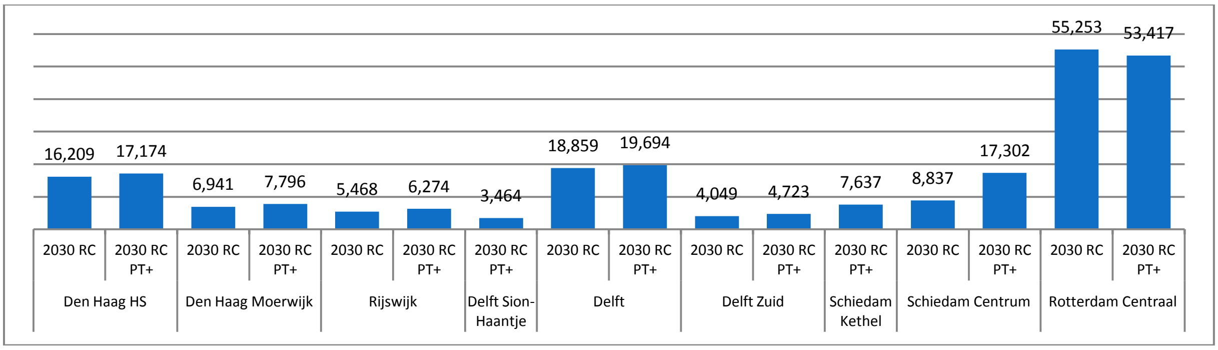

Figure 7-11 Boarding passengers line Den Haag – Rotterdam (2030 RC PT and 2030 RC PT+)

In the case of enhanced public transport the almost all station on the line experience an increasing number of boarding passengers between 2004 and 2030, except Rotterdam Central station. The overall increase can be explained by the increased train frequencies on the line. The overall increased number of boarding passengers is about 18,9%.

The station of Schiedam Centrum profits the most, where the total number of passengers is expected to be doubled. This increase can be explained by the connection of the new metro and the increased frequencies on the reconstructed Hoekse Lijn. Based on figures on the modal split of access and egress passengers at this station almost 41% of the passengers comes by BTM in 2030 RC PT+, compared with 21% in 2030 RC PT (scenario without the new connections). This means that the new BTM-connections together deliver about 5.100 new passengers per day.

The new station on this line, Delft Sion-Haantje, can expect about 3.400 passengers per day. It should be noticed that this expectation only applies in case fully completed spatial developments.

7.3.1.3 Spatial downsizing forecast

The third effect that will be analyzed is the spatial downsizing. Multiple projects along the line, like Rijswijk Zuid, Harnaschpolder, Spoorzone Delft and are assumed to have a large influence on the demand for public transport. In this scenario these spatial project are supposed to be cancelled and therefore removed from the zonal input data.

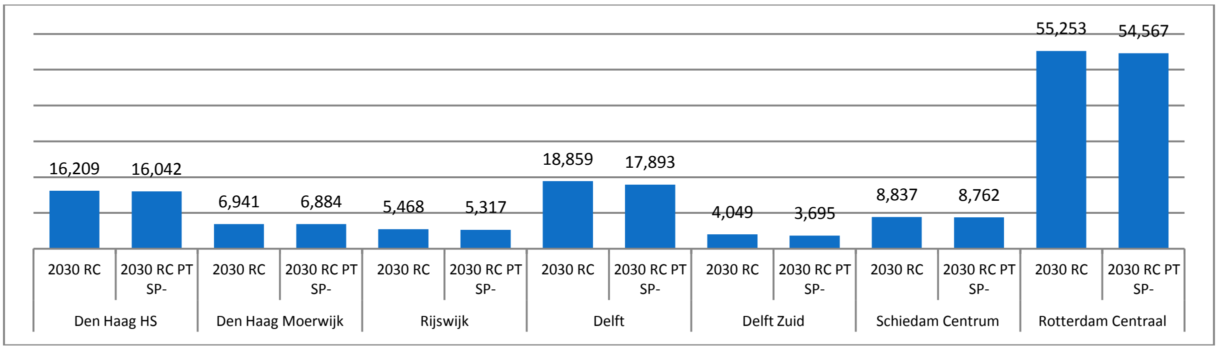

Figure 7-12 Boarding passengers line Den Haag – Rotterdam (2030 RC SP and 2030 RC SP-)

The general trend observed in the diagram above is a slightly negative effect on the number of passengers (which was expected). Overall the decrease is 2,2% on the total number of boarding passengers. At the stations of Delft and Delft Zuid the effect is the largest: respectively -5% and -9%. At Den Haag Moerwijk and Schiedam Centrum the effect is almost null.

7.3.1.4 Influence of the WLO scenario

In order to provide policy makers with figures they can use with enough certainty, the NRM produces forecasts for a RC and a GE-scenario. Together these two scenarios provide a bandwidth between which the actual forecast should be located. The analysis is done based on PT+ for both scenarios.

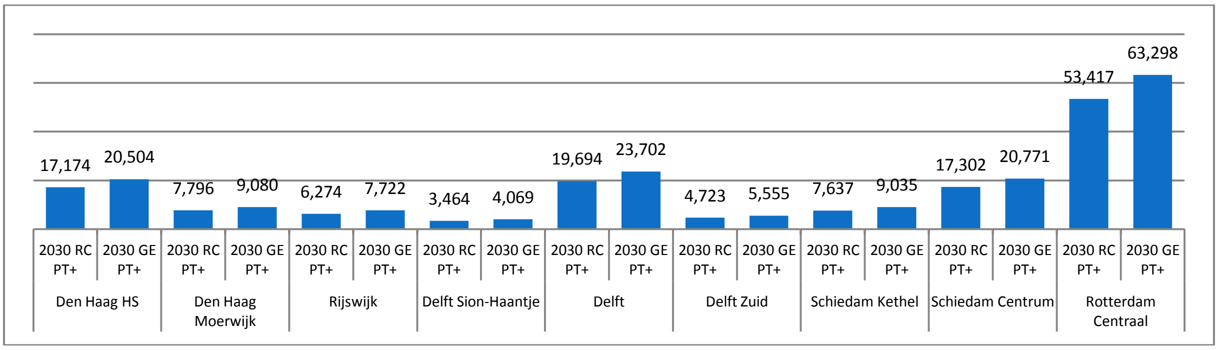

Figure 7-13 Boarding passengers line Den Haag – Rotterdam (2030 RC PT+ and 2030 GE PT+)

As expected the GE-scenario's shows large increases in the number of boarding passengers. The average increase over the line is equal to 19%. At the station of Rijswijk the growth is the largest, 23% and at the station of Den Haag Moerwijk the smallest, 16,5%. In total the line is used by an extra 26.000 extra passengers each day in GE-scenario (with enhanced public transport).

7.3.1.5 Public transport pricing forecast

In this scenario the public transport rates are raised with 10% (on top of inflation). The effects are shown in Figure 7-14.

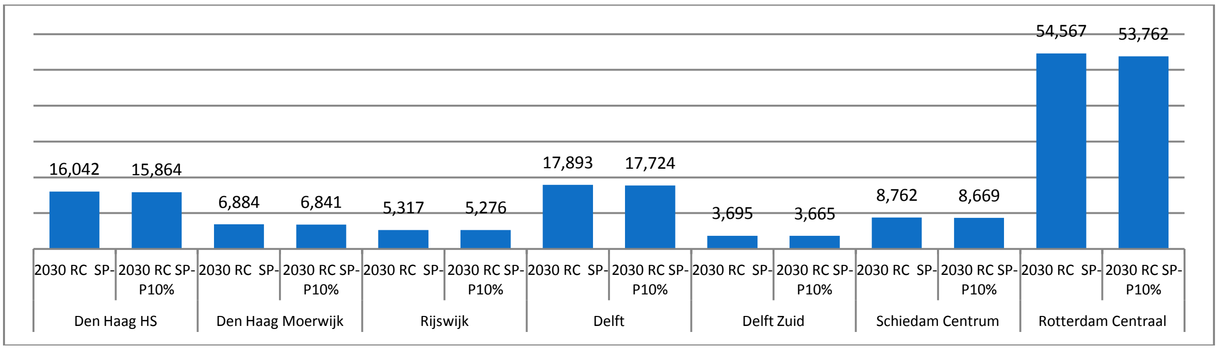

Figure 7-14 Boarding passengers line Den Haag – Rotterdam (2030 RC SP- and 2030 RC SP- P10%)

In the case of increased public transport rates, a small decrease in the number of passengers travelling by train can be seen. Overall this amount is -0,97% for the line Den Haag – Rotterdam, compared with -1,19% for all train stations in the Netherlands. The smallest effect is predicted for the station of Den Haag Moerwijk (-0,64%) and the largest effect for the station of Rotterdam Centraal (-1,48%). Although differences are quite small, the explanation might be that the larger the node/transfer function of a station (and thus the more public transport systems connected), the stronger the effect of increased rates is (in this case the order on effect size is from large to small is Rotterdam Centraal, Den Haag HS, Schiedam Centrum, Delft, Delft Zuid, Rijswijk and Den Haag Moerwijk).

7.3.1.6 Road pricing forecast

The last effect simulated is the introduction of road pricing (paying different for mobility). This means complete abolishment of purchase and road tax for car users, but paying for the amount of distance travelled.

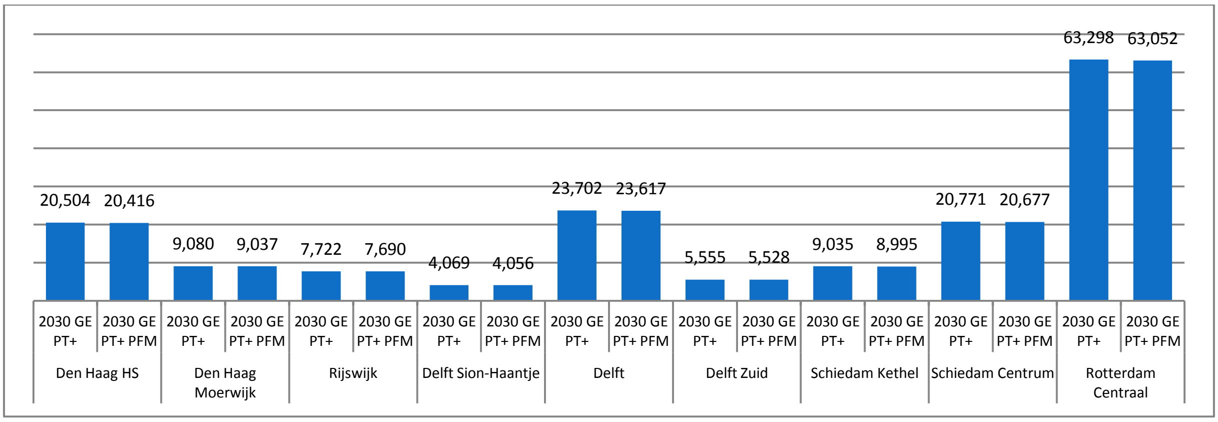

Figure 7-15 Boarding passengers line Den Haag – Rotterdam (2030 GE PT+ and 2030 GE PT+ PFM)

The overall effect is very small, but has decreasing characteristics. The average decrease is only 0,42%. The explanation for this decrease might be the lowered costs for car possession. Especially outside densely populated areas where no parking costs occur, the possession of a car becomes very attractive. This theory is confirmed by the average effect in the Netherlands, where the amount of boarding passengers decreases with 1,37%.

7.3.2 Occupancy

In order to make an assessment of the occupancy rates of the train between Den Haag and Rotterdam looking at the number of boarding passengers only is insufficient. Trains on this line are not only used by people to and from the station lying on it, but also for ongoing passengers traveling via Den Haag and Rotterdam. In order to obtain information about the prognosis's of these passengers, it is necessary to assign all OD-trips produced by the NRM for the different scenario's to the corresponding timetables. This can be done in TRANS. For the line Den Haag – Rotterdam this gives to following three results for respectively the morning peak, rest day and evening peak.

The train frequencies on the route Den Haag – Rotterdam are constant all day in 2004, the 2030 RC-scenario and in the 2030 RC PT+ scenario. Fluctuations in transport demand are therefore compensated by adaptions in train lengths.

7.3.2.1 Morning peak

In the morning peak the occupancy increases the closer the train approaches Rotterdam. In 2004 the average number of passengers per hour increases from about 5.000 at Den Haag to 6.800 per hour at Rotterdam Centraal. For the 2030 RC scenario the train use goes from 4.100 at Den Haag to 5.500 at Rotterdam. For the 2030 RC PT+ scenario is goes from 4.400 in Den Haag to 5.900 in Rotterdam.

