Because they're worth it.

Scenarios and benefits of infrastructure investments

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Because they’re worth it.

Research on the influence of scenario components on benefits of infrastructure investments

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Samenvatting

Infrastructuur en de bijbehorende regionale mobiliteit en bereikbaarheid zijn een noodzakelijke voorwaarde voor het maatschappelijk welzijn. Zij leveren toegang tot werk, voedsel, winkels, gezondheidszorg en sociale voorzieningen, en tot bijvoorbeeld familie en vrienden. Daarnaast is bereikbaarheid van bedrijven voor leveranciers, klanten en werknemers belangrijk voor de economie. Om de bereikbaarheid te verbeteren en daarmee de concurrentiekracht van Nederland investeert de overheid in het hoofdwegennet. Dit is belangrijk maar de investeringen hebben ook nadelen. Ze zijn erg duur en het kost veel tijd om plannen te realiseren. Daarom moeten projecten ver vooruit gepland worden, terwijl de toekomst onzeker is. Daarbij komt dat de rentabiliteit van de investeringen sterk verschilt tussen de verschillende projecten en het aanleggen van wegen niet altijd een positief welvaartseffect heeft. Beleidsmakers hebben bij het maken van keuzes en het plannen van investeringen dus te maken met grote onzekerheid.

Voor het plannen van infrastructuurprojecten heeft het ministerie van Infrastructuur en Milieu richtlijnen ontwikkeld. Deze richtlijnen schrijven voor dat de robuustheid van de aannames voor toekomstige ontwikkelingen moeten worden onderzocht. Hiervoor wordt het gebruik van meerdere scenario's aanbevolen, namelijk een hoog en laag economisch scenario. Op dit moment zijn dat respectievelijk 'Global Economy' (GE) en 'Regional Communities' (RC) voor de zichtjaren 2020, 2030 en 2040.

Deze scenario's zijn in 2006 ontwikkeld door het Centraal Planbureau, het Milieu- en Natuurplanbureau en het Ruimtelijk Planbureau in het rapport Welvaart en Leefomgeving (WLO) en zijn gebaseerd op twee belangrijke en onzekere ontwikkelingen. Dit zijn de bereidheid tot internationale samenwerking en de mate van hervormingen in de publieke sector. In het scenario GE breidt de Europese Unie zich verder uit naar het oosten. Het scenario wordt gekenmerkt door een hoge bevolkingsgroei (vooral door toename van het aantal immigranten), sterke individualisering en hoge economische groei. Als gevolg hiervan neemt de mobiliteit sterk toe, waardoor er meer files en knelpunten ontstaan. In het scenario RC houden landen hun eigen soevereiniteit en de publieke sector zal in dit scenario nauwelijks worden hervormd. Hierbij groeit de arbeidsproductiviteit niet, is de economische groei laag en de werkloosheid relatief hoog. Daarnaast is er in dit scenario een daling van de bevolking na 2020 en de invloed van individualisering is beperkt. De groei van de mobiliteit en de files zijn in het scenario RC veel minder waardoor investeringen in het wegennet minder rendabel zullen zijn.

De overheid schrijft voor dat investeringen voor het hoofdwegennet worden geëvalueerd met behulp van een kosten-baten analyse. De belangrijkste baten zijn hierin de reistijdbaten. De reistijdbaten zijn het welvaartseffect van kortere reistijden of kortere routes. Dankzij de uitbreiding van het wegennet zullen er minder files staan en zijn mensen eerder op hun bestemming. De reistijdwaardering is de economische waarde die wordt toegekend aan bijvoorbeeld een uur reistijdwinst en wordt gebruikt om de reistijdbaten te berekenen.

Onderzoek

Om risico's bij investeringen in infrastructuur goed inzichtelijk te maken is het belangrijk om meer inzicht te verkrijgen over de onzekerheid in de scenario's, van berekende baten van infrastructuurinvesteringen. Daarmee kan een goede strategie geformuleerd worden die goed met deze risico's om kan gaan. Het risico van over-investeren is hoog en de kosten van een meer zorgvuldige besluitvorming zullen in toenemende mate opwegen tegen dit risico. Dit onderzoek heeft tot doel inzicht te verschaffen over de onzekerheid van de reistijdbaten van investeringen in het hoofdwegennet door het analyseren van hun gevoeligheid voor variatie in specifieke scenario instellingen. De onderzoeksvraag is:

Wat zijn de belangrijkste determinanten in scenario's voor de reistijdbaten van investeringen in infrastructuur, in hoeverre beïnvloeden ze hen en hoe onzeker zijn ze?

Methode

Om de hoofdvraag te beantwoorden is het onderzoek in drie onderdelen opgedeeld. De onderdelen zijn:

- scenario's en onzekerheden
- mobiliteit en gevoeligheid
- baten van een investeringspakket

In het eerste deel van het onderzoek, over scenario's en onzekerheden, is geanalyseerd van welke factoren de mobiliteit op middellange en lange termijn (20-40 jaar) afhankelijk is. Daarbij is een selectie gemaakt van variabelen die binnen de scenarioaanpak vallen. In scenario's worden voornamelijk demografische en economische ontwikkelingen beschreven. Andere ontwikkelingen (zoals technologie) zijn vaak moeilijk te voorspellen of zijn juist onderwerp van de analyse (zoals beleid). Vervolgens wordt ingezoomd op de scenario's en wordt de samenhang tussen de scenariovariabelen beschouwd. De onderlinge samenhang tussen variabelen komt tot uiting in de scenario componenten, zoals de huishoudensgrootte, het gemiddeld aantal auto's per huishouden of het percentage werkenden van de potentiele beroepsbevolking. In dit onderzoek is een selectie gemaakt van de belangrijkste scenario componenten voor mobiliteit. Tenslotte is de onzekerheid van deze scenario componenten op globale wijze in kaart gebracht. Dit is belangrijk omdat meer onzekere ontwikkelingen meer invloed hebben op de onzekerheid in voorspelde baten van investeringen.

Het tweede deel van het onderzoek focust concreet op de voorspelde mobiliteit in 2030. Dit is gedaan met behulp van de WLO scenario's GE en RC. Deze scenario's worden zoals eerder is uitgelegd vaak gebruikt voor toekomstanalyses van beleidsmaatregelen en worden geacht de gehele bandbreedte te beschrijven voor ontwikkelingen in mobiliteit. De mobiliteit in beide scenario's is berekend met behulp van het strategisch verkeersmodel LMS, het landelijk model systeem voor verkeer en vervoer. Hierbij is het huidige verkeersnetwerk inclusief de geplande projecten die al vastliggen tot 2020 gebruikt. De mobiliteit in 2030 in deze twee scenario's wordt beschreven aan de hand van vier indicatoren. Dit zijn het aantal tours (een tour is gedefinieerd als een reis die thuis begint en daar ook weer eindigt), het totaal aantal gereisde kilometers, het reistijdverlies op het hoofdwegennet door drukte op de weg en het aantal file uren op het hoofdwegennet. Deze vier indicatoren gelden voor autobestuurders op een gemiddelde werkdag in 2030. Voor de geselecteerde scenariocomponenten is onderzocht hoeveel invloed zij hebben op deze vier indicatoren van mobiliteit. Hierbij is per indicator ook specifieker gekeken naar het verschil in vervoerswijze, reismotief, tijdstip van de dag en type weg.

In het laatste deel van dit rapport wordt een fictief investeringspakket beschreven dat tussen 2020 en 2030 wordt uitgevoerd en bestaat uit ongeveer 20 miljard euro voor de aanleg van 1600 extra rijstrookkilometers op het hoofdwegennet. Hierdoor vermindert het aantal files en verbeteren de reistijden. Dit deel van het rapport berekent de baten van die reistijdverbetering in beide scenario's apart. Voor het GE scenario zullen de baten hoger uitvallen omdat er meer verkeer van de verbetering profiteert. Er is daarna gekeken hoe gevoelig de resultaten zijn voor veranderingen in de geselecteerde scenario componenten. Met behulp van de resultaten van deze gevoeligheidsanalyse en de onzekerheden per component, kan onderscheid gemaakt worden voor scenario componenten in hoeverre zij bijdragen aan de onzekerheid van baten van toekomstige infrastructuurinvesteringen. Dit is tenslotte geïllustreerd door de verschillen per scenariocomponent in de twee scenario's te combineren met hun afzonderlijke invloed op de resultaten. Hiermee is het verschil in mobiliteit en in reistijdbaten tussen de twee scenario's grotendeels te verklaren. Het onderzoek wordt afgesloten met een versimpelde kosten-baten analyse van het investeringspakket om te laten zien hoe de reistijdbaten doorwerken in een uiteindelijke kosten-baten analyse. Met het doel om de robuustheid van de resultaten aan te tonen, is ook een ander investeringspakket doorgerekend. Dit is een implementatie van de ambitie volgens de Structuurvisie Infrastructuur en Ruimte (SVIR) voor 2040, nu als fictief investeringspakket voor 2030.

Resultaten

Componenten en onzekerheid

Er zijn veel verschillende factoren die invloed hebben op mobiliteit in de toekomst. Voor dit onderzoek is een selectie gemaakt van voornamelijk demografische en economische factoren, die worden beschreven door de scenario's. De scenario componenten die nader zijn beschouwd zijn: populatie, huishoudensgrootte, arbeidsparticipatie, autobezit per huishouden, gemiddelde inkomen, kosten van het autogebruik (onder andere afhankelijk van de olieprijs), vrachtvervoer en ruimtelijke spreiding. De componenten zijn in verschillende mate onzeker. Als onzekerheidsmaat is de bandbreedte tussen de uiterste scenario's gekozen, met aanvullend een beperkte studie van historische en prognose data. Voor deze twee WLO scenario's verschillen vooral de huishoudinkomens en de vrachtkilometers, en in mindere mate inwonersaantallen en huishoudensgrootte. De olieprijs is gelijk verondersteld in beide scenario's, maar is volgens verschillende studies zeer onzeker. Hetzelfde geldt voor autobezit per huishouden, dat nauwelijks verschilt in de scenario's maar wel onzeker is.

Mobiliteit in 2030

Het aantal tours en het totaal aantal autokilometers op een gemiddelde werkdag is voor GE ongeveer 25% hoger in vergelijking met RC. Het verschil in reistijdverlies is veel hoger, namelijk bijna 2,5 keer hoger in GE. De file uren zijn zelfs ruim 3 keer zo hoog. De reistijdverliezen en file uren zijn niet gelijkmatig verdeeld over de vervoerswijzen en over de dag. In het RC scenario is er buiten de spits nauwelijks file, terwijl in GE ook dan files zijn. De file-uren voor vrachtverkeer zijn in GE bijna 5 keer zo hoog.

De gevoeligheid van de mobiliteit varieert per indicator. Het totale aantal tours en de autokilometers zijn vooral gevoelig voor een variatie in de bevolking. 10% minder mensen betekent ongeveer 10% minder tours. Deze indicatoren zijn ook gevoelig voor huishoudensgrootte en autobezit. Tijdverlies en congestie zijn over het algemeen veel gevoeliger voor veranderingen in de scenario componenten. In GE is het aantal file uren 25% lager bij een daling van 10% in de populatie. Naast de huishoudensgrootte en autobezit heeft nu ook arbeidsparticipatie veel invloed. Inkomensniveaus en vrachtverkeer hebben minder impact bij een 10% daling, maar nog steeds ongeveer 5%. Over het algemeen is de gevoeligheid in RC hoger. Dit komt door de hogere absolute waarden in GE. Voor beide scenario's geldt dat de gevoeligheden in en buiten de Randstad en voor verschillende vervoerswijzen voor alle componenten vergelijkbaar zijn. Het aantal files en de verliestijd buiten de spits is gevoeliger voor veranderingen in de componenten.

Baten van infrastructuur

Voor deze studie is een investeringspakket ontworpen op het hoofdwegennet van 20 miljard tussen 2020-2030. Hierdoor wordt een deel van de files opgelost en dalen de reistijd verliezen. Vanwege de grote drukte op het wegennet in het GE scenario zijn investeringen in dit scenario meer nodig. De reistijdbaten verschillen dan ook in grote mate, ze zijn in het GE scenario maar liefst 3 keer zo hoog als in RC. Het grote verschil wordt voor een deel veroorzaakt door de reistijdbaten buiten de spitsuren. Deze zijn 6 keer zo hoog in GE als in RC en vormen de helft van de totale reistijdbaten. De baten in GE zijn veel hoger voor het vrachtverkeer, namelijk 5 keer zo hoog als in RC.

De reistijdbaten zijn het meest gevoelig voor het aantal inwoners en autobezit. Een verschil van 10% minder inwoners in GE geeft een daling van 18% in reistijdbaten. Dit is 13% bij een daling van 10% in het autobezit.

Zoals hiervoor uitgelegd is de onzekerheid in reistijdbaten in de toekomst vooral bepaald door componenten die zelf onzeker zijn en ook veel invloed hebben op de reistijdbaten. Dit onderzoek laat zien dat populatie en huishoudensgrootte verschillen tussen de scenario's en veel invloed hebben op de reistijdbaten. Het inkomen en vrachtverkeer hebben relatief minder invloed, maar zijn volgens de scenario analyse zeer onzeker en zijn daarom ook belangrijke componenten. Om dit te illustreren zijn de gevoeligheden van de componenten en de verschillen in waarden tussen GE en RC gecombineerd. Hiermee kunnen verschillen in output tussen GE en RC verklaard worden. Populatie, huishoudensgrootte, het inkomen en vrachtverkeer zijn daarbij de belangrijkste verklarende componenten voor het verschil in baten.

Om een idee te krijgen hoe de reistijdbaten doorwerken in een kosten-baten analyse zoals die wordt voorgeschreven door de overheid, is een versimpelde kosten-baten analyse opgesteld. De verdisconteerde reistijdbaten voor het pakket in GE bedragen meer dan 20 miljard, en worden bovendien meegenomen in robuustheidseffecten en indirecte effecten. De totale baten, inclusief accijns en negatieve externe baten, bedragen meer dan 30 miljard en leiden tot een positief saldo van bijna 6 miljard. Om aan te geven hoe groot de verschillen tussen GE en RC zijn: hetzelfde investeringspakket heeft een negatief batensaldo van meer dan 15 miljard in RC.

De analyse van het SVIR pakket laat vergelijkbare verschillen in reistijdbaten zien tussen GE en RC, ongeveer 3 keer zoveel baten in GE. Het is opvallend dat de jaarlijkse reistijdbaten van dit investeringspakket maar net iets hoger liggen dan het eerder onderzochte investeringspakket, namelijk 1.2 miljard om 1.0 miljard in GE, terwijl het aantal extra kilometers en dus de kosten van het pakket meer dan twee keer zo veel zijn.

Conclusie

Het reistijdverlies in files, en mede daardoor de reistijdbaten van weginvesteringen zijn erg gevoelig voor het gebruikte scenario. De uitgevoerde analyse geeft inzicht in de bijdrage van scenario componenten aan dit grote verschil. Hierbij is er nagegaan welke componenten van de scenario’s het meest bepalend zijn voor het rendement van investeringen in weginfrastructuur.

De belangrijkste determinanten in voor de reistijdbaten van investeringen in infrastructuur zijn bevolkingsomvang, grootte van het huishouden, inkomens en vrachtverkeer. Ze zijn ofwel zeer onzeker (inkomensniveau en vrachtverkeer), of ze hebben veel invloed op de reistijdbaten (bevolkingsomvang, grootte van het huishouden). De scenario componenten die vooral erg onzeker zijn, zijn huishoudensinkomen, olieprijzen en vrachtvervoer. Autobezit en bevolkingsomvang hebben relatief veel invloed. De componenten autobezit per huishouden en de variabele autokosten dragen nauwelijks bij aan de verschillen in mobiliteit tussen de scenario’s GE en RC. Dit komt omdat de componenten zelf slechts marginaal verschillen.

De reistijdbaten van investeringen in infrastructuur kunnen tot 3 keer zo hoog zijn in een hoog economisch scenario in vergelijking met een laag scenario. Een ruwe schatting van de rentabiliteit van het doorgerekende pakket laat een variatie zien in kosten-baten verhoudingen tussen de 1.21 en 0.43. Dit betekent dat het onverstandig is om voor 2030 veel projecten vast te leggen en dat bij de evaluatie van investeringen altijd meerdere scenario’s gebruikt moeten worden.

Voor het opstellen van nieuwe toekomst scenario’s zijn er een aantal aanbevelingen. De componenten die in dit onderzoek een grote invloed lieten zien op onzekerheid in reistijdbaten van investeringen, moeten zorgvuldig worden beschouwd. Populatie, huishoudensgrootte, inkomens en vrachtvervoer zijn zelf onzeker en hebben veel invloed.

Het is goed als de nieuwe scenario’s ook de onzekerheid in olieprijzen en autobezit weerspiegelen. Deze zijn onzeker en kunnen belangrijk zijn voor de mobiliteitsontwikkeling. Er kan ook overwogen worden om transport specifieke scenario’s te ontwikkelen die specifiek rekening houden met ontwikkelingen die de mobiliteit erg beïnvloeden, zoals ICT ontwikkelingen die het thuiswerken bevorderen, kilometerheffing, of de inpassing van het klimaatbeleid.

Abstract

Research on the influence of scenario components on benefits of infrastructure investments

Investments in the road network are costly and provide benefits on a long term. Projects should be planned far ahead because construction takes a lot of time. Additionally the future is uncertain. Policymakers therefore have to deal with uncertainty when making decisions and planning investments. The scenarios in the report Prosperity and Environment give a range of national demographic and economic developments. This research provides more insight into the influence of specific scenario components on the travel time benefits[1] of investments.

For this analysis the scenarios Regional Communities (RC, low) and Global Economy (GE high) are used as a starting point, and then the effect of specific scenario components is tested. The input for the scenarios differs greatly. Besides population growth and household size especially household incomes and freight kilometers show a large bandwidth between the scenarios. The oil price is assumed to be equal. The amount of vehicle-kilometers in 2030 is approximately 25% higher in GE. The travel time loss is almost 2.5 times higher than in RC and the number of congestion-hours is more than 3 times as high. The sensitivity of the output to input variables differs per indicator. The number of tours and traveled distance are especially sensitive to population, size of the household and car ownership. Time loss and congestion-hours are also highly dependent on the participation level (which determines the labour force) and also to household income and freight traffic.

For this study, an investment package was designed for the main road network of 20 billion between 2020-2030. The travel time benefits are in the high scenario up to 3 times as high as in the low scenario. They are especially sensitive to the number of inhabitants and to the relative car ownership per household. Using the sensitivities and differences in the input, the difference in benefits between GE and RC can be explained. Population, household size, income and freight are the main explanatory components for the difference.

The conclusion is that the travel time loss and, partly because of that, the travel time benefits of road investments are very sensitive to the scenario that is used. The analysis provides insight into the contribution of scenario components to this large difference. And also which components of the scenarios are most decisive for the profitability of infrastructure investments. The large differences in outcome shows that the use of different scenarios in cost-benefit studies is important and especially population, household size, income levels and freight traffic deserve attention in the preparation of new scenarios.

[1] The travel time benefits consist of shorter travel times or shorter routes

Contents

Preface

This research is the result of a seven months internship at the environmental assessment agency and concludes my study Civil Engineering at the University of Twente. Both most definitely lived up to the high expectations I had for them.

Many people contributed to this research. I would like to thank Tom Thomas, who was my daily supervisor, for the discussions we had. After every meeting I had inspiration to extend my research on some extra topics, which made it very fun to do. And also Karst Geurs, who maybe visited the Hague more often than I visited Enschede during my research. He also managed to find some time to plan a meeting with me and discuss the research. Jan van de Waard from the Kennisinstituut Mobiliteitsbeleid also joined the supervision on my research and had some very valuable contributions on my concept report, for which I am grateful.

My supervisor at the PBL was Barry Zondag and I am very thankful for all his input on my research. I could always ask him for advice or comments and he had often very practical viewpoints on my results. Thanks for even sending me some remarks on my congress paper during the weekend.

I enjoyed the walks (red or green that is the question) during the lunch breaks with the guys from PBL. It was always nice to get some fresh air. I am very grateful to all of the people at PBL for the nice conversations, discussions and most of all everything I learned because it was much more than just the contents of this research.

During my internship at the PBL I lived at the monastery of the brothers of St. Jan in the Hague. I am very grateful to them for letting me stay there and join the catholic student community for a while. It was a very special experience to stay there and I will certainly miss the beautiful atmosphere.

I thank God for giving me joy and satisfaction in my research. I am thankful to my parents who have taught me to always put my education at the top of my priority list and for supporting me through my study.

Maarten ’t Hoen

Delft, October 2012

1. Introduction

The Dutch government spends a lot of money on infrastructure investments. In 2013 the Dutch Ministry of Infrastructure and Environment has a budget of about 9.9 billion euro for infrastructure, road safety, water safety and environment, of which 2.8 billion will be spent on the main road network. A large part of this budget is spent on infrastructure. In 2010 5,1 billion euro was spent via the Long-Term Program for Infrastructure, Spatial Planning and Transport (in Dutch: Meerjarenprogramma Infrastructuur, Ruimte en Transport, or MIRT) to improve accessibility and competitiveness of the Netherlands.

Infrastructure and the accompanying regional mobility and accessibility are a necessary condition for social welfare. Well-functioning infrastructure networks are therefore of great importance for the economic development of our country. They supply access to jobs, food, shops, health and social services, along with access to family, friends and community in general. This is a fundamental dimension of the quality of life. Moreover, accessibility is essential for the economic functioning of societies, for example, access of firms to employees, access of potential workers to jobs and access of businesses to both suppliers and customer (Geurs 2006). To improve accessibility of regions and stimulate economic development, the government has to invest in improvement or expansion of the infrastructure network. These investments are very expensive and other measures are sometimes also possible. The profitability of the investments differs highly among the different projects (Thissen, van de Coevering et al. 2006) and building roads does not always have a positive effect on welfare (Groot and Mourik 2007). Therefore government has to determine carefully which infrastructure investments she will implement.

1.1 Background

In the election campaign of 2012, prime minister Rutte referred more than once to the Global Competitiveness Report (Schwab 2012) that points out that the Netherlands is one of the most competitive nations in the world. One of the reasons for this is that the Netherlands performs well internationally on infrastructure quality, ranking 11th in the world on quality of roads and 9th on railroad infrastructure. The World Economic Forum stresses the importance of high quality infrastructure. Extensive and efficient infrastructure is critical for ensuring the effective functioning of the economy, as it is an important factor in determining the location of economic activity. Well-developed infrastructure reduces the effect of distance between regions, integrating the national market and connecting it at low cost to markets in other countries and regions. In addition, the quality and extensiveness of infrastructure networks significantly impact economic growth and reduce income inequalities and poverty in a variety of ways. A recent report of the Environmental Assessment Agency in the Netherlands on the competitiveness of top sectors (PBL 2012) has the same conclusions. The investment policy of the Netherlands in the road network resulted in high accessibility and an excellent road network. The most competitive regions deal with high levels of congestion, but compared to their European competitors, the Dutch regions generally have good accessibility (PBL 2012).

This is why the national government gives high priority to investing in infrastructure. In 2011 the national Structure Vision on Infrastructure and Spatial Planning (in Dutch: Structuurvisie Infrastructuur en Ruimte, or SVIR) was published which contains national goals on the mid and long term (2028-2040). The goals stated in the SVIR are to improve competitiveness of the Netherlands, improve accessibility and to ensure a livable and safe living environment. An excellent spatial economic structure that is highly accessible will contribute to the competitiveness. Accessibility will be improved by 'smart investments', innovation and conservation of the main infrastructure network (IenM 2012). From these documents we can also conclude that the importance of accessibility is recognized by the government and is also high on the political agenda. The so called 'smart investments' from the SVIR concern the infrastructure investments that generate the highest economic benefits. The government only wants to invest in projects that are the most profitable for the system as a whole. As said before, these decisions regard the mid and long term. But what if the future is highly uncertain and profitability of infrastructure investments is difficult to determine?

This is a common challenge in Dutch policy making. We have some idea of what the future may look like and make assumptions on how different aspects, like population growth or national income, will develop. But in the mid and long term we have to deal with uncertainties about these aspects and it is also hard to define the economic benefits of projects. To determine the bandwidth of the possible effects of policy measures we use scenarios, based on assumptions of decisive factors that determine the future. Scenarios contribute to identifying, exploring and communicating (the consequences of) uncertainties. In practice, often a high scenario and low scenario are used. The outcomes on profitability of investments differ between the scenarios, but where does this depend on? In retrospect, for example for the period 1985-2008, we can explain the development of mobility and accessibility to a high degree. They depend mainly, besides infrastructure investments, on the factors population growth, jobs, car ownership and fuel prices (Olde Kalter, Loop et al. 2010). However this is more difficult when we make traffic forecasts. We would like to have more detailed knowledge about the factors that influence the development of mobility and accessibility on the mid and long term, both qualitatively and quantitatively. This will be the central topic of my research.

1.2 Policy context

For the near future of the Netherlands the SVIR is the most important policy paper regarding this subject. The SVIR replaces existing policy papers like the national paper on Spatial Planning and the national paper on Mobility and describes the main goals for the Netherlands. The goals stated in the SVIR are to improve competitiveness of the Netherlands, improve accessibility and to ensure a livable and safe living environment. For competitiveness the ambition is that the Netherlands in 2040 are part of the top 10 competitive countries in the world due to the excellent spatial economic structure. This means optimal access to the urban regions and excellent connections between mainports, brainports and greenports with Europe and the rest of the world. Regarding accessibility the ambition is that users in 2040 are able to use optimal chain mobility, consisting of good links between mobility networks via multimodal nodes and coherence of infrastructure and spatial development.

After 2020 the national government gives priority to solving accessibility bottlenecks for the main-, brain- and greenports. An important concept in the paper is to improve accessibility according to the motto 'Smart Investment, Innovation and Maintenance". This is done by realizing a robust and coherent mobility network with the capacity to meet the demand of the medium and long term.

For public transport the government wants that travelers can travel on the rail network 'without a timetable', meaning that the frequency on busy routes is increased to 6 intercity trains and 6 regional trains per hour. The ambition for the main road network is that on highways outside the Randstad with structural congestion problems the standard will be 2x3 lanes and within the Randstad 2x4 lanes. "Smart Utilization" policy that is based on innovative, efficient use of infrastructure will further improve optimal use of the network and the infrastructure projects Ring Utrecht (A12), A7, A8, A10 (north of Amsterdam), A1 east region, A27, A58 solve some of the worst bottlenecks in the network. The focus of 'smart utilization' is on tax and pricing measures, mobility management, public transportation services, logistics, node development, travel information, spatial planning and behavioral aspects (Savelberg and Korteweg 2011). It is important to estimate the impact of those measures, as they will improve accessibility. The benefits of infrastructure investments will otherwise be overestimated.

The SVIR refers to the National Mobility paper (VenW and VROM 2004) for some essential objectives that remain valid in the SVIR. Regarding accessibility, the target for average travel times on the main road network during peak hours between cities is a maximum of two times the travel time outside the peak hour. For main roads around cities and other roads in the main road network the average travel time in the peak hours is at maximum two times the travel time outside the peak hour.

This is remarkable as the objectives go directly against the new approach of 'smart investments' from the SVIR: taking into account all modalities, not only on the basis of traffic engineering principles, but looking at the user and the spatial-economic functioning of the regions and the Netherlands as a whole. And it is also not consistent with the goal of making the system more robust.

According to the commission Elverding, the time interval between establishing preparatory research and the first actual use of infrastructure is for large Dutch infrastructure projects 10-14 years, on average 14 years. Often for important links in the Randstad this even takes longer (Elverding 2008). Therefore we have to make decisions now for the long term, as we cannot afford to only think about the short term. For this issue we have the MIRT, which is an investment program of the government. In the MIRT project book 2010 (VenW 2010) infrastructure projects for the period until 2020 are planned. The objective of the MIRT is to improve consistency and adaptation of investments (IenM 2011).

In the spatial outlook (PBL 2011) the PBL shows the (possible) future development of the Dutch regions and the variety in growth, decline, or uncertain (growth or decline) areas. Growth, stagnation and population decline are all happening at the same time in different regions in the near future. For some regions it is clear that they will grow or show a decline, for other regions this is uncertain. The highest uncertainty is in growth regions, as for example expected housing demand lies between 10% and 90% in 2040 in Almere. The spatial outlook 2011 presents a policy strategy for this uncertainty. The policy consists of three major principles: 1. The use of adaptive planning, 2. Designing a monitoring system and 3. Developing an evaluation framework for high-risk investment decisions. Niekerk and Arts (2008) also advise the use of adaptive planning to improve risk management of infrastructure projects.

It is important to know more of these uncertainties, not only their magnitude but also their origin, because it will probably take longer, if at all, for infrastructure investments that do not respond to the actual demand to pay off, as was explained before. Therefore policy makers should take more caution to invest in infrastructure and by prioritizing projects, using adaptive planning and monitor demographic and economic developments. From the research in this report, it will become clear which components are important to monitor as they mainly affect the impact of infrastructure investments.

2. Scenarios, traffic models and cost-benefit analysis

To understand what this research is all about, it is important to elaborate on a few theoretical concepts. The introduction chapter explained the importance of infrastructure investments, but also reflected on the possible risks of overinvestments due to uncertainties about the future. That is why cost-benefit analysis for large infrastructure investments is mandatory. The figure below shows a very simplified framework for the evaluation of investments.

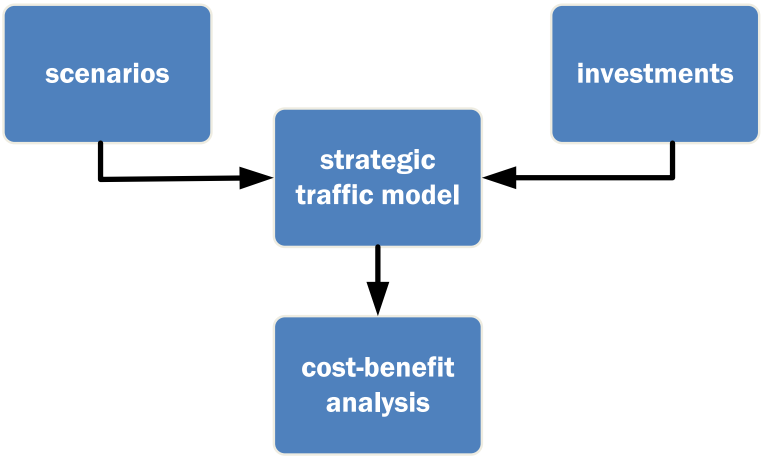


Figure 1: Simplified framework for the evaluation of infrastructure projects

Three important concepts in the evaluation of infrastructure profitability are scenarios, strategic traffic models and cost-benefit analysis. In this chapter these three concepts are further explained. First scenarios, then strategic traffic models and finally cost-benefit analysis.

2.1 Scenarios

This chapter will explain what scenarios are, what they are used for and elaborates on the scenarios that are currently used often.

For the evaluation of infrastructure investments we want to compare different alternatives with regard to their impact in the future. But what future is this? Making use of only one forecast would merely give the appearance of certainty (Eijgenraam, Koopmans et al. 2000). In the case of the MIRT projects, the effects and thus benefits are per definition uncertain because they are hard to estimate and the scope of the projects is that of the long term. One of the requirements for the cost-benefit analysis is that the bandwidth of uncertainties in the forecasts must be clear (Visser and Wortelboer-van Donselaar 2010). To give the decision maker insight into the future uncertainties and their impact on the outcome the OEI prescribes the use of scenario studies. Scenarios are useful for analyzing policies with long-term, uncertain implications and show to what extent the efficiency of a project depends on specific or general environmental factors. They can help to distinguish robust projects which will yield a positive return in good but also in poor conditions.

Scenarios do not forecast what will happen in the future; rather they indicate what might happen (i.e. they are plausible futures). Because the use of scenarios implies making assumptions that in most cases are not verifiable, the use of scenarios is associated with uncertainty at a level beyond statistical uncertainty. It is not possible to formulate the probability of any one particular outcome occurring.

Scenarios have two goals: On one hand the scenarios show possible futures and their overlap with policy ambitions show if policy goals are in line with the possible developments. In other words, scenarios can be used to shape ambitions, which is not uncommon in the Netherlands. The other goal is that of assessing policy. Scenarios can show if the intended policy is efficient and effective in different futures, and therefore is robust. Scenarios show strengths and weaknesses of variants and give the opportunity to come up with strategies such as the no-regret strategy (Groot and Mourik 2007), which favors projects that perform well in all scenarios.

The national government recommends scenario analysis for large infrastructure projects trough a guideline (Eijgenraam, Koopmans et al. 2000). The robustness of the evaluation results for the assumptions that are made should be analyzed. The influence of demographic and economic developments on mobility can be mapped by the use of the different long-term scenarios. The use of a high and low scenario, respectively Global Economy and Regional Communities is recommended (VenW 2008). These scenarios are developed by CPB et al. (2006) in the study Welfare, Prosperity and Quality of the Living Environment' – Welvaart en Leefomgeving, or WLO). It is essential for my research to know about the background of these scenarios and understand their storyline as it is the uncertainty in these scenarios that I want to research.

2.1.1 WLO scenarios

The WLO-scenarios were built around two key uncertainties. One regards the willingness to cooperate internationally and the other the degree of reform in the public sector. The following figure (Mooij and Tang 2003) represents the uncertainties and shows the four scenarios that were developed.

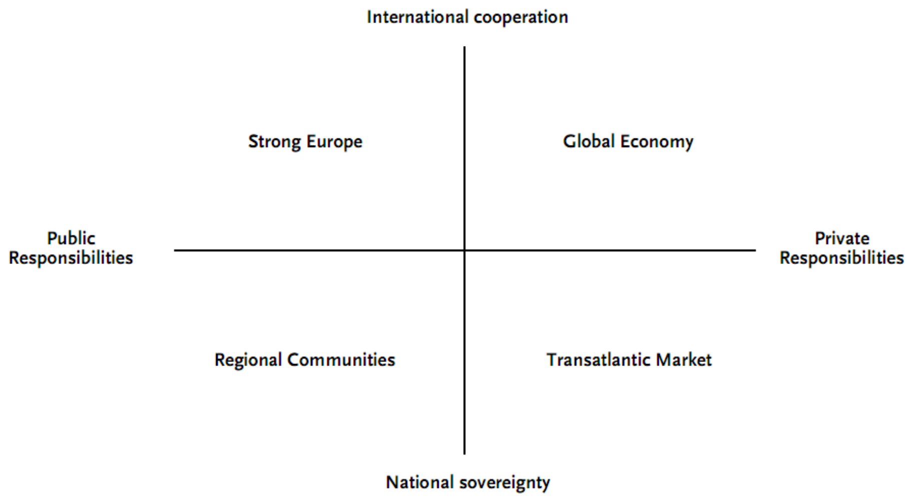


Figure 2: Four futures of Europe

International cooperation is related to the challenge for countries of the EU to work together on trans boundary issues and secure legitimacy of the European Union. National sovereignty means that countries want to determine their own policies to a high extent and hold on to their own identities. Concerning reform in the public sector, trends of the aging population, individualization and income inequality increase the demand for public facilities. These tasks can be performed by the government or by the market via privatization. The two scenarios that are important for my research are ‵ Global Economy’ (GE) and ‘Regional Communities’ (RC).

In the scenario Global Economy the European Union expands further eastwards (CPB/MNP/RPB 2006). The World Trade Organization (WTO) negotiations are successful, which is beneficial for international trade and the economic growth is high. The government emphasizes the individual responsibility of citizens. Labour productivity increases strongly in this scenario because of the global economic integration. The growth of both material wealth and population (mainly because of immigrants) is high. There will not be an agreement for trans boundary environmental issues, which leads to significant environmental pollution, despite local environmental initiatives. Also the growth of mobility and congestion is high.

In the scenario Regional Communities countries keep their own sovereignty. Therefore the EU cannot put forward any institutional reforms. There is no deregulation of global trade and the world is divided into a number of trading blocs. International environmental issues are not addressed adequately but still there is relatively low pressure on the environment, because population and economic growth are modest. The public sector in this scenario is hardly reformed. Collective arrangements remain in place, with an emphasis on income equality and solidarity. Unemployment is relatively high. Businesses do not feel the need to innovate because of less competition. Labour productivity does not grow and economic growth is low. There is a population decline after 2020. The growth of mobility and congestion is low and investments will be less profitable.

The WLO scenarios were developed in 2006. According to Hilbers and Snellen (2010) the WLO-scenarios are still valid, despite the economic crisis. Other research confirms this. Trends of the past three years regarding population, economy and spatial development do not imply that the WLO-scenarios should be adjusted (Wortelboer-van Donselaar, Francke et al. 2009). On the contrary, the researchers state that their observations show the importance of using more than one scenario. The high oil prices are an exception, as price is three to four times as high as predicted in the scenarios. The price of one barrel is predicted to be between 22 and 28 dollars in 2040, while at the moments the prices are around 110 dollar (Bloomberg 2012).

There are some characteristics of the WLO-scenarios that are worthwhile discussing. WLO-scenarios are multi sectoral, which means that a variety of sectors are included, such as economy, infrastructure, energy supplies and urbanization. The scenarios are relatively limited in their exploration of possible futures and do not deviate largely from current developments and policies. Vleugel (2008) is critical towards this. He thinks that the WLO-scenarios are too conservative and that there is insufficient stimulus for policy discussions. In his opinion themes like alternative energy sources, non-polluting vehicles, innovative thinking about the environment would have a large impact on the future.

Another characteristic is that the WLO-scenarios have a modeling approach. This means that the storyline of the scenario are captured quantitatively and systematically in variables and relations that can be modeled. Assumptions have to be made explicit. A large quantity of models is used (and they are input to each other) to generate quantitative data for the future, including the LMS. The output concerns mobility, traffic, congestion, speeds and emissions. There is almost no feedback to other models from the LMS, only towards the car-ownership, -cost and -emissions models. It is assumed that that infrastructure investments do not affect land use, although this is argued in literature (Wegener and Fürst 1999). Freight traffic is modeled separately by another model. Finally, the WLO scenarios are background scenarios. This means that they are not policy-orientated but mainly describe autonomous developments.

2.1.2 Scenarios in practice

In current practice the scenarios are used for ex-ante evaluations of infrastructure investments, to determine the bandwidth of effects. In different scenarios (with e.g. high or low economic growth) different infrastructure projects are more ore less profitable.

In practice, unfortunately, there are examples where only one scenario for the project is used because of technical limitations. In the evaluation of the Schaalsprong Almere (CPB and PBL 2010) only one scenario was available in the used model. This is not wise because the aspects of the scenario cannot be influenced to our desires or only to a limited extent. In this case the decision maker will not receive any information about the robustness of the profitability under other possible developments (Eijgenraam, Koopmans et al. 2000).

This research focuses on profitability of infrastructure investments and how scenarios contribute to our knowledge of the bandwidth of possible effects. There are four factors that have determined the success and effectiveness of large Dutch infrastructure projects in the past 15 years (Koopmans and Beek 2007):

- Traffic-related effectiveness (contribution of projects to solving bottlenecks)
- Contribution to prosperity (profitability of investments to society)
- Social support (citizens often oppose to changes in their living environment)
- Administrative support (difference of opinion or consensus within or between layers of government)

The evaluation of projects contributes to better decision making but the decision is often a political decision and depends on many factors. When a lot of actors are participating, working with many alternatives and different scenarios can be problematic.

Concluding, the use of scenarios is important to show the bandwidth of possible futures regarding the aspects that are relevant for the project. To predict how mobility will develop in either of the possible futures we use strategic traffic models. The next paragraph will elaborate on this topic.

2.2 Strategic traffic models

Mobility and congestion in different scenarios can be modeled using traffic forecasting models. This paragraph will elaborate on the strategic traffic model that was used in this research, the National Model System for transport (LMS), on uncertainty of traffic models in general and the quality of the LMS.

2.2.1 National model system (LMS)

The use of models is necessary for the ex-ante evaluation of policy decisions on a strategic level that are made on the long term. The transport model used in many projects such as the national market and capacity analysis (IenM 2011) and the mobility assessment 2011 (KiM 2011) and therefore also in this study is the Dutch National Model System, LMS (‘Landelijk Model Systeem’).

The LMS is a strategic traffic model. It is a forecasting model for the medium to long term (the forecast year often being 20–30 years ahead), with a focus on passenger transport on the main rail and road network (freight traffic appears only in assignment of an exogenous OD truck matrix to the road network). Therefore it is an important instrument for ex-ante policy evaluation of investment packages and also for determining the future challenges that the network has to overcome. This insight is needed to make better decisions on a strategic level. This way, the LMS contributes to solve the congestion problems in the Netherlands.

The LMS was first developed in the 80’s and has been used since for several policy documents on transport policy and for the evaluation of large transport projects. At the very core of the LMS there is the theory of utility-maximization of households, which was developed by McFadden and operationalized in discrete choice analysis models, which are used to forecast demands. The theory is described by e.g. Ben-Akiva & Lerman (1985) and is based on the behavior of individuals, who follow a sequential decision-making process. It assumes that individuals choose destinations and travel modes that generate the highest utility for them. Because we cannot predict their behavior perfectly, a random term in the model causes variation in the choices that the individuals make. For all (groups of) individuals in a zone, the probability of choosing different alternatives is summed up resulting in the aggregate demand. This system is based on the observed behavior of people and the most important source for this behavior is the survey Mobility Research in the Netherlands (in Dutch: Mobiliteitsonderzoek Nederland, MON). The LMS consists of random utility sub models at the household or person level for:

- License holding, constrained to exogenous forecasts;
- Car ownership, constrained to exogenous forecasts;
- Tour frequency by travel purpose. A tour is defined as a round trip (e.g. home-work-shop-home). Here we distinguish eleven travel purposes. For each of these there is a model for the choice between zero tours and one or more tours and a model for subsequent tours.
- Mode and destination choice: there are eight of these models, one for each of eight travel purposes. The modes distinguished are: car-driver, car passenger, train, bus/tram/metro, non-motorized.

- Departure time choice by travel purpose (11 time periods).

Two important modules are SES and QBLOK. SES concerns trip generation and distribution and QBLOK assignment to the network. The QBLOK and SES output categories can be found in appendix 9.1. The LMS does not model incidents, and therefore only structural congestion. The model works in a pivot-point fashion whereby the demand models produce growth factors for the changes between the base year and forecasts year and a given base matrix represents the traffic pattern in the base year. Then, the OD car driver demand matrices are assigned to the road network and after initial assignment there is a feedback to mode, destination and departure time choice (iterative application) (de Jong, Daly et al. 2007). The LMS is a disaggregated model system that can estimate future traffic flows, both on the trunk road network and in public transport, and calculates traffic conditions on an average working day.

The LMS is a spatial model, which means that the Netherlands and small parts of bordering countries have been compartmented into about 1500 zones, each with its own characteristics. Input for the model consists of road networks, public transport systems, parking costs, socioeconomic and employment data for each zone, driver's license and car ownership data and a description of passenger mobility and freight transport in the base year. The entire main road network, almost 15.000 lane kilometers, is implemented in the LMS network and also more than 40.000 lane km of the secondary roads network.

The output consists of forecasts about passenger mobility in the Netherlands in the forecast year, for example in tours, distance, travel time loss and congestion hours. This can be divided per travel mode and travel motive. The LMS distinguishes between car driver, passenger, train, bus/metro/tram and slow traffic. The population is divided by age, car ownership, social participation or income.

Recently the LMS has been updated. An evaluation of the previous version of the LMS showed that the LMS could not predict congestion and the impact of policy on congestion very well. Also, it was sometimes difficult to interpret the results produced by the LMS (2008). According the National Market and Capacity Analysis (NMCA) (Rijkswaterstaat 2011) the LMS was improved compared to older versions. The modeling of mobility behavior is updated. There is better estimation of congestion, public transport and freight. The manual of the new version states that i.a. external traffic modeling, modeling of license and car ownership in the choice models, the assignment method and integration of the mode and destination choice model with departure time choice were improved and a CBA module for cost-benefit analysis was added.

2.2.2 Uncertainty in traffic models

Models are a mere representation of reality and can never give totally realistic results. They are very limited in various aspects. This research concerns the uncertainty of future mobility and therefore the need to invest in infrastructure. The scenarios represent uncertainty in aspects like population growth or economic growth, but the model itself is also uncertain. Uncertainty produces a risk for the profitability of the project. It might be better to invest in a project that on average is slightly less profitable, but considerably less risky in terms of the variation in future traffic volumes, than in a more profitable, risky project. Quantifying uncertainty in traffic forecasts can therefore lead to better-informed decision-makers and better decision-making.

Uncertainty is caused by (de Jong, Daly et al. 2007):

- Input uncertainty: the future values of the exogenous variables (e.g. the future incomes) are unknown. The bandwidth of values can be expressed by the use of scenarios, as described in the previous paragraph.
- Model uncertainty:
    - Specification error in the model equations (omitted variables, inappropriate assumptions on functional form and statistical distributions for random components)
    - Error due to using parameter estimates instead of the true values
- Uncertainty in the SCBA is caused by uncertainty in the attributed values of time but also the 'revenues' in the future are uncertain. This is dealt with by using a

discount rate for future travel time benefits which generates the net present value of the project.