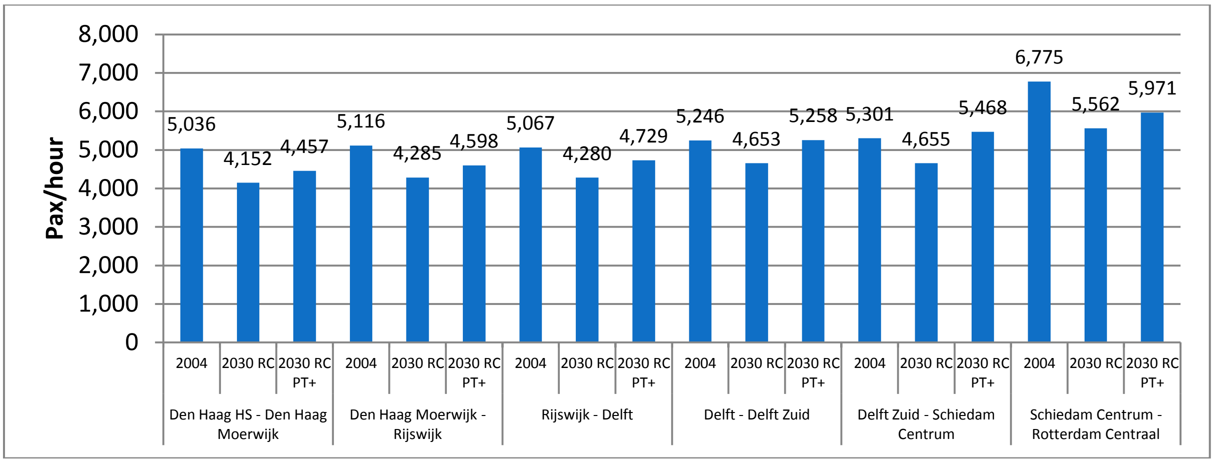

Figure 7-16 Train occupancy Den Haag – Rotterdam (2004, 2030 RC PT and 2030 RC PT+)

Overall observation is thus that the basic prognosis on the number of passengers (ongoing and boarding) decreases between 2004 and 2030 with about 15%. In case of enhanced public transport the total number of passenger's increases, but not to the level as in 2004. The decrease is then about 8%.

7.3.2.2 Rest day

The restday shows similar trends as the morning peak. The average train use during the rest day is about 2.400 till 2.600 passengers per hour in 2004, 2.200 till 2.400 in 2030 RC and 2.300 till 2.600 passengers per hour in 2030 RC PT+.
In the evening peak the average train use is about 2.400 till 2.600 passengers per hour in 2004, 2.200 till 2.400 in 2030 RC and 2.300 till 2.600 passengers per hour in 2030 RC PT+.

7.3.2.3 Evening peak

During the evening peak a different trend shows up. The 2030 RC scenario still produces less passengers as in 2004, but the 2030 RC PT+ scenario goes over it significantly.

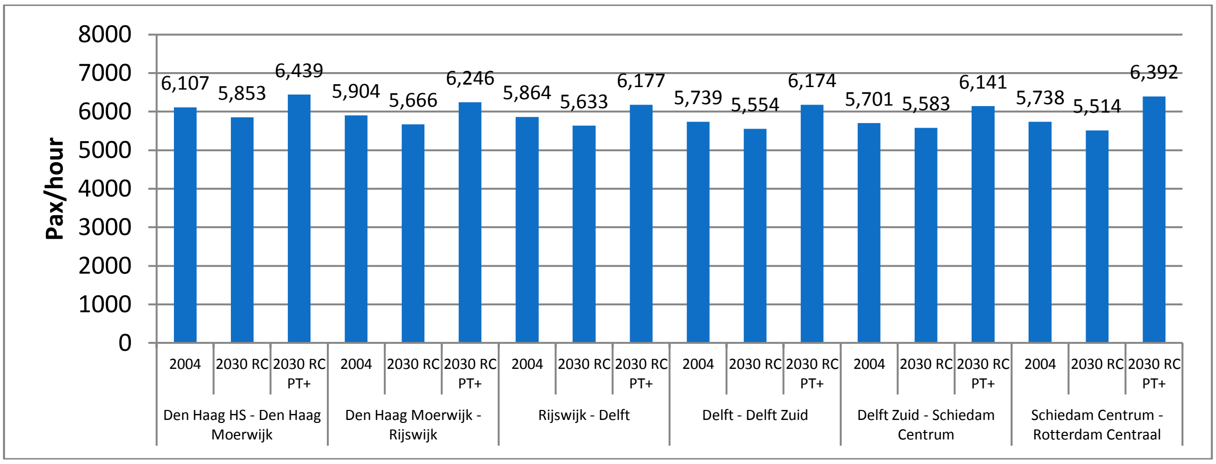

Figure 7-17 Train use during the evening peak (2004, 2030 RC and 2030 RC PT+)

Although during the evening peak no big differences show up during in between the stations, the 2030 RC PT+ scenario produces about 6% more passengers than in 2004.

7.3.3 Train station use

As seen above, the train station of Delft Sion/Haantje attracts somewhere in between 3.500 and 4.000 boarding passengers per day. The figure below shows the modal split of incoming and outgoing passengers in the 2030 RC PT+ scenario.

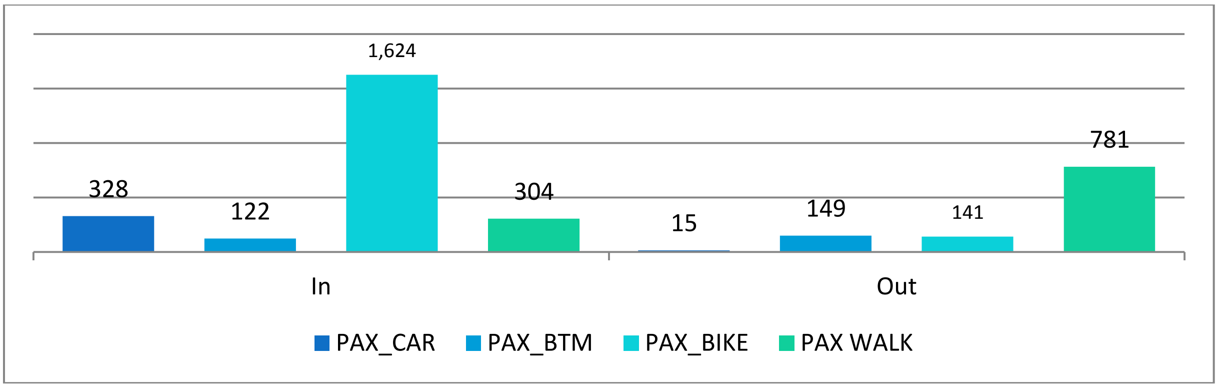

Figure 7-18 Modal split access and egress passengers Delft Sion-Haantje (2030 RC PT+)

From the diagram above it can be observed that the majority of the passengers with Delft Sion as origin, come to the station by bike. Most of the arriving passengers go to their final destination by foot. The share of BTM-passengers per day is relatively small because of the absence of BTM at close proximity. Therefore the node/transfer function of the station of Delft Sion is nihil. The absence of work places near the station makes it a typical station of commuters living close by (<5km).

7.3.4 Project specific conclusions

The realization of the station of Delft Sion cannot be seen independent from the introduction of PHS on this stretch. The realization requires at least a four-track railway line at the location of the train station, since a new local stop does not fit in the timetable in a double-track layout. In case of PHS the new train stop will not lead to any holdbacks for other train traffic, since local trains use a dedicated track. The capacity of a dedicated track for local trains only lies somewhere in between 10 and 12 trains per hour, which is much higher than the actual occupancy (6 trains per hour).

Since the local trains have their own dedicated tracks, the realization of platform only along these track would be sufficient. In south direction this is the outer track, but in north direction local trains use the inner track. Therefore it is advised to create a deflection in the outer track when the tracks are doubled here, to create enough space for the future development of this railway stop.

Based on the development guideline, the station will only be interesting enough for operators to use, when it produces at least 1000 passengers per day. Based on the future prognosis (in between 3.500 and 4.000 passengers per day), this limit is reached when at least $\frac{1.000}{3.750} = 25\%$ of the spatial development is actually built and populated. This corresponds with about a 1000 households in the neighborhood of Rijswijk Zuid.

7.4 PROJECT 2: METRO LINE 6 ROTTERDAM (INCLUDING 1 NEW TRAIN STATION)

7.4.1 Line use

The second project identified is the Rotterdam south tangent metro line. It connects Kralingse Zoom and Schiedam Centrum via Rotterdam Stadionpark and the Zuidplein commercial area. The map below shows the route of the new metro line including the stops. The colored areas are the NRM zones directly connected to any of the stops on the new metro line. The color itself indicates the amount of extra BTM-passengers produced by these zones in case of the PT+ scenario.

Figure 7-19 Project 2 BTM passengers (PT and PT+)

Three different types of passengers can be identified travelling over the line.

A. Passengers to and from the zones directly connected to the metro line using BTM as main transport mode.
B. Passengers using the new metro line to access one of the train stations.
C. Passengers travelling via the new metro line only and transferring onto other BTM lines (so not travelling to or from the zones directly connected to the metro line).

Unfortunately the NRM-structure only allows you to determine the number of trips for passengers of type A and B. Since route choice for BTM mode is not modeled in the NRM, the amount of type C passengers cannot be determined directly. Therefore a workaround is found, which will be explained below.

7.4.1.1 Passenger type A

The passengers of type A are travelers which go to or from the zones connected to the new metro line directly and use BTM as main transport mode. That means that they have an origin or/and destination equal to the zones showed above in Figure 7-19.

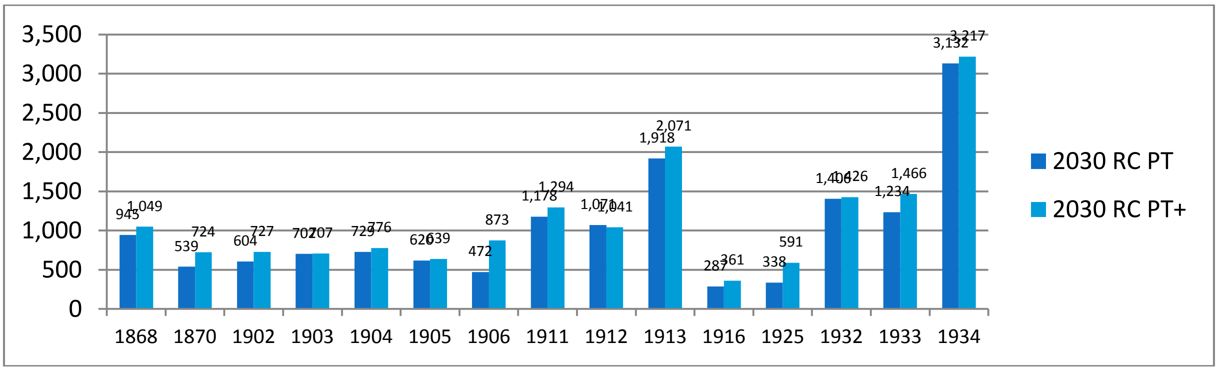

Figure 7-20 Project 2 type A passengers

It can be clearly observed that especially the zones on the line in between the major transfer stations (Schiedam Centrum, Zuidplein and Rotterdam Stadionpark) have an increasing number of BTM-passengers in the PT+ scenario.

The decreasing number of BTM passengers at the transfer zones can be explained by the effect of the PT+ as well. In case of the Rotterdam Stadionpark zone (1912), the new train station becomes directly available (accessible by slow mode) for all passengers who used to take the BTM mode to another station. For the Marconiplein stop (1903) it is likely that now zone 1902 has a better accessibility it will take over some of the passengers from zone 1903. This is in fact not a decrease of BTM-passengers, but just a shift from one zone to another.

The total number of new BTM trips for type A passengers caused by the new metro line, can be found by summing up the total number of passengers for these zones (1.787 passengers per day).

7.4.1.2 Passenger type B

Since the only BTM mode connected to the new train station of Rotterdam Stadionpark, all access and egress passengers using BTM-mode must have travelled via the new metro line. In the 2030 RC PT+ scenario this amount of passengers is equal to 5.580 passengers per day.