This is visualized in the following figure:

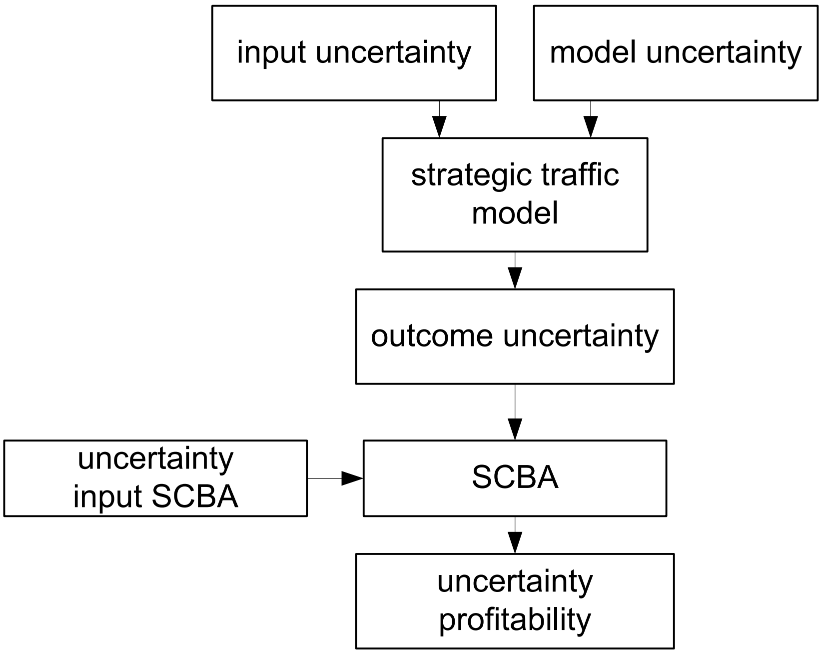


Figure 3: Different causes of uncertainty in profitability

It is important to specify the model boundaries to distinguish between input uncertainty and model uncertainty. In this research the input uncertainty is caused by the scenario input. In the LMS model uncertainty concerns travel behavior, and socio economic characteristics are input for the model, as well as the transport network.

Uncertainty in the forecasts by the LMS is caused mainly by the input (de Jong, Tuinenga et al. 2008). The contribution to the bandwidth in traffic demand due to model uncertainty is much smaller than due to input uncertainty. The total order of magnitude is 10%.

According to Geurs and van Wee (2010) much of the deviation of the forecasts with reality seems the result of errors in the input data of the forecasts. Sensitivity analyses also indicate that uncertainties in forecasts (the number of tours) mainly arise from uncertainties in model input and to a lesser extent from model uncertainties.

Jong, Daly et al (2007) found in their research substantial, but not very large, uncertainty margins for the total number of tours and kilometers (by mode) in the study area of the LMS and for the vehicle flows on selected links. The uncertainty margins for differences between a project and a reference situation are not much larger, unless these differences are of a small magnitude. In many cases, there is greater variation in the number of hours lost due to congestion than in hours travelled.

Policy measures also cause input uncertainty. The Dutch national government refer to their approach as "building, pricing and utilizing". As the Dutch pricing policy was moved to the background for the moment, building and utilizing are the main instruments for improving the mobility system (Rutte and Samsom 29 oktober 2012). This research focuses on infrastructure investments. But the government also invests in 'smart utilization'. The focus of this policy is on tax and pricing measures, mobility management, public transportations services, logistics, node development, travel information, spatial planning and behavioral aspects. Research shows (Savelberg and Korteweg 2011) that four dominant measures have the largest effect on reduction of traffic congestion on the main road network, as measured by the number of vehicle hours lost due to traffic jams.

They are: Application of Dynamic Traffic Management-instruments, abolishment of tax-exemptions for home-to-work and business travel, adjusted car insurance premiums and a 25% excise tax increase with reduction of fixed costs. These measures ensured that congestion decreased by 10 to 15%. This could have large impacts for profitability of new infrastructure, as fewer investments may be needed to achieve the desired situation. These measures also have to be implemented in strategic traffic models. Finally the introduction of pricing policies could also have a large impact on model results.

Flyvberg (Flyvbjerg, Skamris Holm et al. 2005) has a negative conclusion on the uncertainty in models. He performed a study of traffic forecasts in transportation infrastructure projects. The sample used is the largest of its kind, covering 210 projects in 14 nations worth U.S. $59 billion. The study shows with very high statistical significance that forecasters generally do a poor job of estimating the demand for transportation infrastructure projects. For half of the road projects the difference between actual and forecasted traffic is more than ±20%.

The quality of the LMS model is considered to be relatively high. Recently a comparison was made for the year 2010 and predicted mobility in 2010 (de Jong, Tuinenga et al. 2008). Total mobility growth was predicted well. Car driver kilometers were overestimated; those of car passengers and walk/bike were under estimated. A large part of the 'wrong' forecasts was caused by unexpected developments in society outside transportation. In particular, both the population and the work force grew larger than expected. Incomes per household increased less than expected. The anticipated pricing measures (road pricing, kilometer charge) did not materialize. Public transport increased strongly through the introduction of the free public transport pass for students.

2.3 Cost-benefit analysis

Infrastructure facilitates mobility and regional accessibility and thus is a necessity for national prosperity. However, infrastructure and mobility do not only have positive effects, but also negative external effects such as emissions, noise, unsafe situations, congestion and more. Also building new infrastructure is very expensive. Therefore ex-ante evaluation of large infrastructure projects is important.

Profitability of infrastructure investments can be determined with cost-benefit analysis. It is the most adequate method for evaluating investments in infrastructure. Cost-benefit analysis is firmly based in economic science and is often used in practice. Every effect of an investment project can be systematically estimated and, wherever possible, given a monetary value. In addition, the cost-benefit analysis gives an overview of distribution effects, alternatives and uncertainties, since an overall assessment by politicians and others requires complete information (Eijgenraam, Koopmans et al. 2000).

2.3.1 Dutch guidelines

To determine profitability of large infrastructure projects of the central government, cost-benefit analysis is mandatory for all large infrastructure projects (Visser and Korteweg 2008). The cost-benefit analysis is conducted in accordance with the OEI-guideline (Overview of the Effects of Infrastructure, in Dutch: Overzicht Effecten Infrastructuur). These guidelines were developed by Rijkswaterstaat, the implementing body of the Ministry of Transport, Public Works and Water Management, after public debates on the benefits of various major transport infrastructure projects. They describe the methodological design for ex-ante evaluation of infrastructure projects on the basis of social cost-benefit analysis.

The role of CBA in the decision making process is that it provides transparent policy information, which will (partly) determine the decision on a project to be taken. The effects of an infrastructure project are presented clearly and to the point. In an overview the costs of construction and maintenance are presented, and additionally the effects of the infrastructure on accessibility, economy, safety, nature and the environment. All the relevant effects for making a decision should be addressed. The goal is to express the effects in monetary terms much as possible. This will make alternatives and projects comparable.

For each regular project (road or waterway) it is mandatory to fill out at least the standard-format of the OEI (VenW 2008). The standard-format consists of a number of effects:

- Mobility: Monetary effects of the project on total transport costs (including travel time and reliability) of all participants.
- Safety: effects on traffic safety and hazardous risks.
- Environment: effects as air pollution, sound, impact on nature, visual intrusion, soil, recreation, based on standard figures related to the traffic forecasts.
- Financial costs: investment costs for realizing the project, as well as costs to run and maintain it.
- Cost-benefit ratio: The net present value of all monetary effects is calculated. The cost-benefit ratio is determined, as well as the internal rate of return.

The benefits in a CBA of new infrastructure can be divided into two types: direct and indirect benefits. The most important direct benefits are travel time benefits. These benefits are valued according to the ‘willingness-to-pay’ method, differentiated to travel motives like home-work, business and social-recreation (Thissen, van de Coevering et al. 2006). For the quantification of external effects we can for example use figures determined by (Vermeulen, Boon et al. 2004) in the rapport ‘the costs of a trip’.

2.3.2 Rule of half

The conventional approach to measure accessibility benefits of transport strategies in transport infrastructure appraisal is to use the 'rule of half' measure. This computes the change in user benefits as the sum of the full benefit obtained by original travelers and half the benefit obtained by new travelers. This can be calculated by multiplying the average number of trips between a base scenario and a scenario with a project by the difference in travel times and the value of time for different consumers. The practical use of the rule of half is explained in a paper by Rijkswaterstaat (2008). This measure is often used, for example in the CBA project Schaalsprong Almere (CPB and PBL 2010) and is recommended by the government through the guidelines for cost-benefit analysis for infrastructure investments (Eijgenraam, Koopmans et al. 2000). I will shortly explain this method.

If a project leads to a change in the (generalized) costs of a transport service, the change of the consumer surplus is a good approach for the benefits of users. Two categories travelers benefit from a cost decrease: those who already made use of the road and new travelers. The change in consumer surplus is equal to the product of the cost difference and the average of the demand.

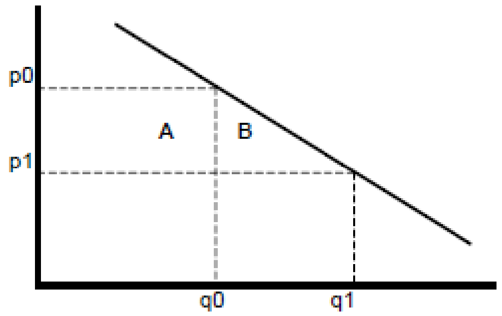


Figure 4: Standard example rule of half (Eijgenraam, Koopmans et al. 2000)

The figure above shows the situation where, for example because of capacity increment of the road, the travel time decreases (p0-p1). The travelers in the reference situation (q0) are attributed the full travel time savings: q0 * (p0-p1). This is area A. New travelers that use the road because of the reduced travel time get half of the savings: ½ * (q1-q0) * (p0-p1). This is area B. The total travel time savings for this road segment consists of the areas A and B. The travel time savings are multiplied by the value of time to get the travel time benefits. This is the classic use of the rule of half.

The valuation of travel time savings varies per individual traveler and depends on factors like the purpose of the journey (eg work related or recreational tours), the income of the traveler and the means of transport. So there is not a fixed value for one hour of travel time savings. Often it is not possible to review individual travelers and therefore we have to use average values of time for broad groups of travelers. For this it is important to distinguish homogenous groups of travelers concerning travel purpose and income level.

In this research the rule of half measure was used to estimate travel time benefits for the infrastructure investments. I distinguished four groups for the travel purposes: work, business, freight and other. The LMS output is used for the rule of half measure on the level of OD matrices.

Now that the topics scenarios, strategic traffic models and cost-benefit analysis are explained, the research design will be discussed. In the next chapter I present the research that I did on the travel time benefits of infrastructure investments, using the WLO scenarios as a starting point and performing a cost-benefit analysis using the output of the LMS model.

3. Research design

In this chapter the research model is presented. After the research objective is given, a visual will outline the research questions. Finally the scope is described.

3.1 Objective

My research focuses on the use of scenario studies for the evaluation of infrastructure investments. The scenarios are used to determine problems on the road network in the future and to see which solutions are effective. The scenarios give an indication of the bandwidth of possible effects of the measures.

This research studies the sensitivity of the travel time benefits for infrastructure investments to components in the background scenarios. From the broad range of aspects that are included in the CBA, I only focus on the travel time benefits. This is done for a specific investment package that is appropriate for the scale of the used traffic model. The scenarios result in different, but equally probable predictions of the future. However, it is not clear which components of the scenarios cause the differences and to what extent. This leads to the following objective:

The objective of this study is to determine the most important components in scenarios that influence the travel time benefits of infrastructure investments and to analyze the sensitivity of the benefits to these components.

3.2 Research questions

To reach the objective of this study the following framework was used. With this quadrant the scenario components can be evaluated regarding their importance for influencing travel time benefits in scenario studies.

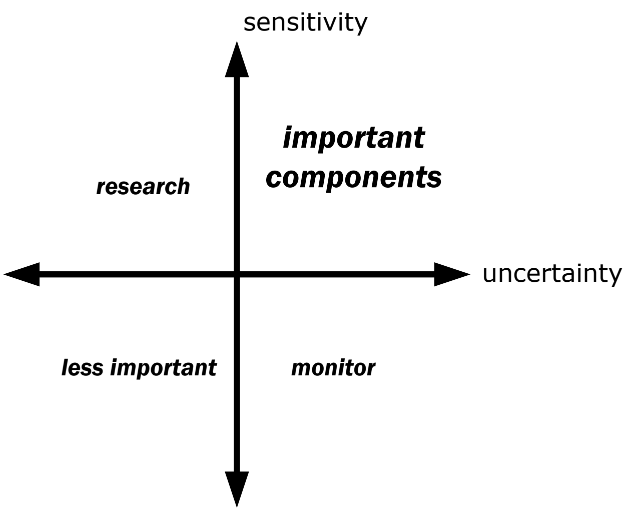


Figure 5: Evaluation framework uncertainty and sensitivity

Components that score high on sensitivity are interesting for further research. A small change in the size of the component has high influence on mobility, but what process determines this? Understanding these relationships means a higher understanding of the complex mechanisms that shape mobility. Components with high uncertainty are important to monitor, as this will help you find out how mobility will develop sooner. Also it is important to know if these components have relations with other components. If, although before you assumed components to be independent, very uncertain components affect other components, this could mean that sensitivity increases. Components that are both very uncertain and have high impact on future mobility are the most important for the travel time benefits of infrastructure investments.

The main research question is:

What are the key determinants in scenarios that influence the travel time benefits of infrastructure investments, how uncertain are they and to what extent do they influence them?

There are three subtopics: Scenario components and uncertainty, Mobility and sensitivity and Benefits of infrastructure investments. For each topic there are some sub questions. The following diagram shows the research questions and underlying relations.

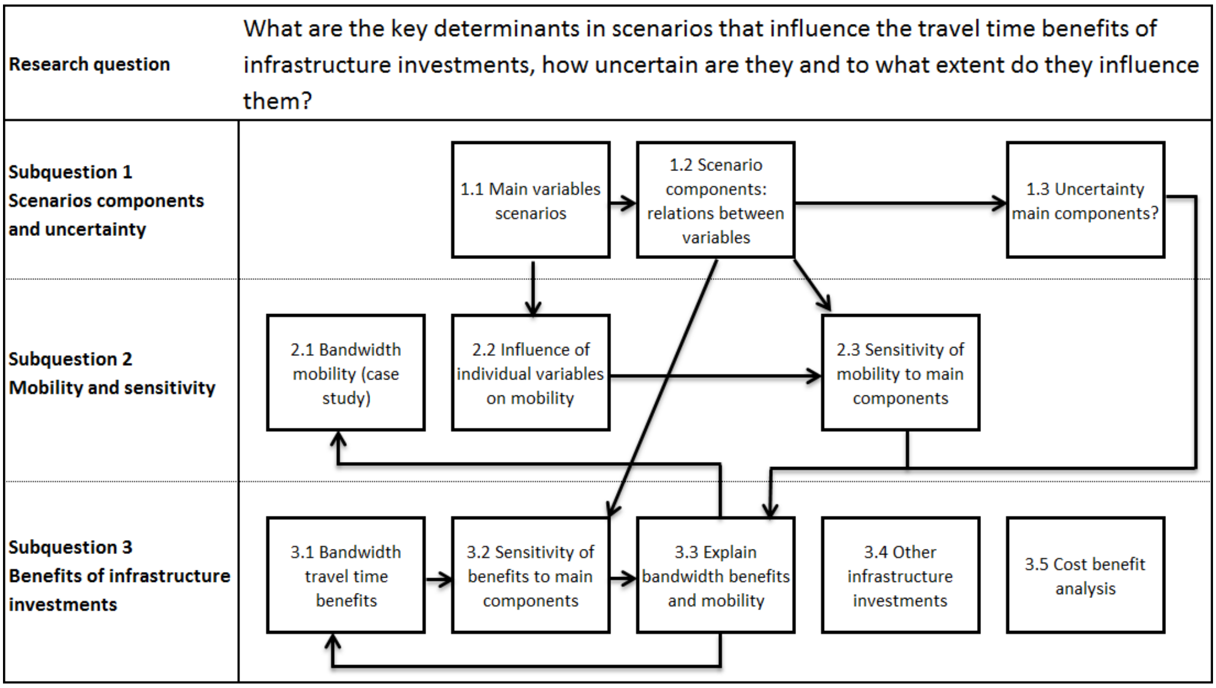


Figure 6: Schematic overview research questions

The sub questions are:

1. Scenario components and uncertainty

1.1 What are the main separate variables in scenarios?

This question focuses on the ingredients for the scenarios that are relevant for mobility in the future. Some of the variables found in literature were population, jobs, car ownership and oil prices. For this sub question I aim to compose a set of separate variables that together determine mobility in the future, concerning the background scenarios. Of course other factors, like policy measures or the road network also have a large influence on future mobility. The scenarios that I specifically researched also have an elaborate input data set. For both scenarios I will determine the values for the main separate variables.

1.2 How are the separate variables related: what are the main components?

An important feature of scenarios is that they represent consistent futures. Therefore I needed to design new consistent scenarios to perform the sensitivity analysis. The relations between the separate variables must be clear. For this purpose I determined scenario components that describe the relations between the separate variables. Together the main scenario components give a complete but simplified overview of the parts of the scenarios that I want to research. Here I will also use the WLO scenarios to illustrate the components.

1.3 How uncertain are the main components in scenarios?

The importance of the main components is determined not only by the sensitivity of the benefits to these components but also by their uncertainty. Components that are very uncertain will contribute more to uncertainty and risk of investments.

2. Mobility and sensitivity

2.1 What is the mobility 2030 for the two scenarios and what are the differences?

To evaluate the sensitivity of different aspects of mobility to variation in the scenario settings, I look at mobility in 2030 for the WLO scenarios RC and in GE. There will be more traffic and congestion in GE compared to RC. The analysis will show how large the bandwidth between the scenarios is.

2.2 What is the influence of the separate variables on mobility?

The difference between the two scenarios is caused by different components that all vary between RC and GE. To get an initial understanding for the sensitivity to the separate variables I performed a brief analysis on all separate variables that I found in sub question 1.1.

2.3 What is the influence of the main components on mobility?

Then the main components from sub question 1.2 were used to design new scenarios. For every component a separate analysis is performed for both scenarios. The analysis is different from that in question 2.2 because now new consistent scenarios are used. The variables should not be adjusted individually because in reality they influence each other.

3. Benefits of infrastructure investments

3.1 What are the travel time benefits of infrastructure investments for different scenarios?

Infrastructure investments on the main road network are supposed to have large travel time benefits, as was explained in the chapter about cost-benefit analysis. For this research a large investment package was implemented. The research focuses on the travel time benefits of this package. The analysis of the two scenarios will provide a bandwidth, as in sub question 2.1

3.2 What is the influence of the main components on the benefits?

Just like in sub question 2.3, the influence of the main components on the benefits are researched. Benefits are likely to be lower when there are less bottlenecks to solve, so the components that affect time loss and congestion hours are likely to also have a large impact on the benefits of investments.

3.3 Can the bandwidth between the high and low scenario be explained using the sensitivities to the separate components?

The bandwidths in mobility and benefits that were found for sub question 2.1 and 3.1 should be explained by the bandwidth in the values for the components and sensitivity of the results to changes in these values. This analysis will show the contribution of each scenario component to the difference in results between RC and GE.

3.4 Are the results comparable for a different package of infrastructure investments?

To show the consistency of the travel time benefit results, the analysis will be repeated for the two scenarios with another investment package. The bandwidth between RC and GE in terms of benefits should be about the same.

3.5 Which impact do the travel time benefits have on a regular cost-benefit analysis

To get an understanding of the role and importance of the travel time benefits in a standard cost-benefit analysis, I made an example of a cost-benefit analysis of the investment package in GE and RC. This will prove to which extent the travel time benefits affect the outcomes of cost-benefit analysis.

Together these subtopics will contribute towards answering the main research question concerning the key determinants in scenarios that influence the travel time benefits of infrastructure investments, their uncertainty and influence. The outline of the rest of this research report covers these three subtopics in three chapters.

3.3 Method

To answer all of these questions the method described in this paragraph was used. The following figure represents the sub questions in the research.

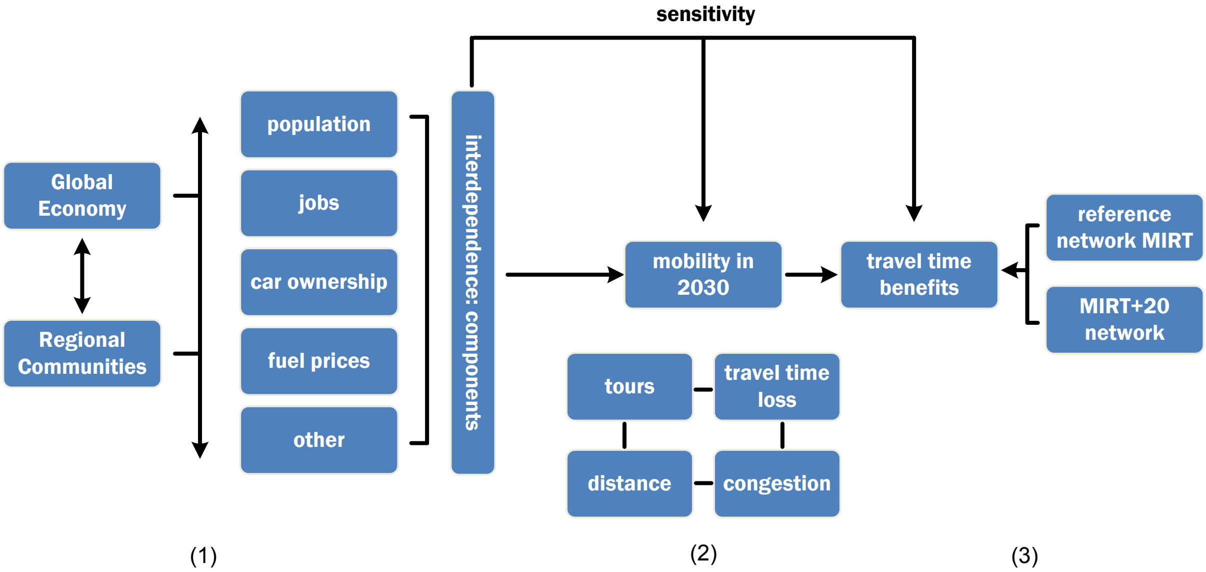


Figure 7: Visualization of the research

The focus and goal of this research concern scenarios from a more general viewpoint. The results of the research can be used to design and reflect on new scenarios in the future. To perform the research, however, two specific scenarios were evaluated that are commonly used in current practice. Starting point for this research are two WLO scenarios: RC (population decrease and lowest economic growth and mobility) and GE (highest economic growth). The scenarios consist of many variables that are uncertain and influence each other (1). They provide the input for the Dutch National Transport Model (LMS) that I use to forecast mobility in 2030. I will determine the difference in output for the two scenarios and analyze the sensitivity of the output to variation in specific scenario settings (2). The analysis covers only relevant components in my research framework, which is limited by the specifications of the model and scenarios. Other possible uncertainties, such as a more flexible economy (extended opening times, telecommuting) are beyond the scope of this research. Finally I will implement an investment package on the main road network (3) and use the output of the LMS to calculate the travel time benefits. The scope of the research is the year 2030, which is commonly used for cost-benefit analysis of projects. Data on the scenario's was provided by the Rijkswaterstaat Centre for Transport and Navigation (DVS). In this chapter I will describe the method used for this research according to three topics, drivers of mobility, an evaluation framework and the designed investment package.

3.3.1 Drivers of mobility

The first step in the analysis is to identify the important variables in scenarios and determine their values for both scenarios. How uncertain are they? Is there more uncertainty to them than is suggested in the scenarios? And finally: what are the relations between the variables? The results of the analysis on these questions are presented in chapter four.

There are many drivers that influence mobility in the future. They are described in chapter 4.1. For this research only the drivers that are part of the scenario approach were selected. The WLO scenarios (Global Economy and Regional Communities) were used for this purpose. Through a literature study and analysis of scenario data, I made a selection of separate scenario variables.

Then the relations between the separate scenario variables were analyzed. For this the database from the two scenarios was used. Each variable was plotted against the others to evaluate if they are related. This analysis resulted in a selection of scenario components that can be used to design new scenarios. The new scenarios are used to evaluate the sensitivity of mobility and travel time benefits to changes in the scenario components. For the new consistent scenarios it I kept relations between dependent variables constant. When the scenario components are adjusted related variables are adjusted consequently. I want to emphasize the difference between separate variables and scenario components.

$$Separate\ variables \neq scenario\ components \tag{1}$$

The separate variables are the variables in scenarios that are input for the traffic model. The scenario components also account for relations between the variables. In my study I analyzed the effect of components by creating new scenarios.

Two examples:

Separate variable	**Scenario component**
1. Population	**1. Population**
Concerns: Number of people	Concerns: Number of people, households, cars jobs, employed people
2. Jobs	**2. Participation**
Number of jobs	Number of employed people, labour force, jobs

The final step to conclude the first part of the research is to evaluate the uncertainty of the selected scenario components. The components that are more uncertain will contribute more to uncertainty and risk of infrastructure investments. To analyze uncertainty I took the two scenarios as a starting point. I choose the bandwidth per component between the scenarios as a measure for uncertainty and complemented this with additional analysis of historical and where possible forecast data by CBS. For every component the uncertainty is presented on a five point scale, from very certain (--) to very uncertain (++) and in the bandwidth between the scenarios.

3.3.2 Evaluation framework for mobility

The part of my research concerns the sensitivity of the output to these components. To do this I designed new scenarios. In this research, it is important to make consistent new scenarios. This means that when one variable changes, some other variables should be changed as well. Otherwise household size, car ownership level or participation level would have unrealistic values.

The output is specified by the following four indicators:

- Tours: Amount of car driver tours that are made by the Dutch population with origin and destination within the Netherlands. A tour is defined as a chain of trips that starts and also ends at home. Freight traffic is excluded.
- Distance (km): Total car driver distance that is travelled with origin and destination within the Netherlands. Freight traffic is excluded.
- Travel time loss (h): The travel time that is lost due to high intensities on the road network. The travel time loss is calculated by comparing the free flow speeds to the actual speeds on a loaded network, and the lost travel time per vehicle is multiplied by the number of road users.
- Congestion hours (h): This is the time that is lost due to congestion on the main road network. It is defined as the cumulative time that people have to wait in congestion compared to free flow travel times. This indicator corresponds to a large extent to the Dutch indicator VVU (voertuigverliesuren) for congestion defined as driving < 50 km/h on the highway.

The transport model that is used in many projects is the Dutch National Transport Model (LMS, version 1.3.3-beta). This model was also used to forecast mobility in 2030 in this research. The model output consists of a number of aspects, including differentiation to time of day and travel purpose. All analysis regarding the first two topics are performed with the reference network. In this network all the 0 and 1 projects in the project book of the MIRT 2012 are included.

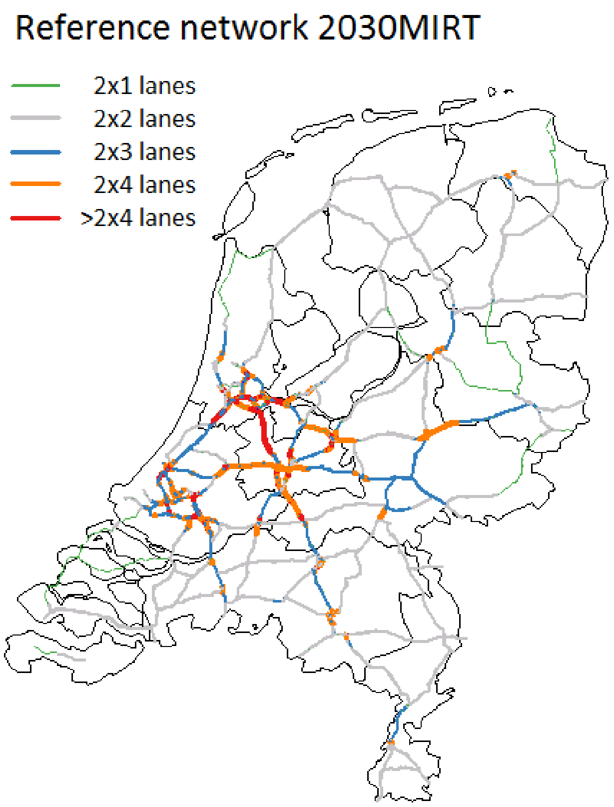


Figure 8: Reference network 2030 (including MIRT 2012)

3.3.3 Investment package and travel time benefits

The analysis above is carried out with the reference network of the LMS for 2030, in which all projects in the MIRT project book 2012 are included. For the analysis on the benefits of investments I designed a fictional investment package. The package includes projects besides the already implemented MIRT projects. It was not feasible due to technical limitations to perform any sensitivity analyses on more different investment packages or policy measures.

The MIRT+20 package consists of about 20 million euros of capacity increments for the period of 2020-2030. This corresponds with the investment rate in infrastructure of the MIRT of about 2 billion per year. There are about 1,500 extra lane kilometers at the most important bottlenecks. I assumed an average cost of 13 million euro per lane-kilometer. For the project Ruimtelijke Verkenningen (PBL 2011) the same assumption was made and the same network was used for calculations. The following figure shows the location of the investments. Details can be found in the table.

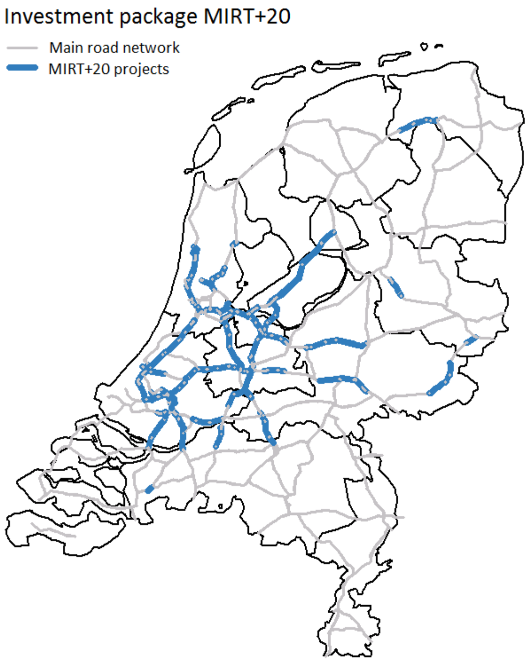


Figure 9: Investment package MIRT+20

Costs MIRT+20		
Budget 2020-2030	€	20,000,000,000
Costs per kilometer lane	€	13,000,000
Lane km - budget		1,538
Realized		1,565
Total costs	€	20,342,270,000

Table 1: Details on the MIRT+20 package

Appendix 9.6 describes in detail more about the reference network and the investment package.

For this investment package the travel time benefits were determined for both scenarios. They consist of the benefits from shorter travel times and shorter routes. The conventional approach to measure accessibility benefits of transport strategies in transport infrastructure appraisal is to use the quite simple and aggregate rule-of-half measure. This computes the change in user benefits as the sum of the full benefit obtained by original travelers and half the benefit obtained by new travelers. This can be calculated by multiplying the average number of trips between a base scenario and a scenario with a project by the difference in travel times and the value of time for different consumers. The practical use of the rule of half was explained in chapter two, and in a paper by Rijkswaterstaat (2008).

The values of time that were used are shown in the table below (4cast 2011). The value of time represents the value that we attribute to one hour of travel time. Note that GE has about 15% higher values. See also appendix 9.7.

Overview Values of Time (price 2012)		
	2030 RC	2030 GE
Work	€ 10.59	€ 12.55
Business	€ 36.69	€ 43.31
Other	€ 7.35	€ 8.63
Freight	€ 51.33	€ 60.64

Table 2: Overview values of time

3.4 Scope

To describe the scope of the research I summarize the assumptions that were made and elaborate a little on the research boundaries, that says something about what I did and did not research.

3.4.1 Assumptions

For this research I made the following assumptions

- A 26 year horizon was used, 2004 serving as the reference year and 2030 as the forecast year. A time horizon of 20 years is not unusual for project evaluation. Often even longer periods (such as 30 years) are applied.
- Information need from the LMS is based on the year 2030
- Population in RC 16,3 million, in GE 18,9 million
- Household gross income is assumed respectively 63.340 and 81.240 euros per year
- The oil price is assumed 70 dollar/barrel (in the original WLO this was 22 and 28 dollar/barrel, the recent RR12 estimated 70/122/175 dollar/barrel)
- The car park is 8.3 (RC) and 10.9 (GE) million cars, which amounts to respectively 1,151 and 1,158 cars per 1000 households.
- Other important assumptions are for the RC and GE scenario the household size (2.26 / 2.00) and participation level (73% / 77%)

3.4.2 Research boundaries

The research only concerns travel time benefits of infrastructure investments. The travel time benefits are relatively easy to determine with the output of the LMS model. Other types of benefits were not included, such as indirect effects concerning the effects on the labour market or external effects such as emissions, noise or traffic safety. An example of what a more complete CBA would look like is given in chapter 6.

The infrastructure investments consist of a large investment package of 20 billion euros implemented in 10 years time. In the research this is assumed to be all ready in the year 2030 for which the benefits are calculated. It was not possible due to the characteristics of the model to look at a specific infrastructure project. This would require the use of a regional model like the NRM. Within the time and limits of the research I could only look at this one measure, which means other (types of) measures were not included, only infrastructure investments. Public transport is part of the model, but was kept the same for all analyses. Pricing or environmental policies were not studied.

4. Scenarios components and uncertainty

So the goal of this research is to find out which scenario components are the most influential on the outcomes of scenario studies. This chapter is about scenarios and components. Chapter two explained that scenarios are used for various purposes, such as the analysis of future bottlenecks on the main road network (to estimate the needed funds to deal with them) or determining the profitability of local projects. For this study the researcher chose to look at the benefits of a large infrastructure investment package and determine the travel time benefits of that package in various scenarios. But first, lets see what the scenarios are all about in more general terms. In the first paragraph scenarios are specified into separate variables that shape mobility in the future. The most relevant variables are highlighted. The second paragraph explains about the relations between the separate variables and introduces scenario components. The last paragraph studies uncertainty of the scenario components by looking at historical and forecast data and also at the input data of the case study.

The scenarios that are primarily used in long term strategic analyses, such as the NMCA (Rijkswaterstaat 2011) or Ruimtelijke Verkenningen (PBL 2011) are those from the study Welvaart & Leefomgeving (CPB/MNP/RPB 2006). Of the four developed scenarios the high (Global Economy) and low (Regional Communities) scenario are used most often. The RC scenario assumes worldwide separate trading blocks and a modest growth of population and economy. The GE scenario assumes a high level of trade worldwide, high growth of labour productivity and population size (mainly because of immigration) and high economic growth.

4.1 Drivers of mobility: Separate variables

Future mobility is dependent on many different factors. Here I will briefly describe some of the most important developments that determine future mobility. However, not all the drivers of mobility are described by the scenarios and therefore some are excluded from this research. The following figure shows different drivers of mobility.

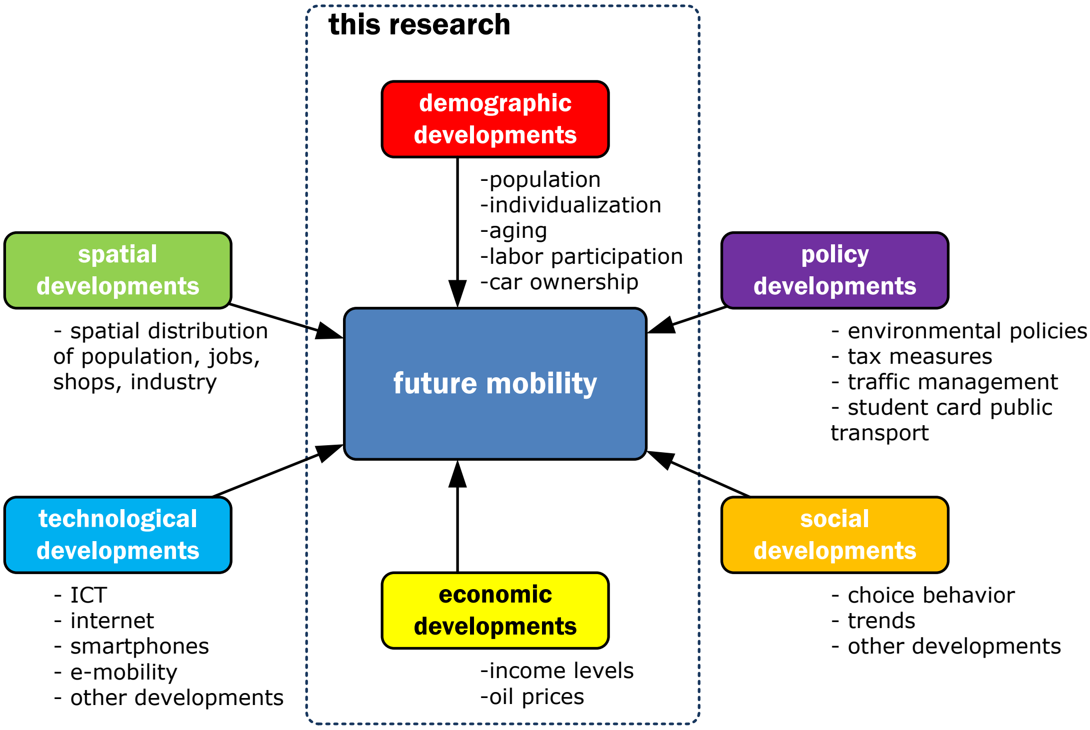


Figure 10: Drivers of future mobility

Mobility is primarily a result of the need of people or groups of people to reach activities or destinations. Therefore the population size is an important driver of mobility. Other factors are for example labour participation, which determines how many people need to travel to work, and car ownership, which determines if people are able to travel by car. These are demographic developments. The government influences the development of mobility by imposing policy measures. The environmental policies are very important as they set limitations and objectives to which other developments have to comply. Tax measures affect the cost of traveling but can also influence car ownership. The implementation of a student card for free public transport use turned out to have a large effect on the use of public transport. Though time the society changes and also behavior of people. Some trends may influence the popularity of specific transport modes or the need to travel. This is very hard to predict. Economic developments, such as income levels and oil prices determine how much people can spend on travel and how expensive it is. Technological developments can have a large impact on mobility. Smartphones and internet increase the information on transport alternatives substantially. The use of ICT applications like telecommuting can reduce the need to travel. Electric vehicles will change the costs of transport. Finally, spatial developments determine where people live and work, and therefore how they will travel.

For the WLO scenarios the choice was made to exclude the factors that can be influenced by policies. The reason is that the scenarios then can be used to study the effects of these policies and measures in more and less favorable circumstances. This research focuses on demographic and economic developments. To see which ingredients of scenarios are important for this purpose, this paragraph describes the drivers of future mobility that are in scenarios. First according to literature and then specifically for this research using the WLO scenarios.

Demographic and economic driving forces of transport demand

De Jong, Daly et al. (2007) performed a literature review on uncertainty in traffic forecasts. They focused on demographic and economic driving forces and found that the literature on this subject is fairly limited. From 23 papers they selected the most important variables that determine the tour generation and the mode destination models. The list does not include policy variables (such as public transport fares, parking costs and speeds of modes) that can be influenced by users of the models (government at different levels, public transport operators). Travel demand uncertainty depends on more factors than the autonomous variables in this list, for example travel behavior and spatial distribution of the population. The list of the main autonomous forces for simulation of input uncertainty on transport demand (defined here as tour generation and mode-destination choice) is as follows:

- Household disposable income
- Car ownership
- Car cost per kilometer (only the fuel cost part, which is partly an autonomous and partly a policy variable, but not the toll and parking cost which are fully policy variables)
- Number of jobs (by sector), which serves as an attraction variable
- Population size
- Household size
- Occupation (employed or unemployed by gender)
- Education (number of students per type of education)
- Part-time and full-time employment
- Freight traffic

Disposable household income

The growth in Gross Domestic Product (in total, not per capita) is used as proxy for the growth of disposable household income. Income influences the number of licenses and the number of tours. An increase in income will lead to a change in destination choice; in general these destinations will be further away.

Car ownership

Income and car ownership are highly correlated. The level of car ownership is a characteristic of the different household- and person types in the model, and has an impact on the mode/destination choice for each type.

Car costs

The car costs are built up out of two statistics:

- Oil price per barrel and the prices of petrol, diesel, and LPG
- Fuel efficiency of the car fleet

Fuel prices are partly a policy variable (fuel taxes), and partly an autonomous variable (determined to a great extent by the oil market). The level of the fuel price has a direct impact on the kilometer costs for car driver. Other modes than car will benefit directly from an increase in the fuel price. Research of Groot and Mourik (2008) shows that high oil prices affect the effectiveness of all policy directed at reducing congestion. The calculations with the LMS indicate that high oil prices have a limited effect on mobility. However, a slight drop in mobility can have a relatively large impact on congestion. This is mainly a result of the exponential nature of the relationship between mobility and congestion. The reducing effect high oil prices have on congestion is thus substantial, as demonstrated by their LMS calculations.

Labour force

The labour force has a significant impact on the number of tours for the purposes 'home-work', 'home-based business' and 'non-home-based business'. The tour frequency model of the LMS reacts to the level of the labour force.

Population and average age

The population is distributed to a zonal level. The midpoint of each age group (0-20, 20-40, 40-65, 65-80, 80+) is assumed to be the average age. People over 80 are assumed to have an average of 85. An increase in population will lead to an increase in demand. An increase of the population above 18 years old will lead to more license holders and potential car owners. This will impact the modal shift.

Household size

A change in the size of household will have an impact on the number of cars. The trend of declining household size will lead to an decrease in relative car ownership per household. This is because larger households generally have more cars. Smaller household sizes result in more households.

Occupation/education

Education in the LMS is divided into three categories: basisonderwijs, VO/MBO and HBO/WO. The number of tours for education (both children and higher education) is related to the number of students.

These drivers are also input for the LMS model. The zonal data is very elaborate. In total it is described in appendix 9.8.

Freight traffic

Freight traffic was included during the research as it has a large effect on the model outcomes. In the LMS freight traffic is not adjusted to other input data but it is an autonomous exogenous matrix. In reality freight traffic can be seen as a derivate of population size and income levels and is not an autonomous variable.

4.2 Scenario components: Relations between variables

The variables are not independent to each other and therefore were not adjusted separately for the sensitivity analysis, as this would implicate inconsistent scenarios with unrealistic household sizes, car ownership levels or participation levels. Therefore I studied the relations between the separate variables and extracted scenario components that define relations between the variables and together describe the scenarios. With these components I built new consistent scenarios, keeping relations between dependent variables constant. To build new and consistent scenarios, it is important to know the relations between the key variables. For instance, if the population declines by 5% in the GE scenario, what kind of impact would this have on the number of households, car ownership, fuel prices, labour force, etc?

I examined the relationships between the scenario variables using CBS data and the data sets of the WLO scenarios. I had two considerable datasets of the scenarios in 2030, namely the RC and GE dataset. For the GE scenario I plotted the key variables against each other for every zone to see relations and consistencies. The dataset of RC showed the same conclusions. With the help of the data set of the WLO scenarios the correlations between scenario components on the zonal, COROP and provincial level were analyzed. Below an example is given. In the appendix 9.9 all graphs are presented.

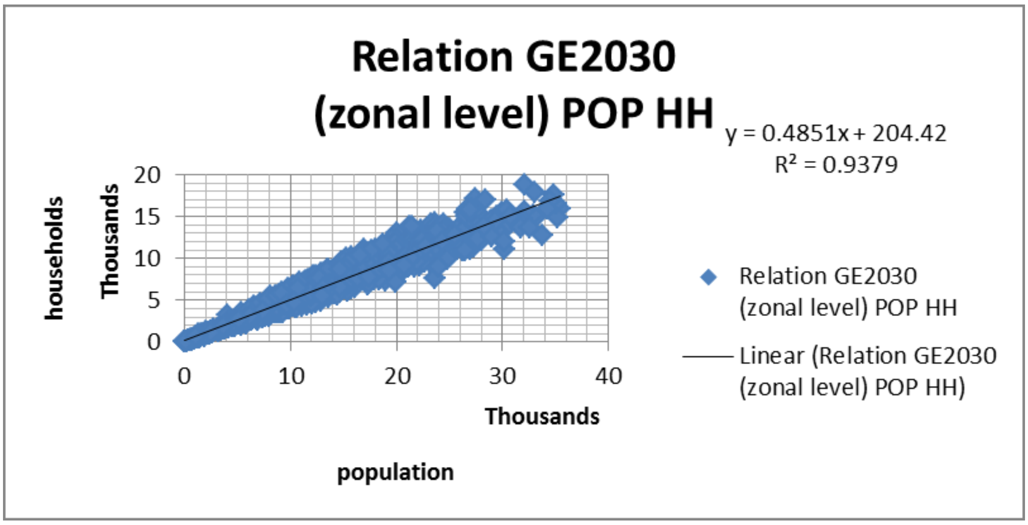


Figure 11: Relation between population and households on the zonal level

The main component that I set centrally in the scenarios is the population size. Many variables depend on this component. More people, more households; more people, more cars; more people, more jobs, etc.

The results of the analysis is that population (POP) and number of households have a strong relationship. I will define this for the rest of my research as the household size (HHS). The average car ownership per household (CAR) relates the number of cars directly to the number of households. A certain percentage of the households has 0, 1, 2 or more than 2 cars. Employed population and labour force are strongly related, the variable jobs seems weakly related to any other variable. I will assume the variables jobs, employed population and labour force to be directly related. If the number of jobs increases, the employed population will too by the same percentage. Employed population and labour force are strongly related to the population. I will define this relationship for the rest of my research as the participation level (PAR). The gross average income (INC) should be related to car ownership level and to participation, but for this research this is also an independent variable. I will assume the variable car cost (CST) prices as an independent variable and also freight traffic (FRG) for practical reasons. I also used CBS data to uncover relations between the separate variables. The results are partially shown in the next paragraph that deals with component uncertainty. Together these analyses resulted in the following figure.

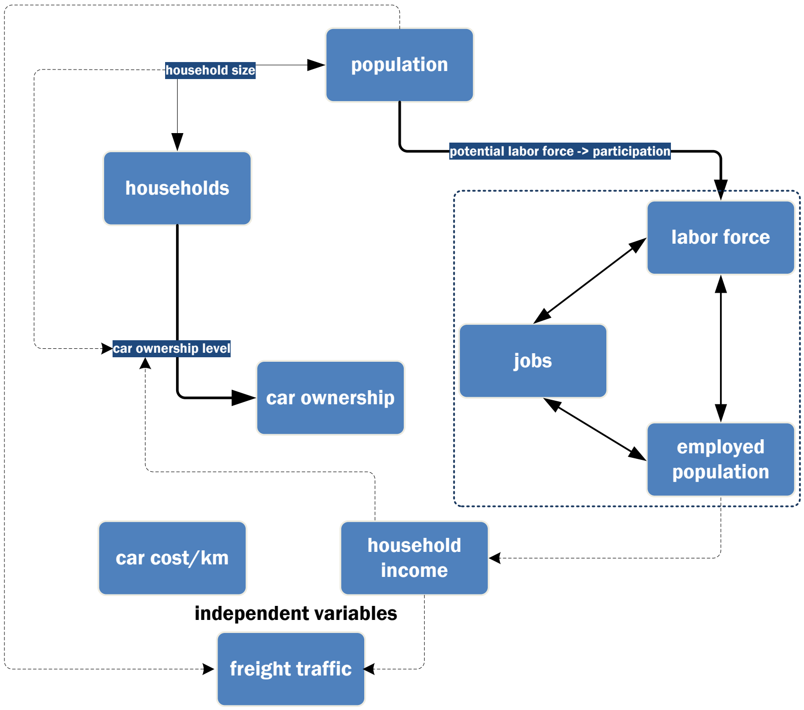


Figure 12: Relations between separate variables

The components are described in the table below.

Description of scenario components		
		Description
Population	POP	The number of registered men and women on January, 1st of that year
Household size	HHS	The household size is defined as the population divided by the households; a household consists of one or more persons who live alone or together in a living space and take care of their own daily needs
Participation level	PAR	The participation level is the labor force divided by the potential labor force. This input variable defines the labor force, employed population and the number of jobs as the relation between these variables is assumed to be constant
		Labor force: Number of men and women in the age of 15-64 years who work at least 12 hours per week, have accepted work that they have to do at least 12 hours per week or have declared that they want to work at least 12 hours per week
		Employed population: Number of men and women who work at least 12 hours per week
		Jobs: Total number of jobs in all sectors for which paid work is carried out for 10 or more hours per week
Car ownership level	CAR	The average number of passenger cars per household; input is the % households with 0, 1, 2 or 2+ cars
Household income	INC	Average gross income per household
Car cost / km	CST	The variable car cost per kilometer in GE and RC, expressed as an index number where the price level in 2004 is 100; the costs are determined by oil prices and the fuel efficiency of the car park
Freight traffic	FRG	The freight traffic is defined by the number of kilometers traveled on the network for the travel purpose freight
Spatial distribution	SPA	The spatial distribution concerns the distribution of the variables to the LMS zones

Table 3: Description of the scenario components

This model was simplified for the purpose of this research. The dotted lines represent relations that are not included in the component analysis. Variable car costs and freight traffic are input variables on an aggregated level in the LMS and couldn't be related to the spatial variables. This model limitation is the main reason that they are treated as an independent variable for this study.

The differences between the two scenario's on the input for these drivers were extensively analyzed.

4.3 Uncertainty of scenario components

So scenarios sketch consistent and equally probably futures. In scenario analysis no probabilities are attached to the various scenarios under study. This means that one scenario is not more likely to 'happen' than the other. Therefore this research is primarily a sensitivity analysis for future mobility to changes in the scenario components. However components that are equally sensitive but more uncertain are very important for scenarios. For the design of new scenarios the starting point are the drivers of mobility that have much influence but are at the same time very uncertain.

This paragraph presents a limited study for the uncertainty of the scenario components that I determined in the previous paragraph. The bandwidth of values between RC and GE serves as an indicator but also forecast data of the CBS and historical data were analyzed. Per component the uncertainty is discussed.

For all separate variables the bandwidth and growth compared to 2004 for the two scenarios are shown in the table below.

Input variables			
	2004	2030RC	2030GE
Population	16,258,000	16,334,000	18,889,000
Households	7,049,000	7,228,000	9,443,000
Labor force	7,538,000	7,355,000	8,833,000
Employed population	7,057,000	7,079,000	8,518,000
Jobs	7,017,000	6,433,000	8,212,000
Students	399,000	453,000	534,000
Household gross income	€ 48,900	€ 63,300	€ 86,700
Cars	7,010,000	8,320,000	10,940,000
Car cost / km	100	91	93
Population	100	100	116
Households	100	103	134
Labor force	100	98	117
Employed population	100	100	121
Jobs	100	92	117
Students	100	113	134
Household income	100	130	177
Cars	100	119	156
Car cost / km	100	91	93

Table 4: Overview of the bandwidth per scenario for the separate variables

Population

According to the LMS data, the population growth in the Netherlands varies in the period from 2004 to 2030 between an increase of 70.000 and 2.630.000 people in the low and high scenario. The population in the low scenario increases only until 2020, after that there will be a slow decline. The difference between the high and low scenario, the bandwidth, amounts to 16% of the population in 2004.

Population growth				
	2004	2004-2020	2020-2030	2004-2030
scenario RC	16,260,000	+240,000	-170,000	+70,000
scenario GE	16,260,000	+1,620,000	+1,010,000	+2,630,000
bandwidth	-	8%	7%	16%

Table 5: Population growth

The following maps show the Netherlands divided into COROP (Coördinatiecommissie Regionaal Onderzoeksprogramma) regions. This is an economic division: every zone has a core with a service area. They divide the Netherlands into 40 zones.

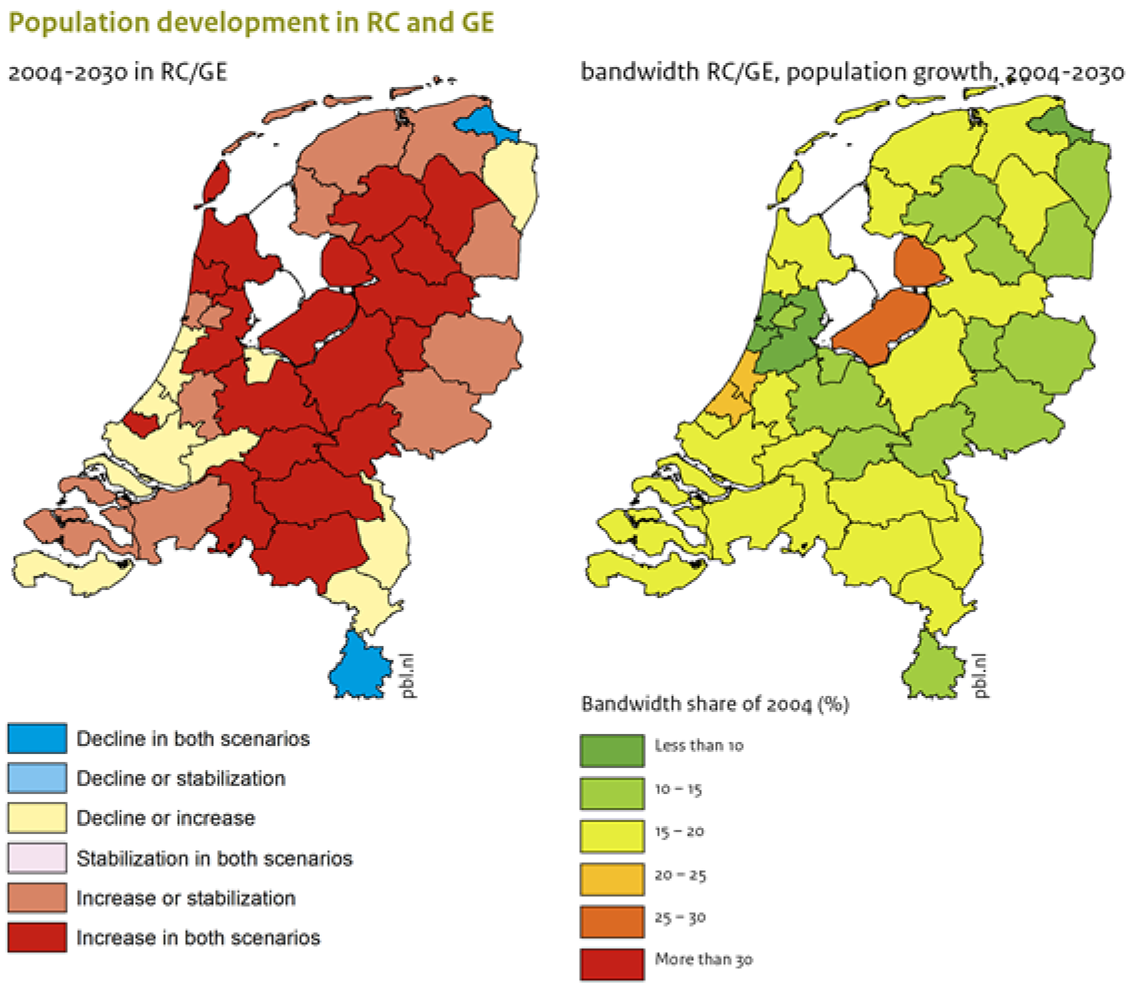


Figure 13: Population development in RC and GE

The development is classified in the first map according to the table below. The second map shows the bandwidth of the development, the difference in growth expressed as a percentage of the COROP value in 2004.

Classification development of variable	
	Compared to 2004
Decline	< -2%
Stabilization	-2% - 2%
Increase	> 2%

Table 6: Classification of population development

In Zuid-Holland and Limburg there are some zones where the population declines in RC but increases in GE. The population in the middle of the Netherlands increases in both scenarios. The average bandwidth for the two scenario's is 16% of the population in 2004. In Utrecht, east-Gelderland and around Amsterdam this bandwidth is smaller, around The Hague and in Flevoland it is larger. The difference in spatial distribution of the population might lead to a different mobility pattern. More people means more trips. In Zuid-Holland there is relatively more uncertainty, around Amsterdam and Utrecht less.

The population forecast of the CBS from 2000-2008 for the population size in 2030 show a range of 5.5% varying from 17.0 million to 17.9 million people. The 67% and 95% confidence intervals for the StatLine tables give an impression of the expected accuracy of the forecast. For these forecast intervals it is assumed that the probability, that the size of the future population will be between these values, is 67% or 95%. It should be noted that this probability distribution is also a forecast since it is based on assumptions whose validity is uncertain.

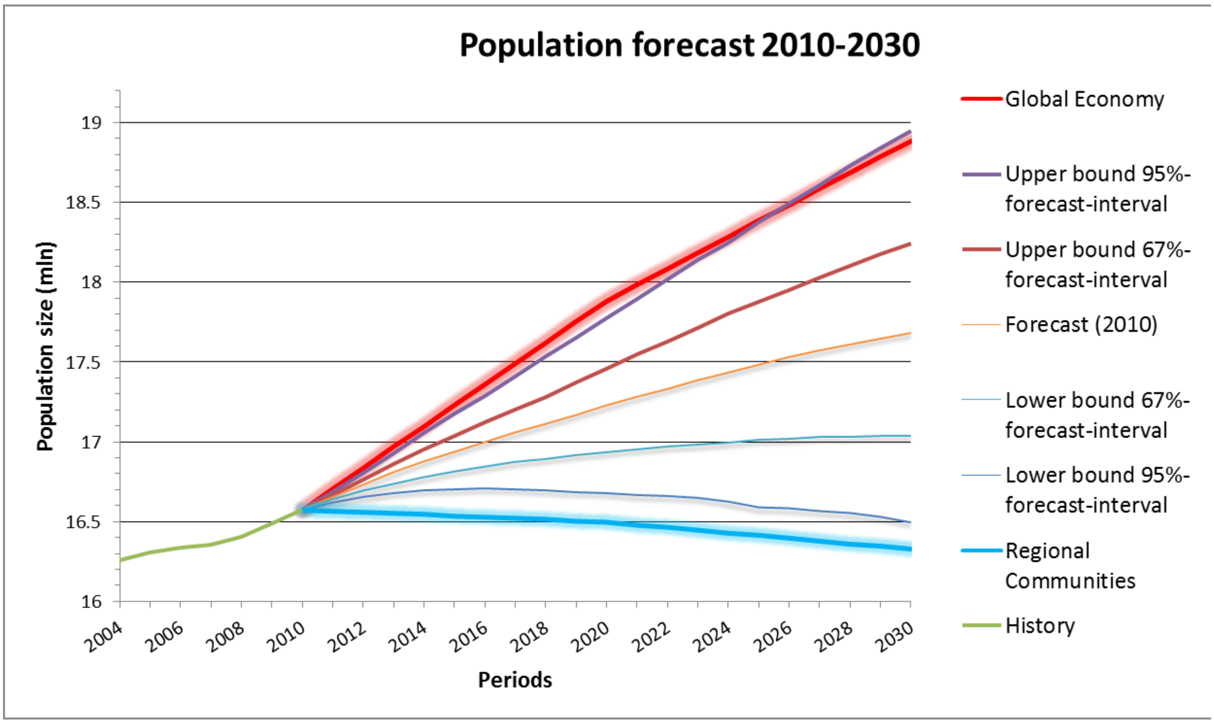


Figure 14: Population forecast for 2030

The 95% upper and lower bound intervals match the high and low scenario for the population. The conclusion is that population is an uncertain component.

Household size

The total number of households increases because of the population growth and the change in household size. The index number for population in 2030GE was 116 for population, and is 134 for households

Households growth				
	2004	2004-2020	2020-2030	2004-2030
scenario RC	7,050,000	+300,000	-120,000	+180,000
scenario GE	7,050,000	+1,580,000	+810,000	+2,390,000
bandwidth	-	18%	13%	31%

Table 7: Household growth

About every two years the CBS makes a forecast on households and population. The household size for 2030 is shown in the figure below.

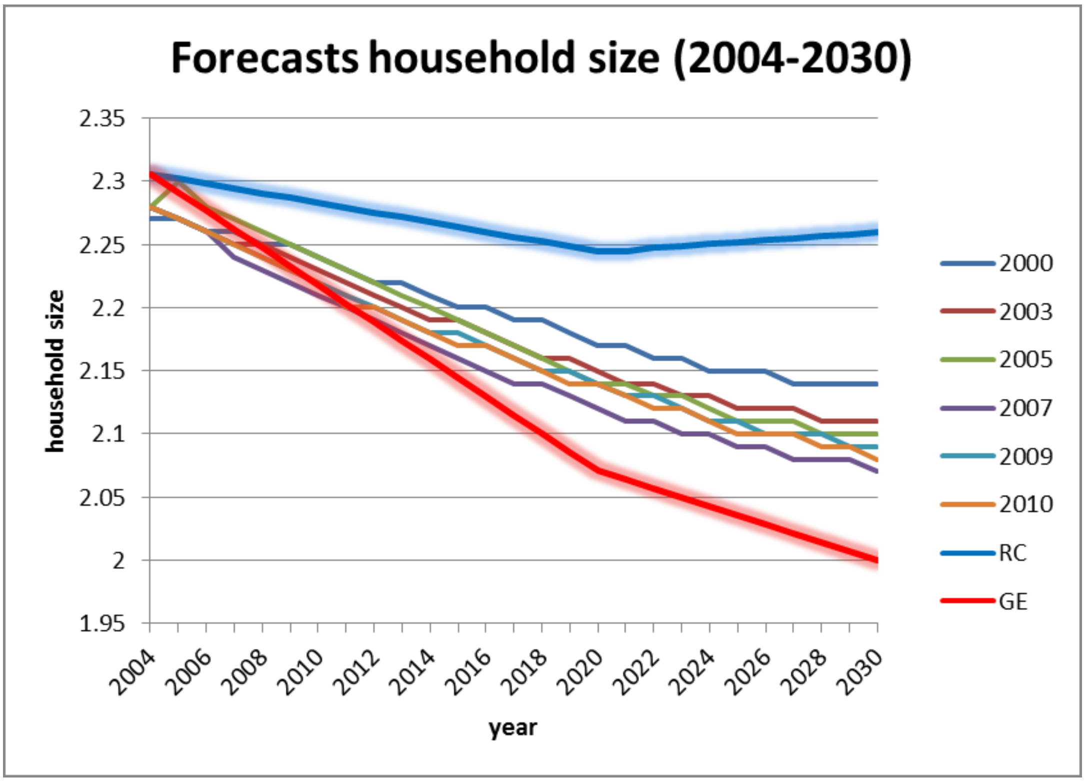


Figure 15: Forecasts of household size in 2030

The average household size is 2.26 in RC and 2.00 in GE. This is a bandwidth of about 12%. Individualization is higher in GE. This variable is important because the travel behavior of a person depends on the type of household he is in. The household determines if the person has a car and which income class he is in.

The smallest average household size in a zone in RC is 1.70 and the largest household size 4.36 people per household. In GE these are respectively 1.25 and 3.32. The CBS data shows that in case of a high prediction of the population, household size is also generally higher. This means that the number of households is relatively less uncertain. The conclusion is that the household size is an uncertain component.

Labour market

The labour market concerns the population that are between 15-64 years old, labour force, jobs and employed population.

The future growth of the employed population is the result of demographic developments, such as growth (positive or negative) of the potential labour force, aging and increasing ethnic diversity, and the change in participation level, brought about by socio-cultural trends and policy changes (Roodenburg and van Vuuren 2004). Demography and participation have opposite effects on the development of the labour market. Mainly because of aging demographic development has a negative effect. In contrast, the participation level has a positive contribution in all scenarios, thanks to social policies. In the long-term the development of the labour market is largely determined by the wedge (the difference between gross and net wages) and the replacement rate (ratio between the social security allowance and net wages) (Broer, Draper et al. 2000). In all scenarios social policies increase both and therefore it will be more attractive to have a job. As a result of these developments, we see that in the scenario Regional Communities the labour force declines. But thanks to a low unemployment rate the employed population stabilizes.

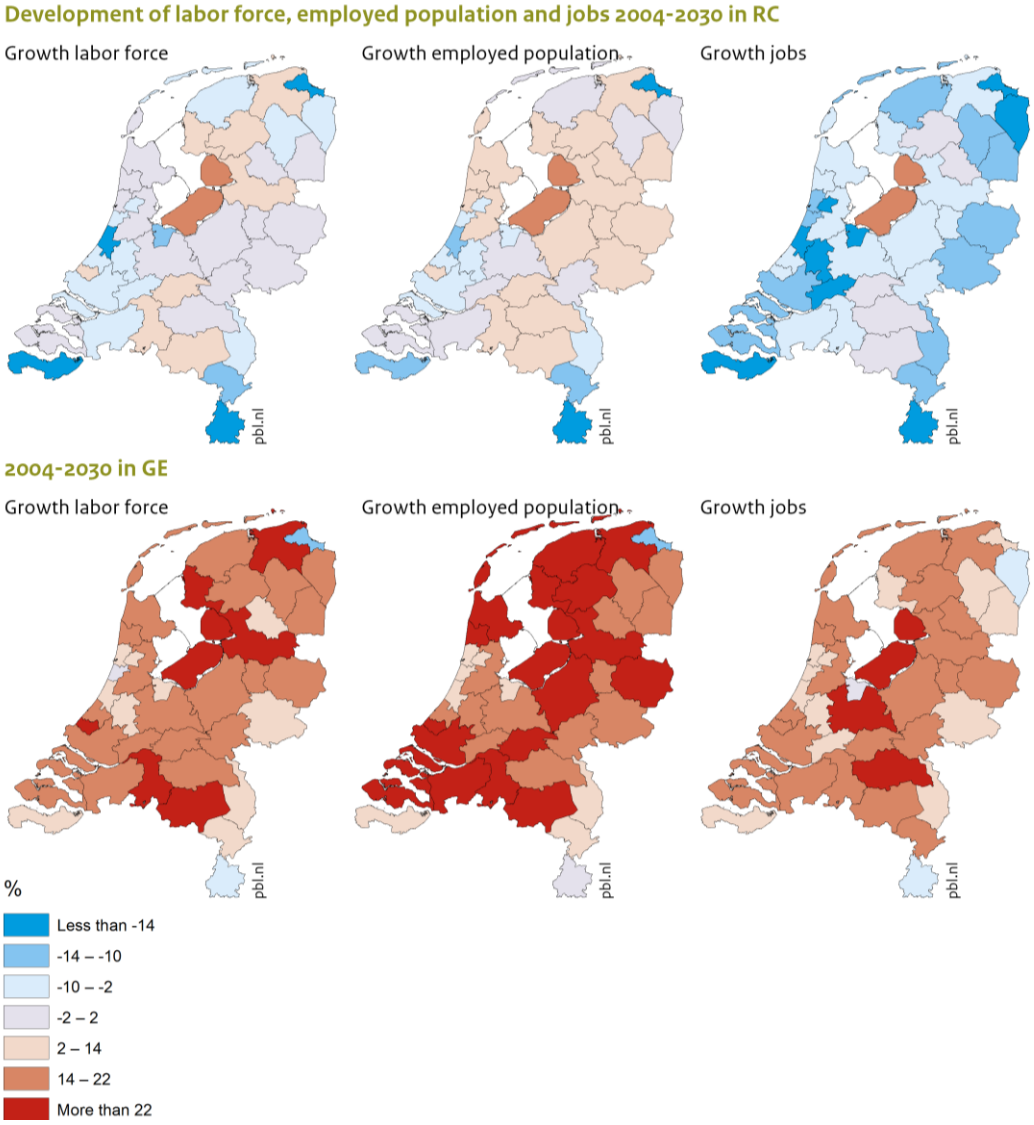


Figure 16: Development of labour force, employed population and jobs in RC and GE for 2004-2030

It is clear that growth of labour force, employed population and jobs is overall higher in GE. In GE the number of jobs and employed population increase almost in every corop zone, while in RC this highly differs per zone for employed people and the jobs even decline in most zones. Only Flevoland seems to be guaranteed an increase. The growth of jobs is uncertain.

As there was no forecast data available on the labour market, I used historical data to see how the participation level varied in the last 15 years. The figure below shows the result.

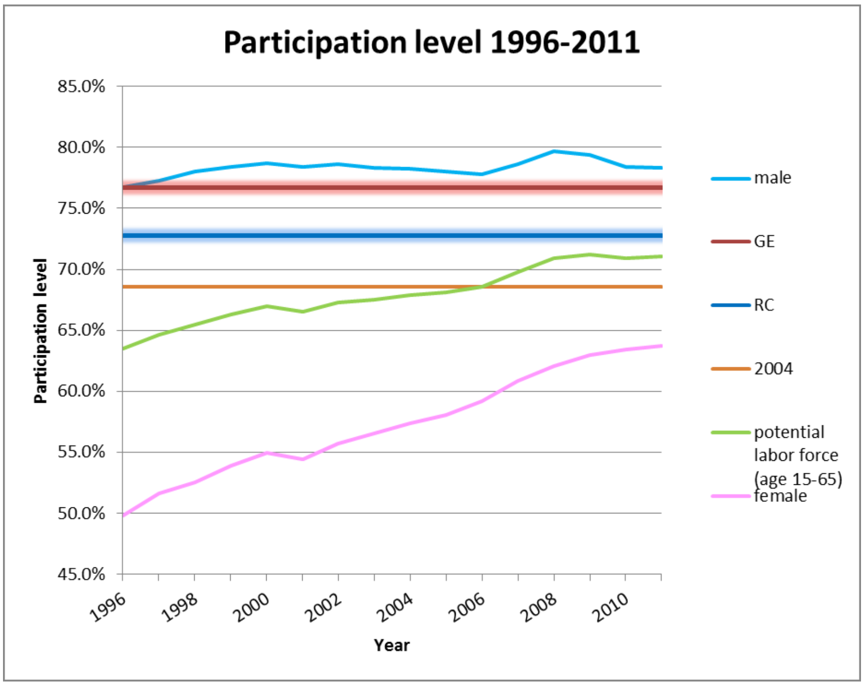


Figure 17: Participation level 1996-2011

The figure above displays historical data on the participation level in the Netherlands (CBS 2012). In the last 15 years the participation level did not come within the range of the scenarios in 2030. From the chart it is obvious that the main reason is the participation of females, as the male participation is more constant. As in GE the household sizes are considerably smaller, it is plausible that relatively more women will participate on the labour market. In the next table it is showed that the increase in participation is mainly for women.

Participation level in both scenarios			
	LMS2030RC	LMS2030GE	difference
participation	72.8%	76.7%	+5.4%
Male	78.0%	79.6%	+2.1%
Female	67.5%	73.7%	+9.2%

Table 8: Participation level in both scenarios

The participation level for the female population is supposed to increase to 2030 and the total participation level is predicted to lie between 72.8% and 76.7%. The difference is mainly because the increase of female participation.

According to many experts employment and working people are important spatial variables. Therefore I compared the development of labour force, employed population and jobs for RC and GE. On a regional level, the following figures illustrate growth in jobs, labour force and employed people in both scenarios

This shows that there is uncertainty in this component.

Car ownership level

The number of cars is much higher in GE compared to RC. However, this is directly connected to the increase in households, as can be seen when the cars are divided by the number of households in that scenario.

Car ownership			
	LMS2004	LMS2030RC	LMS2030GE
households with 0 cars	1,668,994	1,358,163	1,718,812
households with 1 car	3,905,530	3,636,107	4,802,864
households with 2 cars	1,320,568	2,016,111	2,629,392
households with 3+ cars	154,172	218,048	291,766
Cars	7,009,182	8,322,473	10,936,946
# cars / 1000 households	994	1,151	1,158
Index car ownership	100	116	116
Index cars	100	119	156

Table 9: Car ownership bandwidth for RC and GE in 2030

Car ownership level 2030		
	%2030RC	% 2030GE
Households with 0 cars	18.8%	18.2%
Households with 1 car	50.3%	50.9%
Households with 2 cars	27.9%	27.8%
Households with 2+ cars	3.0%	3.1%

Table 10: Car ownership level in percentages in 2030

For the last 10 years, the number of cars per 1000 households has not increased much, as can be seen in the following graph, that also shows the development of car ownership concerning income levels. This clearly shows the relationship between income levels and car ownership levels.

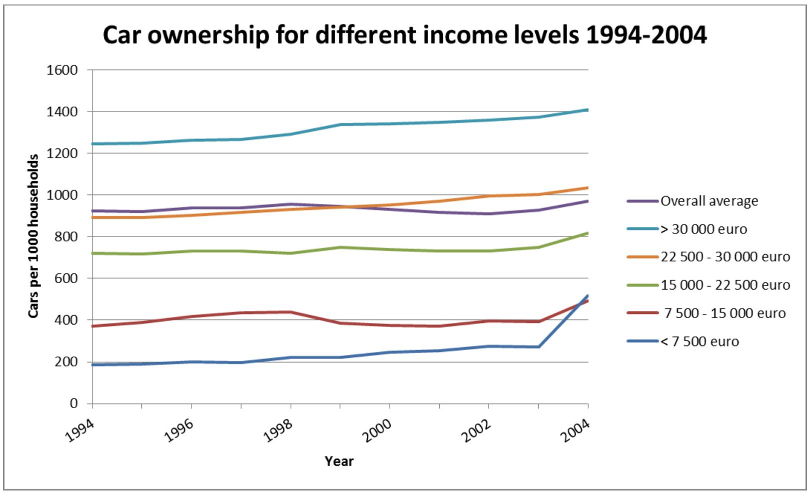


Figure 18: Car ownership for different income levels 1994-2004

The following tables summarize CBS data from 1994 – 2004 on car ownership in the Netherlands.

Car ownership level / urbanization						
	average	1	2	3	4	5
Households with 0 cars	25%	13%	15%	20%	27%	43%
Households with 1 car	58%	61%	61%	61%	58%	49%
Households with 2 cars	16%	23%	22%	18%	14%	8%
Households with 2+ cars	2%	3%	2%	2%	1%	0%
Cars / 1000 households	948	1158	1113	1019	895	662

Table 11: Car ownership level and urbanization

The classes of urbanization of zone where household is located are:

1. Rural area: on average less than 500 addresses/km2
2. Low urbanization: on average 500 to 1000 addresses/km2
3. Medium urbanization: on average 1000 to 1500 addresses/km2
4. High urbanization: on average 1500 to 2500 addresses/km2
5. Very high urbanization: on average 2500 or more addresses/km2

The table beneath shows the car ownership summarized for number of persons per household.

Car ownership level / household size							
	average	1	2	3	4	5	6
Households with 0 cars	25%	53%	14%	9%	5%	5%	8%
Households with 1 car	58%	47%	67%	56%	61%	60%	58%
Households with 2 cars	16%	0%	18%	32%	29%	30%	27%
Households with 2+ cars	2%	0%	0%	3%	4%	4%	7%
Cars / 1000 households	948	477	1049	1292	1330	1338	1325

Table 12: Car ownership level and household size

One could expect a higher car ownership level in GE because the income is much higher. However, urbanization in GE is higher, which implies less cars / household and the household size in GE is lower, which implies less cars / household. Concluding, the bandwidth between the scenarios does not represent the uncertainty in this component, which is +/- uncertain.

Household gross average income

The household gross average income is the primary income plus other types of income such as social security payments, financial support, housing subsidies, study compensations and alimony. There was no forecast data available, therefore the relations to other components are presented. The following graph shows the average income per household size.

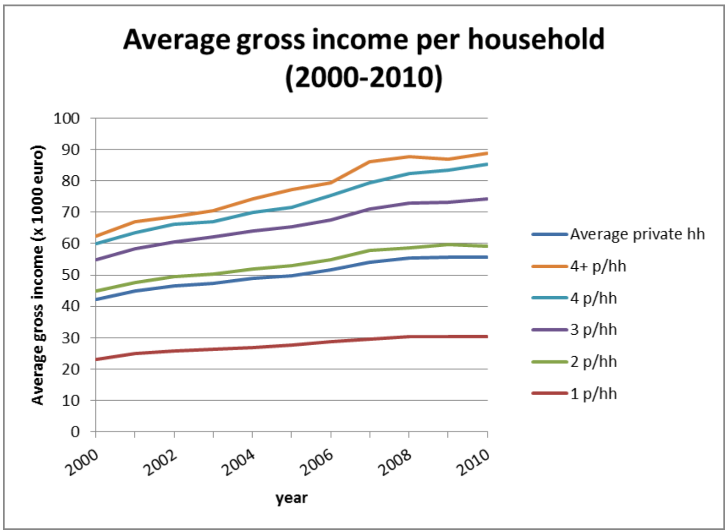


Figure 19: Average gross income and household size

A decrease in household size is expected to lower the average income per household, which is logical as larger households more often have more people with a job and there are more mouths to feed. The incomes have increased in the last 10 years.

From the WLO scenarios input data the following table could be extracted.

Household gross average income					
		2004	2004-2020	2020-2030	2004-2030
scenario RC	€	48,900	+7,500	+6,900	+14,400
scenario GE	€	48,900	+23,000	+14,800	+37,800
bandwidth		-	32%	16%	48%

Table 13: Household gross average income in RC and GE 2030

This shows that according to these scenarios the uncertainty on income levels is very large, when the bandwidth is used as an indicator. In 2030 the average income has increased by 77% in GE compared to only 30% in RC. Historical data also shows a large increase in the period of 10 years. This component can be considered as very uncertain.

Oil price

The oil price is an important driver for mobility as it determines the variable car cost per km. Another important factor is fuel efficiency. To look at the uncertainty of this component, it is important to first understand how the oil price is used in the model. The input for variable car cost per kilometer in GE and RC is designed as an index number, where the price level in 2004 is 100. For this variable several aspects are taken into account: the tax plans for the years 2004 - 2012, the fuel price per liter (based on a crude oil price of 70 dollars per barrel), the composition of the car fleet and EU emission directives, which affect the fuel efficiency of the total fleet (DVS 2012). Uncertainty in the oil price can therefore not be translated directly into uncertainty in variable car costs. When looking at the last six years, it becomes clear that this component is possibly very uncertain.

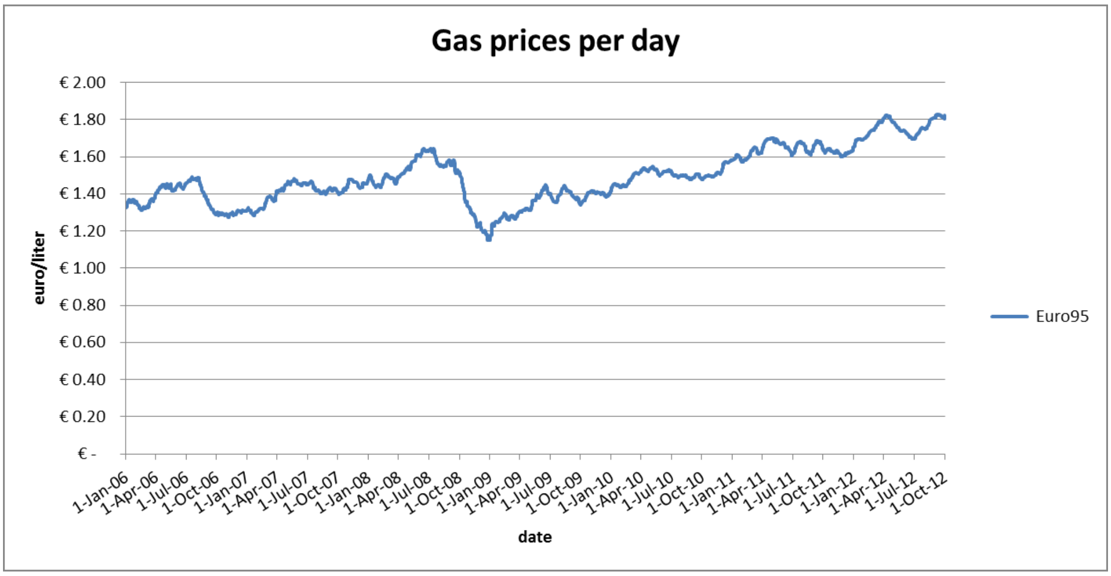


Figure 20: Historical data on the gas prices

In three months' time there was a decrease of 22.8% (1 October 2008 – 1 January 2009) in price of Euro95. This shows that this component is uncertain unlike any other component. However, what's in the past does not necessarily mean much for the future. To see if the oil price is uncertain for the future I used the study Referentieramingen 2012 (RR12).

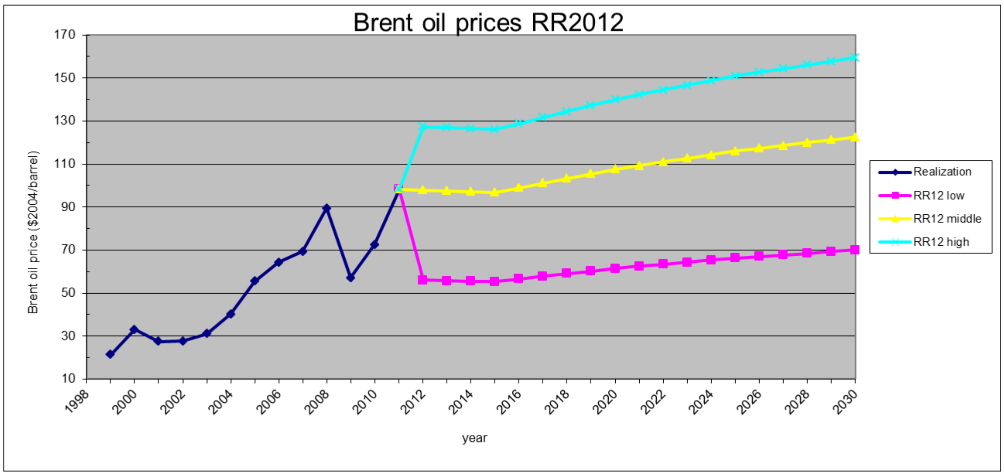


Figure 21: Brent oil prices from the Referentieramingen 2012

The RR12 describe the development oil prices. This is showed in the figure above. Using the 2004 consumer prices the oil price is predicted to increase from $40 in 2004 to about $122.50 in 2030. A bandwidth of 40/70 and 110/70 was used, resulting in a bandwidth from $70 and $175 (Verdonk and Wetzels 2012).

I used this bandwidth as an indicator for uncertainty of the variable car costs. The 70 dollar that is used in the LMS as a starting point for the variable car costs corresponds to the low price level in the bandwidth of the RR12. The RR10 assumed a standard oil price of $70/barrel, while RR12 uses an oil price of $135/barrel with a bandwidth of 77/192 (price level 2010), which corresponds to $123/barrel (70/159), price level 2004. The RR12 uses a dollar exchange rate of €1,- : $1.29 for 2012-2030. The RR12 also provides complying fuel prices for 2030. The information is summarized in the table below:

Oil and gas prices RR2012												
	Brent oil price ($2004/barrel)		Brent oil price (€2004/barrel)		Net fuel price (€2004/liter)		Excise (€2004/liter)		VAT (€2004/liter)		Total price (€2004/liter)	
2004	$	40.24	€	31.45	€	0.385	€	0.667	€	0.200	€	1.252
2030 low	$	70.02	€	54.28	€	0.498	€	0.668	€	0.222	€	1.388
2030 middle	$	122.53	€	94.98	€	0.733	€	0.668	€	0.266	€	1.667
2030 high	$	175.04	€	135.69	€	0.968	€	0.668	€	0.311	€	1.946

Table 14: Oil and gas prices RR12

In the scenarios that I used in this study, 70 dollar / barrel was used to determine the variable car costs / km. When combined with the data above, I can determine a bandwidth for the variable car costs component. In GE the numbers are:

Index gas price			
	2004	2030	2030 corrected
low	100.0	110.9	93.0
middle	100.0	133.2	111.7
high	100.0	155.4	130.4

Table 15: Gas prices in GE

While the gas price increases by 10.9%, higher fuel efficiency reduces the index number to 91 for RC and 93 for GE. There is a slight improvement of the fuel efficiency in RC compared to GE. In GE there is more innovation but RC implies stricter environmental policies which would cause an improvement in fuel efficiency. I used the same correction factor for improved fuel efficiency for low, middle and high fuel prices in RC.

Index gas price			
	2004	2030	2030 corrected
low	100.0	110.9	91.0
middle	100.0	133.2	109.3
high	100.0	155.4	127.6

Table 16: Gas prices in RC

Concluding, the oil price is very uncertain according to latest studies. This also results in high uncertainty considering variable car costs / km. The bandwidth of the WLO scenarios (91 and 93) do not give a good representation of the uncertainty in this variable.

Freight traffic

Although I did not identify freight traffic initially as an important input variable, results from the modeling suggest that the freight traffic is also an important component for the travel time benefits. Freight traffic is defined to be an autonomous component due to technical limitations, but it is very dependent on economic and demographic development. The majority of the freight kilometers have a destination within the Netherlands. 5/6 of the freight kilometers has origin and destination within the Netherlands. Therefore freight traffic is only an autonomous component to a small extent. Freight is separate input in the model and not dependent on other components. Moreover, it is relatively difficult to adjust the input for this component.

From CBS data the following graph was composed. The development is expressed in index numbers. Between 2000 and 2010 the freight traffic increased by more than 20%. It shows much similarities to the development of the GDP.

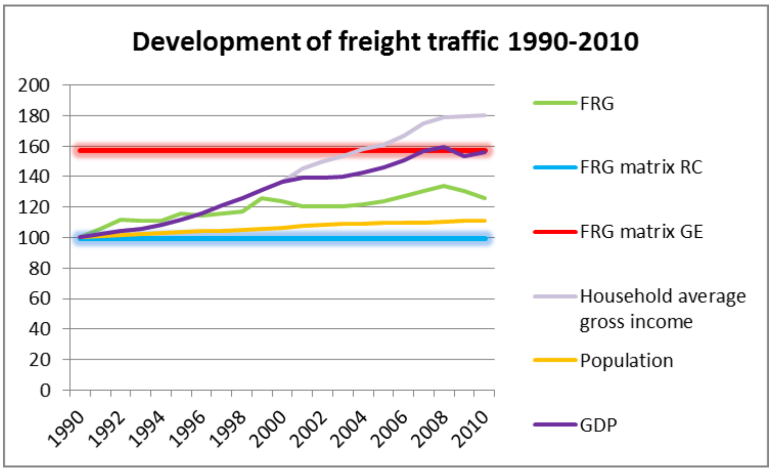


Figure 22: Development of freight traffic 1990-2010

The modeling results for GE scenario with the RC-freight matrix as input, shows that in the scenarios freight is very uncertain. The RC-input matrix generates -37% freight kilometers on an average working day. Freight traffic is very uncertain.

Conclusion

Concluding, there are seven scenario components that I found to make up for the most important part of the scenarios. These are population, household size, participation level, average car ownership per household, average household income, variable car costs per kilometer and freight traffic. The bandwidth of the values for the two WLO scenarios can be used as an indicator for their uncertainty. However this is not complete. Car ownership and variable car costs are much more uncertain than the scenarios would suggest. The bandwidths are displayed in the next figure.

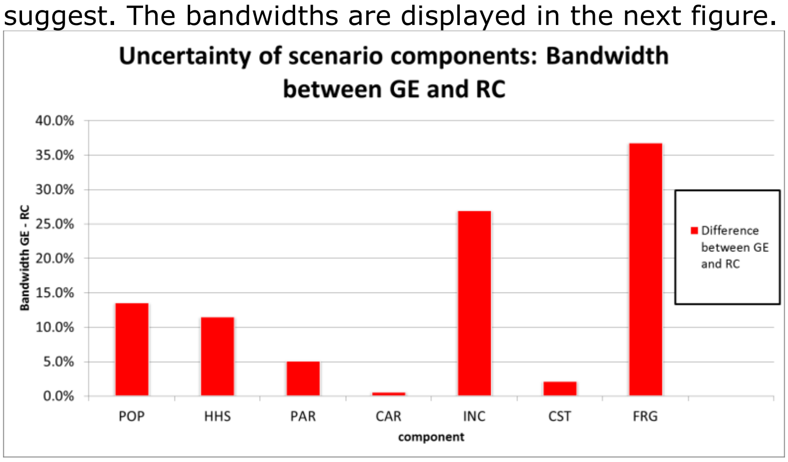


Figure 23: Bandwidths of scenario components

5. Mobility and sensitivity

Now that it is clear which components should have large influence on future mobility, in this chapter we will see if that is indeed the case for this scenario study of the WLO scenarios and to what extent. The input data for the two scenarios was used to compute mobility in the high and low scenario in 2030. On this topic, I also formulated three research questions that are described in chapter 3 and answered in the next three paragraphs.

5.1 Mobility in 2030

First the mobility indicators in 2030 according to the model outcomes for the WLO scenarios are compared, to see what is the starting point for my analysis and what is the bandwidth between the two scenarios for the chosen indicators. I will look at travel kilometers, tours, travel time loss and time loss due to congestion. Maps on IC-ratios, bottle necks and congestion hours are presented in appendix 9.10.

5.1.1 Tours / distance

This paragraph presents the results on mobility for an average working day in 2030. The numbers are from the SES-output of the LMS. SES is a module that covers trip generation in the model. This means that intrazonal tours and kilometers are included and that all origins / destinations (ODs) lie within the Netherlands. Freight traffic is excluded. The indicator tours is defined as the amount of car driver tours that are made by the Dutch population with origin and destination within the Netherlands. A tour is defined as a chain of trips that starts and also ends at home. Freight traffic is excluded.

tours RC / GE						
			car			
	total	randstad	rest	work	business	other
RC	8,073,813	3,634,222	4,439,591	5,444,482	742,025	1,887,306
GE	10,147,691	4,635,672	5,512,020	6,527,561	891,226	2,728,904
GE/RC	+ 25.7%	+ 27.6%	+ 24.2%	+ 19.9%	+ 20.1%	+ 44.6%

Table 17: Tours RC/GE for the car

tours RC / GE			
		public transport	
	total	randstad	rest
RC	1,179,190	677,507	501,683
GE	1,351,153	772,844	578,309
GE/RC	+ 14.6%	+ 14.1%	+ 15.3%

Table 18: Tours RC/GE for public transport

There is not a real difference for the Randstad and the rest of the Netherlands. In GE there are relatively more other-motivated trips and public transport use is 14.5% higher in GE and car use 25.7% higher. This means that there is a small modal shift towards car use. In GE people cycle less and drive more, this is probably because of the higher individualization: more cars per person (510 cars per 1000 people in RC and 590 in GE). Car use is higher outside the Randstad, where the distances are also longer. In the Randstad the use of public transport is higher, and also people walk significantly more. This can also be seen in the modal split table below.