On west side, where the new metro line ends up at Schiedam Centrum, not all access and egress passengers by BTM come via the new metro line. It is assumed that all access and egress passengers, coming from the south east zones. This amount is about 247 passengers per day.

7.4.1.3 Passenger type C

As mentioned above, an easy way of finding the amount of passengers of type C is not available in the NRM, since it models with accessibility quality between origin and destination zone and not by including network layout. That means that route choice for BTM is not modeled. Another workaround for this problem is explained below.

The Rotterdam area has a limited number of BTM-connections between the North and the South. Therefore it would be logical to determine the number of BTM passengers between the north and south at the river crossings.
In case of the new metro line, the following crossings are possible:

- Metro Beneluxtunnel
- Metro Vierhavens (new)
- Metro and tram Erasmusbrug
- Metro De Esch (new)

The maps below show the aggregated zones of which passengers are assumed to use the new river crossings. The new river crossings are indicted by a yellow star and the new crossing by a red arrow. Alternative crossings are indicated by a purple arrow.

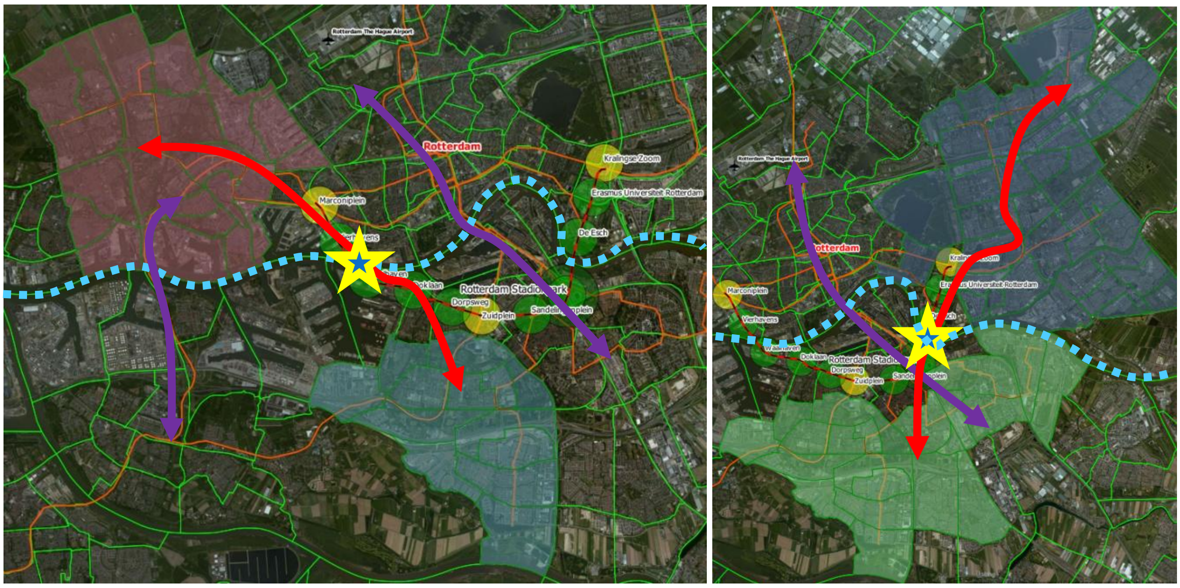

Figure 7-21 Project 2 west river crossings (left) and east river crossings (right)

Based on aggregate trips counting this gives the following table:

Table 7-2 Number of rivercrossing trips in 2030 RC PT and 2030 RC PT+

	2030 RC PT	2030 RC PT+	Extra
East crossing	32,230	32,660	430
West crossing	13,115	13,738	623

Since no double counting can occur (different aggregate zones), the total number of new passengers of type C is 1.053 per day.

7.4.2 Train station use

An important transfer point on the new metro line is the station of Rotterdam Stadionpark. This station will serve as an important crosslink between metro and train network. The figure below shows the modal split of incoming and outgoing passengers in the 2030 RC PT+ scenario.

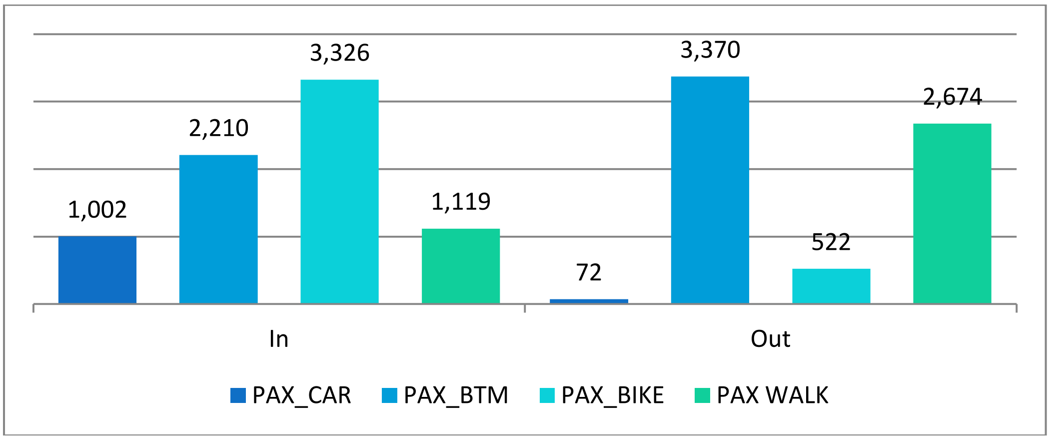

Figure 7-22 Modal split access and egress passengers Rotterdam Stadionpark (2030 RC PT+)

The diagram shows that most people approach the station by bike (3.326 per day) and BTM (2.210 per day). Of the people arriving at the train station the majority leaves by BTM (3.370 per day) and by foot (2.674 per day).

Based on these results it can be concluded that the station will function as an crosslink between train and metro, for both departing and arriving travelers. Of the total of 14.295 passengers per day, 39% (5.580) chooses BTM as access or egress transport.

7.4.3 Project specific conclusions and remarks

Total number of new type A passengers: 1.787
Total number of new type B passengers: 5.580 + 247
Total number of new type C passengers: 1.053
The total number of passengers per day using the new metro line is thus 8.676. In the GE-scenario this is 10.314.

Occupancy
As seen before the new metro line is supposed to have a frequency of 6 times per hour, all day from 6h till 24h. The number of seats per train is 104, so in total 22.464 seats per day per train. At first it looks enough to have one train running all day, giving an average occupancy rate of 39% in the RC-scenario (the overall occupancy rate of Rotterdam metro trains is 18,6%). Adapting the number of trains during peak hours might be necessary; in that case the average occupancy rate will drop a little bit.

Remarks
In the case above only the number of extra passengers are assumed to use the new metro line and existing passengers are assumed to stay on their old BTM-lines. In reality there will also be a shift for from old BTM-lines-users to the new metro line when it is a better alternative. This means the amount of passengers on existing parallel running lines will drop a little bit. Although the amount of passengers changing from old lines to the new metro cannot be determined, the image below shows the idea of this shift.

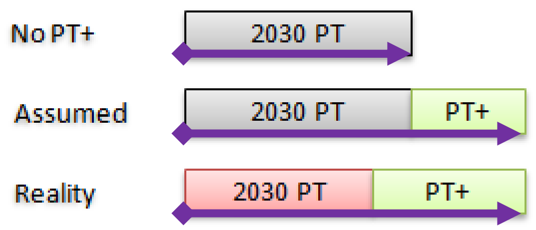

Figure 7-23 Passengers as in 2030 PT, assumed in 2030 PT+ and in reality in 2030 PT+

7.5 PROJECT 3: CONVERSION HEAVY RAIL GOUDA – LEIDEN TO LIGHT RAIL (INCLUDING SEVERAL NEW STOPS)

7.5.1 Line use

The third project modeled is the conversion of the heavy rail line Gouda – Leiden into a light rail line and the extension to Katwijk and Noordwijk. This line can be seen as three parts:

- Part 1: Gouda to Alphen a/d Rijn (heavy rail reconstructed into light rail)
- Part 2: Alphen a/d Rijn to Leiden (light rail combined with train services)
- Part 3: Leiden to Katwijk/Noordwijk (new light rail)

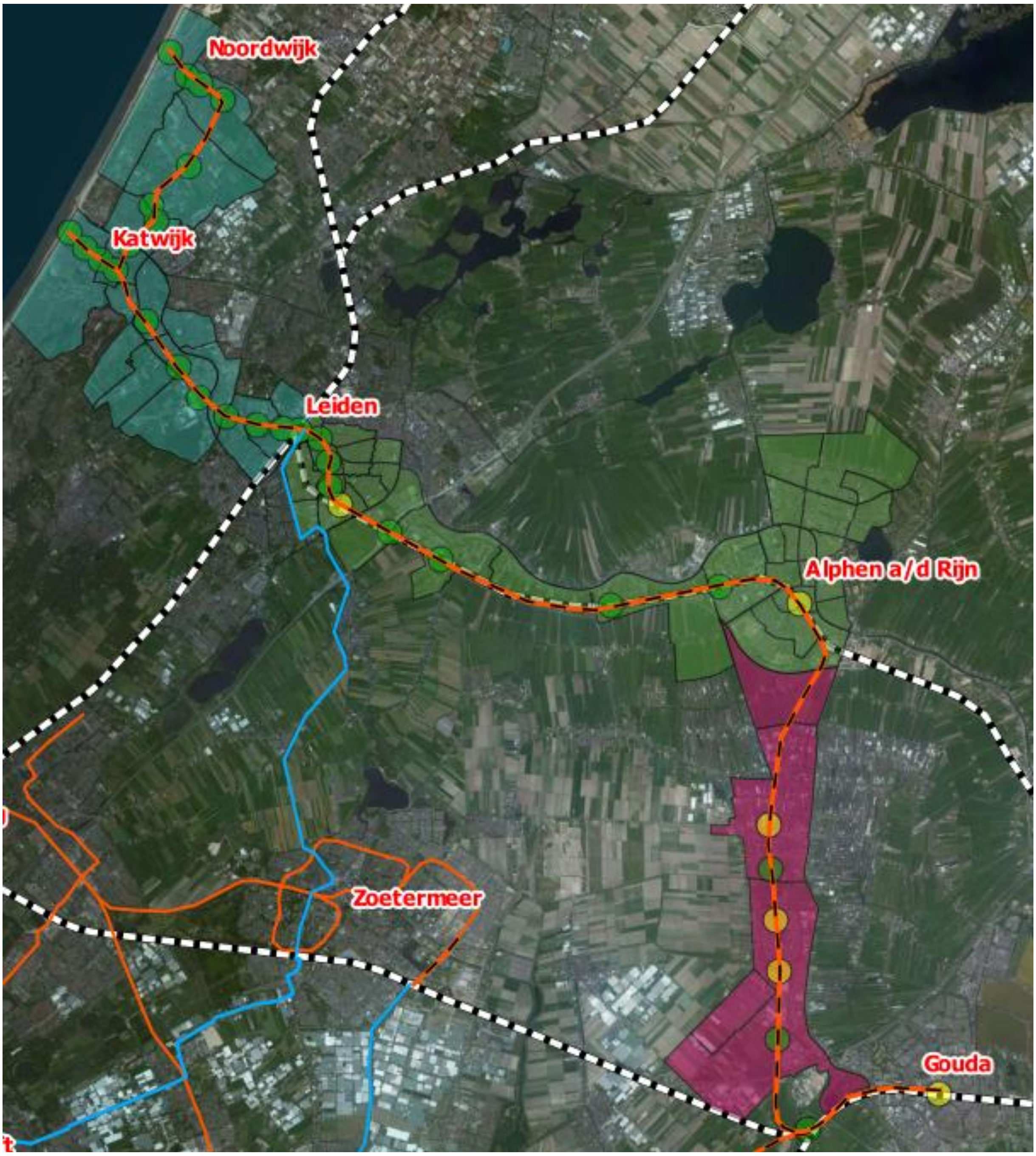

Figure 7-24 Project 3 RijnGouweLijn aggregate zones

7.5.1.1 Part 1: Gouda to Alphen a/d Rijn

The first part of the line the line is reconstructed from heavy rail into light rail. This means that the mode of people using it changes from train into BTM.

Table 7-3 Number of passengers 2030 RC PT and 2030 RC PT+ project 3 part 1

	2030 RC PT	2030 RC PT+	Delta
TRIPS TRAIN	1,780	0	- 1,780
TRIPS BTM Main transport	1,695	2,271	+ 576
TRIPS BTM Access/egress	435	703	+ 268
SUM	**3,910**	**2,974**	**- 936**

From the table above it can be observed that the total number of trips decreases with over 900 per day.

7.5.1.2 Part 2: Alphen a/d Rijn to Leiden

Between Alphen a/d Rijn and Leiden the heavy railway line is shared with the light rail line in the PT+ scenario.

Table 7-4 Number of passengers 2030 RC PT and 2030 RC PT+ project 3 part 2

	2030 RC PT	2030 RC PT+	Delta
TRIPS TRAIN	9,519	4,946	- 4.573
TRIPS BTM Main transport	8,537	10,415	+ 1,878
TRIPS BTM Access/egress	2,621	2,840	+219
SUM	**20,677**	**18,201**	**-2,467**

A decrease of almost 2,500 passengers per day can be observed between Alphen a/d Rijn and Leiden.

7.5.1.3 Part 3: Leiden to Katwijk/Noordwijk

The third part of the line is a new light rail line, which replaces multiple bus services.

Table 7-5 Number of passengers 2030 RC PT and 2030 RC PT+ project 3 part 3

	2030 RC PT	2030 RC PT+	Delta
TRIPS TRAIN	0	0	0
TRIPS BTM Main transport	5,607	5,694	+ 87
TRIPS BTM Access/egress	1,729	1,534	- 195
SUM	**7,336**	**7,228**	**- 108**

When the bus services between Leiden and Katwijk/Noordwijk are replaced by light rail service, the amount of passengers per day is calculated as almost the same.

7.5.2 Project specific conclusions

At can be observed that a change from train to light rail comes with a relatively large decrease in the number of trips made. The most likely explanation is that the mode preference for train is a lot higher than for BTM (-0.154 respectively -0.232). On the other hand the NRM knows no difference between light rail, metro, tram and bus, although research has shown that people have a larger mode preference for modes like light rail, metro and tram than for bus (Bunschoten, Molin, & van Nes, 2012). This might explain why there is almost no difference in the number of trips on part 3.

Based on the negative number of extra trips, the average occupancy per vehicle cannot be determined.

7.6 PROJECT 4: CONVERSION ROTTERDAM – HOEK VAN HOLLAND TO LIGHT RAIL (INCLUDING TWO NEW STOPS)

7.6.1 Line use

The heavy railway line Rotterdam – Hoek van Holland will be converted into a metro line. This means that in the NRM the mode train is fully replaced by BTM.

Figure 7-25 Project 4: Hoekse Lijn aggregate zones

Table 7-6 Number of passengers 2030 RC PT and 2030 RC PT+ project 4

	2030 RC PT	2030 RC PT+	Delta
TRIPS TRAIN	8,653	0	- 8,653
TRIPS BTM Main transport	6,056	7,274	+ 1,218
TRIPS BTM Access/egress	1,629	2,434	+805
SUM	**16,338**	**9,708**	**- 6,630**

7.6.2 Project specific conclusions

The table above shows a large decrease in the number of trips. Although a large part of the train trips is replaced by BTM trips, the total number of public transport trips decreases significantly. Just like in project 3, this can be explained by the different mode preferences for train and BTM. In reality the metro mode has a higher preference than the average BTM preference.

Based on the negative number of extra trips, the average occupancy per vehicle cannot be determined.

7.7 PROJECT 5: METRO LINE EXTENSION NESSELANDE (INCLUDING ONE NEW TRAIN STATION)

The fifth project discussed earlier is the metro extension from Rotterdam Nesselande to Gouda Gouweknoop. The analysis will be done based on line and train station use.

7.7.1 Line use

As already discussed, three types of passengers can be identified:

A. Passengers travelling to and from the zones directly connected with the new line.
B. Passengers using the line for access and egress transport to the station Gouda Gouweknoop.
C. Passengers travelling over the line, with another origin or destination then the ones directly connected.

7.7.1.1 Passenger type A

Figure 7-26 Project 5 aggregate zones

Three different zones are identified. The passengers of type A are represented by the red arrows and the passengers of type C by the blue arrow.

The total number of type A BTM passengers is indicted below and sums up to a total of 802 new passengers per day.

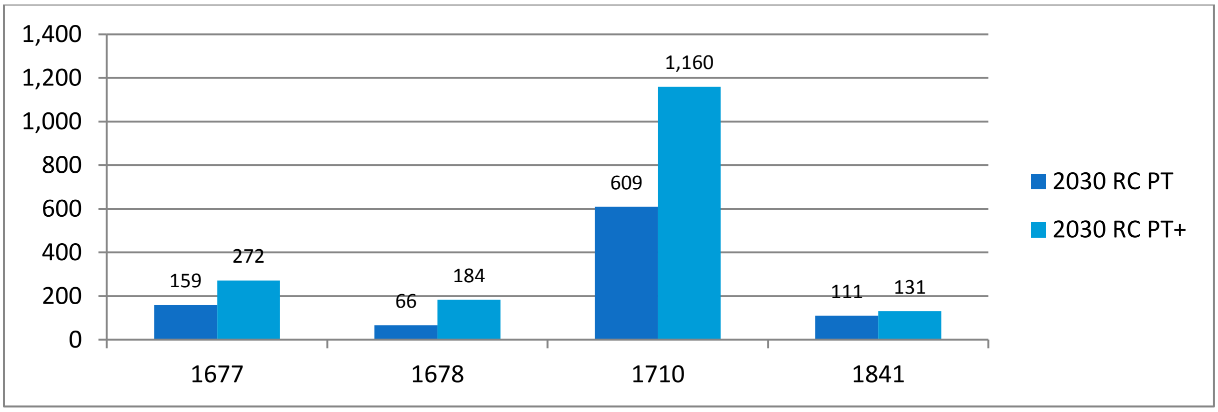

Figure 7-27 Project 5 type A BTM passengers

7.7.1.2 Passenger type B

The passengers of type B are the one's travelling from the north, via the extended metro line to the train stations Rotterdam Alexander or the passengers travelling from the south to the train station of Gouda Gouweknoop.

Table 7-7 Number of access and egress passengers using the metro extension

	2030 PT	2030 PT+	Delta
North to Rotterdam Alexander	422	569	147
South to Gouda Gouweknoop	-	135	135

From the table above it can be concluded that in total 282 passengers per day use the new metro extension for access and egress transport.

7.7.1.3 Passenger type C

The type C passenger's travel from the Rotterdam area to the Waddinxveen and Alphen a/d Rijn area via the new metro line extension (or vice versa).

Based on aggregate trips counting this gives the following table:

Table 7-8 Number of trips in 2030 RC PT and 2030 RC PT+

	2030 RC PT	2030 RC PT+	Extra
Waddinxveen area to Rotterdam area	39	138	99
Rotterdam area to Waddinxveen area	98	231	133

Since no double counting can occur (different aggregate zones), the total number of new passengers of type C is 232 per day.

7.7.2 Train station use

The train station Gouda Gouweknoop will mainly be used as a transfer station between trains (direction Gouda – Rotterdam and Gouda – Den Haag), light rail (Gouda – Alphen a/d Rijn – Leiden) and metro (Nesselande).

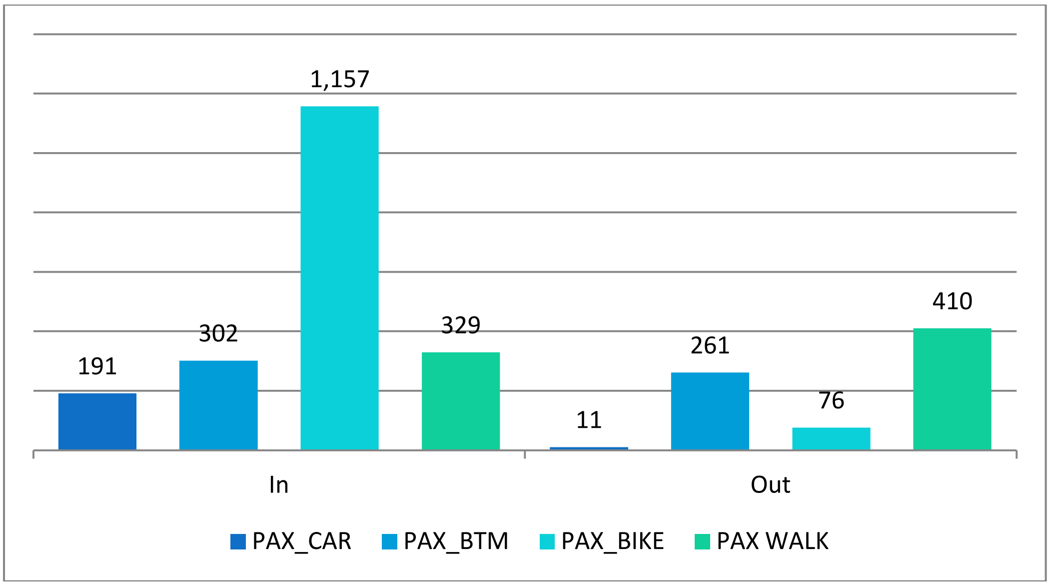

Figure 7-28 Modal split access and egress passengers Gouda Gouweknoop (2030 RC PT+)

The diagram shows that most people approach the station by bike (1.157 per day). Of the people arriving at the train station the majority leaves by foot (410 per day) and by BTM (261 per day).

The share of BTM-passengers per day is limited, but not negligible. An average of 563 passengers per day (21%) use BTM (metro or light rail) as access and egress transport. The total number of passengers per day forecasted to use the station of Gouda Gouweknoop is 2.737 in the RC scenario.

7.7.3 Project specific conclusions and remarks

Total number of new type A passengers: 802
Total number of new type B passengers: 282
Total number of new type C passengers: 232
The total number of passengers per day using the new metro line is thus 1.316. In the GE-scenario this is 1.566.

Occupancy
As seen before the new metro line is supposed to have a frequency of 6 times per hour, from 6h till 23h. The number of seats per train is 104, so in total 21.216 seats per day per train. Running with only one train, gives an average occupancy rate of only 6% in the RC-scenario. Compared with the overall occupancy rate of Rotterdam metro trains of 18,6%, the demand for public transport on this line is assessed as too low. The station of Gouda Gouweknoop produces enough passengers per day, even without the passengers of type B. It is therefore recommended to not extend the metro line to Zuidplas, but to introduce a high frequent bus service to the new train station of Gouda Gouweknoop.

7.8 PROJECT 6: EXTENSION TRAM LINE SCHIEDAM KETHEL (INCLUDING ONE NEW TRAIN STATION)

7.8.1 Line use

Project 6 is the extension of tram line 21 to Schiedam Woudhoek. After the extension it ends up at the new train station of Schiedam Kethel. Based on the set-up of the tram line, two types of passengers can be identified.

A. Passengers travelling to and from the zones directly connected with the new line, but not as access or egress transport (red arrow).
B. Passengers using the line for access and egress transport to the station of Schiedam Kethel or Schiedam Centrum (blue arrow).

Figure 7-29 Project 6 aggregate zones

7.8.1.1 Passenger type A

The passengers of type A are represented by the red arrow. The assumption is made that only the BTM passengers from zone 1963 will use the new tram extension. Passengers from other zones use the existing part of the line or other lines or modes.

The passengers of type A are represented by the red arrow. The assumption is made that only the BTM passengers from zone 1963 will use the new tram extension. Passengers from other zones use the existing part of the line or other lines or modes.

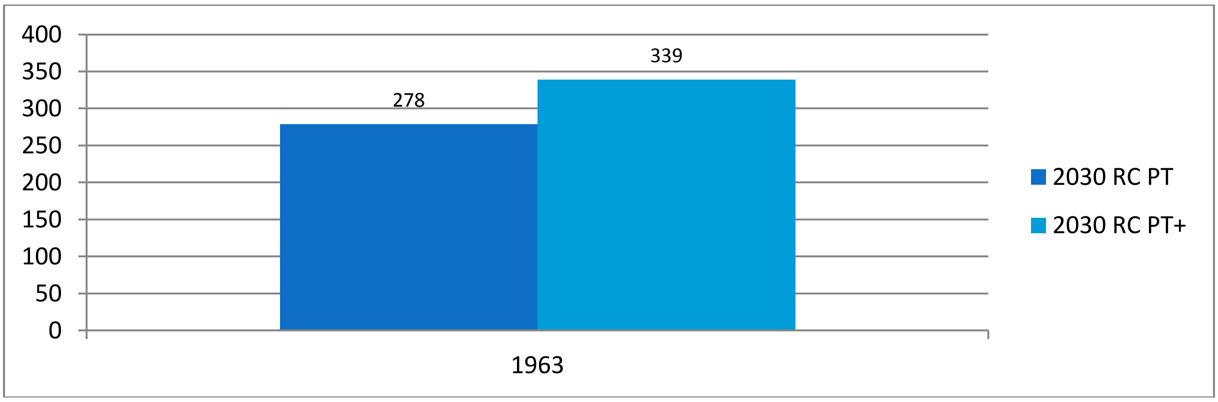

Figure 7-30 Number of passengers 2030 RC PT and 2030 RC PT+ project 6

The total amount of passengers using the new train line as main transport is 339 – 278 = 61 per day.