Modal split in reference scenarios						
	train	car driver	passenger	BTM	Cycling	Walking
RC	2.6%	37.1%	11.9%	2.8%	30.9%	14.7%
randstad	3.5%	35.2%	11.5%	3.1%	31.1%	15.6%
rest	1.9%	38.8%	12.3%	2.5%	30.6%	13.9%
GE	2.5%	39.1%	11.3%	2.7%	29.7%	14.7%
randstad	3.3%	37.6%	10.8%	3.0%	29.8%	15.5%
rest	1.8%	40.6%	11.7%	2.5%	29.6%	13.9%

Table 19: Modal split in GE/RC

The next table shows the total distance traveled in the Netherlands on an average working day by car drivers. The distance is the total car driver distance that is traveled with origin and destination within the Netherlands. Freight traffic is excluded.

kilometers RC / GE						
		car				
	total	randstad	rest	work	business	other
RC	232,305,465	107,031,707	125,273,758	124,315,230	29,427,841	78,562,393
GE	291,616,437	134,123,887	157,492,550	154,550,570	39,862,915	97,202,952
GE/RC	+ 25.5%	+ 25.3%	+ 25.7%	+ 24.3%	+ 35.5%	+ 23.7%

Table 20: Kilometers RC/GE

The total traveled distance on an average working day is 25.5% higher in GE than in RC. The difference in kilometers is relatively higher for business related tours and the difference in public transport kilometers is relatively less. The latter can be explained by the population that is dependent on public transport, for example because they don't own a car. The average tour length is about the same in both scenarios. This can also be observed in the table below.

average tour length RC / GE						
		car				
	total	randstad	rest	work	business	other
RC	28.8	29.5	28.2	22.8	39.7	41.6
GE	28.7	28.9	28.6	23.7	44.7	35.6
GE/RC	-0.1%	-1.8%	+ 1.3%	+ 3.7%	+ 12.8%	-14.4%

Table 21: Average tour length RC/GE

Business tours are generally longer in GE. Other motivated tours, with motives education, shopping or recreation are shorter in GE. People will use the car more often for short trips. The average tour length for public transport (not presented in this table) is much higher than for the car: 65 kilometers on average and even 82 kilometers outside the Randstad. QBLOK is a module in the LMS that assigns the transport demand to the network. The results include trips with a foreign OD, but excludes intrazonal trips. Freight is also included. Therefore the quantitative results are different. However, the two scenarios can be compared.

kilometers / motive (QBLOK)				
	freight	work	business	other
RC	28,826,919	70,805,942	58,025,435	55,993,457
GE	45,413,705	84,316,271	72,068,850	67,769,072
GE/RC	+ 58%	+ 19%	+ 24%	+ 21%

Table 22: Kilometers per travel motive in RC/GE

This shows a significant higher difference in freight traffic compared to other travel purposes.

5.1.2 Travel time loss

The travel time loss is defined as the travel time in hours that is lost due to high intensities on the main road network. The travel time loss is calculated by comparing the free flow speeds to the actual speeds on a loaded network, and the lost travel time per vehicle is multiplied by the number of road users. It is close to the Dutch vvu 100 kmpu measure (voertuigverliesuren).

travel time loss (h)					
	main	randstad	rest	secondary	total
RC	152,522	91,541	60,982	299,599	452,121
GE	374,215	223,273	150,942	625,930	1,000,145
GE/RC	+ 145%	+ 144%	+ 148%	+ 109%	+ 121%

Table 23: Travel time loss in RC/GE

The travel time loss is 2.5 times as high in GE as in RC. This is a very large difference. The difference is about the same for the Randstad and the rest of the Netherlands. Travel time loss increases more on the main road network than on the secondary road network.

travel time loss / time of day (h)			
	am	op	pm
RC	71.749	27.880	52.893
GE	150.151	106.048	118.016
GE/RC	+ 109%	+ 280%	+ 123%

Table 24: Travel time loss and time of day

The travel time loss is significantly lower outside the peak hours in RC. In GE, travel time loss occurs all day. In RC less than 20% of travel time loss in other parts of the day, in GE almost 30%.

travel time loss / motive (h)				
	freight	work	business	other
RC	6.605	80.101	33.050	32.767
GE	31.761	171.494	86.658	84.302
GE/RC	+ 381%	+ 114%	+ 162%	+ 157%

Table 25:Travel time loss per motive

There is a spectacular difference for freight traffic. The time loss for freight traffic increases in GE, where it is almost 5 times higher than in RC.

5.1.3 Congestion hours

Congestion hours are the hours that is lost due to congestion on the main road network. I present both travel time loss and congestion hours, because travel time loss should relate to the travel time benefits according to the theory and congestion hours are politically relevant. It is defined as the cumulative time that people have to wait in congestion compared to free flow travel times. This indicator corresponds to a large extent to the Dutch indicator VVU (voertuigverliesuren 50 kmpu) for congestion defined as driving < 50 km/h on the highway.

congestion hours (h)					
	main	randstad	rest	secondary	total
RC	59,341	46,844	12,497	63,746	123,086
GE	194,218	139,566	54,653	176,060	370,278
GE/RC	+ 227%	+ 198%	+ 337%	+ 176%	+ 201%

Table 26: Congestion hours in RC/GE

Congestion hours is the indicator with the largest difference, with an increase of 227%. Outside the Randstad congestion hours increase relatively more, this is because the level of congestion is higher in the Randstad than in the rest of the Netherlands in RC. There is almost no congestion outside peak hours in RC, in GE about 10% of total congestion hours is outside peak hours.

congestion hours / time of day (h)			
	am	op	pm
RC	35.976	484	22.881
GE	105.943	13.362	74.912
GE/RC	+ 194%	+ 2662%	+ 227%

Table 27: Congestion hours and time of day

congestion hours / motive (h)				
	freight	work	business	other
RC	4.236	34.077	9.628	11.400
GE	21.970	98.475	36.253	37.520
GE/RC	+ 419%	+ 189%	+ 277%	+ 229%

Table 28: Congestion hours per motive

Congestion hours for freight traffic are much higher in GE, more than 5 times as much. However the relative difference to other motives is smaller. The difference in congestion hours for business tours is relatively high and for work related tours relatively low, comparable to the difference for the morning peak hour (most work related trips take place in the morning peak hour).

Concluding, the bandwidth in future mobility for 2030 between GE and RC is very large, especially for travel time loss and congestion hours. The number of tours and total distance traveled on an average working day is 26% higher in GE compared to RC. This means that the average tour length is more or less the same. However the difference in lost vehicle hours is much higher: 145% and the difference in congestion hours is even 227%. This is displayed in the table below.

Difference GE/RC overall				
	Tours	Distance (km)	Time loss (h)	Congestion (h)
2004	7.403,000	192.018,000	167,000	74,000
2030 RC	8.074,000	232.305,000	153,000	59,000
2030 GE	10.148,000	291.616,000	374,000	194,000
GE / RC	+ 26%	+ 26%	+ 145%	+ 227%

Table 29: Overall difference GE/RC

5.2 Separate variable analysis

In this paragraph a sensitivity analysis for the selected variables was made. The goal of this analysis is to get a better understanding of the magnitude of impact and relative importance of the variables. This is only an initial analysis and the results are inconsistent, because the adjustments result in inconsistent scenarios. For example, when the population decreases it can be expected that the households, cars, students etc. also decrease. This analysis is performed in the next paragraph.

I made ten variations on the GE scenario by adjusting the separate variables by -10%. The table underneath summarizes the adjustments. It should be noted that the adjustments for this first analysis are inconsistent: For the 10% decrease in population only that variable is adjusted, not all related variables. This has some implications, also described in the table.

Adjustments initial analysis		
Scenario	Adjustment	Implications
VARP	90% of the total population in GE	smaller households, higher participation, relatively more income per household member, more cars per person
VARH	90% of the households in GE	larger households, higher car ownership level per household
VARJ	90% of the jobs in GE	
VARE	90% of the employed population in GE	high unemployment
VARL	90% of the labor force in GE	lower participation, lower unemployment (employed population is the same)
VARS	90% of the students in GE	smaller share of the total population is student
VARI	90% of the gross household income in GE	
VARC	90% of the cars in GE	car ownership per household is lower
VARF	index car cost / km 103 (was 93)	

Table 30: Adjustments analysis separate variables

This analysis will give a first indication of the key variables and their influence. The results are presented in the following table.

overall results LMS runs				
	Tours	Distance (km)	Time loss (h)	Congestion (h)
2030 GE	10,148,000	291,616,000	374,000	194,000
2030 GE _VARP	-4.4%	-1.4%	-0.4%	0.6%
2030 GE _VARH	0.7%	-0.9%	-1.7%	-1.2%
2030 GE _VARJ	-0.2%	0.0%	-0.4%	-0.2%
2030 GE _VARE	-1.2%	-2.2%	-9.0%	-12.5%
2030 GE _VARL	0.0%	0.0%	0.0%	0.0%
2030 GE _VARS	0.0%	0.0%	0.6%	1.1%
2030 GE _VARI	-0.3%	-1.8%	-5.0%	-5.4%
2030 GE _VARC	-6.9%	-4.5%	-12.0%	-15.9%
2030 GE _VARF	-0.5%	-1.8%	-4.7%	-5.2%
2030 GE _VART	-10.7%	-11.0%	-26.8%	-32.1%

Table 31: Results on the sensitivity analysis of separate variables

The tours are mainly affected by a decrease in population or cars. The total distance traveled is not affected much, only when the number of cars decrease there is a significant difference. The lost vehicle hours are affected most by the number of cars and the employed population, income and car cost/km also have a significant effect. This is even more clear in the congestion hours, which show the same results.

When population decreases by 10% the congestion hours slightly increase. This is a good example of why consistent scenarios should be used. The reason could be that the relative car ownership increases, relative income increases per person or that there is a higher participation as the number of employed people doesn't change. A 10% decrease in the number of households leads to a small increase in the number of tours. This is remarkable but can be explained as follows. The total population and the car park have remained the same size. Relatively there are more cars available per family. This favors the car as a transport mode over public transport.

From this analysis it seems that the labour force is only a statistic and does not participate in the model. In this model a difference in labour force does not have any impact. The number of jobs have almost no influence, this is because in the model this data is used in trip distribution, but not trip generation. The number of jobs are an attraction variable. A decrease in student population causes an increase in travel time loss and congestion hours. This could be because students travel relatively more by public transport than non-students. The number of students have a very small impact and was excluded from the research.

5.3 Influence of the main components

In this part of the report, I will present my research on the main components that I selected. Using the results of the previous research questions, I constructed several new scenarios. They are listed below:

- Population (POP); all related variables are adjusted accordingly
- Household size (HHS); the population stays the same, but the number of households changes (and therefor the car ownership)
- Participation (PAR); the population stays the same, but the labour force, number of jobs and employed people changes
- Car ownership (CAR); only the number of cars changes
- Income (INC); only the average gross income per household changes
- Variable car costs (CST); only the index on variable car costs per km changes
- Freight (FRG); the freight input matrix of the other scenario is used as input
- Spatial distribution (SPA)

The following table indicates the adjustments per scenario.

Overview model runs and adjusted variables

	Population	Households	Number of cars	Labor force	Employed population	Jobs	Household income	Variable car costs	Freight matrices
POP	√	√	√	√	√	√			
HHS		√	√						
PAR				√	√	√			
CAR			√						
INC							√		
CST								√	
FRG									√
INT	√	√	√	√	√	√	√	√	√

Table 32: Overview model runs and adjusted components

Note that for every scenario one or more variables were adjusted. For example, in the POP scenarios not only population was adjusted, but also households, cars and labour market. An elaborate description of the method to adjust zonal data and comparison to another, more complicated method is presented in appendix 9.2 and 8.3. The last scenario is an integrated scenario (INT) where all main components in GE were adjusted to the level of RC, to check if they together can explain the difference in output.

Besides the socioeconomic scenarios I also designed spatial scenarios (SPA) where nothing changed to the input components besides the spatial distribution. The GE scenario with the spatial distribution pattern of RC was implemented.

An overview of all 62 modelling runs is presented in appendix 9.4. An overview of the exact adjustments per run in appendix 9.5. Elaborate output per components is presented in appendix 9.11.

The results are presented in the table below and concern only the main road network. The percentages are scaled to a 10% difference so that the results can be compared.

Sensitivity for %10 change in input: GE 2030				
	Tours	Distance (km)	Time loss (h)	Congestion (h)
2030 GE	10,148,000	291,616,000	374,000	194,000
POP -10%	- 10.0%	- 7.3%	- 19.7%	- 24.4%
HHS -10%	- 5.3%	- 4.6%	- 12.3%	- 15.4%
PAR -10%	- 1.3%	- 2.1%	- 9.9%	- 13.8%
CAR -10%	- 6.9%	- 4.5%	- 12.0%	- 15.9%
INC -10%	- 0.3%	- 2.0%	- 5.4%	- 6.0%
CST +10%	- 0.4%	- 1.5%	- 3.2%	- 3.6%
FRG -10%	+ 0.1%	+ 0.7%	- 4.8%	- 6.9%

Table 33: Overal results sensitivity analysis components GE

The total travel distance increases less than the number of trips, so the average trip length declines. This is to be expected as the congestion increases. For the results of RC (below) it shows that the total travel distance increases less than the number of trips, so the average strip length increases. This is also expected to occur due to a decrease in congestion. For participation the effect on time loss and congestion is relatively high compared to the effect on the distance. This can be expected because the participation level affects mainly work related tours that are made in the peak hours, which are much more busy.

Sensitivity for %10 change in input: RC 2030				
	Tours	Distance (km)	Time loss (h)	Congestion (h)
2030 RC	8,074,000	232,305,000	153,000	59,000
POP +10%	+ 10.0%	+ 8.4%	+ 20.8%	+ 30.3%
HHS +10%	+ 5.9%	+ 5.9%	+ 14.7%	+ 22.2%
PAR +10%	+ 1.1%	+ 2.6%	+ 9.3%	+ 12.5%
CAR +10%	+ 6.7%	+ 4.8%	+ 11.3%	+ 18.6%
INC +10%	+ 0.3%	+ 1.9%	+ 4.9%	+ 6.0%
CST +10%	- 0.6%	- 2.0%	- 3.9%	- 4.7%

Table 34: Overall results sensitivity analysis components RC

Overall, results are a little bit more sensitive to variation in the input variables in RC than in GE. This is mainly a matter of scale, because in absolute figures the difference in GE is much higher. More extensive output is presented on the next pages.

5.3.1 Tours and distance

The following tables present output data of the LMS on tours and car kilometers on an average working day. Tours is the amount of car driver tours that are made by the Dutch population with origin and destination within the Netherlands. A tour is defined as a chain of trips that starts and also ends at home. The total car driver distance is travelled with origin and destination within the Netherlands. Freight traffic is excluded for both.

The first rows give absolute numbers for the GE scenario. The other rows give the effect of a 10% decrease in that component. For example, 10% less households implies 5,3% less tours (the population stays the same). And 10% less employed people means 2,1% less car kilometers.

tours and sensitivity GE 2030	car						public transport		
	total	randstad	rest	work	business	other	total	randstad	rest
GE	10,147,691	4,635,672	5,512,020	3,914,112	648,630	5,584,949	1,351,153	772,844	578,309
POP -10%	- 10%	- 10%	- 10%	- 10%	- 10%	- 10%	- 10%	- 10%	- 9%
HHS -10%	- 5%	- 5%	- 5%	- 6%	- 5%	- 5%	+ 4%	+ 4%	+ 3%
PAR -10%	- 1%	- 2%	- 1%	- 7%	- 4%	+ 3%	- 3%	- 3%	- 3%
CAR -10%	- 7%	- 9%	- 5%	- 7%	- 5%	- 7%	+ 13%	+ 14%	+ 10%
INC -10%	- 0%	- 0%	- 0%	- 0%	- 1%	- 0%	- 1%	- 1%	- 1%
CST +10%	- 0%	- 0%	- 0%	- 0%	- 0%	- 1%	+ 0%	+ 0%	+ 0%

Table 35: Tours and sensitivity GE 2030

A 10% population decrease is exact 10% less tours. There is very small variation between areas or travel purposes. The same applies for household size, only now the effect is half the change. A decrease in employed population causes a shift from work- and business-motivated tours to other. A lower level of car ownership has a large impact on public transport use (which increases). Household income and car cost have small influence on the number of tours.

The car kilometers come from the SES output data in the LMS. Intra-zonal kilometers are included, freight is excluded. These car kilometers have origins and destinations within the Netherlands.

kilometers and sensitivity GE 2030	car						public transport		
	total	randstad	rest	work	business	other	total	randstad	rest
GE	291,616,437	134,123,887	157,492,550	154,550,570	39,862,915	97,202,952	88,305,868	40,917,927	47,387,941
POP -10%	- 7%	- 7%	- 8%	- 7%	- 8%	- 7%	- 9%	- 9%	- 8%
HHS -10%	- 5%	- 4%	- 5%	- 5%	- 4%	- 5%	+ 4%	+ 4%	+ 4%
PAR -10%	- 2%	- 2%	- 2%	- 5%	- 4%	+ 4%	- 3%	- 3%	- 3%
CAR -10%	- 4%	- 6%	- 3%	- 4%	- 4%	- 5%	+ 11%	+ 13%	+ 10%
INC -10%	- 2%	- 2%	- 2%	- 1%	- 4%	- 3%	- 1%	- 1%	- 1%
CST +10%	- 1%	- 1%	- 2%	- 1%	+ 0%	- 3%	+ 0%	+ 0%	+ 0%

Table 36: Kilometers and sensitivity GE 2030

Compared to the tours the overall effect of the variables is smaller for population, households and car ownership. This means that people will make longer trips when these components decrease. Income levels is a more influential component compared to tours. Higher car costs results in less tours and kilometers and an increase of public transport use, but the effect is small. For RC the results are very comparable

5.3.2 Travel time loss and congestion hours

The following tables present the sensitivity of travel time loss and congestion hours to changes in the components.

travel time loss (h) and sensitivity GE 2030								
	main	randstad	rest	am	op	pm	secondary	total
GE	374,215	223,273	150,942	150,151	106,048	118,016	625,930	1,000,145
-10% POP	-20%	-20%	-19%	-15%	-27%	-19%	-19%	-19%
-10% HHS	-12%	-13%	-11%	-10%	-15%	-13%	-11%	-12%
-10% PAR	-10%	-11%	-9%	-11%	-8%	-10%	-7%	-8%
-10% CAR	-12%	-14%	-8%	-10%	-15%	-12%	-13%	-12%
-10% INC	-5%	-5%	-6%	-4%	-8%	-5%	-3%	-4%
+10% CST	-3%	-3%	-3%	-2%	-5%	-3%	-2%	-3%

travel time loss / motive (h) GE 2030				
	freight	work	business	other
GE	31,761	171,494	86,658	84,302
-10% POP	-23%	-18%	-21%	-22%
-10% HHS	-13%	-11%	-12%	-14%
-10% PAR	-10%	-11%	-11%	-6%
-10% CAR	-13%	-11%	-12%	-14%
-10% INC	-6%	-4%	-6%	-6%
+10% CST	-4%	-3%	-3%	-5%

Table 37: Travel time loss and sensitivity GE 2030

Overall, the effects of changes in the components are much larger compared to the tours and distance. For the population, the effect of a 10% decrease is doubled in terms of the travel time loss change. Outside peak hours this effect is larger. Comparable to the previous indicators, the effect of household size is about half of that of population. Participation level has now become a much more important component with about the same influence as the household size. The same applies for car ownership level. This component has a significant larger effect in the Randstad. Here people have relatively better alternatives in terms of public transport, but the relative car ownership level is also lower so a further decrease often means that they cannot access a car at all. Income levels and car costs have smaller effects, but much higher compared to the previous indicators.

The sensitivity analysis for RC shows the same results, again overall being a little bit more sensitive.

travel time loss (h) and sensitivity RC 2030								
	main	randstad	rest	am	op	pm	secondary	total
RC	152,522	91,541	60,982	71,749	27,880	52,893	299,599	452,121
+10% POP	+ 21%	+ 20%	+ 22%	+ 18%	+ 25%	+ 22%	+ 20%	+ 20%
+10% HHS	+ 15%	+ 14%	+ 16%	+ 14%	+ 16%	+ 16%	+ 12%	+ 13%
+10% PAR	+ 9%	+ 8%	+ 12%	+ 9%	+ 7%	+ 12%	+ 6%	+ 7%
+10% CAR	+ 11%	+ 13%	+ 8%	+ 10%	+ 13%	+ 12%	+ 14%	+ 13%
+10% INC	+ 5%	+ 4%	+ 6%	+ 4%	+ 8%	+ 5%	+ 2%	+ 3%
+10% CST	- 4%	- 4%	- 4%	- 3%	- 5%	- 4%	- 3%	- 3%

travel time loss / motive (h) RC 2030				
	freight	work	business	other
RC	6,605	80,101	33,050	32,767
+10% POP	+ 22%	+ 19%	+ 22%	+ 23%
+10% HHS	+ 15%	+ 14%	+ 15%	+ 16%
+10% PAR	+ 10%	+ 10%	+ 11%	+ 5%
+10% CAR	+ 11%	+ 10%	+ 11%	+ 14%
+10% INC	+ 5%	+ 4%	+ 6%	+ 6%
+10% CST	- 4%	- 4%	- 3%	- 5%

Table 38: Travel time loss and sensitivity RC 2030

Congestion hours are even more sensitive to changes in the components, as can be concluded from the tables below.

congestion hours (h) and sensitivity GE 2030								
	main	randstad	rest	am	op	pm	secondary	total
GE	194,218	139,566	54,653	105,943	13,362	74,912	176,060	370,278
-10% POP	-24%	-24%	-26%	-21%	-46%	-25%	-25%	-25%
-10% HHS	-15%	-15%	-17%	-14%	-25%	-16%	-14%	-15%
-10% PAR	-14%	-14%	-14%	-16%	-14%	-11%	-11%	-12%
-10% CAR	-16%	-17%	-12%	-14%	-27%	-16%	-15%	-16%
-10% INC	-6%	-5%	-7%	-5%	-12%	-6%	-3%	-5%
+10% CST	-4%	-3%	-4%	-3%	-8%	-4%	-3%	-3%

congestion hours / motive (h) GE 2030				
	freight	work	business	other
GE	21,970	98,475	36,253	37,520
-10% POP	-23%	-23%	-27%	-26%
-10% HHS	-13%	-15%	-17%	-17%
-10% PAR	-11%	-15%	-16%	-10%
-10% CAR	-14%	-15%	-17%	-18%
-10% INC	-6%	-5%	-7%	-6%
+10% CST	-3%	-3%	-4%	-5%

Table 39: Congestion hours and sensitivity GE 2030

Population has the largest impact on congestion. A 10% decrease means almost 25% less congestion. This effect is almost 50% outside peak hours. HHS, PAR and CAR all cause about 15% when decreased by 10%. For participation the effect is not larger outside peak hours. Income and car cost have about the same impact as for travel time loss. For business tours the effect is always a bit larger.

In RC the effects are not entirely the same. Population has a significantly higher impact, especially outside the Randstad where congestion almost doubles due to a 10% increase in population. Congestion outside peak hours was very limited, and therefore the effects are disproportionally large. Again this does not apply to participation.

congestion hours (h) and sensitivity RC 2030								
	main	randstad	rest	am	op	pm	secondary	total
RC	59,341	46,844	12,497	35,976	484	22,881	63,746	123,086
+10% POP	+ 30%	+ 27%	+ 42%	+ 27%	+ 83%	+ 35%	+ 29%	+ 30%
+10% HHS	+ 22%	+ 21%	+ 29%	+ 20%	+ 30%	+ 25%	+ 16%	+ 19%
+10% PAR	+ 13%	+ 10%	+ 22%	+ 11%	- 6%	+ 16%	+ 12%	+ 12%
+10% CAR	+ 19%	+ 20%	+ 15%	+ 16%	+ 44%	+ 22%	+ 16%	+ 17%
+10% INC	+ 6%	+ 5%	+ 9%	+ 6%	+ 16%	+ 7%	+ 2%	+ 4%
+10% CST	- 5%	- 4%	- 6%	- 4%	- 11%	- 5%	- 3%	- 4%

congestion hours / motive (h) RC 2030				
	freight	work	business	other
RC	4,236	34,077	9,628	11,400
+10% POP	+ 28%	+ 29%	+ 35%	+ 32%
+10% HHS	+ 20%	+ 21%	+ 24%	+ 23%
+10% PAR	+ 13%	+ 13%	+ 16%	+ 9%
+10% CAR	+ 15%	+ 17%	+ 20%	+ 23%
+10% INC	+ 6%	+ 5%	+ 8%	+ 6%
+10% CST	- 5%	- 5%	- 5%	- 5%

Table 40: Congestion hours and sensitivity RC 2030

5.3.3 Spatial scenarios

We have seen for different variables how they affect mobility and the user benefits of infrastructure investments. In literature (Zondag 2007) it is often emphasized that the spatial distribution of activities also has significant impact on mobility.

I designed two spatial variations to the GE scenario and included them in this research: growth in the Randstad and the spatial distribution of the RC scenario. The ‘ growth in the Randstad’ variant has a very large impact on the spatial distribution. This analysis will show the most effect of spatial distribution. The GE scenario with spatial distribution of RC will show if the two scenarios are very different spatially and if this influences the indicators. In the appendix 9.12 more specific details on the spatial scenarios and the method is described. The most important thing to know is that the aggregated totals for all components remain the same for the spatial scenarios. Only spatial distribution was adjusted.

5.3.3.1 Growth in Randstad

The first spatial scenario assumes all growth in the period of 2004-2030 takes place in the Randstad. These are the modeling results:

overall results LMS runs				
	tours	distance (km)	time loss (h)	congestion (h)
GE	10,148,000	291,616,000	374,000	194,000
GE_SPRA	10,118,000	288,338,000	416,000	231,000
GE_SPRA / GE	- 0%	- 1%	+ 11%	+ 19%

Table 41: Overall results Randstad scenario

The overall results show, in contrast to the urbanization scenario, large differences on the aggregated level. More growth in the Randstad means more congestion overall, even though there is a decline outside the Randstad. There is a large increase of travel time loss and congestion hours in the Randstad scenario. Tours and distance overall seem unaffected.

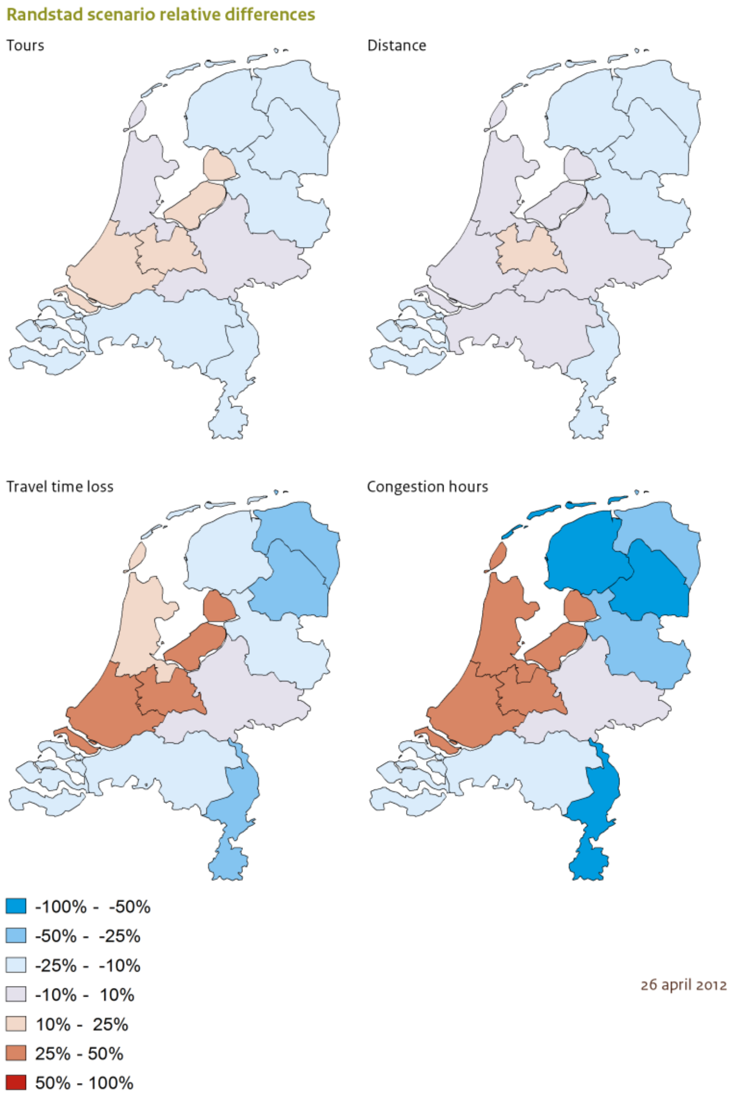


Figure 24: Randstad scenario results per province

tours GE / GE_SPRA				distance GE / GE_SPRA			
		car				car	
	total	randstad	rest		total	randstad	rest
GE	10,147,691	4,635,672	5,512,020	GE	291,616,437	134,123,887	157,492,550
GE_SPRA	10,117,525	5,271,863	4,845,662	GE_SPRA	288,338,274	145,231,186	143,107,087
GE_SPRA/GE	- 0.3%	+ 13.7%	- 12.1%	GE_SPRA/GE	- 1.1%	+ 8.3%	- 9.1%

Table 42: Tours and distance Randstad scenario

Population in Randstad					
	2030GE	%	2030GE_SPRA	%	Δ
Randstad	8,430,000	45%	9,835,000	52%	+ 17%
other	10,460,000	55%	9,055,000	48%	-13%
total	18,889,000	100%	18,889,000	100%	+ 0%

Table 43: Population in Randstad, Randstad scenario

There are 17% more people in the Randstad and 13% less outside the Randstad. The tours are slightly shorter in the Randstad (about 5% shorter). The increase in tours is lower than increase in population, so on average there are less tours per person.

travel time loss (h)				congestion hours (h)			
	hwn	randstad	rest		hwn	randstad	rest
GE	374,215	223,273	150,942	GE	194,218	139,566	54,653
GE_SPRA	415,975	289,936	126,039	GE_SPRA	230,740	187,521	43,219
GE_SPRA/GE	+ 11%	+ 30%	- 16%	GE_SPRA/GE	+ 19%	+ 34%	- 21%

Table 44: Time loss and congestion hours Randstad scenario

The 17% increase in population means a 34% increase in congestion hours. This shows that a different spatial distribution on the national level can be treated as an change of the population component on a regional level. This component affects all spatial separate variables.

5.3.3.2 Spatial distribution of RC

The second spatial scenario concerns the GE scenario but then with the spatial distribution of the RC scenario. I added this analysis to see if the two scenarios were very different in spatial distribution and what effect it had on the output. With this information it was possible to further explain the differences between the scenarios. Per variable, its share in the total per zone for RC is the same in the new GE scenario.

Population in Randstad					
	2030GE	%	2030RC	%	Δ
Randstad	8,430,000	45%	7,254,000	44%	- 0.5%
other	10,460,000	55%	9,079,000	56%	+ 0.4%
total	18,889,000	100%	16,334,000	100%	- 14%

Table 45: Population in Randstad, GE-spatial-RC scenario

The spatial changes are small. 5.0% of the population lives in another zone and 1.3% of the population in another COROP zone. The overall results are:

overall results LMS runs: GE_SPRC				
	tours	distance (km)	time loss (h)	congestion (h)
GE	10,148,000	291,616,000	374,000	194,000
GE_SPRC	10,139,000	291,331,000	366,000	188,000
GE_SPRC / GE	- 0%	- 0%	- 2%	- 3%

Table 46: Overall results GE-spatial-RC scenario

The results show that the number of tours or traveled distance does not change because of the new spatial pattern. However, the total congestion hours decrease by a few percent, especially in the Randstad.

congestion hours (h)			
	main	randstad	rest
GE	194,218	139,566	54,653
GE_SPRC	187,738	132,912	54,826
GE_SPRC/GE	- 3%	- 5%	+ 0%

Table 47: Congestion hours GE-spatial-RC scenario

Conclusion

Concluding on this chapter, the selected indicators of mobility show a large bandwidth between the two scenarios. The amount of vehicle-kilometers in 2030 is approximately 25% higher in GE. The travel time loss is almost 2.5 times higher than in RC and the number of congestion-hours is more than 3 times as high. The sensitivity of the output to input variables differs per indicator. The number of tours and traveled distance are especially sensitive to population, size of the household and car ownership. Time loss and congestion-hours are also highly dependent on the participation level and also to household income and freight traffic.

Combined with the graph at the end of chapter four, this gives the next figure for the indicator travel time loss:

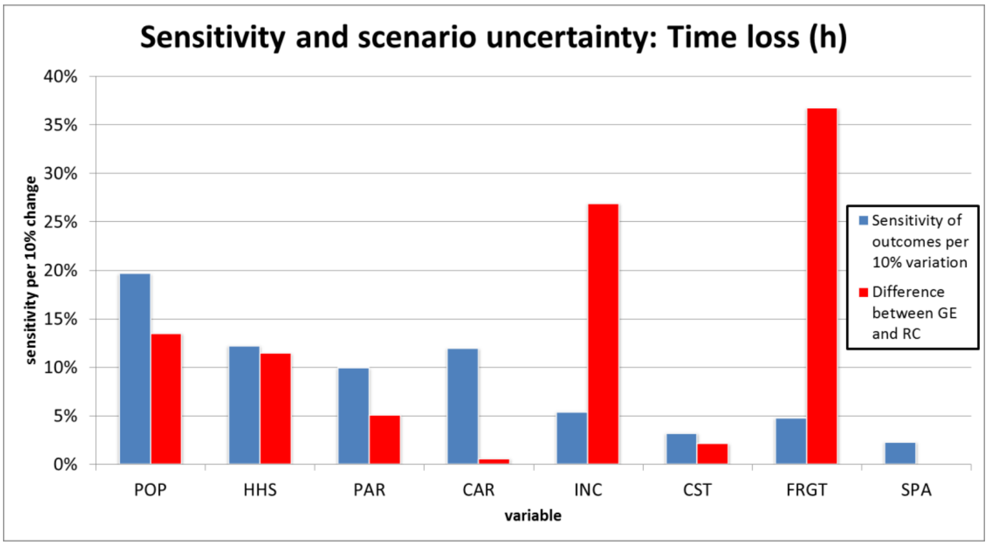


Figure 25: Sensitivity and scenario uncertainty: Time loss

6. Benefits of infrastructure investments

So there are many drivers of mobility that are very uncertain. In scenario analysis mainly demographic and economic developments are expressed of which car ownership, oil prices, income levels and freight traffic are very uncertain. Especially the last two show a large bandwidth in the WLO scenarios GE and RC. Future mobility also differs highly between these scenarios. There are more than 3 times as much congestion hours in the GE scenario. The components that have much influence are population, household size, participation level and the car ownership level. In this chapter the travel time benefits of a fictional infrastructure investment package will be determined and also their sensitivity to changes in the scenario components. It is expected that the same components will have a large impact on travel time benefits, but how much exactly and what is the difference between benefits in the two scenarios?

In the end the performance of the road network depends on the interaction between supply and demand. The supply is the road network with characteristics as shortest routes, free flow travel times, capacity and road design. Also the quality of public transport is included. The government is responsible for the provision of infrastructure and public transport. The future demand depends on many demographic and economic factors , like the number of population, household size, labour market, car ownership, income and transportation costs. Demand is also influenced by other factors such as policies, which affects mainly transportation costs. Investing in infrastructure is very expensive, but necessary if the government wants to assure high accessibility.

The evaluation of these expensive investments is performed by cost-benefit analysis. From the benefits, the travel time benefits are the most important. On this topic I formulated my research objective and final research goal.

What are the key variables in scenarios that determine the travel time benefits of infrastructure investments and to what extent do they influence them?

We already saw that different scenarios result in huge differences in mobility for 2030. This means that the challenges that we have to face on the main road network are dependent on the scenario. The benefits of investments in the future will depend on this as well. In this chapter there are three paragraphs that answer the three sub questions formulated in chapter 3.

6.1 Benefits of the MIRT+20 investment package

In this paragraph the benefits of the MIRT+20 investment package are presented. The investment package concerns about which is an investment package of 20 billion euro in the period of 2020-2030, taken from the The MIRT+20 package consists of about 20 million euros of capacity increments for the period of 2020-2030. With an assumed an average cost of 13 million euro per lane-kilometer, this corresponds with the current investment tempo in infrastructure of the MIRT of about 2 billion per year. There are about 1,500 extra lane kilometers at the most important bottlenecks. This package was adapted from study Spatial Outlook (PBL 2011).

The investment package increases road capacity at parts of the network where big travel time losses were and congestion. The next tables show the effects of the investments on tours, distance, travel time loss and congestion hours.

Results GE runs	tours	distance (km)	time loss (h)	congestion (h)
GE	10,148,000	291,616,000	374,000	194,000
MIRT+20	10,171,000	303,828,000	293,000	140,000
MIRT+20 / GE	+ 0%	+ 4%	- 22%	- 28%

Table 48: Effects MIRT+20 in GE 2030

The investments reduce the time loss and congestion by 20 to 30% and generate about 4% more car kilometers on the main roads. The increase is from slightly longer trips. The table beneath shows that the effects on time loss and congestion are much higher in RC although the absolute reduction is less.

Results RC runs				
	tours	distance (km)	time loss (h)	congestion (h)
RC	8,074,000	232,305,000	153,000	59,000
MIRT+20	8,085,000	237,971,000	106,000	33,000
MIRT+20 / RC	+ 0%	+ 2%	- 30%	- 45%

Table 49: Effects MIRT+20 in RC 2030

The difference in relative effects can be explained by the principle in traffic engineering that 'you can only solve a traffic jam once'. The MIRT+20 package only targets a part of the total network and on this part the congestion is reduced. In RC this is relatively a much bigger reduction in congestion.

The travel time savings have a value to the road users and with the measure of the rule of half, which is explained in paragraph 2.3.2, this was converted to the travel time benefits. The following table presents the travel time benefits per year for the implementation of MIRT+20 in million euros / year.

Benefits (mln * euros / year)						
	total	autonomous	new users	am	op	pm
RC	376	357	19	151	92	133
GE	1,049	990	59	275	536	238
GE/RC	+ 179%	+ 177%	+ 215%	+ 83%	+ 480%	+ 79%

Benefits / motive (mln * euros / year)				
	freight	work	business	other
RC	42	109	152	72
GE	206	210	423	209
GE/RC	+ 387%	+ 92%	+ 179%	+ 190%

Table 50: Bandwidth in benefits between RC and GE

In GE the benefits are almost 3 times higher. Two categories travelers benefit from a cost decrease: those who already made use of the road (autonomous) and new travelers. The first group accounts for 95% of the benefits. The investments generate little new travelers. The difference is very high for benefits outside peak hours, which amount to 50% of the total benefits in GE and only 25% in RC. Freight traffic is affected much more by the investments in GE. The investment has an 387% higher return.
When the absolute reductions are compared, we see that the reduction in GE is twice as much regarding congestion hours and 1.74 times more in travel time losses. But the difference in travel time benefits was almost 3 times as much.

Absolute effect GE / absolute effect RC					
	tours	distance (km)	time loss (h)	congestion (h)	benefits
GE/RC	2.03	2.16	1.74	2.03	2.79

travel time loss / motive				
	freight	work	business	other
GE/RC	3.53	1.22	2.18	1.98
congestion hours / motive				
	freight	work	business	other
GE/RC	3.64	1.61	2.58	2.10

Table 51: Relative absolute effects of MIRT+20 on different aspects

This seems a large gap, but when we split the time losses and congestion hours into motives and compare the absolute differences, it is clear where the gap comes from. Especially freight and business tours show a large gap in absolute effects of the MIRT+20 package and remember that for these motives the value of time is very high. For freight the VoT is 7 times higher than 'other' and 5 times higher than work related tours, the business VoT is 5 and 3.5 times higher.

The following table shows elaborate output on the benefits.

Overview REF: CBA output						
	GE			RC		
total	1049			376		
type						
autonomous	990			357		
extra demand	59			19		
total: motive / time of day						
	am	op	pm	am	op	pm
freight	63	103	40	24	3	15
work	90	57	62	57	12	40
business	94	232	97	52	48	52
other	27	143	39	18	29	26
extra demand: motive / time of day						
	am	op	pm	am	op	pm
freight	0	0	0	0	0	0
work	11	3	8	5	0	4
business	5	6	4	2	1	2
other	3	13	5	2	1	3

Table 52: Overview output travel time benefits MIRT+20 (bln euro)

In GE the benefits for business, other and freight outside peak hours stand out. The reason that the benefits are high is that the roads outside peak hours are much busier in GE. Freight traffic has a high value of time and is relatively even distributed for the day. Business travel also has a high value of time and other traffic is mainly outside peak hours. Appendix 9.13 shows maps of the effects of the MIRT+20 package concerning IC ratios, solved bottlenecks and congestion hours.

6.2 Scenario components and travel time benefits

Now that the bandwidth between the two scenarios is clear, this paragraph shows the sensitivity of the travel time benefits to changes in the scenario components. The same approach as in 5.2 was used. For all previously defined scenarios, the user benefits were calculated. The next tables present information about the influence of the key variables on the benefits of the MIRT+20 package.

The absolute difference in benefits are given per 10% difference in the variable. So a decrease of 10% in population would cause a decrease of 188 million euros per year in travel time benefits. The benefits consist of travel time benefits and distance benefits. For this research the distance benefits attributed without exception only 1 or 2 million to the total, which is about 0.1% in GE.

Sensitivity of travel time savings for %10 change in input				
	GE		RC	
	1,049		376	
POP Δ10%	-188	- 18.0%	+ 55	+ 14.5%
HHS Δ10%	-113	- 10.8%	+ 29	+ 7.8%
PAR Δ10%	-93	- 8.9%	+ 29	+ 7.6%
CAR Δ10%	-138	- 13.1%	+ 23	+ 6.1%
INC Δ10%	-68	- 6.5%	+ 10	+ 2.6%
CST Δ10%	-32	- 3.1%	- 8	- 2.2%
FRG Δ10%	-66	- 6.3%	na	na
SPA RC	-18	- 1.7%	na	na

Table 53: Sensitivity of travel time savings for the input components (per 10% variation)

More detailed output is presented in appendix 9.16. The most important explanatory components are population, household size, income and freight traffic. The value of time in GE is also more than 15% higher and also contributes to the difference in benefits. This is because in GE the people have higher incomes and they value the travel time savings higher. The following figure combines sensitivity of the component and uncertainty, expressed by the difference in input between RC and GE. Although sensitivity for income and freight are relatively low, the differences are so large between the input that they have a large impact. The opposite is true for car ownership. This can all be see in the following table.

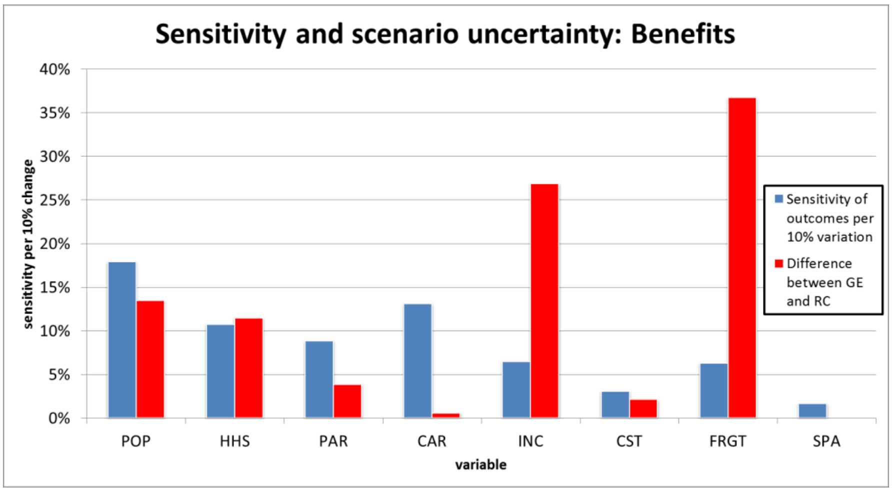


Figure 26: Sensitivity and scenario uncertainties in GE

6.3 Bandwidth in benefits explained

The main goal of this research was to identify the most important scenario components according to their uncertainty and influence. The last three chapters have described first the selection of components that was made and the uncertainty of the components, then their influence on mobility in 2030 for two scenarios according to the four indicators. And finally this chapter was about the sensitivity of the travel time benefits to changes in the selected components.

To illustrate the concept of combining uncertainty and sensitivity to see which components are important, I will look at the bandwidth between the components again. The differences between the scenarios regarding the scenario components are combined with their separate influence on the mobility indicators and travel time benefits to explain the total bandwidth between GE and RC.

The 'uncertainty' for the components, expressed by the relative difference of the components in RC compared to GE, is presented in the table below.

The two scenarios compared regarding the main components			
	2030 GE	2030 RC	RC / GE
POP	18,889,000	16,334,000	-13.5%
HHS	2.00	2.26	-11.5%
PAR	76.7%	72.8%	-5.1%
CAR	1,158	1,151	-0.6%
INC	€ 86,684.38	€ 63,340.03	-26.9%
CST	93	91	-2.2%
FRG	45,414,000	28,827,000	-36.8%

Table 54: Difference in the input on the main components

Next are the results of the sensitivity analysis. These are presented below for the selected mobility indicators and the travel time benefits in GE.