7.8.1.2 Passenger type B

As said before, the amount of passengers accessing the train station is represented by the blue arrow. This amount sums up to 1.332 passengers per day.

7.8.2 Train station use

The train station of Schiedam Kethel is a planned station on the line Rotterdam - Delft and is supposed to be coupled to an extended tram line as well.

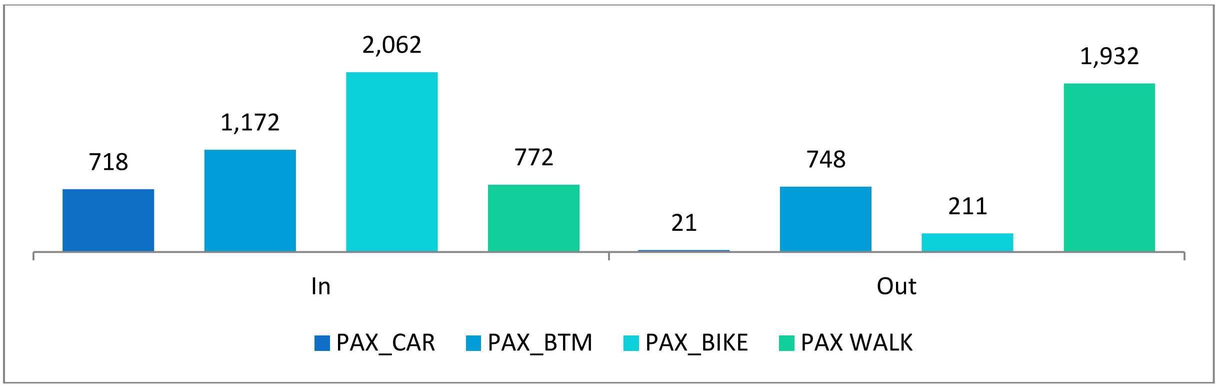

Figure 7-31 Modal split access and egress passengers Schiedam Kethel (2030 RC PT+)

The diagram shows that most people approach the station by bike (2.062 per day) and by BTM (1.172 per day). Of the people arriving at the train station the majority leaves by foot (1.932 per day) and by BTM (748 per day). This means that 1.920 of 7.636 passengers per day (25%) uses BTM.

7.8.3 Project specific conclusions

Total number of new type A passengers: 61
Total number of new type B passengers: 1.332
The total number of passengers per day using the new metro line is thus 1.393. In the GE-scenario this is 1.658.

Occupancy
As seen before the tram line has a frequency of 4 times per hour, from 6h till 23h. The number of seats per train is 56, so in total 7.616 seats per day. The average occupancy rate will then be 18,2% in the RC-scenario and 21,8% in the GE-scenario (the overall occupancy rate of Rotterdam trams is 21,2%). Based on the average occupancy the tram line is supposed to be feasible.

7.9 PROJECT 7: EXTENSION LIGHT RAIL LINE ZOETERMEER (INCLUDING ONE NEW TRAIN STATION)

7.9.1 Line use

Project 7 is the extension of light rail line 4 from Zoetermeer Javalaan to Zoetermeer Bleizo. Zoetermeer Bleizo is a new train station on the line Den Haag - Gouda. As seen in project 6 two types of passengers can be identified.

A. Passengers travelling to and from the zones directly connected with the new line, but not as access or egress transport (red arrow).
B. Passengers using the line for access and egress transport to the station of Bleizo(blue arrow).

Figure 7-32 Project 7 aggregate zones

7.9.1.1 Passenger type A

The passengers of type A are represented by the red arrow. Only the BTM passengers from the zones 1522, 1532 and 1743 will use the new tram extension.

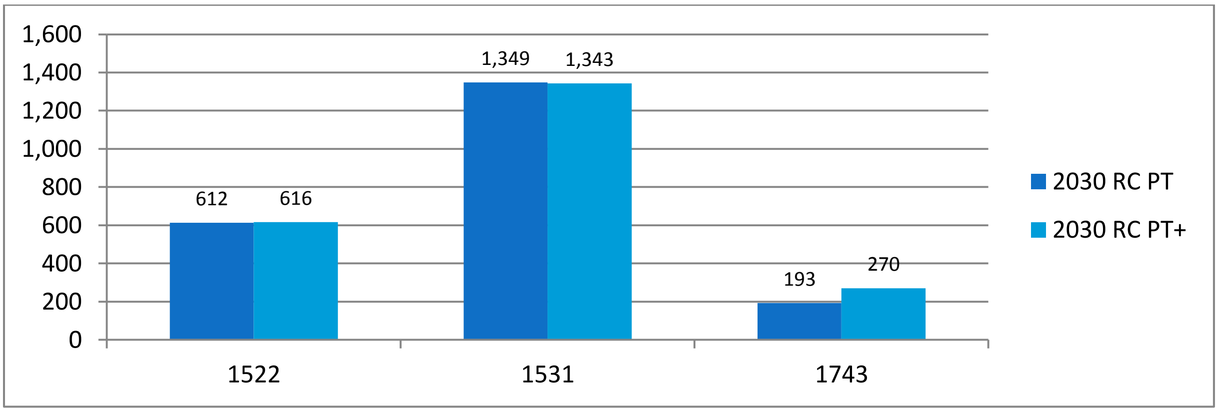

Figure 7-33 Number of passengers 2030 RC PT and 2030 RC PT+ project 7

The total amount of passengers using the new train line as main transport is 75 per day.

7.9.1.2 Passenger type B

As said before, the amount of passengers accessing the train station is represented by the blue arrow. The only BTM-mode connected to the train station is the new extension. Therefore the amount of access and egress passengers by light rail is directly observable from the train station use diagram.

7.9.2 Train station use

The train station of Bleizo is a planned station on the line Den Haag - Gouda and is supposed to be coupled to an extended light rail line as well.

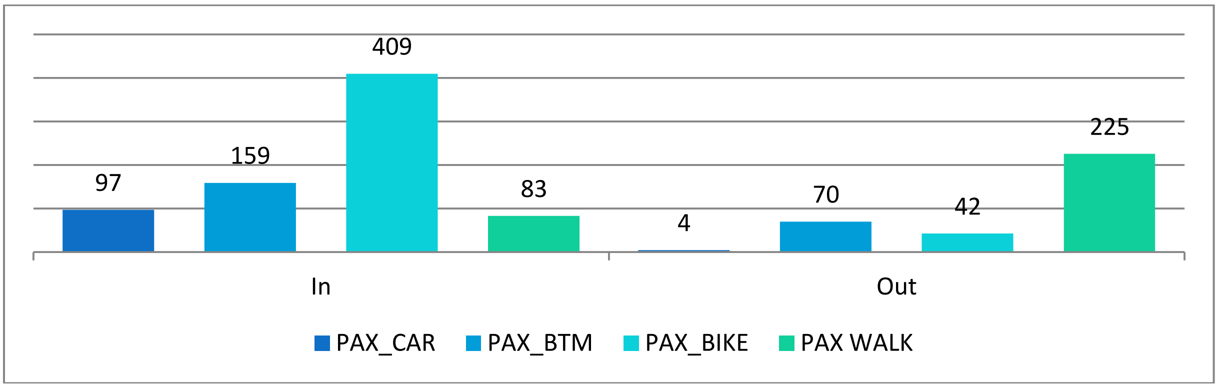

Figure 7-34 Modal split access and egress passengers Bleizo (2030 RC PT+)

The diagram above shows that most people approach the station by bike (409 per day) and by BTM (159 per day). Of the people arriving at the train station the majority leaves by foot (225 per day) and by BTM (70 per day). This means that 229 of 1.089 passengers per day (21%) use BTM.

7.9.3 Project specific conclusions and remarks

Total number of new type A passengers: 75
Total number of new type B passengers: 229
The total number of passengers per day using the new metro line is thus 304. In the GE-scenario this is 362.

Occupancy

Randstadrail line 4 has a frequency of 6 times per hour during the day and 4 times per hour in the evening. The number of seats per train is 84, so in total 15.792 seats per day. This gives an average occupancy rate of only 2,1% in the RC-scenario and 2,3% in the GE-scenario . Compared with the overall occupancy rate of Randstadrail line 4 (Oosterheem-part) of 9,3%, the demand for public transport on this line is assessed as too low. The station of Gouda Gouweknoop produces enough passengers per day, even without the passengers of type B. It is therefore recommended to not extend the metro line to Zuidplas, but to introduce a high frequent bus service to the new train14 station of Gouda Gouweknoop the average occupancy the tram line is supposed to be feasible.

7.10 PROJECT 8: BUS RAPID TRANSIT LINE DEN HAAG – DELFT – ZOETERMEER – LEIDEN

7.10.1 Line use

Project 8, the bus rapid transit service between Den Haag, Delft, Zoetermeer and Leiden is assessed by looking at the number of BTM trips produced by the zones directly connected to the stops on the bus service.

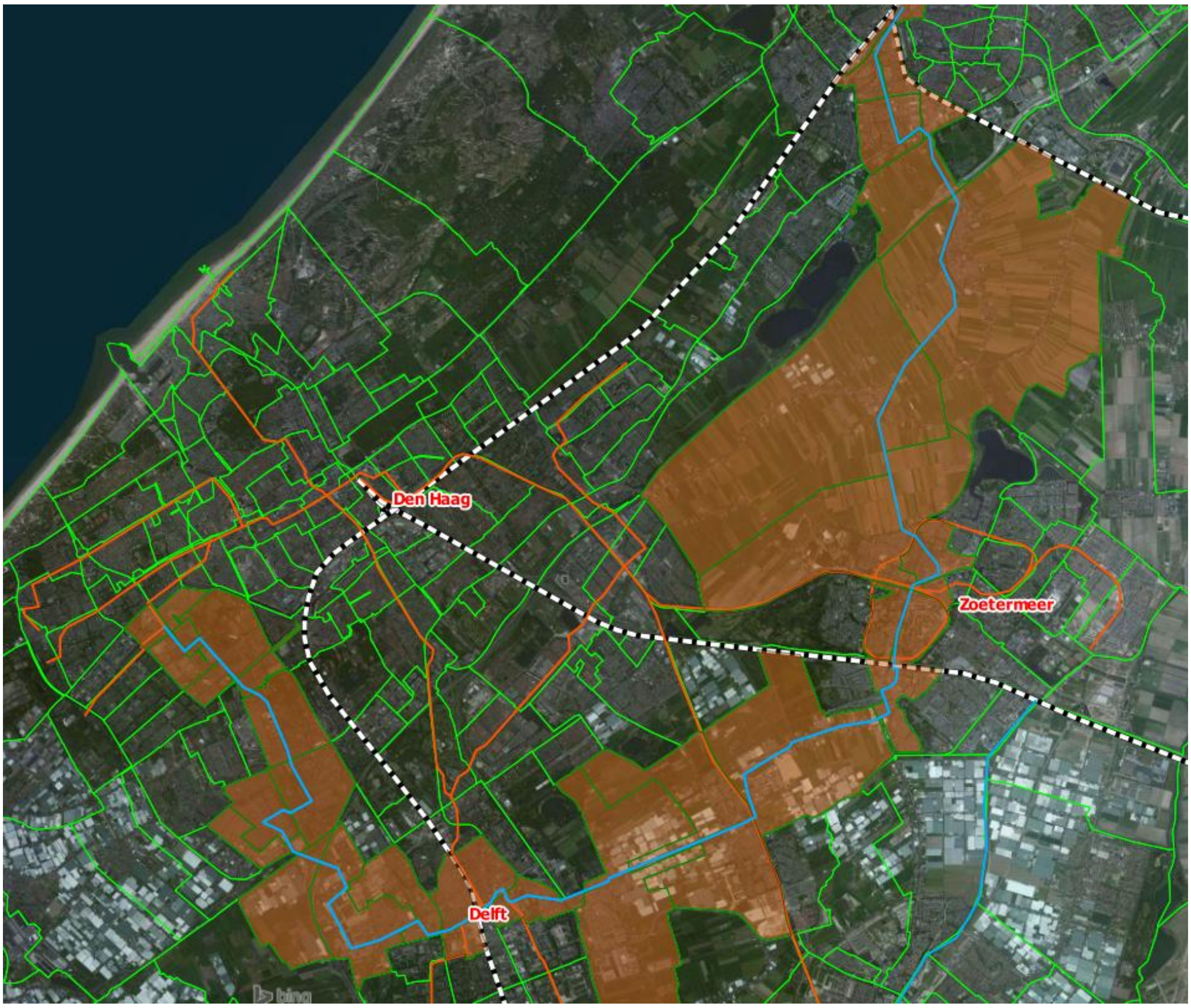

Figure 7-35 Project 8 aggregate zones

All zones together the following results are produced:

Table 7-9 Number of passengers 2030 RC PT and 2030 RC PT+ project 8

	2030 RC PT	2030 RC PT+	Extra
Number of BTM passengers of zones connected to BRT-line	20.296	21.204	908

7.10.2 Project specific conclusions

The BRT-service has a frequency of 4 times per, from 6h till 23h. The number of seats per bus is 32, so in total 4.352 seats per day. The average occupancy rate will then be 21% in the RC-scenario and 25% in the GE-scenario (the overall occupancy rate of Den Haag bus services is 15,8%). Based on the average occupancy the new bus line is supposed to be feasible.

7.11 PROJECT 9: TRAM LINE EXTENSION ROTTERDAM THE HAGUE AIRPORT

Project 9 is the tram line extension of Rotterdam tram 25 to the Airport.

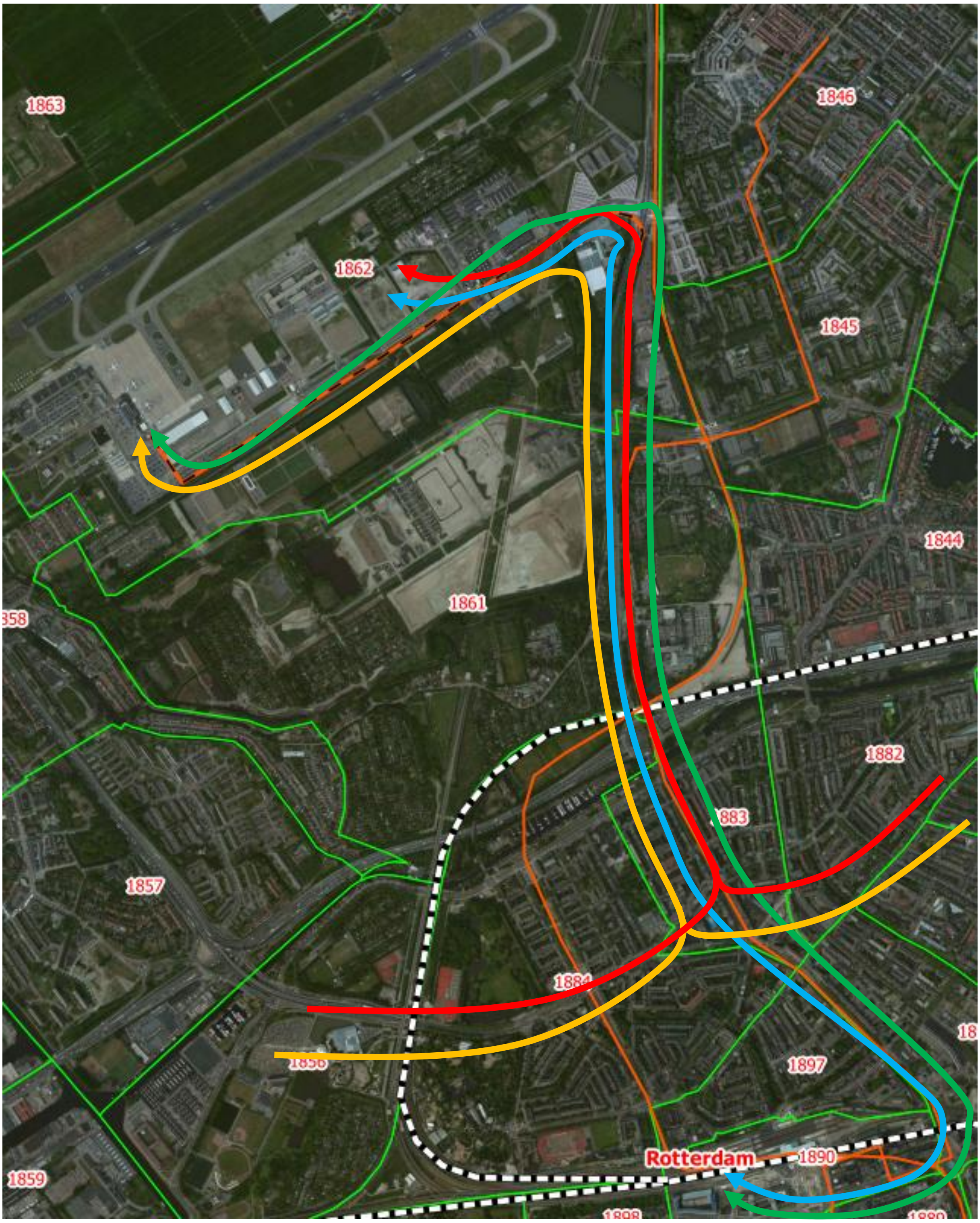

Figure 7-36 Project 9 aggregate zones

7.11.1 Line use

Passengers on the tram line to the airport can be divided over 4 types of passengers:

- Type A: passengers travelling to and from the zones connected to the tram line as main transport (red arrow).

- Type B: passengers using the tram line as access or egress transport to travel to the train station of Rotterdam Centraal (blue arrow).
- Type C: passengers travelling to and from the airport by tram as main transport (yellow arrow).
- Type D: passengers using the tram line as access or egress transport to travel between the train station of Rotterdam Centraal and the Airport (green arrow).

7.11.1.1 Passenger type A

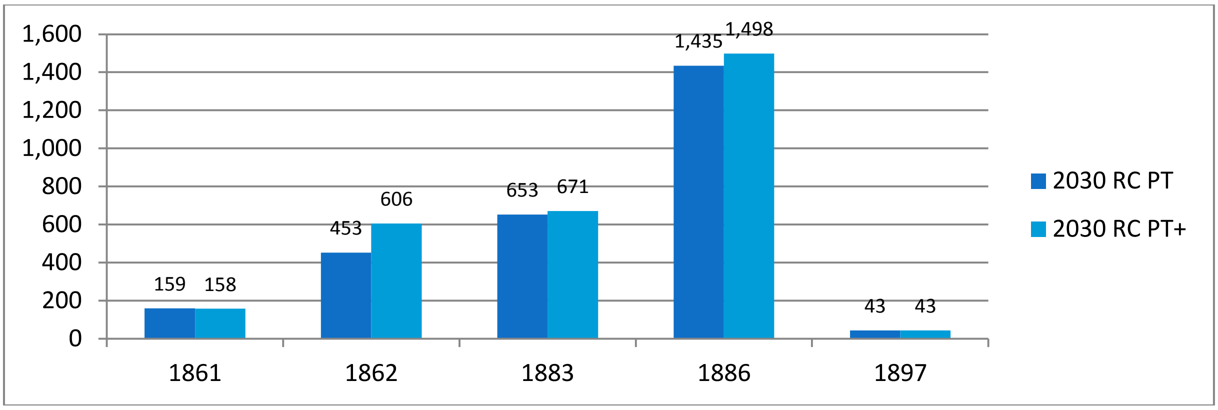

Figure 7-37 Number of passengers 2030 RC PT and 2030 RC PT+ project 9

In total at least 233 new passengers of type A will use the tram line.

7.11.1.2 Passenger type B

In total 402 passengers will use the tramline as access/egress transport for the train station of Rotterdam Centraal.

7.11.1.3 Passenger type C

In total 23 new BTM passengers will be produced by enhancing the airport accessibility.

7.11.1.4 Passenger type D

In total 264 new BTM passengers will be produced by enhancing the airport accessibility.

7.11.2 Project specific conclusions and remarks

Total number of new type A passengers:	233
Total number of new type B passengers:	402
Total number of new type C passengers:	23
Total number of new type D passengers:	264

The total number of passengers per day using the new metro line is thus 922. In the GE-scenario this is 1.098.

Occupancy

The new tramline to the airport will have a frequency of 3 times per during the whole day (6-24h). The number of seats per train is 56, so in total 12.096 seats per day. This gives an average occupancy rate of only 8% in the RC-scenario and 9% in the GE-scenario (the overall occupancy rate of Rotterdam tram is 21,2%). Based on the average occupancy the demand for the new tram line is assessed as too low.

7.12 CONCLUSION

Now that the 9 projects of the case study have prepared, modeled and reviewed the final policy advises can be drawn. These are mentioned below:

Table 7-10 Project assessment summary

Project	Subproject		Assessment summary
Project 1	Program high frequent train services Rotterdam – Den Haag	✓	Feasible; enough demand for train travelers seems to be generated.
	Station of Delft Sion		Feasible, only if the residential area of Rijswijk Zuid will be fully constructed. It is advised to realize this station already in the early phase, in order to avoid irreversible trends on car use.
Project 2	Metro Rotterdam Kralingse Zoom – Rotterdam Stadion – Zuidplein – Schiedam	✓	Feasible; enough demand for BTM travelers seems to be generated.
	Station of Rotterdam Stadionpark	✓	Feasible; the amount of daily passengers expected to use this station is far more than the average guideline of 1,000 passengers per day NS uses.
Project 3	Conversion RijnGouwLijn	?	Doubtful; large decrease in the number of public transport users is computed by the NRM. This decrease can be explained by the unfairly low preference for the light rail mode. Further research is suggested (e.g. with use of a local model).
Project 4	Conversion Hoekse Lijn	?	Doubtful; a large decrease in the number of public transport users is computed by the NRM. This decrease can be explained by the unfairly low preference for the light rail mode. Further research is suggested (e.g. with use of a local model).
Project 5	Metro Nesselande - Gouda	✗	Infeasible; the amount of expected passengers on the line is assessed as to low. A bus rapid transit system between Nesselande and Gouda Gouweknoop will be more appropriate.
	Station of Gouda Gouweknoop	✓	Feasible; the train station of Gouda Gouweknoop is supposed to attract enough daily passengers, even without a connecting BTM service.
Project 6	Tram line Schiedam Kethel	?	Doubtful; the amount of passengers expected on this tramline extension are about equal to the average occupancy rate of the Rotterdam trams. Since the (operation) costs of a tram extension are expected to be lower than the costs for a new tram connection, the project is assessed as probably feasible. Further research is suggested (e.g. with use of a local model).
	Station of Schiedam Kethel	✓	Feasible; due to low uncertainties in spatial developments (the residential area of Schiedam Kethel has already been built); this train station is assessed as feasible.
Project 7	Light rail line Zoetermeer Bleizo	?	Doubtful; the light rail line extension to Bleizo will be most probably used by visitors to the recreational facilities planned nearby. Since the NRM generates too little trip attraction to such facilities, this might be the explanation for the low demand. Further research is suggested (e.g. with use of a model which simulates recreational facilities in better way).
	Station of Bleizo	?	Doubtful; the trip production and attraction to the station of Bleizo is about equal to the minimum number of passengers required by NS to operate the station. This might as well be the explained by the limited attraction to the recreational facilities nearby. Further research is suggested (e.g. with use of a model which simulates recreational facilities in better way).

Project	Subproject		Assessment summary
Project 8	BRT Den Haag – Delft – Zoetermeer – Leiden	✓	Feasible; the BRT system between Den Haag and Leiden will attract enough passengers per day in order to reach an occupancy equal to the average bus occupancy for the Den Haag region.
Project 9	Tram line Rotterdam Airport	✗	Infeasible; the occupancy of the tram line between Rotterdam central station and Rotterdam The Hague Airport simulated by the NRM is assessed as too low.