Sensitivity for %10 change in input: GE 2030					
	Tours	Distance (km)	Time loss (h)	Congestion (h)	Benefits
2030 GE	10,148,000	291,616,000	374,000	194,000	1,049
POP -10%	- 10.0%	- 7.3%	- 19.7%	- 24.4%	- 18.0%
HHS -10%	- 5.3%	- 4.6%	- 12.3%	- 15.4%	- 10.8%
PAR -10%	- 1.3%	- 2.1%	- 9.9%	- 13.8%	- 8.9%
CAR -10%	- 6.9%	- 4.5%	- 12.0%	- 15.9%	- 13.1%
INC -10%	- 0.3%	- 2.0%	- 5.4%	- 6.0%	- 6.5%
CST +10%	- 0.4%	- 1.5%	- 3.2%	- 3.6%	- 3.1%
FRG -10%	+ 0.1%	+ 0.7%	- 4.8%	- 6.9%	- 6.3%
SPA RC	- 0.1%	- 0.1%	- 2.3%	- 3.3%	- 1.7%

Table 55: Sensitivity results GE 2030

The sensitivities presented in the table above are to a 10% change in the component. The population size is 13.5% lower in RC compared to GE and for example the sensitivity of the tours is -10% for a 10% decrease in population. This means the difference in the population component between GE and RC should cause that the number of tours in RC are 13.5% lower compared to GE. Other components also affect the number of tours.

This was done for all components and all indicators. The following table shows this step by step.

From GE to RC in 10 steps	Tours	Distance (km)	Time loss (h)	Congestion (h)	Benefits
2030 GE	10,148,000	291,616,000	374,000	194,000	1049
1 POP -14%	- 13%	- 10%	- 27%	- 33%	- 24%
2 HHS -11%	- 6%	- 5%	- 14%	- 18%	- 12%
3 PAR -5%	- 1%	- 1%	- 5%	- 7%	- 5%
4 CAR -1%	- 0%	- 0%	- 1%	- 1%	- 1%
5 INC -27%	- 1%	- 5%	- 15%	- 16%	- 18%
6 CST +2%	- 0%	- 0%	- 1%	- 1%	- 1%
7 FRG -37%	+ 0%	+ 3%	- 18%	- 25%	- 23%
predicted RC	8,119,000	237,868,000	155,000	61,000	352
8 synergy	- 0%	- 1%	+ 3%	+ 1%	+ 5%
INT	8,089,000	234,382,000	159,000	62,000	370
9 SPRC	- 0%	- 0%	- 2%	- 3%	- 2%
10 unknown	- 0%	- 1%	- 2%	- 1%	+ 3%
2030 RC	8,074,000	232,305,000	153,000	59,000	376

Table 56: From GE to RC in 10 steps

The first seven steps result in a prediction for RC. As explained, the percentages are the result of a combination of sensitivity and uncertainty of the components. Remember that the component POP includes the population but also the related input variables households, cars, jobs and employed population. Besides a 14% difference due to a decline in population the number of households is another 11% lower because of an increase in household size, in total 23% less. The number of cars is directly related to the number of households. Note that the effect of car ownership is insignificant, because of the small difference (on average -1% cars per household). The total number of cars is very different because it is related to the number of households which is -14% (POP) and -11% (HHS) lower. The component car costs (CST) also have small effects because of the small difference.

Note that for the model runs that I performed I did not adjust the components by 10% each time. The adjustment per component was appropriate to the uncertainty of that component. In this report the results are scaled to 10% differences, to make the sensitivity of the components comparable. An elaborate description of the model run adjustments can be found in appendix 9.4

Also note that I assume the sensitivity of the output to changes in the components to be linear. However I tested this and the effects decline when the adjustment to the component is larger. The sensitivities found in the last paragraph and in the previous chapter were the result of analysis using adjustments to the components that are appropriate to the bandwidth (also see appendix 9.4).

The eight step accounts for the interaction between the scenario components. This is explained below. From the spatial analysis I saw that the spatial distribution of RC had small effects on time loss and congestion. I included these in the ninth step.

6.3.1 Integrated scenario

The combined effects of the changes in scenario components might deviate from the actual effect of the combined differences in components. This is because the effects might interact with each other. To evaluate the interaction between scenario components I made an integrated scenario (INT). For this scenario all the components in GE were adjusted to the level of RC. An elaborate description of the design of this scenario can be found in the appendix 9.4. Spatial distribution was not adjusted. The freight matrix of RC was used as input. This gave the following results.

Integrated scenario results					
	tours	distance (km)	time loss (h)	congestion (h)	benefits
predicted	8,119,000	237,868,000	155,000	61,000	352
INT	8,089,000	234,382,000	159,000	62,000	370
predicted / INT	- 0%	- 1%	+ 3%	+ 1%	+ 5%

Table 57: Results on the integrated scenario

For the sub-aspects that were presented for the initial integrated scenario, the results are the same: tours and distance almost zero and time loss and congestion hours about 5% more than in RC.

6.3.2 Illustration of the explanation in bandwidth

By multiplying the difference in the input by the sensitivity, the value of the indicators for RC can was predicted. This is shown in 10 steps, the tenth being a factor for unknown or other drivers that affect the outcomes of the model. The explanation in difference is illustrated by the following figure (for the indicator time loss):

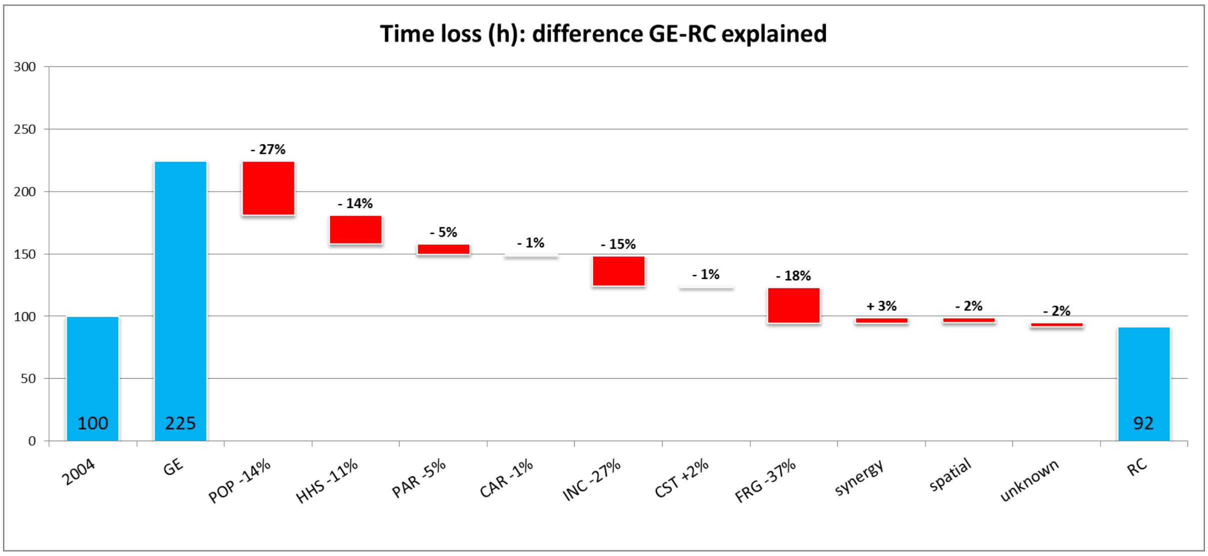


Figure 27: Time loss bandwidth explained

Per indicator it is different which ones influence the indicator most between the scenarios. For tours they are POP and HHS, for distance also INC. Time loss and congestion are mainly determined by POP, HHS, INC and FRG. These are the most important components. It is important to realize that on a national level the differences are mainly volume differences, not spatial. Less than 2% of the population is located in a different COROP zone when comparing the scenarios, this has a small effect. However, on a regional level the different spatial distribution could be treated as a change in population, which has significant effects.

The next figure illustrates the difference in benefits in the 10 steps.

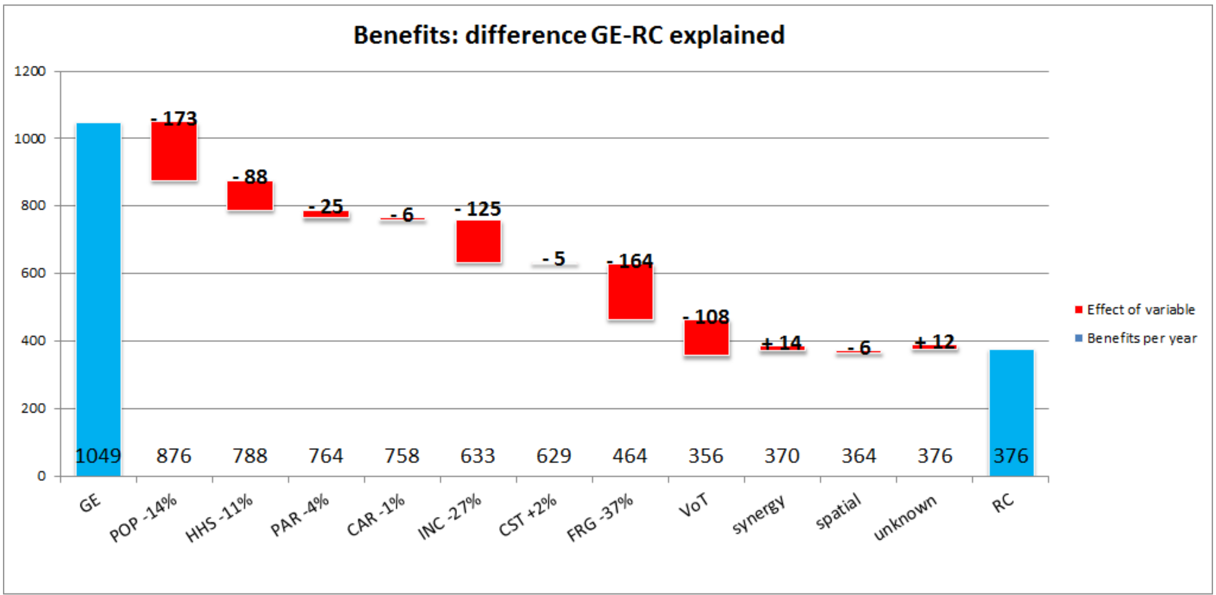


Figure 28: Explanation of the difference in benefits for GE and RC

The four components that explain 70% of the difference are population, household size, income and freight traffic. Together with the new value of time this is 95%. The first 7 components were also used in the integrated scenario in which the total benefits of the MIRT+20 investment are 370 million a year. This is a little bit closer to the 376 million than the 356 million that results from a combination of sensitivities and differences in input. This means that there is interaction between the components (the so called synergy effect), together they have slightly less impact than would be expected. The difference in spatial distribution explains a very small part of the differences and the remaining percentages are because of unknown drivers. They might be caused by variables that are not in this research, such as the number of students, inconsistent adjustments to the labour market or demographic differences in age or sex.

Analysis for RC shows comparable results. I did not make an integrated scenario for RC adjusted to GE input values and therefore don't know the synergy effects. Without these effects the effect of unknown drivers is 11% (was 8% for GE without synergy effects).

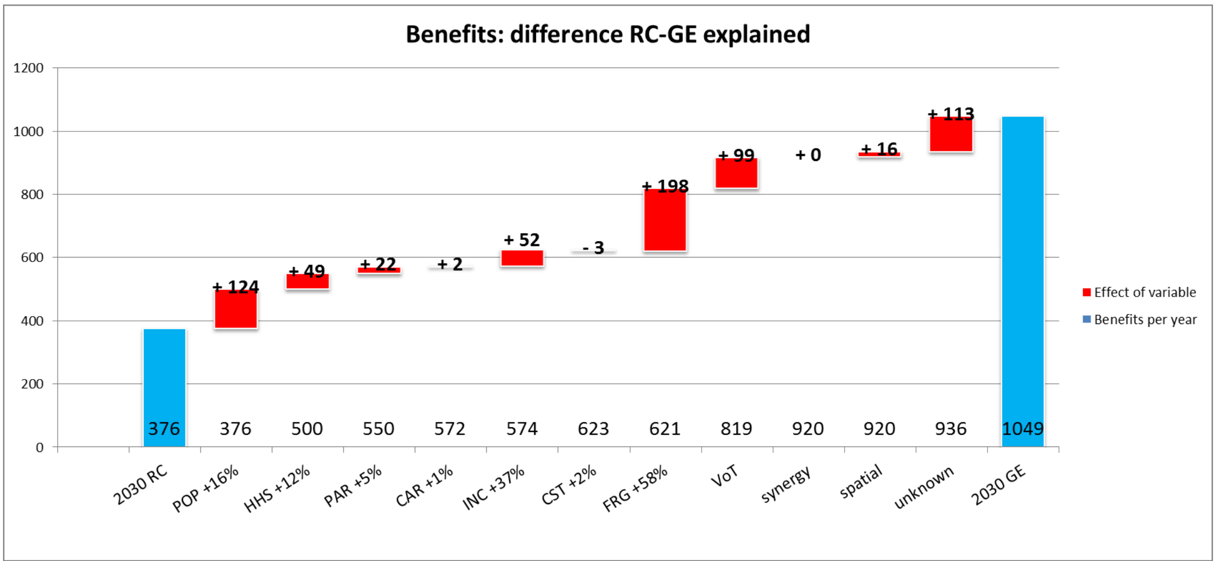


Figure 29: Explanation of the difference in benefits from RC to GE

Figures on all indicators can be found in appendix 9.17.

6.4 Benefits for another infrastructure package

To show the consistency of the travel time benefit results, the analysis will be repeated for the two scenarios with another investment package. The bandwidth between RC and GE in terms of benefits should be about the same.

The second investment package consists of the ambition in the SVIR for 2040, stating that all main road connections should be 2x3 lanes and in the Randstad 2x4 lanes. The map in the SVIR illustrating this ambition was used to model the investments. In my analysis I assume this ambition to be fulfilled in 2030, which will cost about 48 billion euros.

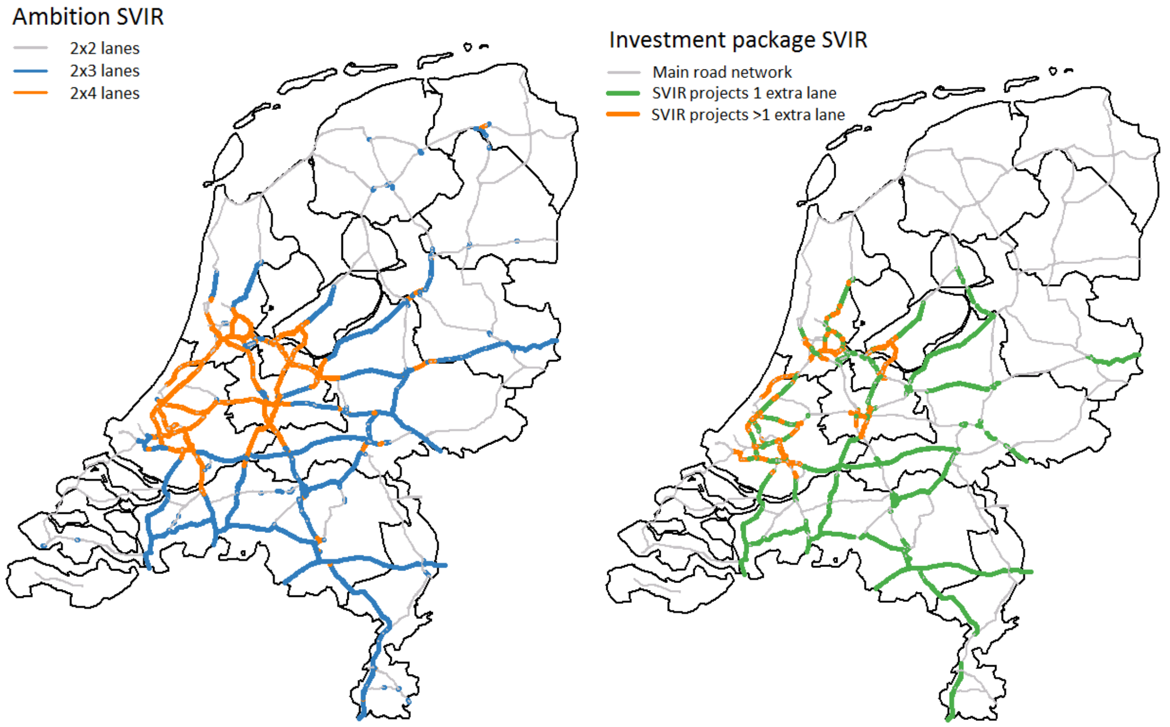
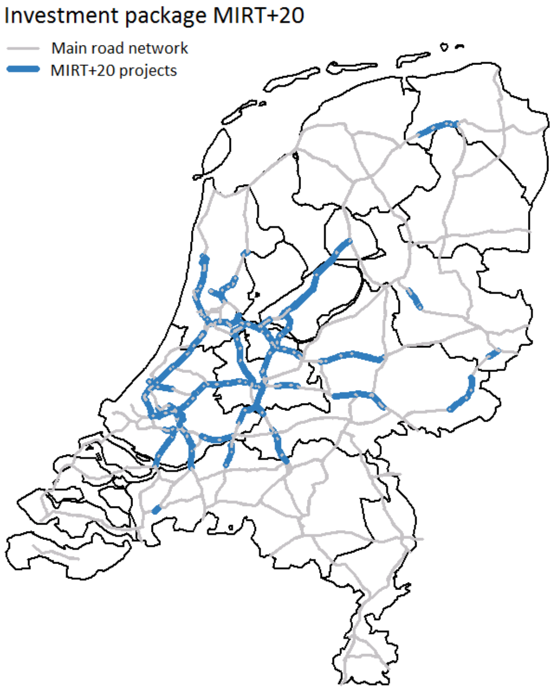


Figure 30: Ambition and investment package SVIR

The following maps show the packages in a simplified way.



MIRT+20 investments (lane kilometers)			
Region	Secondary	Main	Total
North	-	37	37
East	-	204	204
West	7	1,293	1,301
South	1	23	24
Total	8	1,557	1,565

SVIR investments (lane kilometers)			
Region	Secondary	Main	Total
North	-	-	-
East	-	666	666
West	-	1,961	1,961
South	-	1,061	1,061
Total	-	3,688	3,688

Figure 31: Comparison of the MIRT+20 and SVIR package

The four parts of the Netherlands are shown in appendix 9.14.

The benefits are given below for the MIRT+20 and SVIR package.

Benefits (mln * euros / year) MIRT+20						
	total	autonomous	new users	am	op	pm
RC	376	357	19	151	92	133
GE	1,049	990	59	275	536	238
GE/RC	+ 179%	+ 177%	+ 215%	+ 83%	+ 480%	+ 79%

Table 58: Benefits MIRT+20

Benefits (mln * euros / year) SVIR investment						
	total	autonomous	new users	am	op	pm
RC	403	388	15	123	173	107
GE	1,246	1,181	65	251	775	219
GE/RC	+ 209%	+ 204%	+ 322%	+ 103%	+ 349%	+ 105%

Table 59: Benefits SVIR

In RC, 20 billion additional investments only generate 7% extra direct benefits (in GE 20%). This shows that the MIRT+20 package specifically targets locations that solve bottlenecks more efficiently and the SVIR ambition is not designed optimally. The reason could be that the SVIR ambition is somewhat vague. The differences between RC and GE are larger for the SVIR package, 209% instead of 179% for the MIRT+20 package. It is the same order of magnitude. The distribution of benefits is different, the SVIR package performs much better outside peak hours. The reason is that much of the capacity increments are outside the Randstad, and much of the congestion and travel time losses in the peak hours are in the Randstad.

For different travel purposes the following tables show that the difference in benefits for freight are substantial. This is also caused by the small benefits in RC.

Benefits / motive (mln * euros / year) MIRT+20				
	freight	work	business	other
RC	42	109	152	72
GE	206	210	423	209
GE/RC	+ 387%	+ 92%	+ 179%	+ 190%
Benefits / motive (mln * euros / year) SVIR investment				
	freight	work	business	other
RC	31	103	186	84
GE	228	231	534	252
GE/RC	+ 645%	+ 125%	+ 188%	+ 200%

Table 60: Benefits/motive for MIRT+20 and SVIR packages

For other motives, the difference between scenarios are similar. Elaborate analysis and results are presented in appendix 9.15.

Finally, the difference in SVIR benefits for GE and RC could also be explained by the scenario bandwidth and sensitivities found in chapter 4 and 6, using the same method as in paragraph 6.3.

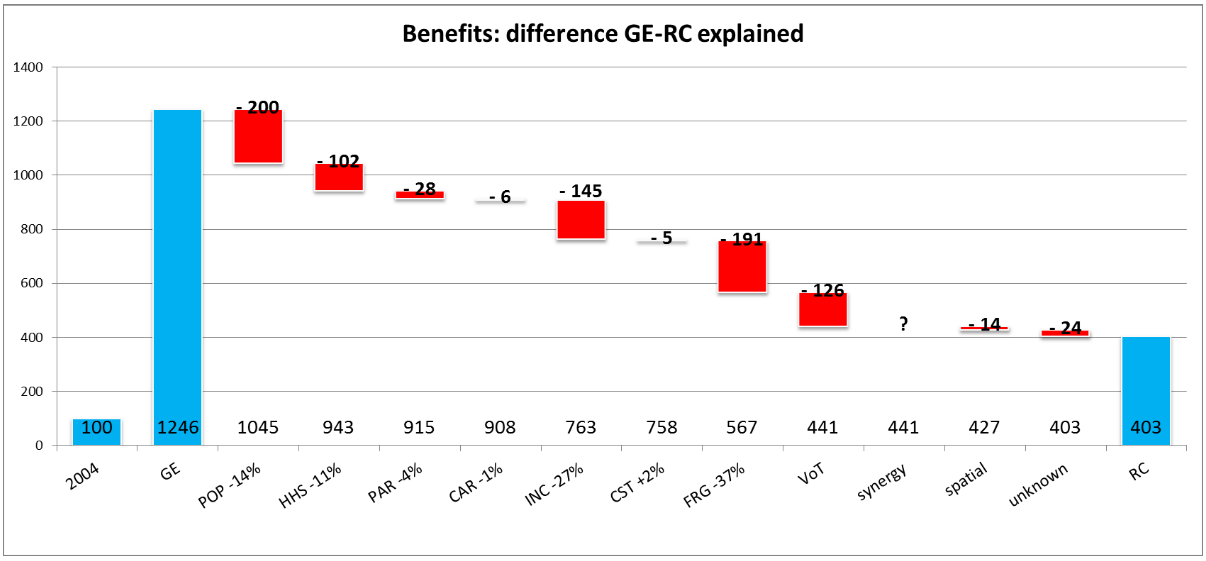


Figure 32: Explanation of the difference in SVIR benefits from GE to RC

6.5 Cost-benefit analysis

In my research I determined the travel time benefits for an average working day in 2030 for GE or RC. For the purpose of my research, which is to evaluate the sensitivity and bandwidth of the benefits for the scenario components, this is sufficient. However, to get an idea of the profitability of the MIRT+20 package that I designed, and to understand the role and importance of the travel time benefits in cost-benefit analysis, I also performed a simple cost-benefit analysis as prescribed by the OEI guidelines.

The travel time benefits were added up for future years to get the net present value of the benefits. This was done for a 5.50% discount rate. The network becomes more robust because of the congestion mitigation; these benefits are 25% of the travel time benefits. Other indirect effects, such as labour market effects are estimated as 20% of the travel time benefits. Excise is also a welfare effect. This is because the individual traveler is willing to pay the extra costs to make the trip. The excise is on average 4.14 cents per kilometer (Zwaneveld, Romijn et al. 2009).

The external costs are estimated based upon the total kilometers traveled. Extra or less kilometers traveled result in an effect on air quality, traffic safety and noise. For the MIRT+20 measure car kilometers increased by about 4% and public transport kilometers decreased by about 0.2%. The table below shows the external costs per aspects in eurocents / km.

Overview external costs in eurocents / km				
	emissions	safety	noise	excise
car	1.5	2.3	0.3	-4.14
public transport	0.3	0.9	0.3	0

Table 61: Overview external costs in eurocents/km (Hilbers, van de Coevering et al. 2009)

The costs of the MIRT+20 package were very roughly estimated. The costs per kilometer lane were estimated to be 13 million euro. This means that the investments will cost in total a little more than 20 billion euro. Maintenance is estimated as 1% of the investment costs per year. Travel time losses because of road construction are not included.

Costs MIRT+20		
Budget 2020-2030	€	20,000,000,000
Costs per kilometer lane	€	13,000,000
Lane km - budget		1,538
Realized		1,565
Total costs	€	20,342,270,000

Table 62: Costs of the MIRT+20 investments

The resulting table is presented below.

Social cost benefit analysis MIRT+20 investment package			
		GE	**RC**
Benefits			
direct effects	(bln euro)		
travel time benefits		+ 22.9	+ 8.2
robustness		+ 5.7	+ 2.0
indirect effects	(bln euro)		
excise		+ 3.6	+ 1.6
other indirect effects		+ 4.6	+ 1.6
external effects	(bln euro)		
emissions car		-1.3	-0.6
emissions public transport		+ 0.01	+ 0.00
noise car		-0.3	-0.1
noise public transport		+ 0.01	+ 0.00
traffic safety car		-2.0	-0.9
traffic safety public transport		+ 0.02	+ 0.01
Total benefits	(bln euro)	**+ 33.2**	**+ 11.9**
Costs			
costs	(bln euro)		
investment costs		- 20.3	- 20.3
maintenance		- 7.1	- 7.1
Total costs	(bln euro)	**- 27.5**	**- 27.5**
Result cost benefit analysis			
Net present value	(bln euro)	**+ 5.7**	**-15.6**
Cost benefit ratio		1.21	0.43

Table 63: Social cost-benefit analysis MIRT+20

The results show a large difference in the profitability of the package. The cost-benefit ratio is 1.21 in GE and 0.43 in RC. This shows that it is not realistic to assume large investments in a low economic scenario for 2030 and the importance of using more scenarios for project evaluation as the scenarios represent equally probable futures.

It also shows that it is not wise to fix the projects of the MIRT until 2028, because the profitability of these investments is very uncertain.

6.6 Evaluation framework for uncertainty and sensitivity

The objective of this research was to determine the most important components in scenarios that influence the travel time benefits of infrastructure investments and to analyze the sensitivity of the benefits to these components. In the research design, paragraph 3.2, a conceptual quadrant was introduced which can be used to distinguish the components to their importance. On the axes of the quadrant are uncertainty and sensitivity.

With the results of this research we can put the components on the y-axis, according to the sensitivity of future mobility to changes in the component. As we have seen in this research, the sensitivity varies per indicator, so for every indicator another map can be drawn. This research also briefly explored uncertainty of the components and based on this the components can be placed on the x-axis, for example on a 5-point scale or according to the bandwidth between the scenarios.

The figure underneath shows sensitivity and uncertainty for the travel time benefits in GE 2030 of the MIRT+20 package in my research. To quantify uncertainty I used the bandwidth between the RC and GE scenario.

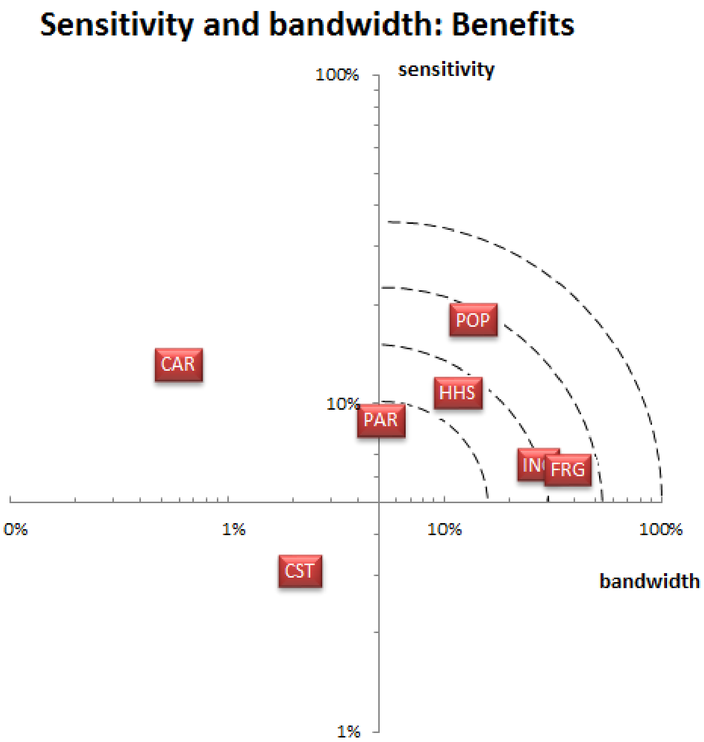


Figure 33: Framework results for travel time benefits in GE

Sensitivity is considered not sensitive for values between 0% and 5%. Remember that this is sensitivity to a 10% change in the input. The scale is logarithmic, because the effect can be seen as a factor of the change in input (twice as much is 20%, half is 5%). A component is considered to be uncertain if the bandwidth is higher than 5%. Note that the cost component (CST) scores low on both aspects. However, as explained in chapter four, the component is more uncertain than the scenario bandwidth suggests. This bandwidth only expresses a difference in fuel efficiency, while many studies indicate that oil price is also very uncertain. The rings indicate the level of importance within the upper right quadrant. After the population (POP), freight (FRG) and income levels (INC) are most important for travel time benefits. This fits with the results of the stepwise analysis from GE to RC.

Sensitivity and bandwidth are different in the two scenarios that I researched. The reason is the difference in absolute values. The same change in a component, viewed from the high or low scenario results in a different bandwidth. Also the sensitivity to for example benefits is higher when compared to the value of 1049 or 376 (the travel time benefits in respectively GE and RC). This can be observed in the following figure.

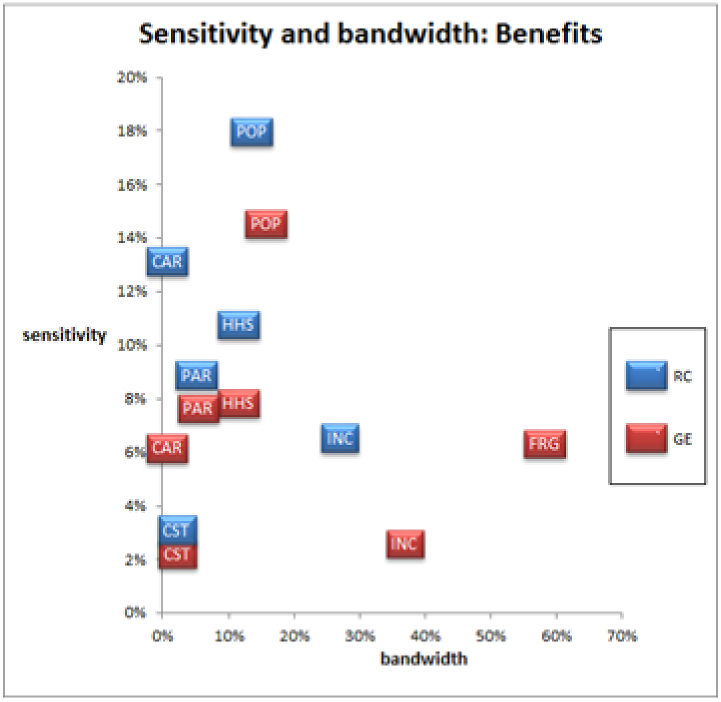


Figure 34: Framework results GE and RC

Sensitivity is always higher in RC, as was also concluded in previous chapters. The only exception is FRG, freight traffic, for which I have no results in the RC scenario. The figure below shows that the result depends on the chosen indicator.

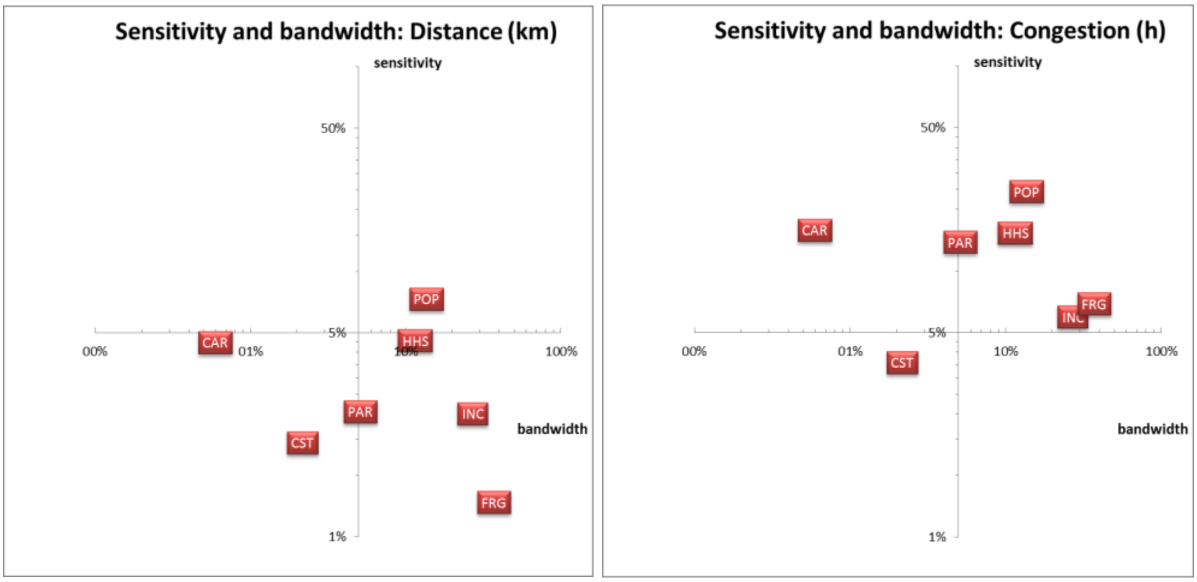


Figure 35: Framework results distance and congestion in GE

While bandwidth obviously stays the same, sensitivity differs for distance or congestion in 2030 GE. Traveled distance depends on the population component (and somewhat less on the household size), while congestion hours depend mainly on population, household size, freight traffic and income levels.

The developed framework can be used to explain and discuss the importance of variables for scenario studies or new scenarios.

7. Conclusions and recommendations

In this chapter I conclude my research by answering the main research question and all the sub questions. Then I give some policy recommendations on policy and further research. Finally the limitations of my research will be discussed.

7.1 Conclusion

The key determinants in scenarios that influence the travel time benefits of infrastructure investments are population size, household size, household income levels and freight traffic. They are either very uncertain (income levels and freight traffic) or they influence the benefits a lot (population size, household size). The benefits of investments can be up to 3 times as high in a high economic scenario compared to a low scenario.

For this research the WLO scenarios were used as a case study. The main variables in scenarios are population size, households, total number of cars, employed population, jobs, income levels, car costs and freight traffic. In order to design consistent scenarios not variables but scenario components should be used as a starting point. Components represent the relations between variables and determine the input variables for scenarios. In this research the population size was used as a starting point. Important components are the population, household size, participation level, relative car ownership per household, average gross income level for households, variable car costs per kilometer and freight traffic. Uncertainty was determined using the bandwidth between the scenarios as in indicator and additional analysis of historical and forecast data.

Besides population growth and household size especially household incomes and freight kilometers show a large bandwidth between the scenarios. The oil price is assumed to be equal in the WLO scenarios. The amount of vehicle-kilometers in 2030 is approximately 25% higher in GE. The travel time loss is almost 2.5 times higher than in RC and the number of congestion-hours is more than 3 times as high. The sensitivity of the output to input variables differs per indicator. The number of tours and traveled distance are especially sensitive to population, size of the household and car ownership. Time loss and congestion-hours are also highly dependent on the participation level and also to household income and freight traffic.

For this study, an investment package was designed for the main road network of 20 billion between 2020-2030. The travel time benefits are in the high scenario up to 3 times as high as in the low scenario. They are especially sensitive to the number of inhabitants and to the relative car ownership per household. Using the sensitivities and differences in the input, the difference in benefits and in mobility between GE and RC can be explained. Population, household size, income and freight are the main explanatory components for the difference.

The table below summarizes qualitatively how uncertain the components are and to what extent they influence the benefits.

Uncertainty of scenario components and sensitivity of benefits		
	Level of uncertainty	Level of sensitivity
Population	+	++
Household size	+	+
Participation	+/-	+
Car ownership per household	+/-	++
Household gross income	++	+/-
Oil price: Variable car cost/km	++	-
Freight traffic	++	+/-

Table 64: Summary of uncertainty and sensitivity

The analysis of a different investment package, the implementation of the SVIR ambition, shows comparable results on the bandwidth of the travel time benefits in the two scenarios, which are about 3 times as high. It is striking that the annual travel time benefits of this investment package is only slightly higher than the MIRT+20 investment package (namely 1.2 billion to 1.0 billion in GE), while the number of extra kilometers and therefore the cost of the package is more than twice as much.

Finally a simplified cost-benefit analysis was performed. The net present value of the travel time benefits of the MIRT+20 investment package in GE amounts to more than 20 billion. When all the benefits (including robustness effects, indirect effects and externalities) are included the net present value of the package is more than 30 billion. Compared to the costs (about 24 billion euros) this leads to a positive balance of almost 6 billion. To indicate how large the differences between GE and RC are: the same investment package has a negative balance of 15 billion in RC.

7.2 Recommendations

At the end of this research I formulated some policy recommendations and recommendations on further research.

7.2.1 Policy recommendations

For the design of new scenarios in the future, the successors of the WLO, there are some recommendations. The components that proved to have large impact of mobility forecasts and benefits of the investment should be specified carefully in the new scenarios and ideally the bandwidth should represent uncertainty in these commponents. Freight traffic, which is a very important determinant for the model output, deserves much attention when designing the scenarios. As variables cannot be seen separately in scenario studies it will relieve the black-box level of the calculations when the relations between the variables are made more clear. Values of time should be monitored and adjusted to newest insights. Finally the bandwidth of the scenarios should also cover uncertainties in oil prices and car ownership. One possible option is to assign specific oil prices for the different scenarios. However it is important that the effects of the scenario settings can be distinguished. Another evaluation of uncertainty due to scenario settings is therefore recommended.

The scenarios that were researched in this study were not designed specifically for mobility analysis. The consequence is that the key uncertainties may not be the same as they would be for transport scenarios. The uncertainty in some important aspects are not expressed by the scenarios, such as oil prices or car ownership. Trends that are important specifically for future mobility, such as telecommuting or ICT developments should also be considered. The implementation of important policy uncertainties (such as climate policies or pricing) might be something to reconsider as they are expected to have huge impact on future mobility and therefore on the profitability of infrastructure investments or other measures. Solely for the purpose of evaluating transport related measures, transport specific scenarios could be developed. In 1998 the QUESTA scenarios were designed, which focused on transport (Egeter, Korver et al. 1998). Eventually it was decided not to use them, because the scenarios were not consistent with scenarios for other sectors.

Presentation of uncertainty is important. However this is often not done very well, because it would degrade the usability of the cost-benefit analysis. When the results are reported to be very uncertain, who would make a decision based on those results? However, that is exactly why uncertainty should be reported. If the uncertainty of project profitability is so large that a wise approval of the measure would not proceed, it should not. This does not mean that every project should be cancelled because the future is so uncertain. Reporting on uncertainty contributes to better design of alternatives (that account for uncertainty because they are flexible), stepwise implementation of projects, and reducing the risks. Presentation of CBA results should be transparent and honest, cover the bandwidth of possible futures and therefore contribute to better decision making.

The final question that remains is how we should deal with the large differences in profitability of the infrastructure investments. In different scenarios (with e.g. high or low economic growth) different infrastructure projects are profitable to a more or lesser extent. For a robust policy on infrastructure investments, high risk projects should be developed with caution. One option to deal with this is prioritizing the projects to profitability. When mobility grows faster than expected, less profitable projects can be executed as well. This is called the no-regret strategy and aims to minimize the possibility of overinvestment, which is highly undesirable in the current economic situation. Projects that are not cost-effective in the high scenario should not be carried out. Robustness can be expressed in the bandwidth between results for the high and the low scenario. Some projects will have a higher risk than others. This should be a quality of every alternative. A project that is less profitable on average could be preferred to a high risk project. For projects that show large bandwidth in benefits, delay of the project decision can be a good option.

Flexible planning is essential in this strategy. Any opportunity that comes up to create flexible areas should be seized. One of the respondents of the research of Mouter (2012) also comments: *If you complete the part of the project of which you know that it will be profitable, you can observe how the future develops. After a few years it is possible that uncertainty has decreased and you can possibly decide on progressing the next part of a project. This is a smart way of dealing with uncertainty.*

Future developments can profoundly influence costs or expected benefits of infrastructure investments and can lead to projects becoming unprofitable. Therefore such uncertainties should be carefully considered when assessing a project's need and necessity, and that one agrees on including certain adjustment options to adapt in advance, in case these risks should materialize. Scenarios and sensitivity analysis provide crucial information for assessing risks. At least two realistic future scenarios – that is, a minimum and a maximum scenario – can be employed to illustrate the maximum bandwidth of future uncertainties. Prior to initiating necessary preparations and establishing agreements about 'when and how to make adjustments' in cases involving unexpected events, it is important then to ensure that adjustments can be made at a later stage (for example, by means of land reservation, a capacity reserve or financial reserve). After a decision has been taken, it must then be determined which project components can still be adapted, given the fact that the conditions have changed.

Finally, the results suggest that it is wise not to fix the projects of the MIRT until 2028, because the profitability of these investments is very uncertain.

7.2.2 Further research

It would be interesting to extend the research to other measures besides infrastructure investments. Especially for pricing policies and dynamic traffic management, in different variants, this might be interesting to implement.

This research was simplified because of limited time. Many assumptions on the relations between variables were made. For example income and car ownership are assumed to be independent but they should be related as they are highly correlated. This can be an improvement for further research.

From this research it seems possible to develop a monitoring system. The development of such a monitoring system is recommended and can be used in flexible planning of projects. Combined with updated forecasts on the important components, future mobility predictions can be updated.

The measure that is used to determine the benefits of infrastructure investments was the rule of half. However, according to Geurs, Zondag, de Jong, & de Bok (2010) this does not result in accurate user-benefit computations. The calculations can get complicated when taking into account changes in route choice, time of day, destination and/or modes of transport and the rule of half does not pick up all accessibility impacts resulting from the land-use changes. They propose another measure: the logsum measure. A case study by Geurs et al. (2010) shows large differences in accessibility benefits between the rule-of-half and logsum measures. Therefore I also recommend further research on the method and measure to estimate benefits.

7.3 Limitations

There are limitations to this research that are important to keep in mind. Uncertainty in the model outputs is caused by input uncertainty (the future values of the exogenous variables) and model uncertainty (specification errors and errors due to the use of parameter estimates) (de Jong, Daly et al. 2007). The model uncertainty is significantly lower. The uncertainty that you put into the model determines largely the uncertainty of the output. However, the validation of the LMS model, thus model uncertainty was not part of this research, only input uncertainty was analyzed. Secondly, only the benefits of infrastructure investments on the main road network were analyzed. In Dutch policy making there are other important topics for which the LMS model and scenario studies are used, such as pricing policies or tax measures. All the conclusions of this research only apply to the specific measure that was implemented and might differ for other measures.

Another consideration is that I used the standard rule-of-half method prescribed by the government to calculate the benefits. The validation or influence of the method was not part of this research. However the results show that benefits also depend on the value of time that is used. Finally, in this research the biggest challenge was to make a robust analysis within the available time. The running time of the model is very long which limited the possibility for doing sensitivity analysis a lot. Therefore I could not do much analysis on the combined effect of component uncertainty.

It is important to realize that congestion is not only dependent on the components that I researched. Other factors are bad weather, accidents, taxes, speed limits, road works, traffic management and also very important: new roads. The package from this research reduces congestion itself by about 30%, which is almost as much influence as the population difference between RC and GE. Especially for the evaluation of local projects the surrounding network is of high importance. The LMS model only models structural congestion, incidental congestion caused by e.g. accidents is not modeled.

The scenarios are used to evaluate many sorts of measures: ‘smart utilization’ measures, like tax and pricing measures, mobility management, public transportation services, node development, travel information, or spatial planning. The results of this study only apply to infrastructure investments.

The outcomes of this research show that on a national level the spatial distribution does not have a large impact on mobility in the future. However, on a regional level spatial distribution has a large impact. Although it was not subject of this research a different spatial distribution means for example a higher population in a specific region. Therefore the effects will have the same order of magnitude as an increase in population according to this research. Measures like the implementation of new road infrastructure are very local measures and their success is highly dependent on the spatial distribution of jobs, employees, commerce, etc. On the aggregate national level of the LMS these details are not included.

While this study focuses on uncertainty in travel time benefits of infrastructure investments, profitability is also determined by the costs of the infrastructure. Estimating costs was not considered problematic by the respondents of the research of (Mouter, Annema et al. 2012). However literature suggests that this can have high impact on uncertainty in profitability (Flyvbjerg, Holm et al. 2003).