PART III GENERAL CONCLUSIONS

8 CONCLUSIONS AND RECOMMENDATIONS

8.1 GENERALIZABILITY OF THE CASE STUDY

As mentioned before transit oriented development has been used as a method for planning spatial developments and public transport network expansions only for small areas, like city districts. StedenbaanPlus is actually an overall name for multiple different small TOD projects at close proximity from each other. All of these projects differ from each other in multiple ways. It is about new train stations with different service levels and on different railway lines. It is about new metro, light rail and tram expansions and conversions of existing railway lines into light rail. At last it is about new bus rapid transit systems connecting other major networks.

Not only the public transport adjustments differ from each other, the spatial developments appear in multiple varieties as well; residential and industrial sites, differences in employment sector, average household size, education level, car possession and income are observable throughout all projects taken into account in the case study.

The external factors discussed in chapter 3 also do not apply for the StedenbaanPlus project alone. They are factors which are applicable on all spatial and network developments, even in the case when the developments do not take place based on the transit oriented development methodology.

Based on the diversity of the projects assessed within the case study, the conclusions about the results are therefore considered to be generally applicable for all TOD projects in and outside the Randstad south wing.

8.2 CONCLUSIONS

The main research question was:

> *What is the relation between spatial developments and public transport use in case of application of TOD for StedenbaanPlus and can this relation be generalized for other projects as well?*

As discussed above the diversities in the StedenbaanPlus infrastructural adjustments and spatial developments lead to the conclusion that the StedenbaanPlus case shows generalizable results which can be used for other purposes as well.

The relation between spatial developments and public transport enhancements appeared to be built up out of two different elements. Spatial developments have a direct influence on public transport use and public transport enhancements have a direct effect on public transport use as well. These two effects together form the case of TOD and showed to strengthen each other. The effects have been quantified using the StedenbaanPlus case study and the NRM in order to produce, attract and distribute trips.

8.2.1 The effect of spatial developments on public transport use

The effect of spatial developments on public transport use have been determined by simulating both trip production and distribution for the case of no new spatial projects and the case of building all of the planned spatial projects. Based on all projects evaluated, the following values have been derived from the model results:

- Maximum number of PT trips per household: 0,917
- Average number of PT trips per household: 0,236
- Minimum number of PT trips per household: 0,001
- Standard deviation: 0,072

The average number of PT trips per household, based on historic statistics (Centraal Bureau voor de Statistiek, 2012) is 0,20 for normal area's and 0,24 for high density areas. It can therefore be concluded that in the case of spatial developments at close proximity from public transport network access points the trip production is in line with high density areas.

8.2.2 The effect of public transport enhancements on public transport use

The effect of enhanced public transport has been expressed as accessibility quality. Accessibility quality is defined as the minimum travel time for train and BTM mode in minutes from one zone to reach all other zones (thus the lower the better). Based on the evaluated zones (the ones where spatial projects are developed) the following values have been derived from the model results:

- Maximum number of PT trips per minute less accessibility quality: 0,545
- Average number of PT trips per minute less accessibility quality: 0,158
- Minimum number of PT trips per minute less accessibility quality: 0,034
- Standard deviation: 0,130

8.2.3 The success of TOD for StedenbaanPlus

In the case of enhanced public transport combined with spatial developments in accordance with Hansen's theory the two effects discussed above strengthen each other. The figures below represent the number of public transport trips for the spatial development zones only.

- Total number of PT trips in 2030 RC PT : 24,133
- Total number of PT trips in 2030 RC PT+: 26,872 (+11.3%)
- Total number of PT trips in 2030 RC PT Hansen: 25,762 (+6.8%)

Based on the figures above the total number of trips expected in the RC PT+ Hansen situation would be 1.113 x 1.068 x 24,133 = 28,687 PT trips per day. Model calculations showed similar results: 28,912 PT trips per day.

Since the model is does not include behavioral developments/adaptations, these effects are not modeled. This means that if in some zones with good public transport accessibility a trend is developed of preferring public transport over car use, people are more likely to travel by public transport then they would when they were the only one in that zone. The success of TOD can be partly explained by these behavioral adaptations, but it can also work right against the success. If the public transport enhancement is carried out too late, early residents are already designated to other modes like car and bike. New residents will take over this behavior and changing it after implementation of enhanced public transport will be very hard.

8.2.4 Other influence factors

Besides enhanced public transport and spatial downsizing other influence factors have been defined and quantified in the case study. These effects are discussed below.

The effect of the introduction of road pricing appeared to be very small in all projects assessed. The average effect on the total number of public transport trips (train and BTM) was somewhere in between +0% and +0.45%. Therefore the effect of road pricing is considered to be negligible.

The second other influence factor assessed are the increasing public transport rates. All model results for the different projects show an average decrease of 2,5% in the number of train trips in the Randstad south wing and a decrease of about 1,7% for BTM mode.

The last secondary effect taken into account in the case study is the influence of the WLO scenario. The WLO scenario shows the transport prognoses for two different economic scenarios; Regional Community and Global Economy. Although all most of the influences are assessed based on the RC scenario, the GE scenario is modeled for each case as well. Model results have shown an average increase in the number of train trips of +19% and +17% in the number of BTM trips. Since the current WLO prospective tends more towards the RC scenario (Welfare index of 79% RC and 21% GE), the actual number of train trips is expected to be about 4% higher and the number of BTM trips about 3,6% higher than the values derived in the RC scenario.

8.2.5 Remarks

The conclusion above is based on the results produced by the NRM model. Although the model is supposed to represent the values in reality as much as possible, some remarks must be made which might have influence on the conclusions drawn specifically for the infrastructural projects discussed in chapter 8.

The first point which might have influence on the demand for public transport is the way how public transport is modeled by the NRM. The calculation of accessibility quality (for BTM) is done externally (in CUBE), which leads to the fact that the NRM does not know how public transport lines are routed and what alternative parallel lines exist. This means that in fact there is an all-or-nothing assignment to the line with the shortest travel time, while in reality some travelers might also choose for the slower route, which leads to less demand for the faster line. Besides this, the slower line might be able to add a higher frequency to the route in question, which might cause shifts between BTM and other modes (e.g. when a route is service by a frequent tram service as well as a frequent bus service, using public transport might become more interesting for car users than in the case of only the tram connection).

A second remark must be placed on the fact that the NRM considers all modes of BTM as equal modes, while in reality preferences show major differences for modes like metro, tram, light rail and bus. This means that in the case when a bus service is replaced by a tram service (without changing frequency and travel times), the model does not distribute trips differently and the amount of passengers choosing for the BTM mode will stay the same. In reality travelers have shown to have different preferences for all different BTM modes. For an example a metro connection is more likely to be chosen on the same route than a bus service. Although the NRM does distinguish mode preference for BTM and train, the projects where heavy rail was converted into light rail showed a large decrease in demand for BTM on these relations. This is most probably caused by the lower preference for BTM than for train, but in reality the preference for light rail might be much higher and even approaching the train preference.

Another interesting point is the way public transport alternatives are rated, especially the elasticity's. Research into the validity of the NRM showed that especially the elasticity's for BTM are much higher than the values found in literature (Haaijer, et al., 2012). The high elasticity's are explained by the fact that they have been determined using travel distances based on the free flow car network instead of the BTM level of services distances. Using the BTM level of service distances will lead to lower elasticity's, which are more in line with the ones found in literature. The effect of a low price and time elasticity manifests itself in a weak correlation between public transport price rates and public transport use. This effect showed up in the assessment of the price dependency and is therefore in line with the expected.

Future public transport demand is based on simulating the demand for the base year and multiplying it with a certain pivot value, which is based on elasticity's and variables. The result is then the future demand. This demand of the base year is determined by combining on the one hand predictions and on the other hand counts on real life demand. A disadvantage of the NRM is there are very little counts used for train mode (only the number of passengers for the largest 10 train stations) and no counts at all for the BTM mode. This might lead to incorrect simulation of the base year flows and thus also incorrect simulation of the future year prognosis.

Some of the projects evaluated (Rotterdam Stadionpark and Bleizo) are related to some recreational spatial developments, like sports facilities and shopping centers. These facilities are represented in the zonal data by the number of retail jobs located in that particular zone. In reality recreational facilities are not always directly related to the number of retail jobs and in most of the cases the rate between the number of retail jobs and the number of attracted travelers differs per situation. This means that simulation of such facilities is not sufficiently similar to reality. As a consequence simulated public transport demands may turn out to be lower than the actual demand will be. Most important conclusion is thus that the NRM is insufficiently suitable for simulation of transport demands to recreational facilities.

8.3 RECOMMENDATIONS

8.3.1 Improvements on the used methodology

The methodology used in this research project is the simulation of transport demand for multiple modes using a regional transport model. Occupancy rates for BTM mode have been derived by aggregating zones into larger regions and evaluating the additional number of BTM trips between these regions. Another way to do this would be building a new distribution model which distributes the BTM trips produced by the NRM over the available BTM lines. Advantage of this method is that the occupancy rates per line can be determined in a much more accurate way and distinctions between metro, tram, light rail and bus use can be observed. Disadvantage for this method are the extra amount of data and variables needed, in order to make a good representative distribution.

The occupancy rates for the mode train have been derived in a similar way. Setting up a new distribution model was not necessary, since the program TRANS from ProRail is already capable of distributing OD matrix over the corresponding lining and timetable. This has led to comprehensive insights into the actual occupancy rate per route segment, individual service and station (stop).

8.3.2 Further research

The main purpose of this project was to look into the relationship between spatial developments, public transport enhancements and public transport use. This relation has been assessed using multiple TOD projects, which have also been assessed individually. As mentioned above the BTM results have been derived using aggregate zoning. Further study can be performed into the individual projects using other, for an example local, models in order to retrieve more detailed data on public transport use and occupancy.

Another restriction in this project was the impossibility of simulating the effect of the abolishing of the student public transport travel card. Since no tariff distinction is made for specifically students, effects of this change cannot be determined with the used version of the NRM. Rijkswaterstaat has indicated that this distinction will be made possible in the next version, so a nice research proposal will then be determining the effect with the NRM and assessing the validity.

8.3.3 Social and scientific relevance

This thesis is especially socially relevant for the specific projects. The rough indication of the feasibility of the proposed 9 projects has been determined. With this indication it can be taken into consideration whether or not to perform additional research or to assess the project as infeasible. As a result the available budget for further research and project preparation can be used in a more efficient way.

The scientific relevance expresses itself in further insight into model elasticity's and shortcomings. The remarks made above show where the model can be further improved and which future model developments are advised.

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LIST OF ABBREVIATIONS

Table 8-1List of abbreviations

Abbreviation	*English explanation*	*Dutch explanation*
ACC	Access transport	Voortransport
BRT	Bus Rapid Transit system	Hoogwaardig Openbaar Vervoer bus
BTM	Bus/Tram/Metro	Bus/Tram/Metro
EGR	Egress transport	Natransport
GE	Global economy scenario	Global economy scenario
HST	High speed train	Hogesnelheidstrein
HTM	HTM Personenvervoer N.V.	HTM Personenvervoer N.V.
I&M	Ministry of infrastructure and environment	Ministerie van infrastructuur en mileu
IC	Intercity train	Intercity
LMS	National Model System	Landelijk Model Systeem
LOS	Level of service	Bereikbaarheidskwaliteit
LR	Light rail	Light rail
LRT	Light rail transit	Light rail systeem
LT	Local train	Stoptrein/sprinter
MIRT	Multi-annual program for infrastructure, space and transport	Meerjarenprogramma Infrastructuur, Ruimte en Transport.
MRDH	Metropolitan region of Rotterdam and Den Haag	Metropoolregio Rotterdam – Den Haag
NRM (West)	Dutch Regional Model (West-region)	Nederlands Regionaal Model (regio west)
NS	Dutch Railways	Nederlandse Spoorwegen
OD-pair	Origen-destination pair	Herkomst-bestemmingspaar
OV	Public transport	Openbaar vervoer
P10%	Public transport price rates + 10%	Openbaar vervoer tarieven +10%
PC4 zone	4-digit postal code zone	Postcode-4 gebied
PFM	Pay for mobility (road pricing)	Betalen voor mobiliteit (rekening rijden)
PFP	Pay for possession (Purchase tax and road tax)	Betalen voor bezit (BPM en wegenbelasting)
PHS	Program of high-frequent train operation	Programma hoogfrequent spoor
PT	Public Transport as in NRM RC	Openbaar vervoer
PT+	Enhanced public transport	Verbeterd openbaar vervoer
RC	Regional community scenario	Regional community scenario
RET	Rotterdamse Elektrische Tram N.V.	Rotterdamse Elektrische Tram N.V.
RWS	Rijkswaterstaat	Rijkswaterstaat
SP	Spatial data as in NRM RC-scenario	Ruimtelijke gegevens als in RC-scenario van het NRM
SGH	Urban distric of Den Haag	Stadsgewest Haaglanden
SP-	Spatial data downsized with actual program.	Ruimtelijke gegevens naar beneden gesteld met de werkelijke ontwikkelingsplannen.
SRM	Train stops relation matrix	Stationsrelatiematrix
SRR	Urban distric of Rotterdam	Stadsregio Rotterdam
TOD	Transit Oriented Development	OV-georienteerde ontwikkeling
TPI	Train network and timetable file	Trein network en dienstregelingsbestand
TRP	Trips	Reizen
WLO	Welfare and environmental scenarios	Welvaart en leefomgeving scenarios.