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9. Appendix

Contents

9.1 Appendix output of the LMS model

SES vervoerwijze- bestemmingskeuze

- Afstandsklasse
  - 0 – 10 – 30 – 50 – 80 - 200, > 200
- Relatie
  - Interzonaal / Intrazonaal
- Regio
  - 12 provincies
  - Frankrijk, België, Luxemburg, Duitsland
- Variabele
  - Reizen: *Een keten van verplaatsingen die thuis begint en daar ook weer eindigt*
  - Afstand *km*
  - IVT *min*
  - OVT *altijd 0*
  - Kosten *euro's*
- Vervoerswijze
  - Trein, Autobestuurder, Autopassagier, BTM, Fietsen, Lopen, BTM Voor/Na
- Motief
  - Woon – (Educatie, Werk, Zakelijk, Winkel, Overig)
  - Werk – (Zakelijk , Overig)
  - Kind – (Educatie, Winkel, Overig)
- Scenario
- Iteratie

QBLOK toedeelresultaten

- Dagdeel
  - Ochtendspits / schouder
  - Restdag
  - Avondspits / schouder
- Rijstroken
  - 1 tm 9
- HWN
  - HWN/OWN
- Doelgroep
  - Alle personen / autoverkeer / vrachtverkeer
- Linktype
  - 1 tm 24
- Gebruikersgroep
  - Vracht
  - Woon-Werk
  - Zakelijk
  - Overig
- Blokkade
  - Ja/Nee
- Regio
  - 12 provincies
  - Frankrijk / België / Luxemburg / Duitsland
- Variabele
  - Kilometrage *km*
  - Totale tijd *uur*
  - Verliestijd *uur*
  - Tijd in file *uur* (voertuigverliesuren)
  - Voertuigen in file
- Iteratie
- Scenario

9.2 Appendix adjusting the zonal data

It is important to build new scenarios in a methodologically sound way. I analyzed the datasets of GE and RC for all the variables. The analysis shows that zones have about the same share of the total in two different scenarios. However, growth factors for 2004-RC and 2004-GE are not always consistent on a zonal level. When aggregated, the growth factors are consistent. Using these results I came up with two methods for adjusting the scenarios.

- The first is to multiply every zone in the input data by a constant for the selected variables
- The second is to multiply the dataset of 2004 by a new growth factor, that is the same for each zone in a COROP area. The new growth factor is constructed using the desired new total for the selected variable and keeping the share of the COROP area in the total the same

The first method implies that the share of each zone remains constant in the original and new scenario.

The second method implies that the share of each corop area remains constant and that the zones in the corop area have the same growth factor per selected variable for 2004.

To keep the procedure of my research simple and relatively easy to understand, I used the first method. The implications are of a spatial nature, eg not only the new amount of people in the population, but also where they live. To check if this assumption leads to a bias in the results, I performed a comparative analysis with the second method. This resulted in very small differences.

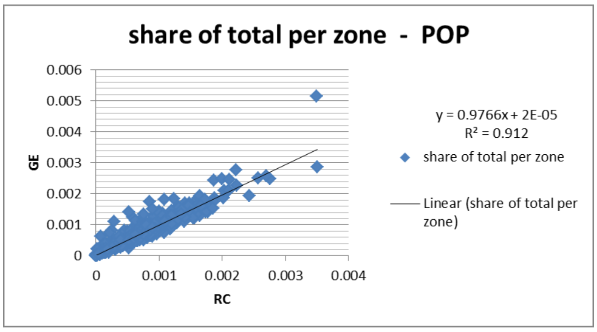
An example of the first method:
What if the population in 2030 will be α% higher than estimated according to the RC scenario?
For the input this would mean:

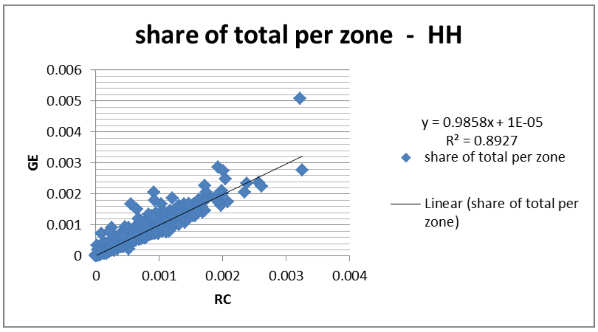
- For all zones POPULATION * (1 + α%)
- For all zones HOUSEHOLDS * (1 + α%)
- For all zones LABOUR FORCE * (1 + α%)
- For all zones EMPLOYED POPULATION * (1 + α%)
- For all zones JOBS * (1 + α%)
- For all zones STUDENTS = STUDENTS
- For all zones INCOME = INCOME

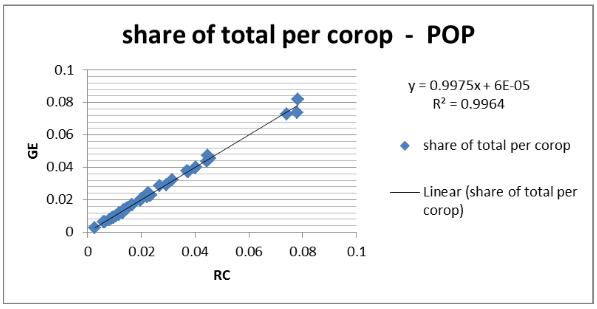
9.3 Appendix another method for adjusting zonal data

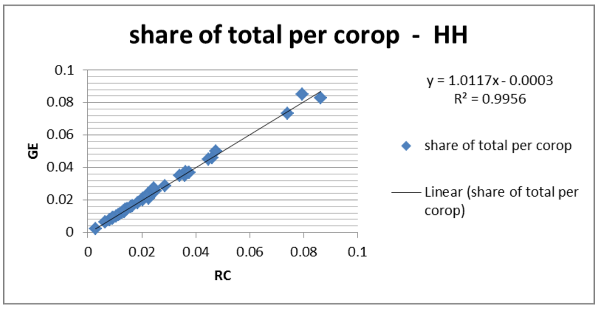
In the method I used there is one constant factor by which the value in every zone in the Netherlands is multiplied. This method will be justified by the following analysis.

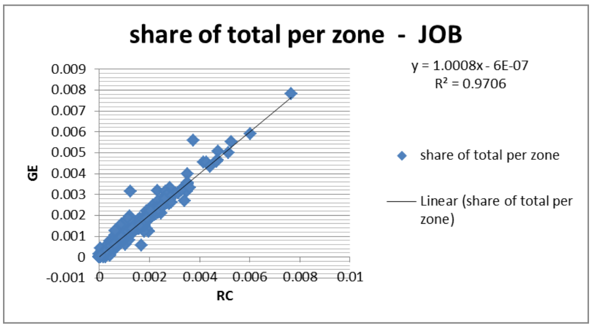
In the next graphs, one can see for every zone or COROP area their share in of the total of a selected variable for the scenarios RC and GE, in these graphs population, households, jobs and students. From this it can be concluded that the share of a zone in the total is more or less constant. The share of the total per corop has an even higher consistency.

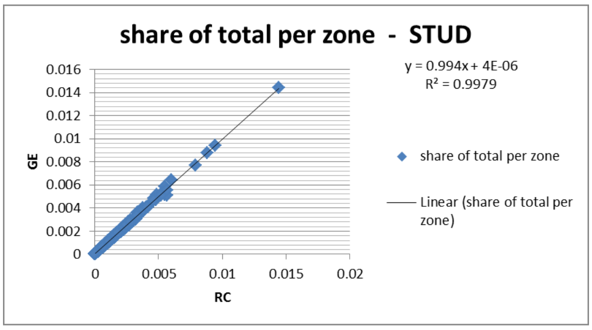


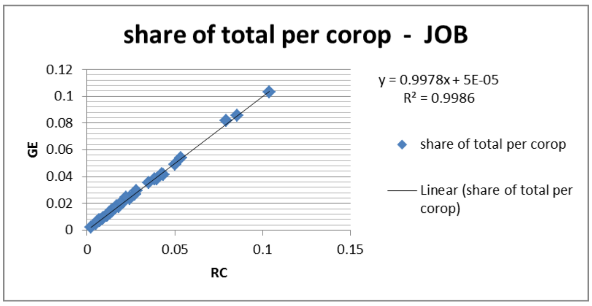


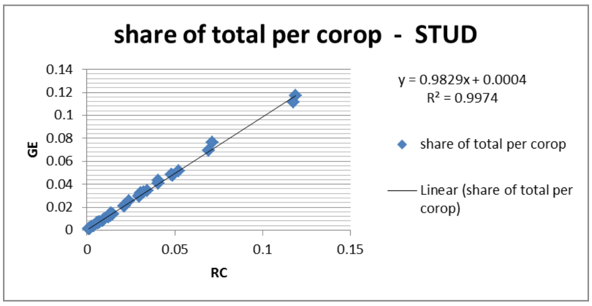












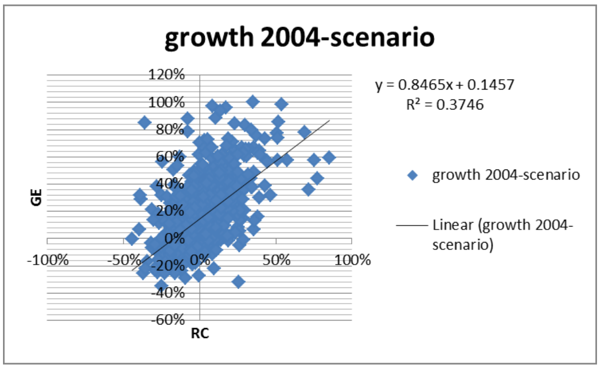
In my method of adjusting the zonal data I used this information to calculate new zonal values per variable. For example, the population:

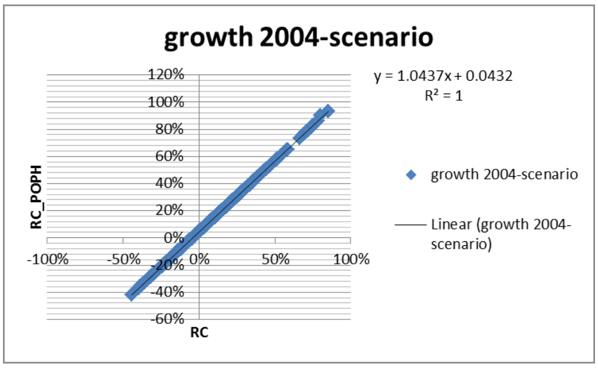
$pop_{i,new} = (pop_{i,old} / \Sigma pop_{i,old}) * \Sigma pop_{i,new} = pop_{i,old} * \beta$

(because $\Sigma pop_{i,new} = \Sigma pop_{i,old} * \beta$)

The same β applies to other variables, as for example the household size and participation rate remains constant.

However, there is a problem with this method. This becomes clear in the following graph.



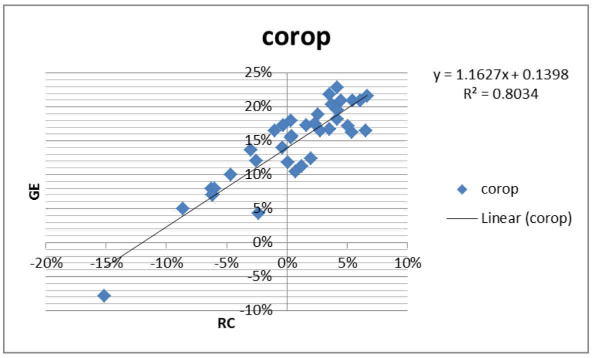


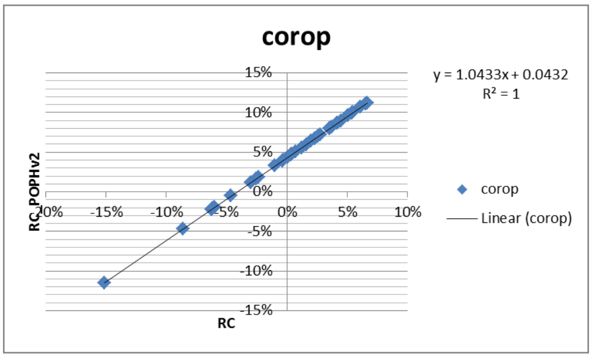
The graph shows for every zone the growth factors 2004-RC and 2004-GE. The growth factors for 2004–RC and 2004-GE are not constant, they are scattered around the plot. This means that if the population in a zone increases by 50% in one scenario, it does not imply that the population will increase in another scenario by a comparable percentage. The new scenario and relating growth numbers, using the method described before are displayed in the graph on the right. The relation is linear, as is predictable from the method of multiplying every zone with the same constant.

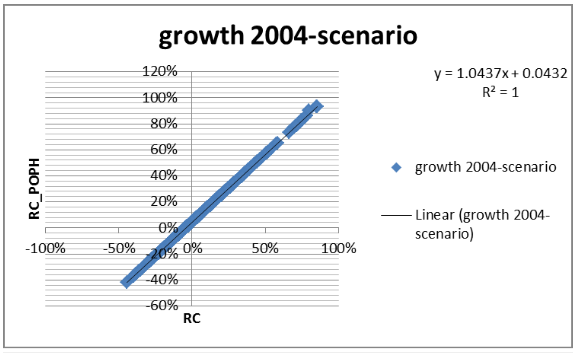
Another method of adjusting the data is using fixed growth factors per corop and variable. This means that every zone in the same corop area has the same growth factor for a certain variable.

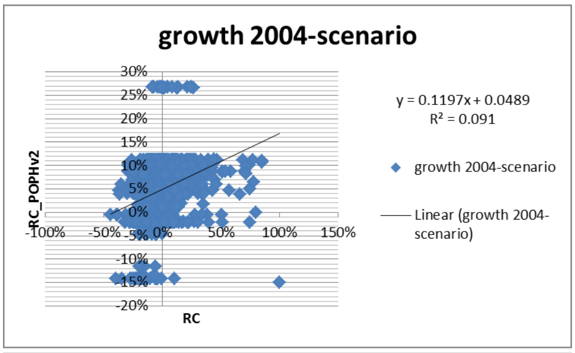
This method is a little bit more complicated and follows these steps:

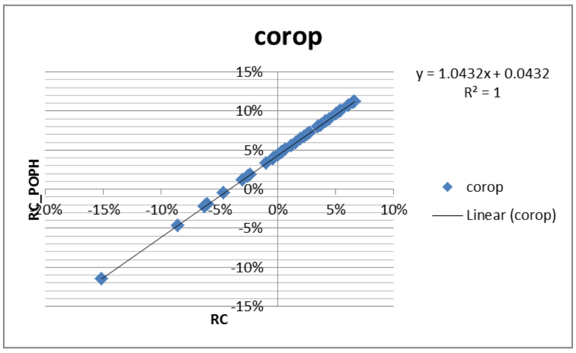
1. Determine the share of every corop area of the total for the variable in 2030
2. Determine the new total for the variable in the new scenario
3. Determine the new total per corop area for the variable in the new scenario
4. Determine the growth factor for 2004-2030_new_scenario per corop area
5. Multiply the value of each zone in 2004 with the growth factor according to the corop area it is in to get new zonal data.

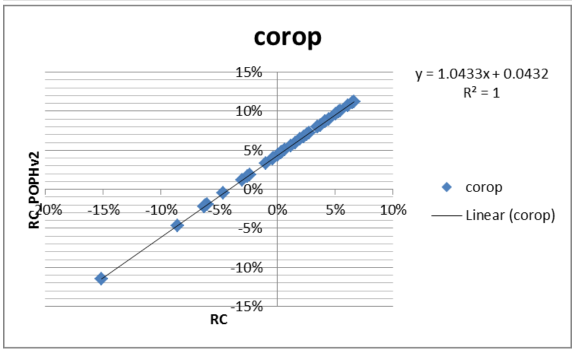


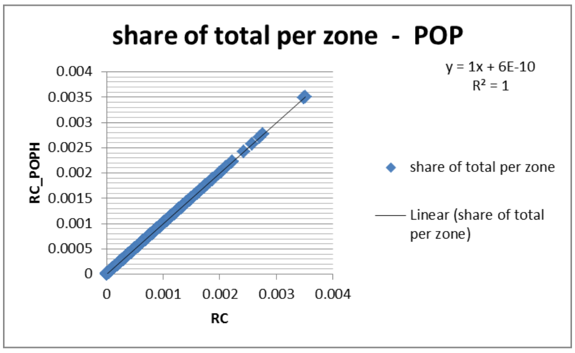


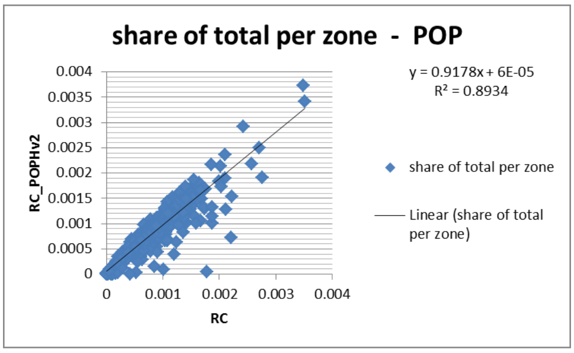

growth 2004-scenario
y = 1.0437x + 0.0432
R² = 1
growth 2004-scenario
Linear (growth 2004-scenario)
RC_POPH
RC

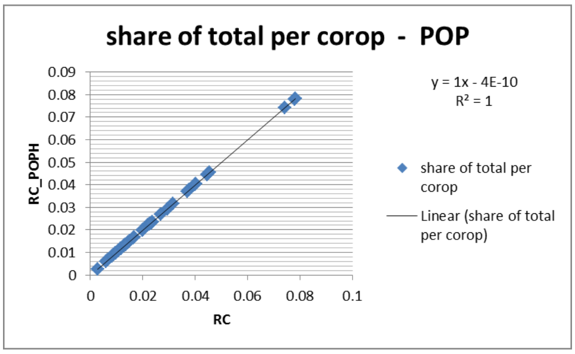

growth 2004-scenario
y = 0.1197x + 0.0489
R² = 0.091
growth 2004-scenario
Linear (growth 2004-scenario)
RC_POPHv2
RC

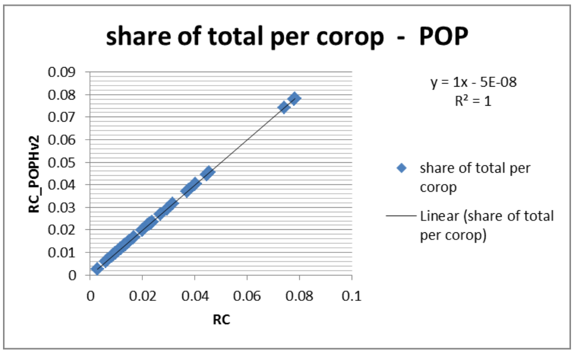

corop
y = 1.0432x + 0.0432
R² = 1
corop
Linear (corop)
RC_POPH
RC


corop
y = 1.0433x + 0.0432
R² = 1
corop
Linear (corop)
RC_POPHv2
RC


share of total per zone - POP
y = 1x + 6E-10
R² = 1
share of total per zone
Linear (share of total per zone)
RC_POPH
RC


share of total per zone - POP
y = 0.9178x + 6E-05
R² = 0.8934
share of total per zone
Linear (share of total per zone)
RC_POPHv2
RC


share of total per corop - POP
y = 1x - 4E-10
R² = 1
share of total per corop
Linear (share of total per corop)
RC_POPH
RC


share of total per corop - POP
y = 1x - 5E-08
R² = 1
share of total per corop
Linear (share of total per corop)
RC_POPHv2
RC

Both methods were tested for one of the runs: high population in RC. The results show very small differences, also for subdivisions of results.

Results POP run in RC for two methods of adjusting data				
	Tours	Distance (km)	Time loss (h)	Congestion (h)
2004	7,403,000	192,018,000	167,000	74,000
2030 RC	8,423,000	240,813,000	165,000	67,000
2030 RC2	8,426,000	241,269,000	166,000	66,000
RC / RC2	+ 0%	+ 0%	+ 0%	-1%

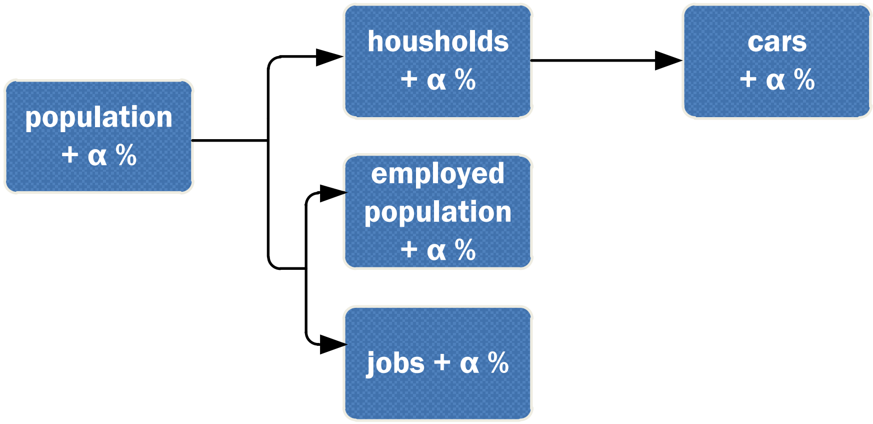
9.4 Appendix runs and adjustments

POP

For the pop runs, the following variables were adjusted in the zonal data:

- Population
  - M_0_14
  - M_15_34
  - M_35_64
  - M_65_EO
  - V_0_14
  - V_15_34
  - V_35_64
  - V_65_EO
  - INWONERS
- Households
  - HUISH
  - % Households with 1 car
  - % Households with 2 cars
  - % Households with 2+ cars
- Employed population
  - BBV_MAN
  - BBV_VROUW
  - WERKZ_M
  - WERKZ_V
  - PT_MAN
  - PT_VROUW
- Jobs
  - LANDBOUW
  - INDUSTRIE
  - DETAIL
  - OVERIG
  - BANENTOT

And presented in a figure:



These variables were all multiplied for each zone by the same constant.

But what are realistic variations on the scenarios? To answer this question I used the most recent CBS forecast data, which is represented in the figure below. The CBS makes a forecast for 2030 but also uses 67% and 95% upper/lower bound intervals.

I used the forecast data to make variations on the RC and GE scenarios. The next table shows the adjustments in percentages to the scenarios. For example, the adjustment to GE for the 67% upper bound forecast is -3.44%.

Difference forecast-scenario		
	2030GE	2030RC
2004	-14%	0%
Upper bound 95%-prognosis-interval	+ 0%	+ 16%
Upper bound 67%-prognosis-interval	-3.44%	+ 12%
2030 forecast	-6.36%	+ 8.29%
Lower bound 67%-prognosis-interval	-10%	+ 4.32%
Lower bound 95%-prognosis-interval	-13%	+ 1%
GE	+ 0%	+ 16%
RC	-14%	+ 0%

I made four new scenarios with a different population level. Two variations on GE and two variations on RC. The adjustments to the reference scenarios can be seen in the table below:

POP runs			
	description	adjustment	multiplication factor
2030GE_POPL	Upper bound 67%-forecast-interval (2030)	-3.44%	0.9656
2030GE_POPLL	Forecast (2030)	-6.36%	0.9364
2030RC_POPHH	Forecast (2030)	+ 8.29%	1.0829
2030RC_POPH	Lower bound 67%-forecast-interval (2030)	+ 4.32%	1.0432

The adjustments I made are according to the population forecast, 2010-2060 by CBS. The multiplication factors in the table were used on the values on every zone for every adjusted variable.

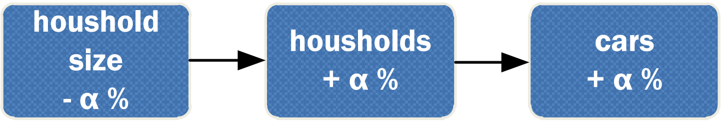
Also, the number of cars was adjusted in the model scenario settings. The car ownership is defined as the number of households with 0/1/2 or more cars. There are less households and thus also less cars:

Car ownership level 2030		
	%2030RC	% 2030GE
Households with 0 cars	18.8%	18.2%
Households with 1 car	50.3%	50.9%
Households with 2 cars	27.9%	27.8%
Households with 2+ cars	3.0%	3.1%

HHS

For the HHS runs, the household size was adjusted. This meant adjusting the following variables:

- Households
    - HUISH
    - % Households with 1 car
    - % Households with 2 cars
    - % Households with 2+ cars



The household size is 2.26 in RC and 2.00 in GE. Here I also used CBS forecast data to find realistic variation to the scenarios. In the new scenarios the household size both in RC and GE was adjusted to 2.10. This changed only the zonal variable HUISH, and the number of cars accordingly (keeping the relative car ownership constant.

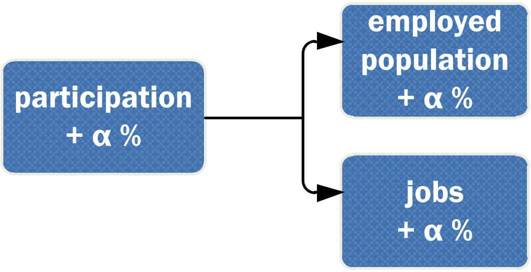
HHS runs			
	description	adjustment	multiplication factor
2030GE_HHSH	The new household size is 2.1	-4.74%	0.9526
2030RC_HHSL	The new household size is 2.1	7.60%	1.0760

The number of households in GE decreased by 4.74% and therefore the number of cars as well. In RC the increase was 7.60% for households and cars.

PAR

The sensitivity of the output of the model to the participation level was researched by adjusting the zonal data for the following variables:

- Employed population
    - BBV_MAN
    - BBV_VROUW
    - WERKZ_M
    - WERKZ_V
    - PT_MAN
    - PT_VROUW
- Jobs
    - LANDBOUW
    - INDUSTRIE
    - DETAIL
    - OVERIG
    - BANENTOT



For my analysis I will use the participation level of the other scenario, which means an adjustment of about 5% to both scenarios.

PAR runs			
	description	adjustment	multiplication factor
2030GE_PARL	GE with participation level of RC	-5.09%	0.9491
2030RC_PARH	RC with participation level of GE	+ 5.36%	1.0536

CAR

For the CAR runs, only relative car ownership was adjusted in both scenarios. This means that the population size or the number of households stays the same. Car ownership is input in the LMS on an aggregated level, not on the zonal level. It is not part of the socio-economic data per zone. The reference scenarios show a bandwidth from 1151 to 1158 cars per 1000 households. The relative percentages of households with 1, 2 or 2+ cars is almost the same. However, statistical analysis proves that there are strong relations between car ownership and urbanization, household size and income levels. For these variations the bandwidth is much higher. Therefore I analyzed a change of 10 percent in the total number of cars in GE and RC. In RC 10% more cars, in GE 10% less.

CAR runs			
	description	adjustment	multiplication factor
2030GE_CARL	10% less cars in GE	-10.00%	0.9000
2030RC_CARH	10% more cars in RC	+ 10.00%	1.1000

The table below shows the percentages of the reference scenarios. As can be seen, this doesn't differ much.

Car ownership level 2030		
	%2030RC	% 2030GE
Households with 0 cars	18.8%	18.2%
Households with 1 car	50.3%	50.9%
Households with 2 cars	27.9%	27.8%
Households with 2+ cars	3.0%	3.1%
cars per 1000 households	1151	1158

The adjusted scenarios have higher or lower car ownership levels. As said before, the car ownership level is assumed to be an independent variable in this research. No other variables were adjusted. The ratio between the number of households with 1, 2 or more than 2 cars stays the same, the percentage households without a car increases or decreases.

Car ownership level 2030 (CAR)		
	%2030RC	% 2030GE
Households with 0 cars	10.7%	26.3%
Households with 1 car	55.3%	45.8%
Households with 2 cars	30.7%	25.1%
Households with 2+ cars	3.3%	2.8%
cars per 1000 households	1266	1044
adjustment	10% more cars	10% less cars

INC

To research the influence of income levels to passenger mobility and benefits of infrastructure, initially I adjusted the income levels per household in RC to the level of GE and vice versa. Because this was a large adjustment, I tested the sensitivity also for a 10% change in income for GE.

INC runs			
	description	adjustment	multiplication factor
2030GE_INCL	GE with income level RC	-26.93%	0.7307
2030RC_INCH	RC with income level GE	+ 36.86%	1.3686

INC check			
	description	adjustment	multiplication factor
2030GE_VARI	Household income -10% in GE	-10.00%	0.9000

CST

Variable car costs is separate input in the LMS and can be changed via policy settings. As described in chapter four, I researched the effect of the highest oil price in 2030 according to the Referentieramingen 2012 report, €175 per barrel. This corresponded to a new variable car cost index number of 130.4 and 127.6 in GE and RC.

CST runs			
	description	old cost	new cost
2030GE_HHSH	Oil price €175 / barrel in 2030	93	130.4
2030RC_HHSL	Oil price €175 / barrel in 2030	91	127.6

I also implemented an increase to 103 to see if sensitivity was dependent on the magnitude of the adjustment.

CST check			
	description	old cost	new cost
2030GE_VARF	Index variable car cost / km +10	93	103

FRG

It was relatively difficult to adjust this component. The freight traffic is predefined by in input matrix. Therefore I used the freight matrix of RC in GE and vice versa.

INTF

For this scenario I adjusted sequentially step by step the 6 variables:

- Population (factor 0.86 so that the population is 16334000)
- Households (factor 0.89 so that the household size is 2.26 and the number of households 7228000)
- Participation (factor 0.95 so that the participation level is 72.8%, this influences jobs as well)
- Car ownership (factor 0.99 so that the number of cars is 8322473)
- Household income (factor 0.73 so that the average income is 63340)
- Variable car cost/km (the new index number is 91, just as in RC)

Now the zonal data and scenario settings for the INT scenario are similar to the RC scenario.

Input:

Integrated scenario in steps	2004	2030GL	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2030RC
population	16,258,000	18,889,000	16,334,000	16,334,000	16,334,000	16,334,000	16,334,000	16,334,000	16,334,000
households	7,049,000	9,443,000	8,165,000	7,228,000	7,228,000	7,228,000	7,228,000	7,228,000	7,228,000
potential labor force	10,991,000	11,517,000	9,959,000	9,959,000	9,959,000	9,959,000	9,959,000	9,959,000	10,103,000
labor force	7,538,000	8,833,000	7,638,000	7,638,000	7,250,000	7,250,000	7,250,000	7,250,000	7,355,000
employed population	7,057,000	8,518,000	7,366,000	7,366,000	6,991,000	6,991,000	6,991,000	6,991,000	7,079,000
jobs	7,017,000	8,212,000	7,102,000	7,102,000	6,740,000	6,740,000	6,740,000	6,740,000	6,433,000
students	399,000	534,000	534,000	534,000	534,000	534,000	534,000	534,000	453,000
household income	€ 48,900	€ 86,684	€ 86,677	€ 86,677	€ 86,677	€ 86,677	€ 63,340	€ 63,340	€ 63,340
car park	7,009.000	10,937.000	9,457,000	8,372,000	8,372.000	8,322,000	8,322.000	8,322.000	8,322.000
car cost / km	100	93	93	93	93	93	93	91	91
household size	2.31	2.00	2.00	2.26	2.26	2.26	2.26	2.26	2.26
pot labor force / population	68%	61%	61%	61%	61%	61%	61%	61%	62%
participatiegraad	69%	77%	77%	77%	80%	73%	73%	73%	73%
unemployed	481.000	315.000	272.000	272.000	259.000	259.000	259.000	259.000	276.000
unemployment rate	6.4%	3.6%	3.6%	3.6%	3.6%	3.6%	3.6%	3.6%	3.8%
jobs / pot labor force	64%	71%	71%	71%	68%	68%	68%	68%	64%
jobs / labor force	93%	93%	93%	93%	93%	93%	93%	93%	87%
students / population	2.5%	2.8%	3.3%	3.3%	3.3%	3.3%	3.3%	3.3%	2.8%

The table on the next page gives an extensive overview of the input. The last column shows the difference to the RC scenario.

Integrated scenario all input variables			0.8647	0.8852	0.9491	0.9941	0.7307		
	LMS2030RC	LMS2030GE	POP	HHS	PAR	CAR	INC	CST	Difference
ZONE_ID	1379	1379	1379	1379	1379	1379	1379	1379	0.0%
LMSSUB	1379	1379	1379	1379	1379	1379	1379	1379	0.0%
LMS	413	413	413	413	413	413	413	413	0.0%
REG19	19	19	19	19	19	19	19	19	0.0%
NUTS2	31	31	31	31	31	31	31	31	0.0%
PROV	12	12	12	12	12	12	12	12	0.0%
LAND	1	1	1	1	1	1	1	1	0.0%
COROP	40	40	40	40	40	40	40	40	0.0%
LANDSDEEL	4	4	4	4	4	4	4	4	0.0%
XCOORD	-	-	-	-	-	-	-	-	-
YCOORD	-	-	-	-	-	-	-	-	-
OPP	3,509,176	3,509,176	3,509,176	3,509,176	3,509,176	3,509,176	3,509,176	3,509,176	0.0%
INTRA_DIST	-	-	-	-	-	-	-	-	-
VAM_LDL	-	-	-	-	-	-	-	-	-
LMSVAM	-	-	-	-	-	-	-	-	-
TOD	-	-	-	-	-	-	-	-	-
PT_KP	-	-	-	-	-	-	-	-	-
PT_LP	-	-	-	-	-	-	-	-	-
LANDBOUW	112,629	139,472	120,605	120,605	114,472	114,472	114,472	114,472	1.6%
INDUSTRIE	871,678	1,270,554	1,098,681	1,098,681	1,042,813	1,042,813	1,042,813	1,042,813	19.6%
DETAIL	570,982	717,229	620,207	620,207	588,669	588,669	588,669	588,669	3.1%
OVERIG	4,878,060	6,085,227	5,262,056	5,262,056	4,994,480	4,994,480	4,994,480	4,994,480	2.4%
BANENTOT	6,433,349	8,212,478	7,101,545	7,101,545	6,740,432	6,740,432	6,740,432	6,740,432	4.8%
M_0_14	1,265,791	1,720,322	1,487,608	1,487,608	1,487,608	1,487,608	1,487,608	1,487,608	17.5%
M_15_34	1,970,540	2,316,071	2,002,767	2,002,767	2,002,767	2,002,767	2,002,767	2,002,767	1.6%
M_35_64	3,118,113	3,466,749	2,997,789	2,997,789	2,997,789	2,997,789	2,997,789	2,997,789	-3.9%
M_65_EO	1,747,460	1,876,036	1,622,258	1,622,258	1,622,258	1,622,258	1,622,258	1,622,258	-7.2%
V_0_14	1,203,577	1,639,342	1,417,582	1,417,582	1,417,582	1,417,582	1,417,582	1,417,582	17.8%
V_15_34	1,900,049	2,270,858	1,963,671	1,963,671	1,963,671	1,963,671	1,963,671	1,963,671	3.3%
V_35_64	3,114,784	3,463,034	2,994,576	2,994,576	2,994,576	2,994,576	2,994,576	2,994,576	-3.9%
V_65_EO	2,013,734	2,136,858	1,847,797	1,847,797	1,847,797	1,847,797	1,847,797	1,847,797	-8.2%
HUISH	7,228,429	9,442,834	8,165,467	7,228,429	7,228,429	7,228,429	7,228,429	7,228,429	0.0%
INWONERS	16,334,048	18,889,270	16,334,048	16,334,048	16,334,048	16,334,048	16,334,048	16,334,048	0.0%
STUDENTEN	452,785	534,024	534,024	534,024	534,024	534,024	534,024	534,024	17.9%
PERS_AUTO	-	-	-	-	-	-	-	-	-
ACT_WAG	-	-	-	-	-	-	-	-	-
BASIS_OW	1,278,571	1,740,179	1,740,179	1,740,179	1,740,179	1,740,179	1,740,179	1,740,179	36.1%
SPEC_OW	79,866	101,734	101,734	101,734	101,734	101,734	101,734	101,734	27.4%
VOORTG_OW	792,239	1,007,832	1,007,832	1,007,832	1,007,832	1,007,832	1,007,832	1,007,832	27.2%
MBO	468,671	553,053	553,053	553,053	553,053	553,053	553,053	553,053	18.0%
HBO_WO	612,115	721,711	721,711	721,711	721,711	721,711	721,711	721,711	17.9%
BBV_MAN	3,968,363	4,605,105	3,982,155	3,982,155	3,779,663	3,779,663	3,779,663	3,779,663	-4.8%
BBV_VROUW	3,387,023	4,228,295	3,656,318	3,656,318	3,470,394	3,470,394	3,470,394	3,470,394	2.5%
WERKZ_M	3,820,051	4,462,751	3,859,058	3,859,058	3,662,825	3,662,825	3,662,825	3,662,825	-4.1%
WERKZ_V	3,259,339	4,055,616	3,506,998	3,506,998	3,328,667	3,328,667	3,328,667	3,328,667	2.1%
PT_MAN	248,344	290,113	250,868	250,868	238,112	238,112	238,112	238,112	-4.1%
PT_VROUW	1,388,474	1,727,692	1,493,981	1,493,981	1,418,012	1,418,012	1,418,012	1,418,012	2.1%
INK_GEM	€ 63,340	€ 86,684	€ 86,684	€ 86,684	€ 86,684	€ 86,684	€ 63,340	€ 63,340	0.0%
input settings: car ownership	8,322,473	10,936,946	9,457,465	8,372,162	8,372,162	8,322,473	8,322,473	8,322,473	
input settings: car costs	91	93	93	93	93	93	93	91	

- The number of jobs in industry are higher, this is because there is relatively more industry in GE
- The population under 15 and over 64 differs, because there are relatively more children in GE and less older people. These people however do not travel a lot by car
- The number of students and capacity of schools was not adjusted. The first model results show that this has a very small impact on car mobility
- The relative number of female workers is higher in GE and the number of male workers lower. When combined the number of (part-time) employed population is the same.

From GE to RC in 10 steps

1. less people (population decreases from 18,889,000 to 16,334,000 people)
    a. -14% population
    b. -14% households
    c. -14% cars
    d. -14% employed population
    e. -14% jobs
2. larger household size (not 2.00 but 2.26 people per household in new scenario)
    a. -11% households
    b. -11% cars
3. lower participation (participation from 76.7% to 72.8%)
    a. -3.9% employed population
    b. -3.9% jobs
4. less cars / household (not 1,158 but 1,151 cars / household)
    a. -0.6% cars
5. lower income per household (from €86,684 to €63,340 per household per year)
    a. -26.9% gross household income
6. lower variable car cost/km (91 instead of 93)
    a. -2.2% car cost/km
7. less freight traffic (freight input matrices RC)
    a. -36.8% freight traffic
8. lower Value of Time
9. synergy effects
10. different spatial distribution (spatial distribution of RC)

The remaining difference is due to other and unknown drivers, which have small impact on mobility and benefits of infrastructure investments.

9.5 Appendix overview of modeling runs

The next pages present an overview of all modeling runs.

Run overview

#	Run	Projectnummer	Year	Scer	Input	Network	Description	Start	End	Runtime	Treads
	1	201205291	2004			REF		29/05/2012 11:01	29/05/2012 14:05	3:03:50	24
	2	201205293	2030	RC_		ALTv1		29/05/2012 18:08	30/05/2012 10:10	16:02:09	12
	3	201205292	2030	RC_		REF		29/05/2012 16:31	30/05/2012 07:04	14:32:19	16
	4	201205311	2030	RC_		ALT		31/05/2012 17:30	01/06/2012 05:08	11:37:36	24
	5	201205301	2030	GE_		REF		30/05/2012 10:04	31/05/2012 02:26	16:22:47	16
	6	201205312	2030	GE_		ALT		31/05/2012 17:31	01/06/2012 07:55	14:24:35	16
	7	201206041	2030	GE_	POPL	REF	3.44% less population	04/06/2012 10:40	11/06/2012 15:52		24
	8	201206061	2030	GE_	POPL	ALT	3.44% less population	06/06/2012 11:07	07/06/2012 10:00	22:52:42	24
	9	201206211	2030	GE_	POPLL	REF	6.36% less population				
	10	201206212	2030	GE_	POPLL	ALT	6.36% less population				
	11	201206213	2030	RC_	POPHH	REF	8.29% more population	26/06/2012 16:42	27/06/2012 09:01	16:18:39	12
	12	201206214	2030	RC_	POPHH	ALT	8.29% more population	27/06/2012 09:47			16
	13	201206251	2030	RC_	POPH	REF	4.32% more population	25/06/2012 15:32	26/06/2012 07:06	15:33:56	12
	14	201206252	2030	RC_	POPH	ALT	4.32% more population	25/06/2012 15:42	26/06/2012 03:29	11:46:38	24
	15	201206261	2030	GE_	POPL	REF	3.44% less population	26/06/2012 18:34	27/06/2012 12:55	18:21:08	8
	16	201206262	2030	GE_	POPL	ALT	3.44% less population	26/06/2012 18:35	27/06/2012 13:05	18:30:35	8
	17	201206281	2030	GE_	POPL	REF	3.44% less population	29/06/2012 09:31	30/06/2012 10:40	25:08:25	8
	18	201206282	2030	GE_	POPL	ALT	3.44% less population	29/06/2012 09:32	03/07/2012 14:37	33:41:41	8
	19	201206283	2030	GE_	POPLL	REF	6.36% less population	29/06/2012 09:33	04/07/2012 05:10	38:32:28	8
	20	201206284	2030	GE_	POPLL	ALT	6.36% less population	29/06/2012 09:35	30/06/2012 11:40	26:04:58	8
	21	201206285	2030	RC_	POPH	REF	4.32% more population	29/06/2012 09:36	30/06/2012 11:38	26:02:34	8
	22	201206286	2030	RC_	POPH	ALT	4.32% more population	29/06/2012 09:41	03/07/2012 01:47	44:03:11	12
	23	201206287	2030	RC_	POPHH	REF	8.29% more population	04/07/2012 12:30	17/07/2012 02:41	50:21:49	12
	24	201206288	2030	RC_	POPHH	ALT	8.29% more population	04/07/2012 14:09	17/07/2012 00:49	49:46:32	12
	25	201207161	2030	GE_	HHSH	REF	household size 2.1	17/07/2012 15:01	25/07/2012 08:26	17:24:22	12
	26	201207162	2030	GE_	HHSH	ALT	household size 2.1	24/07/2012 18:56	25/07/2012 08:50	13:53:39	16
	27	201207163	2030	RC_	HHSL	REF	household size 2.1	25/07/2012 08:57	26/07/2012 01:04	16:07:48	12
	28	201207164	2030	RC_	HHSL	ALT	household size 2.1	25/07/2012 08:57	27/07/2012 01:20	16:22:36	12
	29	201207251	2030	GE_	VARP	REF	population -10%	27/07/2012 12:06	31/07/2012 05:29	44:41:52	12
	30	201207252	2030	GE_	VARH	REF	households -10%	27/07/2012 12:07	29/07/2012 03:06	38:59:12	12
	31	201207253	2030	GE_	VARL	REF	labor force -10%	28/07/2012 08:57	30/07/2012 03:39	42:42:10	12
	32	201207254	2030	GE_	VARE	REF	employed population -10%	29/07/2012 04:30	29/07/2012 20:05	15:35:22	12
	33	201207255	2030	GE_	VARJ	REF	jobs -10%	28/07/2012 08:54	28/07/2012 22:51	13:56:37	16
	34	201207256	2030	GE_	VARS	REF	students -10%	27/07/2012 12:07	28/07/2012 05:17	17:09:32	16
	35	201207257	2030	GE_	VARI	REF	income -10%	27/07/2012 12:08	30/07/2012 05:09	65:01:09	12

Run overview

#	Run	Projectnummer	Year	Scer Input	Network	Description	Start	End	Runtime	Treads
	36	201207258	2030	GE_ VARC	REF	car ownership -10%	30/07/2012 09:17	30/07/2012 20:40	11:22:22	24
	37	201207259	2030	GE_ VARF	REF	fuel prices +10%	29/07/2012 04:30	30/07/2012 13:54	33:24:01	16
	38	201007301	2030	GE_ VART	REF	all of the above (exept students)	30/07/2012 12:07	31/07/2012 15:19	27:11:48	12
	39	201207302	2030	GE_	SVIR	network SVIR	01/08/2012 11:36	02/08/2012 10:42	23:06:23	12
	40	201207303	2030	GE_	SVIR_NOZ	network SVIR - not randstad	31/07/2012 09:49	31/07/2012 23:47	13:58:20	16
	41	201207304	2030	GE_	SVIR_WEST	network SVIR - randstad	31/07/2012 13:36	01/08/2012 01:01	11:24:22	24
	42	201208051	2030	RC_	SVIR	network SVIR	31/07/2012 13:36	01/08/2012 01:01	11:24:22	24
	43	201208011	2030	GE_ PARL	REF	participation RC	02/08/2012 08:33	03/08/2012 12:29	27:55:33	12
	44	201208012	2030	GE_ PARL	ALT		01/08/2012 11:06	02/08/2012 06:17	19:11:35	12
	45	201208013	2030	RC_ PARH	REF	participation GE	01/08/2012 11:01	02/08/2012 06:13	19:12:04	12
	46	201208014	2030	RC_ PARH	ALT		01/08/2012 11:07	02/08/2012 01:07	14:00:37	16
		201208015	2030	GE_ CARL	REF	= 2030GE_VARC	nvt	nvt	nvt	nvt
	47	201208016	2030	GE_ CARL	ALT	car ownership -10%	02/08/2012 11:30	03/08/2012 07:31	20:00:43	12
	48	201208017	2030	RC_ CARH	REF	car ownership +10%	02/08/2012 15:45	03/08/2012 13:58	22:13:05	16
	49	201208018	2030	RC_ CARH	ALT		02/08/2012 16:46	03/08/2012 08:37	15:51:25	12
	50	201208021	2030	GE_ INCL	REF	income RC	03/08/2012 13:27	04/08/2012 05:15	15:47:40	12
	51	201208022	2030	GE_ INCL	ALT		03/08/2012 10:14	06/08/2012 16:58	78:44:40	12
	52	201208023	2030	RC_ INCH	REF	income GE	03/08/2012 00:14	03/08/2012 14:16	14:01:15	16
	53	201208024	2030	RC_ INCH	ALT		03/08/2012 15:22	04/08/2012 10:13	18:50:21	12
	54	201208025	2030	GE_ CSTH	REF	fuel prices +20%	04/08/2012 10:49	05/08/2012 02:33	15:44:27	12
	55	201208026	2030	GE_ CSTH	ALT		04/08/2012 18:04	05/08/2012 06:10	12:05:59	24
	56	201208027	2030	RC_ CSTH	REF	fuel prices +20%	04/08/2012 10:41	05/08/2012 00:24	13:43:34	24
	57	201208028	2030	RC_ CSTH	ALT		03/08/2012 15:57	04/08/2012 05:57	14:00:24	16
	58	201208041	2030	GE_ SPUR	REF	all growth in urban area	03/08/2012 00:11	03/08/2012 18:07	17:56:23	12
	59	201208042	2030	GE_ SPUR	ALT		04/08/2012 10:37	09/08/2012 06:17	28:54:50	12
	60	201208043	2030	GE_ SPRC	REF	spatial pattern rc	05/08/2012 23:16	06/08/2012 11:15	11:58:14	24
	61	201208044	2030	GE_ SPRC	ALT		06/08/2012 11:48	06/08/2012 23:55	12:07:28	24
	62	201208045	2030	GE_ SPRA	REF	all growth in randstad	03/08/2012 23:02	04/08/2012 17:37	18:35:02	12
	63	201208046	2030	GE_ SPRA	ALT		05/08/2012 23:16	08/08/2012 23:42	72:26:28	16
	64	201208061	2030	GE_ INT	REF	integrated scenario values RC	07/08/2012 11:26	08/08/2012 22:57	35:31:01	12
	65	201208062	2030	GE_ INT	ALT		07/08/2012 11:28	08/08/2012 17:28	30:00:25	16
	66	201208071	2030	GE_ HHSH	REF	hhs 2.1 -> 4.74% more hh	07/08/2012 21:52	08/08/2012 12:13	14:21:05	16
	67	201208072	2030	GE_ HHSH	ALT		07/08/2012 21:53	08/08/2012 13:50	15:57:32	12

Run overview

#	Run	Projectnummer	Year	Scer Input	Network	Description	Start	End	Runtime	Treads
	68	201208073	2030	RC_ HHSL	REF	hhs 2.1 -> 7.60% less hh	07/08/2012 11:52	08/08/2012 12:59	25:07:31	24
	69	201208074	2030	RC_ HHSL	ALT		07/08/2012 11:52	08/08/2012 18:08	30:16:05	24
	70	201208091	2030	GE_ VARI	ALT	income -10%	09/08/2012 00:32	09/08/2012 16:44	16:12:13	12
	71	201208092	2030	GE_ VARF	ALT	fuel prices +10%	09/08/2012 00:28	09/08/2012 15:02	14:34:16	16
	72	201208093	2030	GE_ FRG	REF	freight matrices RC	10/08/2012 09:38	10/08/2012 21:58	12:19:40	24
	73	201208094	2030	GE_ FRG	ALT		10/08/2012 09:40	11/08/2012 00:21	14:41:06	16
	74	201208131	2030	GE_ INTF	REF	combination INT and FRG	13/08/2012 11:59	14/08/2012 00:26	12:27:25	24
	75	201208132	2030	GE_ INTF	ALT		13/08/2012 11:59	14/08/2012 02:38	14:38:55	16
	76	201208211	2030	RC_ POPH2	REF	POPH adjusted per COROP	21/08/2012 11:59	21/08/2012 23:43	11:44:24	24
	77	201208212	2030	RC_ POPH2	ALT		21/08/2012 11:59	22/08/2012 02:18	14:18:51	16

Summary of LMS runs

Total number of runs	77
Succesful runs	62
Fastest run	11:22:22 hours
Slowest run	78:44:40 hours
Average time per run	22:39:15 hours
Total modeling time	1268:37:47 hours
	53 full time days
	159 working days
	32 working weeks
Work computer / work Maarten	1.22

Scheduled runs

	year	scenario	variable	runs
0	2004-2030	GE / RC		5
1	2030	GE / RC	POP	10
2	2030	GE / RC	HHS	4
3	2030	GE	SVIR	3
4	2030	GE	VAR	10
5	2030	GE / RC	PAR	4
6	2030	GE / RC	CAR	3
7	2030	GE / RC	INC	5
8	2030	GE / RC	CST	5
9	2030	GE	SPA	6
10	2030	RC	SVIR	1
11	2030	GE	INT	2
12	2030	GE	FRG	2
13	2030	GE	INTF	2

Completed runs

	GE		RC	
	MIRT	**MIRT+20**	**MIRT**	**MIRT+20**
2004	1			
Reference	1	1	1	1
Population	2	2	3	3
Households	1	1	1	1
Participation	1	1	1	1
Car ownership		1	1	1
Household income	1	2	1	1
Car cost / km	1	2	1	1
Integrated scenario	2	2		
Freight	1	1		
SVIR		3		1
Spatial pattern	3	3		
Separate variables	10			
Total # runs	62			

9.6 Appendix which infrastructure investments can we expect on the mid and long term?

For the analysis of infrastructure investments, it is important to realize that at the scale of the LMS (which is a national scale model) it is not possible to see what the effect of a local measure will be. Therefore I chose not to model any local measures, but infrastructure packages. The local effects of the measures will not be exactly modeled. However the model is able calculate the effect of the investment package when aggregated to the national level.

As input for my research I used the investments that are specified in the MIRT project book 2012, which is the reference situation. The road network is provided by DVS and consists of the main road network and a part of the secondary road network. I used for my research the most up to date version, that of April 2012. For the network of 2030 all projects from the MIRT2012 are adopted and assumed to be implemented in 2030. These projects should all be completed in 2020. After 2020 no more projects will be executed. This is the reference situation for 2030. The reference network is summarized in the next table.

2020 MIRT (lane kilometers)			
Region	OWN	HWN	Total
North	6,820	2,088	8,908
East	8,860	3,257	12,117
West	15,132	7,314	22,446
South	11,458	4,069	15,527
Total	42,268	16,729	58,997

I modeled two separate investment packages additional to the MIRT 2012 project book, two variants for alternative infrastructure investments, and used each in both scenarios (high and low).

- Between 2020 and 2030 investments conform the MIRT-investment rate (=20 billion euro between 2020 and 2030)
- Realizing the ambition of the SVIR for 2040 in 2030, with at least 2x4 lanse in the Randstad and 2x3 lanes on the important routes outside the Randstad (international trading routes)

In my research the focus is on the first investment package of the Ruimtelijke Verkenningen. The other packages were modeled to show that the study is not dependent on just one package.

The first investment package consists of about 20 million euros for the period of 2020-2030. This corresponds with the investment rate in infrastructure of the MIRT of about 2 billion per year. For the project Ruimtelijke Verkenningen (2011) the same assumption was made and roughly the same network was used for calculations. To implement the package I analyzed the projects from Ruimtelijke Verkenningen and adjusted the reference network in some iterations. This means that I also solved the bottlenecks that occurred after the first adjustment to the network.

The 20 billion investment in the period of 2020-2030 corresponds to about 1,500 kilometer extra lanes, at an average cost of 13 million euro per lane-kilometer. Technically it was very complicated to adjust the network. That is why I decided not to build new roads (which would have been more difficult and increase the possibility of errors) but only implement capacity increments, which means extending the number of lanes at the most important bottlenecks.
The investments take place mainly at the HWN and at locations that suffer from congestion problems. Three quarters of the investments are divided according to

congestion hours in 2030 without investments, ie at locations where most congestion occurs. The remainder of the investments are divided based on the population in regions and within these regions again according to congestion hours. The next tables and figures show the investments.

Congestion hours and population GE 2030 - reference network					
Region	congestion (h)	%	population	%	required
North	1,131	1%	1,955,740	10%	3%
East	23,271	12%	1,828,217	10%	11%
West	139,566	72%	10,613,110	56%	68%
South	30,251	16%	4,492,412	24%	18%
Total	194,218	100%	18,889,479	100%	100%

#kilometers difference MIRT+20 - MIRT			
Region	OWN	HWN	Total
North	0	37	37
East	0	204	204
West	7	1,293	1,301
South	1	23	24
Total	8	1,557	1,565

2020 (MIRT) - 2030 (MIRT+20)				
Region	realized	required	difference	realized/required
North	37	47	- 10	0.79
East	204	175	+ 28	1.16
West	1,301	1,045	+ 255	1.24
South	24	271	- 247	0.09
Total	1,565	1,538	+ 26	1.02

The approach of this research is not to do a case study of one or more projects but calculate benefits for a large investment package. This approach was chosen because the LMS is designed for long term strategic analysis of the road network. The model cannot be used to evaluate the impact of a local measure, ie just one or two projects. This research implements a combined investment package of 20 billion euros, for which the model can provide an estimate of what the impact will be.

Costs MIRT+20		
Budget 2020-2030	€	20,000,000,000
Costs per kilometer lane	€	13,000,000
Lane km - budget		1,538
Realized		1,565
Total costs	€	20,342,270,000

Lane kilometers in 2004, 2020 and 2030			
	2004	MIRT	MIRT+20
Main	14,813	16,729	18,286
Secondary	40,306	42,268	42,277
Total	55,119	58,997	60,562

Train / other public transport
In both the reference situation in 2030 and the MIRT+20 variant the same assumptions for railroad infrastructure and other public transport were made. The program of Hoogfrequent Spoor (2008) will be carried out (the 6/6 variant; six intercity trains and six regional trains). For other public transport (bus, tram, metro) a generic improvement is assumed for the service level by reducing waiting and travel times by 5% compared to 2020.

For the investment package I assumed that the planned MIRT-projects will be realized according to plan until 2020. The investment is similar to the approach of the study Ruimtelijke Verkenningen and assumes an investment rate of about 2 billion euros a year in the period of 2020-2030. This means about 1500km of new highway lanes.

This research analyses the benefits of infrastructure investment packages and their sensitivity to uncertainties in the input variables of the scenarios.

9.7 Appendix how can we calculate the user benefits of an infrastructure investment?

For this I used the standard approach which is used in cost-benefit analysis of infrastructure. This is the Rule of Half and it is prescribed by the OEI guidelines. A specific explanation is available from Rijkswaterstaat(Rijkswaterstaat 2008). There is a tool available from DVS which uses the output of the LMS to calculate travel time benefits and distance benefits. The tool also uses the methodology of the rule of half.

The travel time benefits consist of the time that is saved due to higher travel speeds on the network. Solving the congestion bottlenecks attributes highly to the travel time benefits. For different motives (home-work, business, freight and other) a Value of Time is defined that converts the saved travel time to benefits.

The values of time used are presented in the table below.

Overview Values of Time (price 2012)		
	2030 RC	**2030 GE**
Work	€ 10.59	€ 12.55
Business	€ 36.69	€ 43.31
Other	€ 7.35	€ 8.63
Freight	€ 51.33	€ 60.64

The distance benefits attribute a value to the extra kilometers that people will drive because of the improved network.
These benefits are calculated for an average working day. To calculate the benefits per year, increment factors are used. The benefits per year can be used to compute the total net present value of the investment (with a rate of return of 5,5%).
The values of time in the manual for the cost-benefit analysis tool (4cast 2011) were at the price level of 2004. The VoT were converted to 2012 price levels using the GDP figures from the CBS website.

9.8 Appendix input SEG zonal data

The following table shows the zonal input data for the LMS aggregated to the national level.

All input variables			
	LMS2004	LMS2030RC	LMS2030GE
ZONE_ID	1379	1379	1379
LMSSUB	1379	1379	1379
LMS	413	413	413
REG19	19	19	19
NUTS2	31	31	31
PROV	12	12	12
LAND	1	1	1
COROP	40	40	40
LANDSDEEL	4	4	4
XCOORD	-	-	-
YCOORD	-	-	-
OPP	3,509,176	3,509,176	3,509,176
INTRA_DIST	-	-	-
VAM_LDL	-	-	-
LMSVAM	-	-	-
TOD	-	-	-
PT_KP	-	-	-
PT_LP	-	-	-
LANDBOUW	229,966	112,629	139,472
INDUSTRIE	1,394,149	871,678	1,270,554
DETAIL	618,892	570,982	717,229
OVERIG	4,774,342	4,878,060	6,085,227
BANENTOT	7,017,076	6,433,349	8,212,478
M_0_14	1,543,028	1,265,791	1,720,322
M_15_34	2,127,354	1,970,540	2,316,071
M_35_64	3,433,287	3,118,113	3,466,749
M_65_EO	942,328	1,747,460	1,876,036
V_0_14	1,472,708	1,203,577	1,639,342
V_15_34	2,076,347	1,900,049	2,270,858
V_35_64	3,354,231	3,114,784	3,463,034
V_65_EO	1,308,853	2,013,734	2,136,858
HUISH	7,049,264	7,228,429	9,442,834
INWONERS	16,257,991	16,334,048	18,889,270
STUDENTEN	399,350	452,785	534,024
PERS_AUTO	6,910,458	-	-
ACT_WAG	6,515,463	-	-
BASIS_OW	1,547,896	1,278,571	1,740,179
SPEC_OW	105,513	79,866	101,734
VOORTG_OW	891,544	792,239	1,007,832
MBO	451,669	468,671	553,053
HBO_WO	526,867	612,115	721,711
BBV_MAN	4,348,631	3,968,363	4,605,105
BBV_VROUW	3,189,623	3,387,023	4,228,295
WERKZ_M	4,101,028	3,820,051	4,462,751
WERKZ_V	2,956,458	3,259,339	4,055,616
PT_MAN	278,449	248,344	290,113
PT_VROUW	1,467,425	1,388,474	1,727,692
INK_GEM	€ 48,900	€ 63,340	€ 86,684

The data that was used as input for the reference situation in 2004 and 2030, in both scenarios, was provided by DVS. The LMS version and data of November 2011 were used for the calculations. The data corresponds with the WLO figures and the same data was used for example for the NMCA-analysis of 2011. An elaborate description of the input variables is presented on the next page.

Zonal input data: Description of all SEG input variables

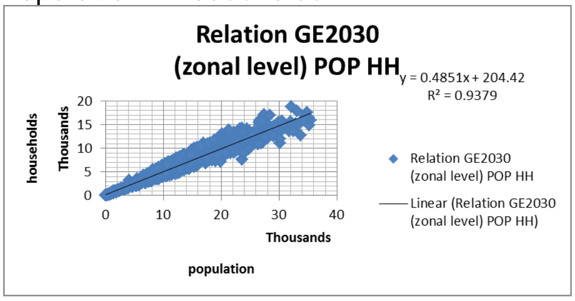
	Name	Description
ZONE_ID	zone_id	De nummering van het NRM waarvan de SEG in het betreffende bestand zijn opgenomen
LMSSUB	number LMS-subzone	
LMS	number LMS-zone	
REG19	number-region19 division	Volgens de studie Regionale Langetermijnscenario's - ABF Research, Delft, 2008
NUTS2	NUTS2-code	Europese indeling
PROV	number province	Nummer provincie: 20 = Groningen, 21 = Friesland, 22 =Drenthe, 23 = Overijssel, 24 = Flevoland, 25 = Gelderland, 26 = Utrecht, 27 = Noord-Holland, 28 = Zuid-Holland, 29 = Zeeland, 30 = Noord-Brabant, 31 = Limburg, 40 = België, 41 = Duitsland, 42 = Luxemburg, 43 = Frankrijk
LAND	country number	1=Netherlands; 2 = Belgium 3 = Germany; 4 = Luxembourg; 5 = France
COROP	COROP number (2004)	COROP-verdeling van Nedelrand (40 regio's)
LANDSDEEL	part of the country	in 4 delens: 1 = Noord (Groningen, Friesland, Drenthe) 2 = Oost (Overijssel, Gelderland) 3 = West (Noord-Holland, Zuid-Holland, Flevoland, Utrecht) 4 = Zuid (Zeeland, Noord-Brabant, Limburg) 5 = Buitenland
XCOORD	x-coordinate	
YCOORD	y-coordinate	
OPP	surface area	in Ha
INTRA_DIST	intrazonal distance	Intrazonale afstand in hm = 0,5 * ?(oppervlakte/π)
VAM_LDL	model procedure variable	Division RGM-procedure
LMSVAM	model procedure variable	Gerelateerde VAM-zone, deze zonenummering is nodig om de RGM procedures te kunnen toepassen
TOD	0 for all zones	nvt
PT_KP	parking fee short	Uurtarief kortparkeren (in eurocenten), waarbij voor kortparkeren een tijdsperiode geldt t/m drie uur
PT_LP	parking fee long	Uurtarief langparkeren (in eurocenten), waarbij voor langparkeren een tijdsperiode geldt van meer dan drie uur
LANDBOUW	employment in agriculture	Aantal banen van werknemers in deze sector waarbij betaalde arbeid wordt verricht voor 10 of meer uren per week. Als peildatum voor het aantal arbeidsplaatsen in een bepaald jaar hanteert het CBS 31 december van het vorig jaar
INDUSTRIE	employment in industry	Aantal banen van werknemers in deze sector waarbij betaalde arbeid wordt verricht voor 10 of meer uren per week. Als peildatum voor het aantal arbeidsplaatsen in een bepaald jaar hanteert het CBS 31 december van het vorig jaar
DETAIL	employment in retail	Aantal banen van werknemers in deze sector waarbij betaalde arbeid wordt verricht voor 10 of meer uren per week. Als peildatum voor het aantal arbeidsplaatsen in een bepaald jaar hanteert het CBS 31 december van het vorig jaar
OVERIG	employment other	Aantal banen van werknemers in deze sector waarbij betaalde arbeid wordt verricht voor 10 of meer uren per week. Als peildatum voor het aantal arbeidsplaatsen in een bepaald jaar hanteert het CBS 31 december van het vorig jaar
BANENTOT	total employment	Totaal aantal banen van werknemers waarbij betaalde arbeid wordt verricht voor 10 of meer uren per week. Als peildatum voor het aantal arbeidsplaatsen in een bepaald jaar hanteert het CBS 31 december van het vorig jaar

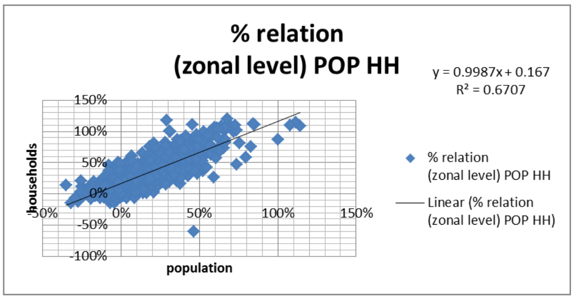
M_0_14	male population 0 to 14 years	Het aantal geregistreerde mannen in deze leeftijdsgroep op 1 januari van het betreffende jaar
M_15_34	male population 15 to 34 years	Het aantal geregistreerde mannen in deze leeftijdsgroep op 1 januari van het betreffende jaar
M_35_64	male population 35 to 65 years	Het aantal geregistreerde mannen in deze leeftijdsgroep op 1 januari van het betreffende jaar
M_65_EO	male population 65 years and older	Het aantal geregistreerde mannen in deze leeftijdsgroep op 1 januari van het betreffende jaar
V_0_14	female population 0 to 14 years	Het aantal geregistreerde vrouwen in deze leeftijdsgroep op 1 januari van het betreffende jaar
V_15_34	female population 15 to 34 years	Het aantal geregistreerde vrouwen in deze leeftijdsgroep op 1 januari van het betreffende jaar
V_35_64	female population 35 to 65 years	Het aantal geregistreerde vrouwen in deze leeftijdsgroep op 1 januari van het betreffende jaar
V_65_EO	female population 65 years and older	Het aantal geregistreerde vrouwen in deze leeftijdsgroep op 1 januari van het betreffende jaar
HUISH	number of households	Het aantal huishoudens. een huishouden bestaat uit een of meerdere personen die alleen of tezamen in een woonruimte gevestigd zijn en zelf in hun dagelijks onderhoud voorzien
INWONERS	total population	Het aantal geregistreerde mannen en vrouwen op 1 januari van het betreffende jaar
STUDENTEN	resident students	Het aantal WO en HBO studenten dat woonachtig is in de betreffende zone
PERS_AUTO	number of passenger cars	Totaal aantal personenauto's
ACT_WAG	number of personal vehicles	Totaal aantal personenauto's exclusief personenauto's in bezit van autobedrijven en importeurs
BASIS_OW	capacity primary schools	
SPEC_OW	capacity special schools	
VOORTG_OW	capacity high schools	
MBO	capacity intermediate vocational education	
HBO_WO	capacity higher vocational education and universities	
BBV_MAN	male labor force	Aantal mannen die ten minste 12 uur per week werken, werk aanvaard hebben waardoor ze ten minste 12 uur per week gaan werken danwel verklaard hebben ten minste 12 uur per week te willen werken
BBV_VROUW	female labor force	Aantal vrouwen die ten minste 12 uur per week werken, werk aanvaard hebben waardoor ze ten minste 12 uur per week gaan werken danwel verklaard hebben ten minste 12 uur per week te willen werken
WERKZ_M	employed male population	Aantal mannen die ten minste 12 uur per week werken
WERKZ_V	employed female population	Aantal vrouwen die ten minste 12 uur per week werken
PT_MAN	male parttimers	Aantal mannen die ten minste 12 uur maar minder dan 30 uur per week werken (vast percentage van de zonale omvang van de mannelijke werkzame beroepsbevolking)
PT_VROUW	female parttimers	Aantal vrouwen die ten minste 12 uur maar minder dan 30 uur per week werken (vast percentage van de zonale omvang van de mannelijke werkzame beroepsbevolking)
INK_GEM	average gross household income	Gemiddelde bruto besteedbaar inkomen per huishouden

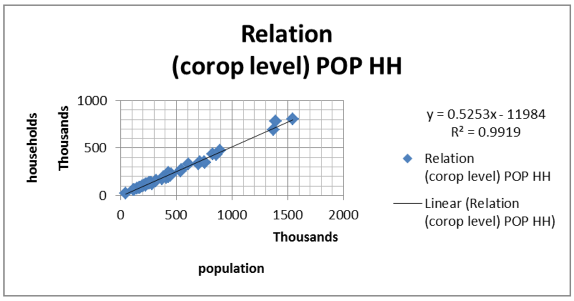
9.9 Appendix how are the key variables related?

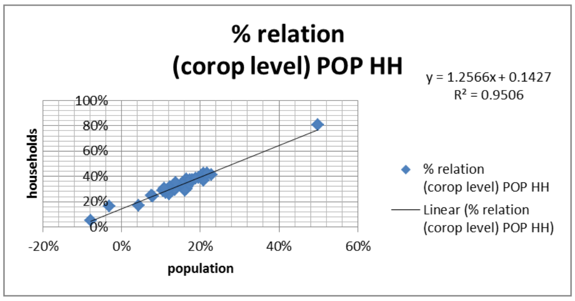
When performing my research, it is important to make consistent new scenarios. This means that when I change one variable, some other variables should be changed as well. To see which variables are related to another I made the following graphs from the scenario input data.

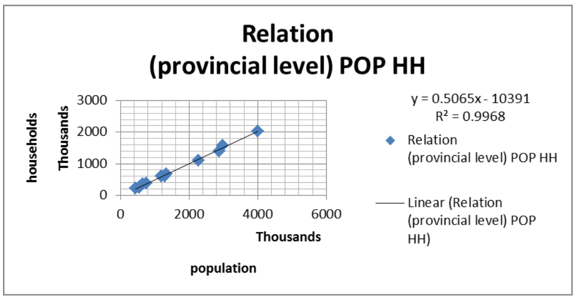
Population - households

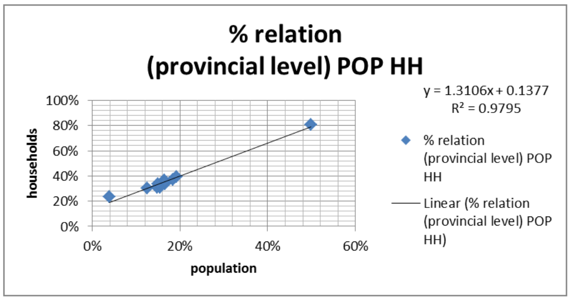




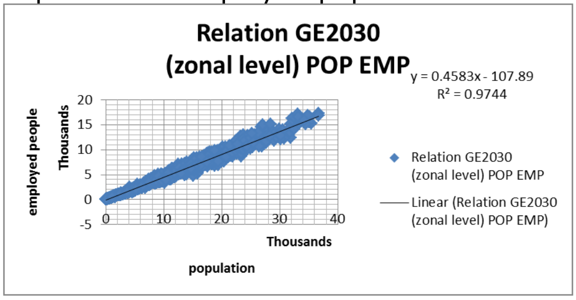


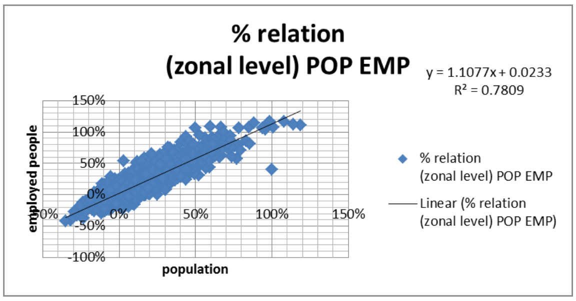


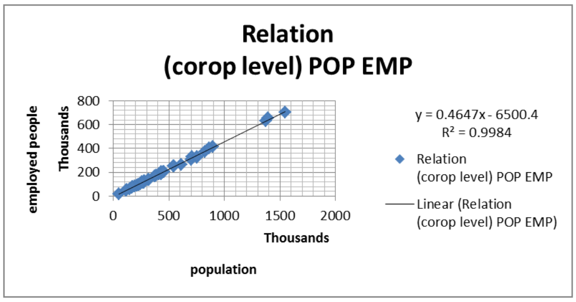


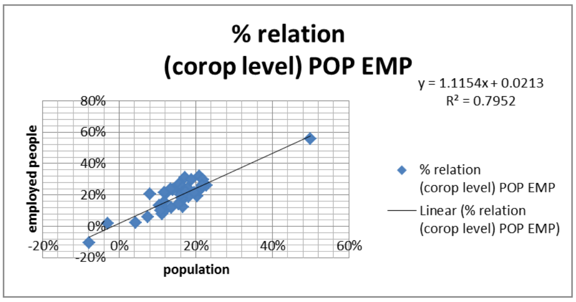


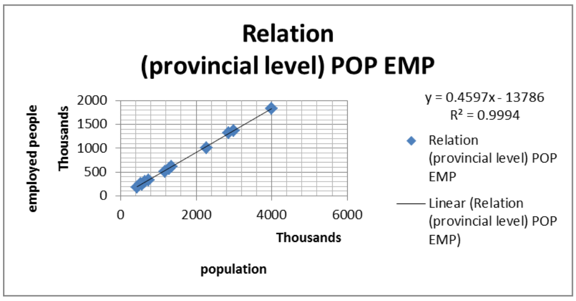
Population – employed population

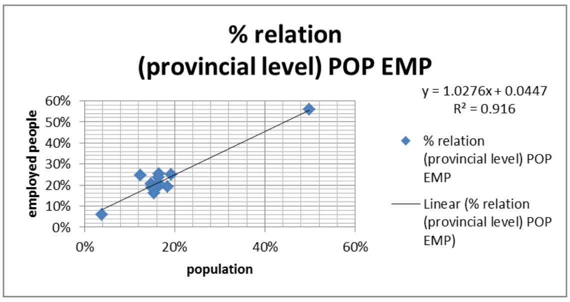




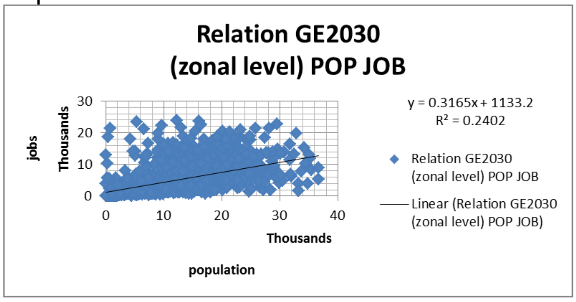


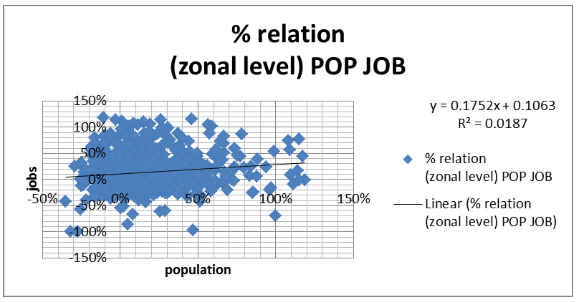


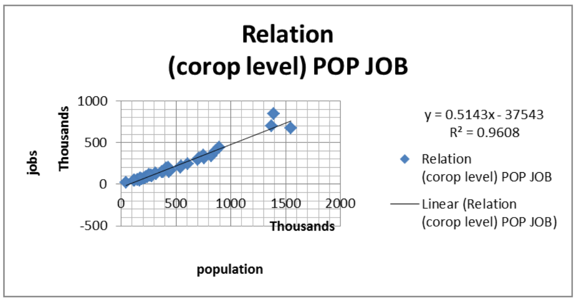


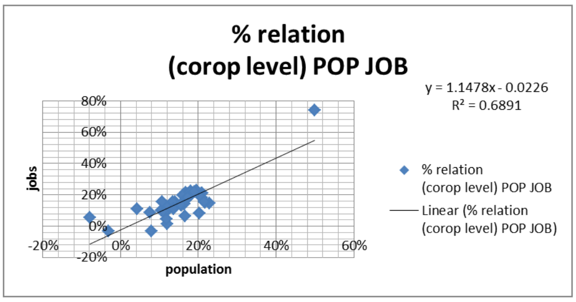


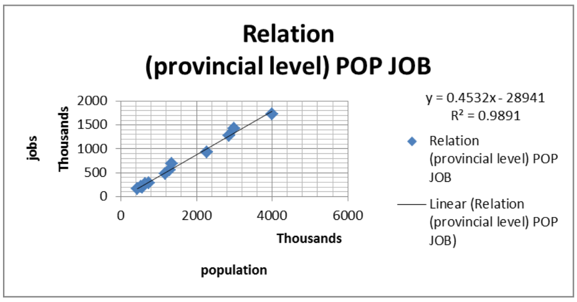
Population - Jobs

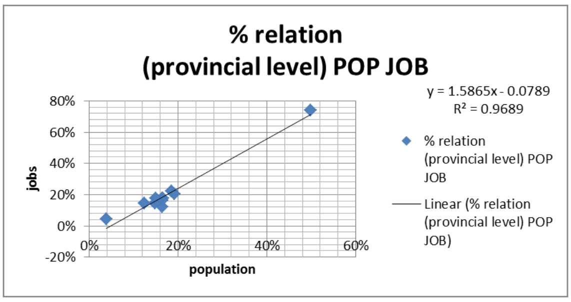




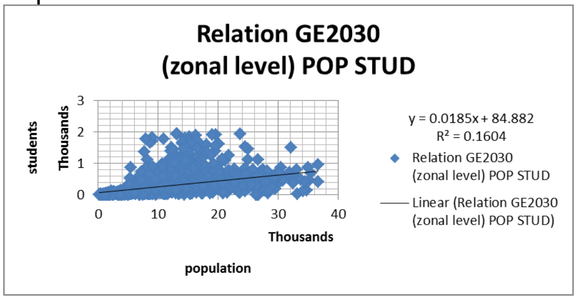


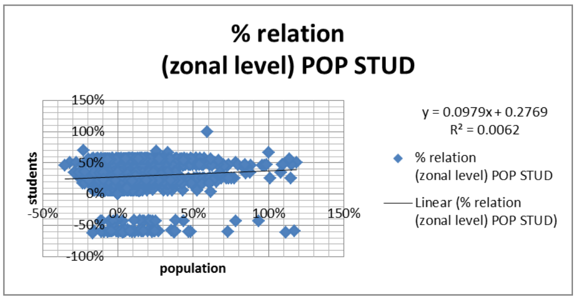


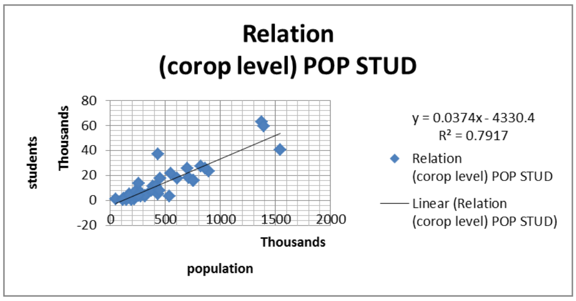


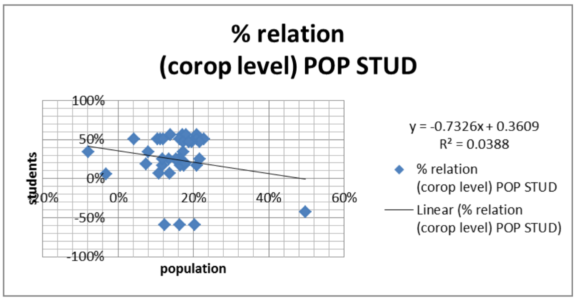


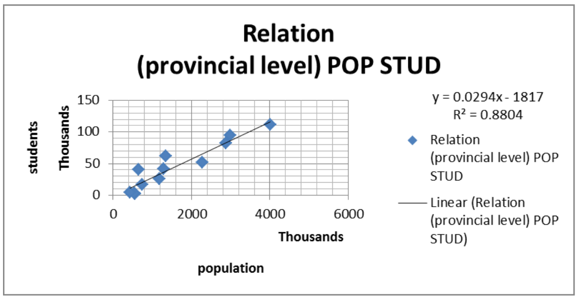
Population – students

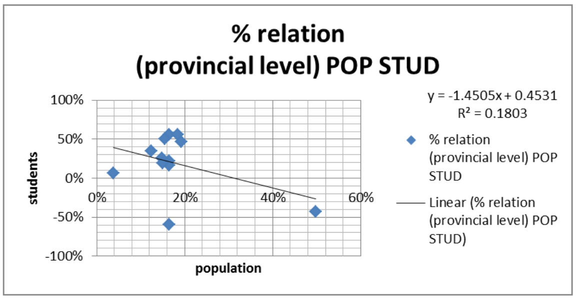




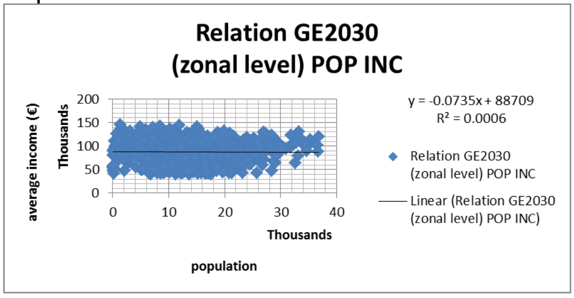


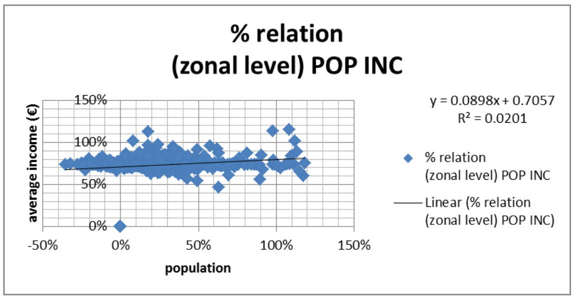


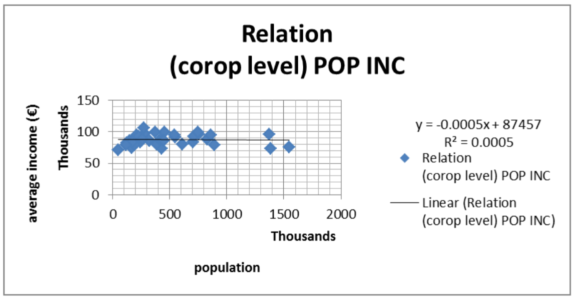


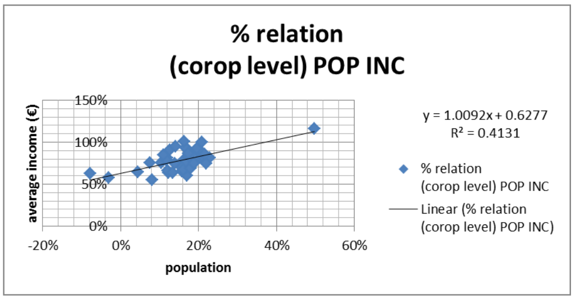


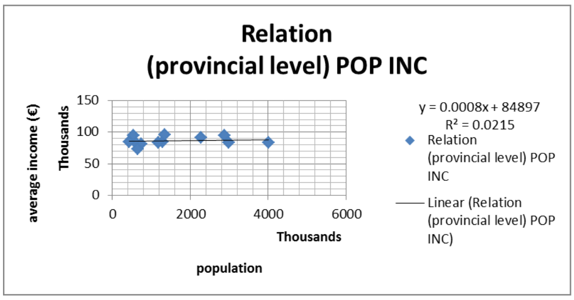
Population- Income levels

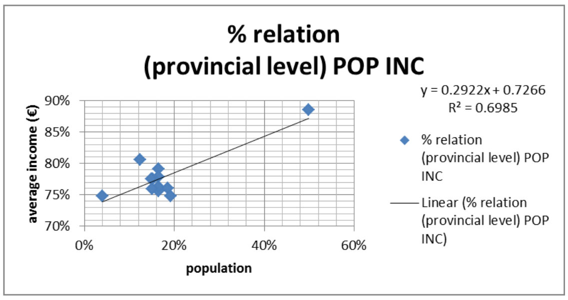




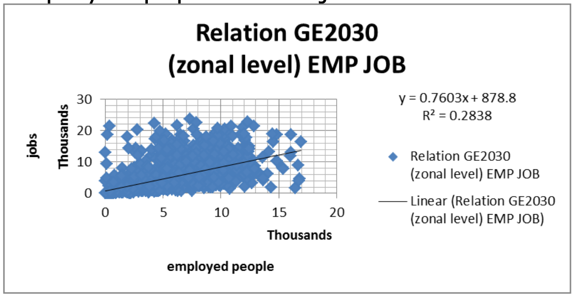


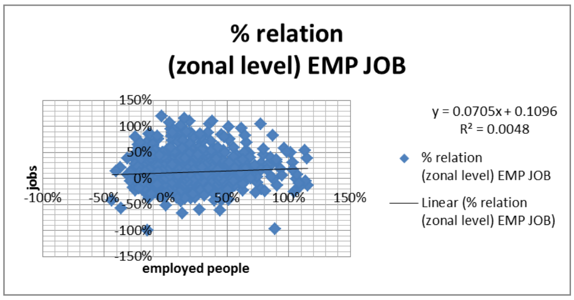


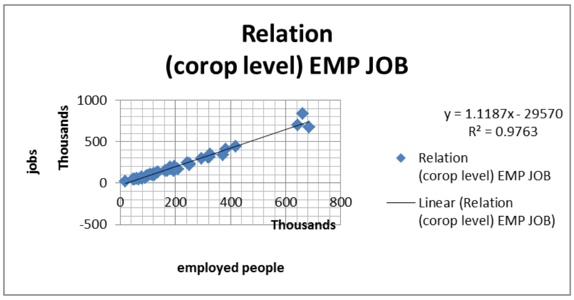


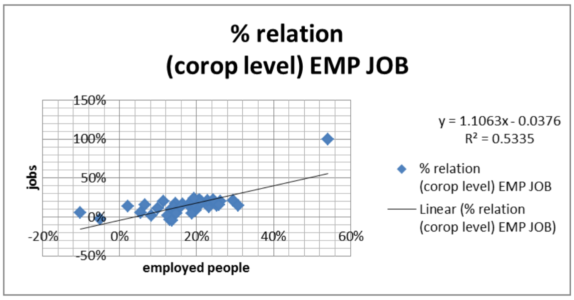


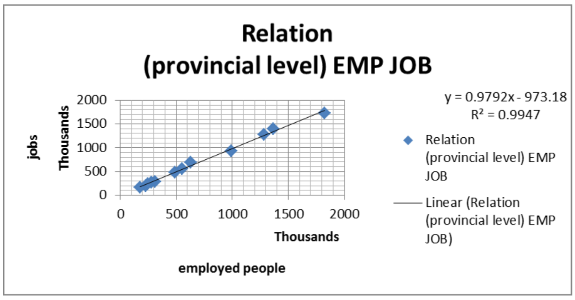
Employed population – jobs

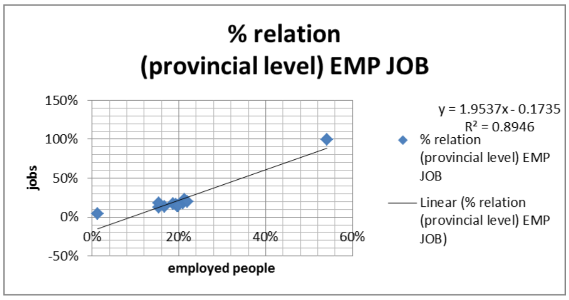






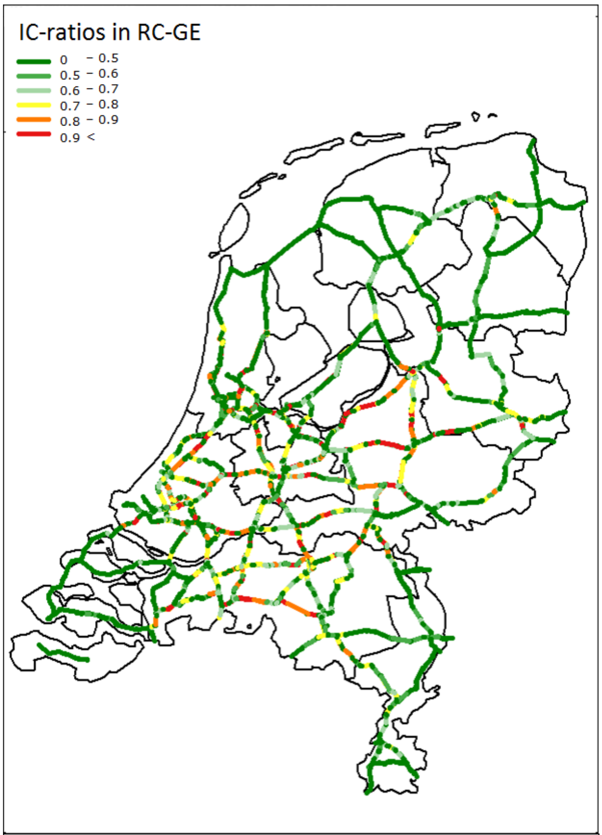


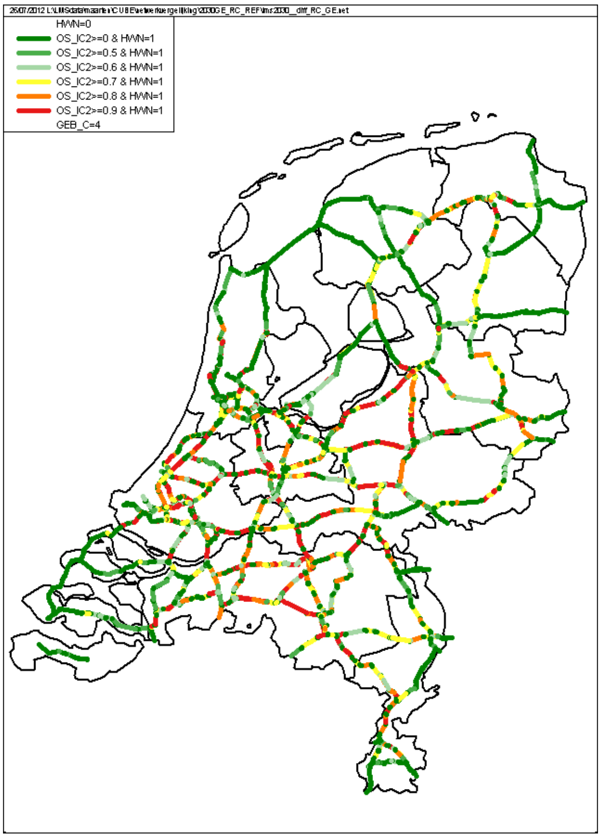




9.10 Appendix maps on mobility in 2030 for RC and GE

IC-ratio in RC-GE-difference

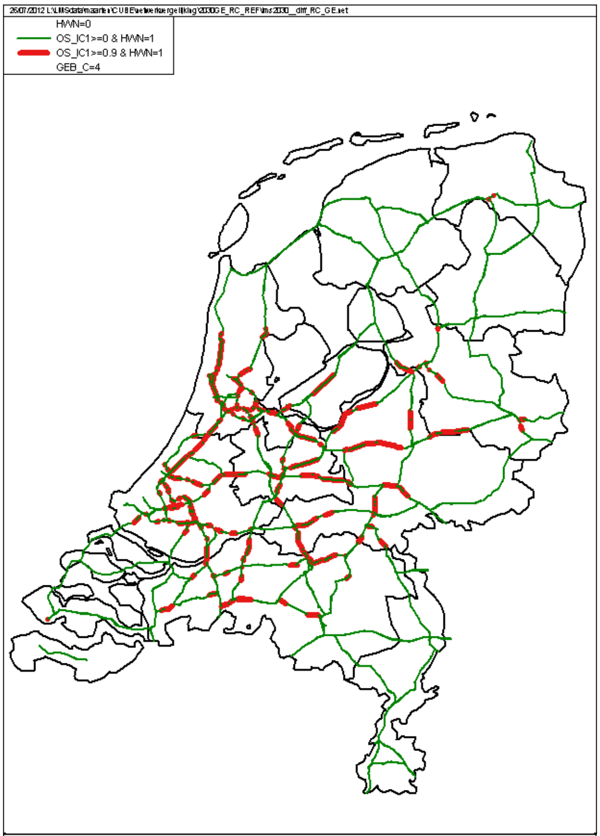


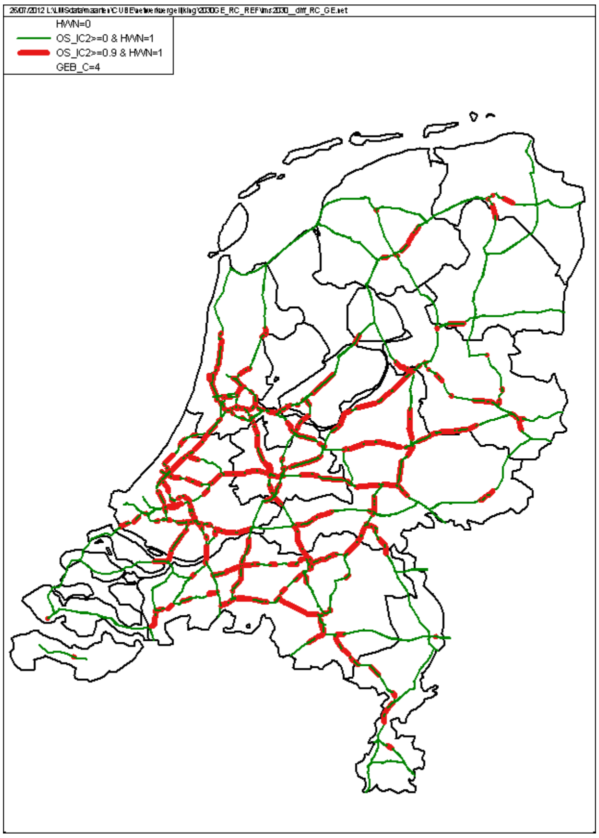


This map shows the difference in IC ratio. It is almost always more than 0.1 higher in GE.