A. MODEL STUDY

Humans always want to be one step ahead of the current present and try to predict almost everything. Sometimes this is done via fortunetellers and prophets, but if one wants to have more reliable predictions, scientifically tested future models often offer a solution. Some of these models try to predict future economic situations, some of them demographic developments and others predict future transport use. This appendix discusses the 12 most used transport models.

TIGRIS (Zondag, Pieters, & Schoemakers, TIGRIS, 2004)
TIGRIS is a model which predicts how traffic, infrastructure and land-use will influence each other in the next few years. TIGRIS will answer questions as which live and work locations will be most favorable to developed due to the good accessibility? Or the other way around: which infrastructural adaptations should be made in order to enhance the climate for location choice?
TIGRIS stands for "transport infrastructuur grondgebruik interactie simulatie" (transport, infrastructure and land use interaction model). TIGRIS calculates these relations from one year to another, which means that the output of year $t-1$ is the input for the year t and requires the following input data:

- A national growth scenario (demographic details, population size, household size, car possession and costs for car and public transport use)
- Zonal details (location of inhabitants, work places, amenities and parking costs)
- Network details (infrastructure, types, capacities, speeds).

The different scenarios are composed of changes in one of the variables above, like new residential areas, new infrastructure or price adaptations. The output of TIGRIS comes in two ways:

- Indicator graphs: the developments for predefined indicators (inhabitants, work places, mobility etc.) are shown per zone or per group of zones.
- Maps: for the same predefined indicators maps are generated which show the developments per year, per period or the differences per year between different scenarios.

TIGRIS can be applied on both a regional as a national scale and has a time horizon of about 20 to 30 years. The model can be used for policy development and is easy to use. The runtime is only a few hours per scenario and the costs vary between €55.000,- and €80.000.-.

SMILE (Clement, 2002)
SMILE predicts future trends in logistics and freight transport and especially the mutual relations between policy, economy and freight transport. SMILE stands for Strategisch Model Integrale Logistiek en Evaluatie (strategic model integral logistic and evaluation) and constantly tries to find the equilibrium between economic demand and logistic supply. This process starts with simulating the future demand for freight and goods by looking at the economic future prospective. Second step is to compare this demand with the available logistic supply and to evaluate the effects on price and quality. These relations become clear because, compared to many other models, especially the logistic choices a shipper can make have been built in the model.

A large part of the static model input is based on the international and regional economic structure, international trade patterns and production and consumption structures in the base year. The variable model inputs policy, economic and demographic developments. Also other input as a (virtual) multimodal network including transshipment facilities, and shippers costs of transportation, handling, storage and time have been added to the model.
Output of SMILE are year totals for indicators as production, consumption, work places, trade, distribution, mobility and costs. SMILE is an easy-to-use model and costs about €20.000,- to €50.000,- to use, strongly dependent of the amount of additional input data needed. The time horizon is up to 25 years and the run time is about 12 hours.

TEM (Rijkswaterstaat, 2006)
The Transport Economic Model describes the demand for freight transport to, from and in the Netherlands, based on assumptions on regional-economic prospectives domestically and abroad. Starting point is a database with all details about freight transport for the base year. By coupling the economic growth to the database with freight transportation figures, the future demand for transport can be derived, divided over all available modes. The runtime of TEM is only a few minutes, costs vary between €20.000,- and €50.000,- and the time horizon is about 20 years.

MOBILEC (Clement, 2002)
Predicting the relations between transport policy and mobility is what MOBILEC does. The model describes the relation between economy, mobility, infrastructure and other regional characteristics, since the consumption of mobility is dependent of economic growth. The model distinguishes 40 regions within the Netherlands. The input of MOBILEC are technological innovations, production structures, population size, urbanization and loan rates. The output are changes in the loading and occupancy rates, changes in travel costs per unit, changes in infrastructure capacities and changes in travel time and growth in public transport.
MOBILEC is not openly available, but is only used for policy purposes by Rijkswaterstaat.

MOVE (Clement, 2002)
MOVE is a model which investigates developments in mobility. MOVE stands for Mobiliteitsverkenner (Mobility scout) and elaborates prognoses about the mobility of cargo and passenger transport by using an elasticity model, broken down to mode, motive, day and time-of-day. Twelve variables are used input: demography, car possession, employment, national income, private income, car costs, road network, travel times per public transport, public transport costs and fiscal policy. Output is then de daily transport performance. Costs of MOVE are about €250,- and the model is easy to use.

Scenarioverkenner (Ministerie van Verkeer en Waterstaat, 1999)
The scenarioverkenner (scenario scout) is an easy to use instrument which calculates in about half a day consistent scenario's for long term purposes. The time horizon is 15 to 60 years. The input variables of the scenarioverkenner are demography, social-economic data, social-cultural data, spatial developments, technology, infrastructure and pricing. The output consists of the transport performance, car possession, time and money expenditures on transport and accessibility (travel times and speeds). The model can be bought for about €1.000,- and can be used by anyone.

FACTS (Ministerie van Verkeer en Waterstaat, 1996)
FACTS stands for Forecasting Air pollution by Car Traffic Simulation. Input of FACTS is national income, private income, demographic data, fuel costs, fuel use, car costs and emission laws. Output is car possession, car emission and car use in 18 classes, inhabitants in 18 classes and distinction in private and business cars. The model has a time horizon of 15 to 35 years. The model is not available for use by externs.

NRM (Rijkswaterstaat, 2011)
The NRM, the Nederlands Regional Model (Dutch regional model) is a toolbox which allows users to build strategic passengers transport models for four regions (North, East, South and West). The NRM is developed by Rijkswaterstaat in 1989 and since then constantly updated. The input is very extensive: social-economic data, spatial developments, infrastructure, demographic details, social, economic data, passenger networks, freight transport, car possession and foreign data. Numerous variables are built in for calibrating the model. The output of the NRM are matrices for 7 motives, 5 modes and 3 periods. Compared to other models the NRM presents the best results for regional purposes. The time horizon of the NRM is 10 to 20 years. The NRM can only be used by externs with permission from Rijkswaterstaat.

LMS (Rijkswaterstaat, 2011)
The LMS, Landelijk Model Systeem (National model system) is the big brother of the NRM. The NRM is built with the same 'toolbox', only with the difference that it can be used for national purposes instead of regional. In other words: the NRM is a simplified version of the four regional NRM models together. The LMS has the same input and output variables and the same time horizon. The costs for using the LMS vary between €5.000,- and €20.000,-.

Nationaal Verkeersmodel (Goudappel Coffeng, 2014)
The NVM, National Verkeersmodel, developed by Goudappel Coffeng is a model which can be best used for region public transport studies. Based on the WLO-scenarios of the CPB, (mid)long term studies can be performed on public transport use. The figures for the base year are based on actual car use and over a thousand public transport counts. The time horizon of the NVM is 10 to 20 years and the level of detail is PC4. Costs for using the NVM vary between €10.000,- and €20.000,-.

RVMK (Stadsregio Rotterdam, 2006)
The RVMK, regionale verkeers- en milieukaart (regional traffic and environmental map) is a model used by the urban district of Rotterdam and the municipalities within this region. It simulates the effects of spatial developments on transport and the changes in the use of roads, railways, trams and metro's as a result of new infrastructure. The model has been developed in the nineties, but in 2006 completely refurbished, especially for public transport studies. The model is owned by the urban district of Rotterdam and managed by the municipality of Rotterdam. The model has a time horizon of 20 years and can either be executed by the municipality of Rotterdam, Goudappel Coffeng or AGV.

Verkeers- en vervoermodel Haaglanden (Stadsgewest Haaglanden, 2011)
The traffic and transport model Haaglanden (owned by the urban district of Haaglanden) calculates the level of mobility for the Haaglanden area, for different modes and purposes. Inputs for the model are the social-economic details per zone. The base year is 2009 and the time horizon is 20 years.

B. TRIP OVERVIEW

	# TRIPS / DAY				
Region / Scenario	**CAR**	**TRAIN**	**BTM**	**BIKE**	**WALK**
PZH					
2004	**1,160,107**	**83,458**	**101,549**	**884,608**	**664,867**
HT	1,155,938	83,458	80,918	859,760	632,670
VT_NT	4,169	0	20,631	24,848	32,197
2030 RC PT	**1,207,936**	**87,105**	**84,641**	**740,931**	**573,046**
HT	1,203,717	87,105	65,146	714,135	538,016
VT_NT	4,218	0	19,495	26,796	35,031
2030 RC PT+	**1,207,853**	**80,525**	**90,494**	**738,228**	**567,158**
HT	1,203,646	80,525	70,142	713,421	537,566
VT_NT	4,207	0	20,352	24,807	29,593
2030 RC PT SP-	**1,192,198**	**85,648**	**83,373**	**727,839**	**563,535**
HT	1,188,055	85,648	64,128	701,648	529,005
VT_NT	4,143	0	19,246	26,190	34,529
2030 RC PT HANSEN	**1,208,986**	**79,638**	**83,029**	**706,872**	**518,583**
HT	1,204,658	79,638	64,424	681,552	488,824
VT_NT	4,328	0	18,605	25,320	29,760
SGH					
2004	**984,590**	**112,690**	**113,287**	**831,621**	**589,439**
HT	981,132	112,690	88,199	803,026	534,938
VT_NT	3,458	0	25,087	28,595	54,502
2030 RC PT	**1,084,597**	**107,356**	**104,194**	**733,086**	**526,792**
HT	1,081,161	107,356	79,379	705,920	475,855
VT_NT	3,437	0	24,815	27,166	50,937
2030 RC PT+	**1,083,309**	**114,581**	**105,202**	**732,575**	**530,207**
HT	1,079,608	114,581	78,779	703,781	475,629
VT_NT	3,701	0	26,423	28,794	54,579
2030 RC PT SP-	**1,059,399**	**105,024**	**101,461**	**714,847**	**514,133**
HT	1,056,079	105,024	77,145	688,357	464,198
VT_NT	3,319	0	24,316	26,490	49,935
2030 RC PT HANSEN	**1,082,666**	**114,739**	**104,164**	**702,157**	**490,648**
HT	1,078,971	114,739	78,078	673,215	435,712
VT_NT	3,695	0	26,085	28,941	54,936
SRR					
2004	**1,171,967**	**125,993**	**146,477**	**952,167**	**707,973**
HT	1,168,073	125,993	116,050	922,451	647,387
VT_NT	3,894	0	30,427	29,717	60,585
2030 RC PT	**1,245,323**	**117,816**	**122,228**	**821,786**	**604,518**
HT	1,241,215	117,816	95,116	793,454	547,672
VT_NT	4,108	0	27,112	28,332	56,846
2030 RC PT+	**1,243,080**	**127,133**	**129,854**	**818,739**	**606,297**
HT	1,238,435	127,133	97,919	789,089	546,989
VT_NT	4,645	0	31,935	29,650	59,308

Region / Scenario	# TRIPS / DAY CAR	TRAIN	BTM	BIKE	WALK
2030 RC PT SP-	**1,231,446**	**116,338**	**120,368**	**812,683**	**598,800**
HT	1,227,406	116,338	93,665	784,649	542,635
VT_NT	4,040	0	26,702	28,034	56,164
2030 RC PT HANSEN	**1,243,381**	**125,012**	**122,251**	**786,775**	**560,955**
HT	1,238,594	125,012	93,402	756,552	501,466
VT_NT	4,787	0	28,849	30,223	59,489

HT = Main transport
VT_NT = Access/egress transport