Bottlenecks RC-GE-difference

Bottlenecks are locations with an ic ratio >0.9

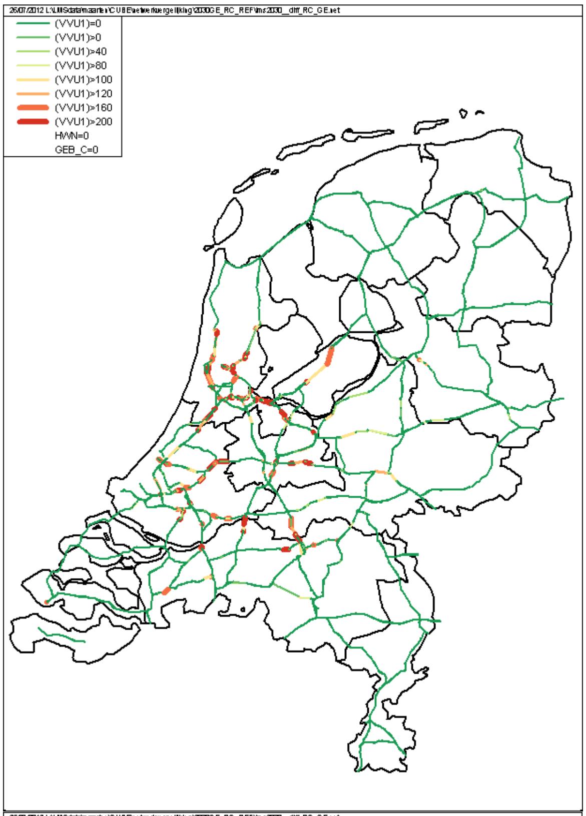


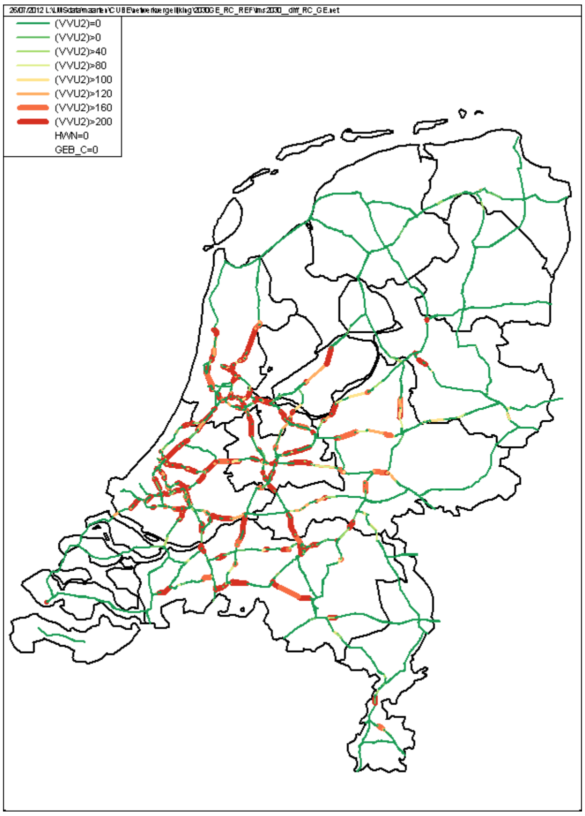


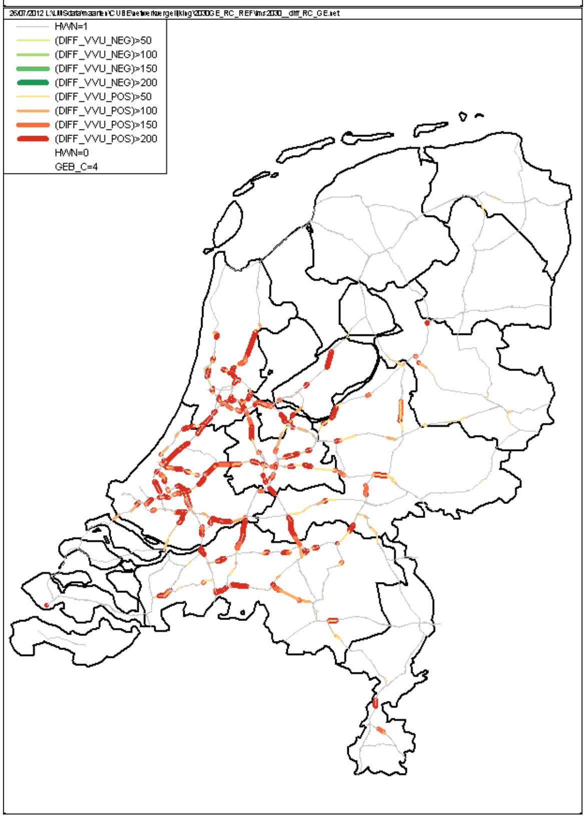
This map shows bottlenecks in GE that are not in RC.

Congestion time in RC-GE-difference

These maps show the congestion hours.







And the difference in congestion hours between the two scenarios

9.11 Appendix Model output per component

POP

POP analysis - SES output per 10% variation

	GE		RC	
	tours	distance	tours	distance
total	10.0%	7.3%	10.0%	8.4%
area				
randstad	9.7%	6.9%	9.9%	8.4%
non-randstad	10.2%	7.7%	10.1%	8.4%
motive				
work	9.7%	7.1%	9.6%	8.1%
business	9.8%	8.1%	9.7%	8.8%
other	10.1%	7.4%	10.3%	8.9%

POP analysis - QBLOK output per 10% variation

	GE		RC	
	travel time loss	congestion	travel time loss	congestion
total	19.2%	24.8%	20.4%	29.7%
area				
randstad	20.3%	23.6%	19.8%	27.1%
non-randstad	18.8%	26.4%	22.3%	42.2%
network				
main	19.7%	24.4%	20.8%	30.3%
secondary	18.9%	25.3%	20.3%	29.2%
time of day				
am	14.8%	21.1%	17.9%	26.5%
op	27.3%	46.4%	25.4%	82.8%
pm	19.1%	25.1%	22.3%	35.0%
motive				
freight	23.1%	22.6%	22.2%	28.3%
work	17.5%	22.9%	19.4%	28.6%
business	20.9%	27.5%	22.0%	34.6%
other	21.6%	26.4%	22.8%	32.2%

HHS

HHS analysis - SES output per 10% variation				
	GE		RC	
	tours	distance	tours	distance
total	-5.3%	-4.6%	-5.9%	-5.9%
area				
randstad	-5.5%	-4.4%	-5.9%	-5.9%
non-randstad	-5.1%	-4.7%	-5.9%	-5.9%
motive				
work	-5.6%	-4.5%	-5.7%	-5.6%
business	-4.5%	-4.4%	-4.6%	-5.2%
other	-5.2%	-4.7%	-6.1%	-6.7%

HHS analysis - QBLOK output per 10% variation				
	GE		RC	
	travel time loss	congestion	travel time loss	congestion
total	-11.6%	-14.9%	-13.3%	-19.2%
area				
randstad	-12.9%	-14.9%	-14.2%	-20.5%
non-randstad	-11.3%	-16.6%	-15.5%	-28.6%
network				
main	-12.3%	-15.4%	-14.7%	-22.2%
secondary	-11.2%	-14.4%	-12.5%	-16.4%
time of day				
am	-9.8%	-13.9%	-13.5%	-20.1%
op	-15.4%	-24.7%	-15.9%	-30.2%
pm	-12.6%	-15.7%	-15.8%	-25.4%
motive				
freight	-12.7%	-13.4%	-15.2%	-20.0%
work	-11.3%	-14.8%	-14.2%	-21.5%
business	-12.3%	-16.7%	-14.6%	-24.4%
other	-14.0%	-16.8%	-16.1%	-23.4%

PAR

PAR analysis - SES output per 10% variation				
	GE		RC	
	tours	distance	tours	distance
total	1.3%	2.1%	1.1%	2.6%
area				
randstad	1.5%	2.0%	1.3%	2.6%
non-randstad	1.1%	2.1%	1.0%	2.6%
motive				
work	6.6%	5.3%	6.4%	5.8%
business	3.8%	4.3%	3.5%	4.6%
other	-2.8%	-4.0%	-2.7%	-3.2%

PAR analysis - QBLOK output per 10% variation				
	GE		RC	
	travel time loss	congestion	travel time loss	congestion
total	8.2%	12.4%	7.2%	12.3%
area				
randstad	10.5%	13.6%	7.8%	9.9%
non-randstad	9.1%	14.3%	11.6%	22.4%
network				
main	9.9%	13.8%	9.3%	12.5%
secondary	7.2%	10.8%	6.2%	12.1%
time of day				
am	11.2%	15.6%	8.7%	10.6%
op	8.3%	14.1%	6.6%	-5.6%
pm	9.8%	11.3%	11.7%	15.9%
motive				
freight	9.7%	11.1%	10.3%	12.9%
work	11.4%	15.1%	10.3%	12.8%
business	11.0%	15.8%	11.0%	15.6%
other	6.0%	10.1%	5.1%	9.0%

CAR

CAR analysis - SES output per 10% variation				
	GE		RC	
	tours	distance	tours	distance
total	6.9%	4.5%	6.7%	4.8%
area				
randstad	8.9%	5.8%	9.1%	6.7%
non-randstad	5.2%	3.4%	4.8%	3.2%
motive				
work	6.6%	4.3%	6.0%	4.3%
business	5.2%	3.5%	4.9%	3.5%
other	7.3%	5.2%	7.4%	6.1%

CAR analysis - QBLOK output per 10% variation				
	GE		RC	
	travel time loss	congestion	travel time loss	congestion
total	12.5%	15.7%	12.8%	17.5%
area				
randstad	14.5%	17.5%	13.5%	19.6%
non-randstad	8.3%	11.7%	8.0%	14.7%
network				
main	12.0%	15.9%	11.3%	18.6%
secondary	12.8%	15.4%	13.6%	16.4%
time of day				
am	10.0%	14.3%	9.9%	16.1%
op	15.3%	26.5%	13.3%	43.8%
pm	11.6%	16.1%	12.1%	21.9%
motive				
freight	13.4%	13.9%	10.9%	14.9%
work	10.8%	15.0%	10.2%	17.3%
business	12.0%	17.0%	11.1%	20.1%
other	13.9%	18.2%	14.0%	22.6%

INC

INC analysis - SES output per 10% variation				
	GE		RC	
	tours	distance	tours	distance
total	0.3%	2.0%	0.3%	1.9%
area				
randstad	0.3%	1.8%	0.3%	1.7%
non-randstad	0.3%	2.2%	0.3%	2.0%
motive				
work	0.2%	1.2%	0.2%	1.1%
business	0.7%	4.0%	0.6%	3.6%
other	0.3%	2.5%	0.3%	2.4%

INC analysis - QBLOK output per 10% variation				
	GE		RC	
	travel time loss	congestion	travel time loss	congestion
total	3.6%	4.7%	2.8%	3.9%
area				
randstad	5.1%	5.4%	4.1%	5.1%
non-randstad	5.9%	7.5%	5.9%	9.3%
network				
main	5.4%	6.0%	4.9%	6.0%
secondary	2.5%	3.3%	1.8%	1.9%
time of day				
am	3.9%	5.1%	3.9%	5.5%
op	8.2%	12.1%	7.6%	15.9%
pm	4.8%	6.1%	4.7%	6.6%
motive				
freight	5.9%	5.9%	4.6%	5.8%
work	4.4%	5.3%	4.0%	5.5%
business	6.4%	7.4%	5.9%	7.5%
other	6.3%	6.4%	5.8%	6.4%

CST

CST analysis - SES output per 10% variation				
	GE		RC	
	tours	distance	tours	distance
total	-0.4%	-1.5%	-0.6%	-2.0%
area				
randstad	-0.4%	-1.4%	-0.6%	-1.9%
non-randstad	-0.4%	-1.5%	-0.5%	-2.0%
motive				
work	-0.4%	-1.0%	-0.5%	-1.4%
business	-0.2%	0.0%	-0.3%	-0.2%
other	-0.5%	-2.8%	-0.6%	-3.5%

CST analysis - QBLOK output per 10% variation				
	GE		RC	
	travel time loss	congestion	travel time loss	congestion
total	-2.7%	-3.3%	-3.1%	-3.6%
area				
randstad	-3.2%	-3.5%	-3.6%	-4.3%
non-randstad	-3.2%	-3.9%	-4.4%	-6.0%
network				
main	-3.2%	-3.6%	-3.9%	-4.7%
secondary	-2.3%	-3.0%	-2.6%	-2.7%
time of day				
am	-1.9%	-2.6%	-3.5%	-4.4%
op	-5.1%	-8.1%	-5.3%	-10.5%
pm	-3.3%	-4.2%	-3.8%	-5.1%
motive				
freight	-3.5%	-3.3%	-3.9%	-4.6%
work	-2.7%	-3.2%	-3.6%	-4.6%
business	-2.8%	-3.5%	-3.3%	-4.5%
other	-4.6%	-4.6%	-5.1%	-5.3%

FRG

FRG analysis - SES output per 10% variation		
	GE	
	tours	distance
total	-0.1%	-1.0%
area		
randstad	-0.2%	-1.2%
non-randstad	-0.1%	-0.9%
motive		
work	-0.1%	-1.0%
business	-0.1%	-0.7%
other	-0.1%	-1.2%

FRG analysis - QBLOK output per 10% variation		
	GE	
	travel time loss	congestion
total	4.3%	5.3%
area		
randstad	4.9%	5.3%
non-randstad	4.5%	7.4%
network		
main	4.7%	5.9%
secondary	4.0%	4.6%
time of day		
am	2.8%	5.1%
op	9.8%	18.9%
pm	2.6%	4.8%
motive		
freight	15.2%	14.5%
work	2.7%	4.1%
business	5.0%	6.2%
other	4.7%	5.4%

9.12 Appendix spatial scenarios

This appendix describes for the three spatial scenarios in this research how the research was performed.

1. High urbanization

First it has to be clear how urban area is defined. The CBS defines urbanization by the number of households per km2. If this that number is higher than 1500 households per km2 the zone is considered to be urban area. This definition was used to make the table in the report.

Method

For every zone I determined if the zone is an urban zone in 2030GE. Then I summed up the population in urban and rural area. When added up, it is easy to see that most of the growth takes place in urban area: about 70%. The total increase in population is 16%, as we have seen earlier in the scenario analysis. This will remain 16%.

Now for this analysis, not 70% but 100% of the growth takes place in urban area. The new growth numbers are:

Growth new scenario 2004-2030				
	GE	%	GE urban	%
Rural area	789,000	30%	-	0%
Urban area	1,842,000	70%	2,394,000	100%
Total	2,394,000	100%	2,394,000	100%

And the new totals, where the share of urban zones has increased to more than 40% of the total number of households:

Population in new scenario		
	GE urban	change to GE
Rural area	10,883,000	-14.5%
Urban area	8,006,000	+ 29.9%

To calculate new household numbers for every zone, I used a similar approach as in the other analyses, but now distinguishing the rural and urban zones. This means that the share of the zone in the total will be the same. For example, an urban zone first had 6.100 population, about 0,1% of the total number of people in urban zones. Then in the new scenario the zone will have about 8.000 people, 0,1% of the new population in urban zones.

The number of households and all other related variables to the population were also adjusted for every zone. This was done by keeping the household size and participation level the same. For every zone, the number of households and household size is known and thus the population can be easily calculated.

Of course, the number of urban zones are the same in the new scenario: 412 zones. However there are now 309 highly urbanized zones.

For this spatial scenario I used the criterion of households/km2.
In total, the total population increases from 16257991 to 18889270. In GE 70% of this growth is in rural area (<1500 hh / km2) and only 33% of the population lives in urban area. In the new scenario all growth takes place in urban area (the 412 high density zones) and now 42% will live in urban area.

Example

a. LMSzone 1 has 49 households per km2
b. The multiplication factor is: 0.8552
c. The new population is 0.8552 * 15495 = 13251

d. LMSzone 4 has 2590 households per km2
e. The multiplication factor is: 1.2990
f. The new population is 1.2990 * 11714 = 15216

This was done for all variables related to the population (keeping hhs and participation level constant).

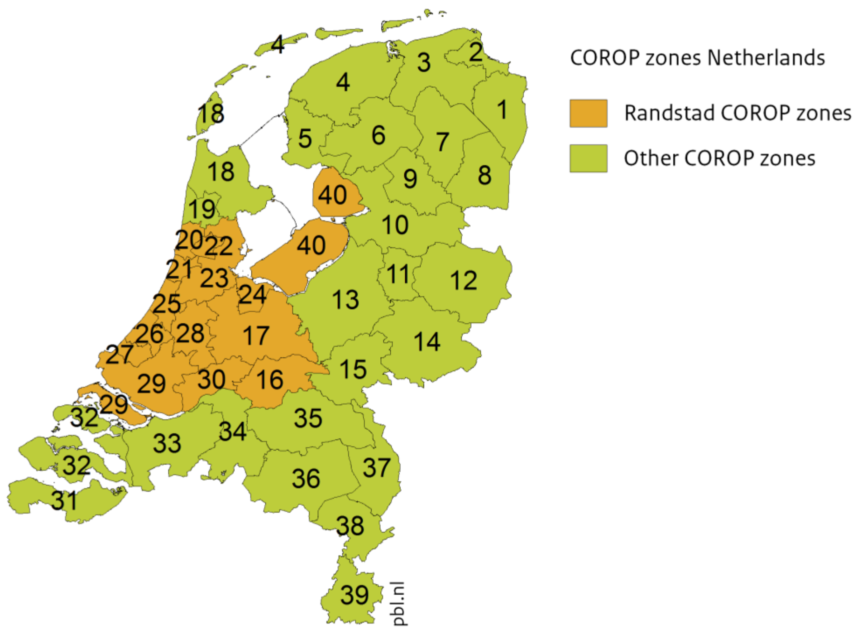
Population in urban area						
	2004	%	2030GE	%	2030GE_SPUR	%
urban	5,375,000	33%	6,163,000	33%	8,006,000	42%
rural	10,883,000	67%	12,726,000	67%	10,883,000	58%
total	16,258,000	100%	18,889,000	100%	18,889,000	100%

Increase in population		
	2004-2030GE	2004-2030GE_SPUR
urban	+15%	+49%
rural	+17%	+0%
total	+16%	+16%

2. Growth in Randstad

For this spatial scenario I used the criterion of Randstad COROP areas. The corop zones that are part of the Randstad are presented in the next figure:

Area classification



In total, the total population increases from 16257991 to 18889270 (2004-2030GE). In GE 47% of this growth takes place in the Randstad and 45% of the population lives in the Randstad area.

In the new scenario all growth takes place in the Randstad and then 52% will live in the Randstad. The share of the total population in the Randstad/other for each zone is constant.

Population in Randstad						
	2004	%	2030GE	%	2030GE_SPRA	%
Randstad	7,203,000	44%	8,430,000	45%	9,835,000	52%
other	9,055,000	56%	10,460,000	55%	9,055,000	48%
total	16,258,000	100%	18,889,000	100%	18,889,000	100%

In the new scenario all population growth takes place in the Randstad, defined by the COROP zones 16-17, 20-30 and 40. The population totals are multiplied by the factors 1.6667 (zones in the Randstad) and 0.8657 (outside Randstad) so that the total population is 18,889,000 as in 2030GE.

Example

a. LMSzone 43 is located in the Randstad
b. The multiplication factor is 1.1667
c. The new population is 15827 * 1.1667 = 18465

This was done for all variables related to the population (keeping hhs and participation level constant).

Increase in population		
	2004-2030GE	2004-2030GE_SPRA
Randstad	+17%	+37%
other	+16%	+0%
total	+16%	+16%

3. RC spatial pattern

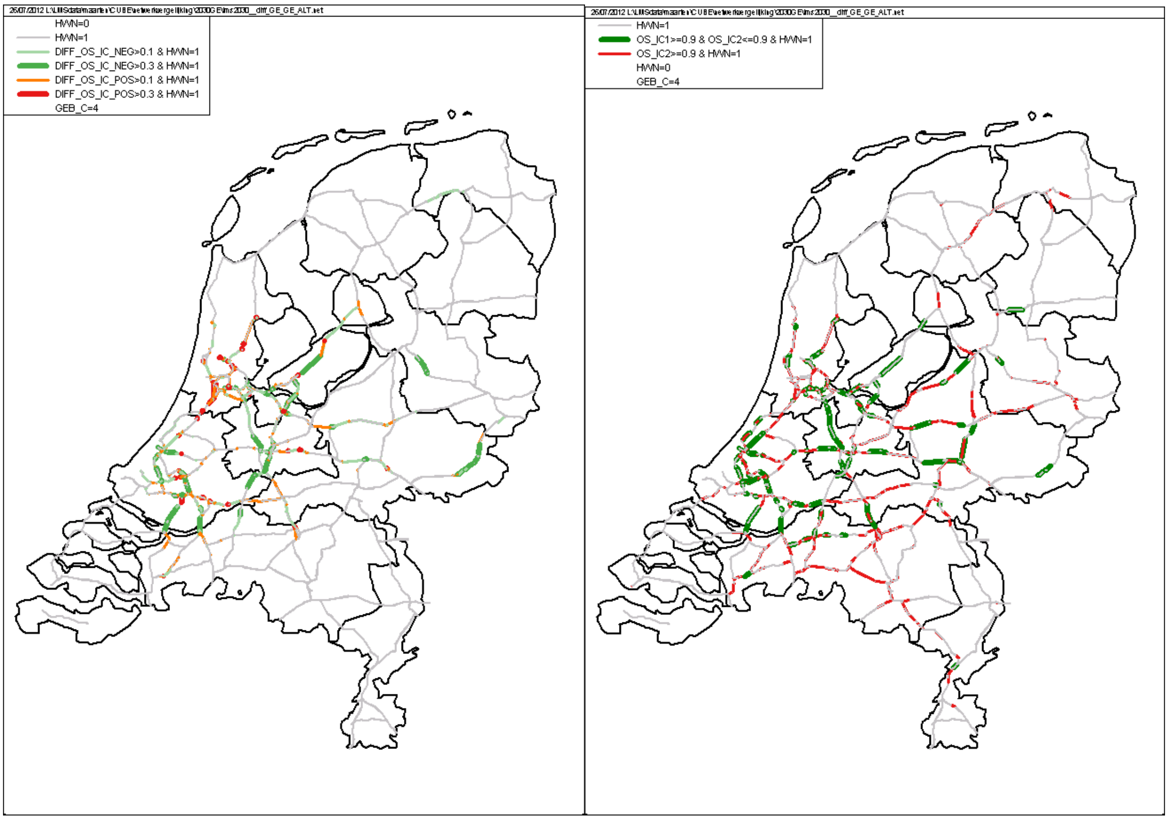
In this scenario I redistributed the variables to the spatial pattern in RC. Per variable, its share in the total per zone for RC is used to design the new GE scenario. The totals do not change, as in the other spatial scenarios.

Example

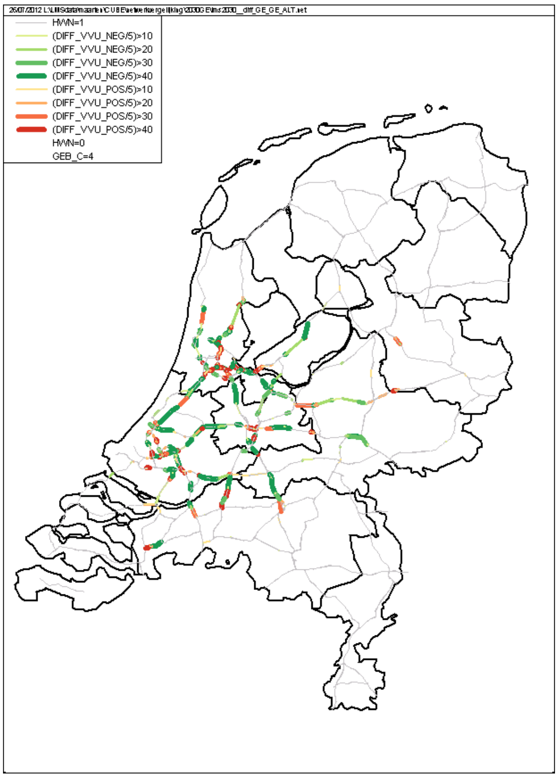
a. LMSzone 1 has 0.08778% of total population in RC
b. The total population in GE is 18889267
c. The new population is 0.0008778 * 18889267 = 16581

This is carried out for all spatial variables, including educational related variables.

9.13 Appendix effects MIRT+20 in GE2030



Difference IC ratios and bottlenecks



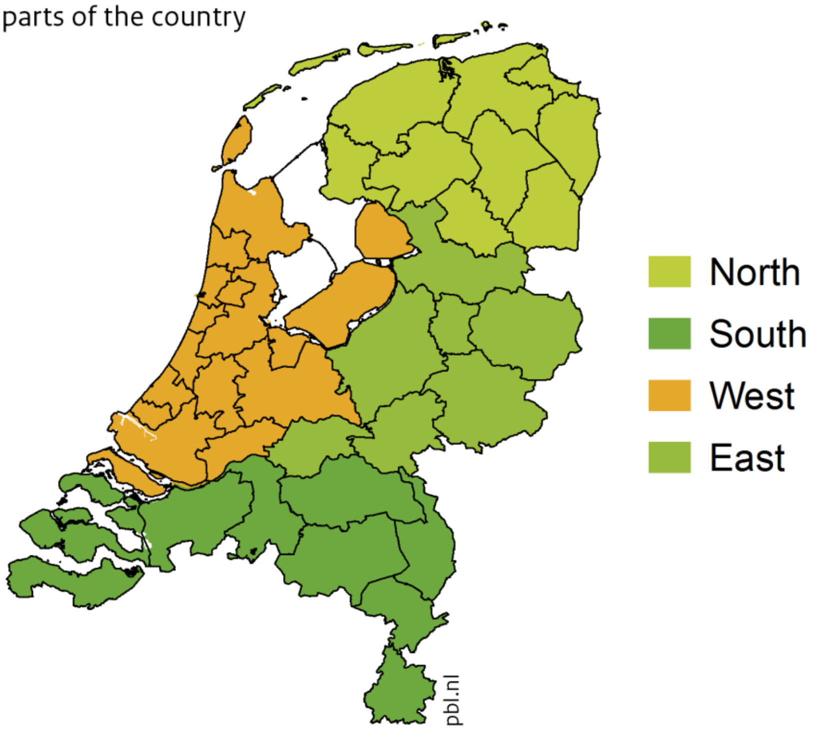
Difference congestion hours

9.14 Appendix four areas of the Netherlands

The LMS divides in her network but also in her output the Netherlands in four parts, north east south and west. They are defined by the provinces. When I reported output on the Randstad in this report, it was always according to the following map (West). This is consistent with the output of the LMS transport model.

The Netherlands in four areas

parts of the country



Also the tables on the investments and de deviation of the SVIR ambition were based on this division.

9.15 Appendix analysis SVIR

This appendix provides more elaborate results and analysis on the SVIR investment research.

Results GE runs					Results RC runs				
	tours	distance (km)	time loss (h)	congestion (h)		tours	distance (km)	time loss (h)	congestion (h)
GE	10,148,000	291,616,000	374,000	194,000	RC	8,074,000	232,305,000	153,000	59,000
MIRT+20	10,171,000	303,828,000	293,000	140,000	MIRT+20	8,085,000	237,971,000	106,000	33,000
MIRT+20 / GE	+ 0%	+ 4%	- 22%	- 28%	MIRT+20 / RC	+ 0%	+ 2%	- 30%	- 45%

Results GE runs					Results RC runs				
	tours	distance (km)	time loss (h)	congestion (h)		tours	distance (km)	time loss (h)	congestion (h)
GE	10,148,000	291,616,000	374,000	194,000	RC	8,074,000	232,305,000	153,000	59,000
SVIR	10,175,000	307,433,000	261,000	138,000	SVIR	8,086,000	239,414,000	103,000	42,000
SVIR / GE	+ 0%	+ 5%	- 30%	- 29%	SVIR / RC	+ 0%	+ 3%	- 32%	- 29%

In GE the effects of both investment packages is similar. Congestion hours decrease by almost 30%. The decrease in travel time loss is higher for the SVIR investments. RC shows a different result. The effect on congestion hours is much higher for the MIRT+20 package.

There are three important differences between the investment packages. The first is obvious, ie that the SVIR ambition includes more than twice as much lane kilometers than the MIRT+20 package. The second is the location of these lane kilometers. While MIRT+20 focuses on the Randstad, with more than 80% of the lane kilometers. In the SVIR package this is relatively less, 50% of the extra lane capacity will be built in the Randstad. The south of the Netherlands is prominent in the SVIR ambition, with more than 1000 extra lane kilometers compared to MIRT+20. Finally, the capacity increase per project is distributed differently between the two packages. the SVIR ambition is to have at least 2x4 lanes in the Randstad. This results in an extra 1 or 2 lanes for most projects, while in the MIRT+20 package up to 6 extra lanes will be built. The MIRT+20 investment package was designed to address the most important bottlenecks in 2030 and the SVIR represents more of a general ambition to implement a consistent and coherent network of international oriented routes. The main goal of the SVIR analysis was to see if the results of my research would also apply to another investment package.

Overview MIRT+20: SES output					Overview SVIR: SES output				
	GE		RC			GE_SVIR		RC_SVIR	
	tours	distance	tours	distance		tours	distance	tours	distance
total	+ 0%	+ 4%	+ 0%	+ 2%	total	+ 0%	+ 5%	+ 0%	+ 3%
area					area				
randstad	+ 0%	+ 6%	+ 0%	+ 3%	randstad	+ 0%	+ 5%	+ 0%	+ 3%
non-randstad	+ 0%	+ 3%	+ 0%	+ 2%	non-randstad	+ 0%	+ 5%	+ 0%	+ 3%
motive					motive				
work	+ 0%	+ 5%	+ 0%	+ 3%	work	+ 0%	+ 6%	+ 0%	+ 4%
business	+ 0%	+ 4%	+ 0%	+ 2%	business	+ 0%	+ 5%	+ 0%	+ 3%
other	+ 0%	+ 3%	+ 0%	+ 1%	other	+ 0%	+ 4%	+ 0%	+ 2%

Overview MIRT+20: QBLOK output					Overview SVIR: QBLOK output				
	GE		RC			GE_SVIR		RC_SVIR	
	travel time loss	congestion	travel time loss	congestion		travel time loss	congestion	travel time loss	congestion
total	- 8%	- 15%	- 11%	- 26%	total	- 10%	- 12%	- 10%	- 12%
area					area				
randstad	- 29%	- 32%	- 41%	- 49%	randstad	- 26%	- 24%	- 24%	- 23%
non-randstad	- 11%	- 17%	- 15%	- 29%	non-randstad	- 37%	- 41%	- 45%	- 52%
network					network				
main	- 22%	- 28%	- 30%	- 45%	main	- 30%	- 29%	- 32%	- 29%
secondary	+ 0%	- 1%	- 1%	- 9%	secondary	+ 2%	+ 6%	+ 1%	+ 4%
time of day					time of day				
am	- 14%	- 24%	- 32%	- 44%	am	- 19%	- 23%	- 27%	- 28%
op	- 31%	- 48%	- 25%	- 44%	op	- 52%	- 68%	- 51%	- 90%
pm	- 22%	- 30%	- 31%	- 46%	pm	- 26%	- 29%	- 29%	- 30%
motive					motive				
freight	- 33%	- 35%	- 45%	- 50%	freight	- 43%	- 40%	- 37%	- 40%
work	- 17%	- 24%	- 30%	- 44%	work	- 24%	- 24%	- 29%	- 27%
business	- 26%	- 34%	- 31%	- 50%	business	- 35%	- 32%	- 38%	- 32%
other	- 22%	- 28%	- 29%	- 43%	other	- 33%	- 31%	- 34%	- 30%

MIRT+20 is focused on the Randstad, while the SVIR package concerns the main road network in almost the whole country. Only the north of the Netherlands is not included in the ambition.

For tours and distance the investment packages don't differ much in effects. The SVIR ambition has a slightly higher effect on the total kilometers, consistently for different travel purposes.

However for travel time loss and congestion hours there is a large difference. In GE the MIRT+20 package reduces the congestion hours more than the SVIR package. This is because of the higher impact on congestion in the Randstad. In the low economic scenario the MIRT+20 package is much more effective to address congestion in the Randstad. Outside the Randstad the SVIR investments have more impact.

For congestion hours both packages have about the same impact in GE, in RC MIRT+20 reduces congestion hours more. However for the rest of the day the SVIR reduces more travel time loss and congestion in both scenarios. In RC the SVIR investments even solve almost all of the congestion outside peak hours. For the travel time benefits this means 2 or 3 times higher benefits outside peak hours in RC, varying per motive. But the benefits outside peak hours only represent 40% of the total benefits, and 25% for the MIRT+20 package.

Overview SVIR: CBA output						
	GE_SVIR			RC_SVIR		
total	+ 19%			+ 7%		
type						
autonomous	+ 19%			+ 9%		
extra demand	+ 10%			- 18%		
total: motive / time of day						
	am	op	pm	am	op	pm
freight	- 16%	+ 36%	- 15%	- 27%	+ 24%	- 40%
work	- 5%	+ 53%	- 6%	- 17%	+ 93%	- 19%
business	- 8%	+ 52%	- 3%	- 15%	+ 97%	- 10%
other	- 6%	+ 36%	- 17%	- 18%	+ 74%	- 26%
extra demand: motive / time of day						
	am	op	pm	am	op	pm
freight	+ 0%	+ 0%	+ 0%	+ 0%	+ 0%	+ 0%
work	- 12%	+ 73%	- 10%	- 27%	+ 205%	- 37%
business	- 8%	+ 75%	+ 2%	- 20%	+ 175%	- 27%
other	- 7%	+ 23%	- 32%	- 25%	+ 114%	- 57%

SVIR

MIRT+20

These maps show the bottlenecks that were solved. MIRT+20 is very focused on solving bottlenecks in the Randstad. MIRT+20 also solves bottlenecks between Utrecht and Amsterdam. MIRT+20 works for Almere. SVIR also invests in Brabant and Gelderland, not only the A12. Neither investment packages solve bottlenecks in Groningen or Friesland.

Compared to MIRT+20, the SVIR ambition package solves much more bottleneck kilometers:

Congested lane km in GE 2030			
	MIRT	MIRT+20	SVIR
total	3,352	3,235	2,702
Main	2,755	2,669	2,105
Secondary	597	566	598
		- 3%	- 19%

Congested lane km in RC 2030		
	MIRT	MIRT+20
total	1,533	1,219
Main	1,294	980
Secondary	240	239
		- 21%

As an addition to the SVIR analysis check, I split the SVIR ambition into two parts: East and West. The two parts of the investments package both cover about half of the total investments. The research show that at least on a large scale, the effects of investments add up and can be combined to predict the effect of the total package. For congestion the combined effects are even slightly higher. This is because a better throughput in the other part of the network increases the total transport demand.

SVIR investments east/west		
	kilometers	%
SVIR west	1,755	48%
SVIR east	1,933	52%
SVIR	3,688	

Figure 36: SVIR investments east and west

For distance, travel time loss and congestion hours the index numbers are presented. When the effects of east and west are combined, it is possible to predict the effect of the total package. The prediction comes pretty close to the combined effects, but there also is a small synergy effect.

distance			
	Nederland	Randstad	Non-Randstad
2030 GE	100.0	100.0	100.0
2030 GE _SVIR_EAST	103.2	101.5	104.6
2030 GE _SVIR_WEST	102.3	104.1	100.7
2030 GE _SVIR expected	105.5	105.6	105.4
2030 GE _SVIR	105.4	105.5	105.4

travel time loss			
	Nederland	Randstad	Non-Randstad
2030 GE	100.0	100.0	100.0
2030 GE _SVIR_EAST	83.8	97.6	63.2
2030 GE _SVIR_WEST	85.2	75.5	99.4
2030 GE _SVIR expected	71.3	73.7	62.9
2030 GE _SVIR	69.8	74.4	63.1

congestion hours			
	Nederland	Randstad	Non-Randstad
2030 GE	100.0	100.0	100.0
2030 GE _SVIR_EAST	88.2	99.4	59.6
2030 GE _SVIR_WEST	83.0	76.4	99.7
2030 GE _SVIR expected	73.2	76.0	59.4
2030 GE _SVIR	71.2	76.0	59.0

Table 65: Distance, travel time loss and congestion hours index numbers for the SVIR packages

For an average working day the total travel time benefits are 612 million for the eastern part of the package and 591 million for the western part. Together this would be 1203 but the benefits of the total package are 1246 million, about 4% higher. This synergy effect can be expected as the total demand increases because of a better quality infrastructure network.

9.16 Appendix detailed output of the travel time benefit sensitivity analysis

The difference between GE and RC is high. The following tables show more elaborate output on the analysis

GE:

benefits (mln * euros / year)						
	total	autonomous	new users	am	op	pm
GE	1,049	990	59	275	536	238
-10% POP	-188	-174	-14	-38	-140	-10
-10% HHS	-113	-105	-8	-26	-96	9
-10% PAR	-93	-87	-6	-41	-53	1
-10% CAR	-138	-128	-9	-25	-106	-7
-10% INC	-68	-64	-4	-10	-51	-7
+10% CST	-32	-30	-2	-2	-29	-1

benefits / motive (mln * euros / year)				
	freight	work	business	other
GE	206	210	423	209
-10% POP	-51	-26	-78	-33
-10% HHS	-38	-13	-44	-19
-10% PAR	-31	-19	-42	-1
-10% CAR	-35	-19	-54	-29
-10% INC	-17	-9	-29	-13
+10% CST	-9	-4	-11	-9

RC:

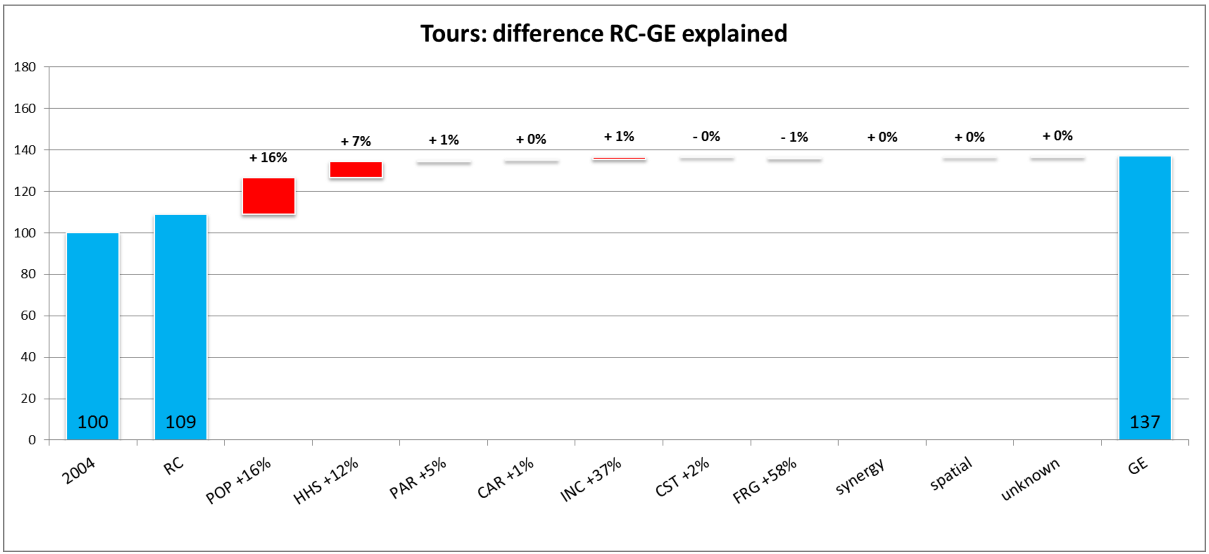
benefits (mln * euros / year)						
	total	autonomous	new users	am	op	pm
RC	376	357	19	151	92	133
+10% POP	+ 55	+ 51	+ 4	+ 12	+ 30	+ 13
+10% HHS	+ 29	+ 27	+ 2	+ 3	+ 18	+ 8
+10% PAR	+ 29	+ 27	+ 2	+ 12	+ 6	+ 10
+10% CAR	+ 23	+ 21	+ 2	+ 0	+ 16	+ 7
+10% INC	+ 10	+ 9	+ 0	+ 3	+ 7	+ 0
+10% CST	-8	-8	-1	-2	-5	-1

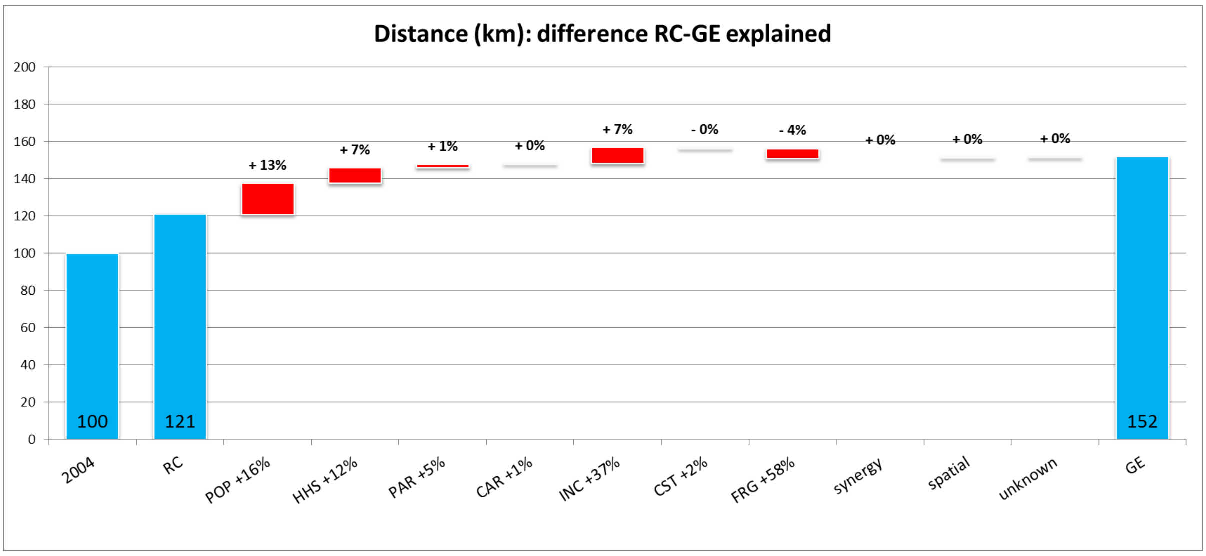
benefits / motive (mln * euros / year)				
	freight	work	business	other
RC	42	109	152	72
+10% POP	+ 6	+ 10	+ 25	+ 14
+10% HHS	+ 2	+ 5	+ 14	+ 8
+10% PAR	+ 3	+ 9	+ 15	+ 1
+10% CAR	+ 2	+ 3	+ 11	+ 8
+10% INC	+ 1	+ 1	+ 6	+ 2
+10% CST	-1	-2	-3	-3

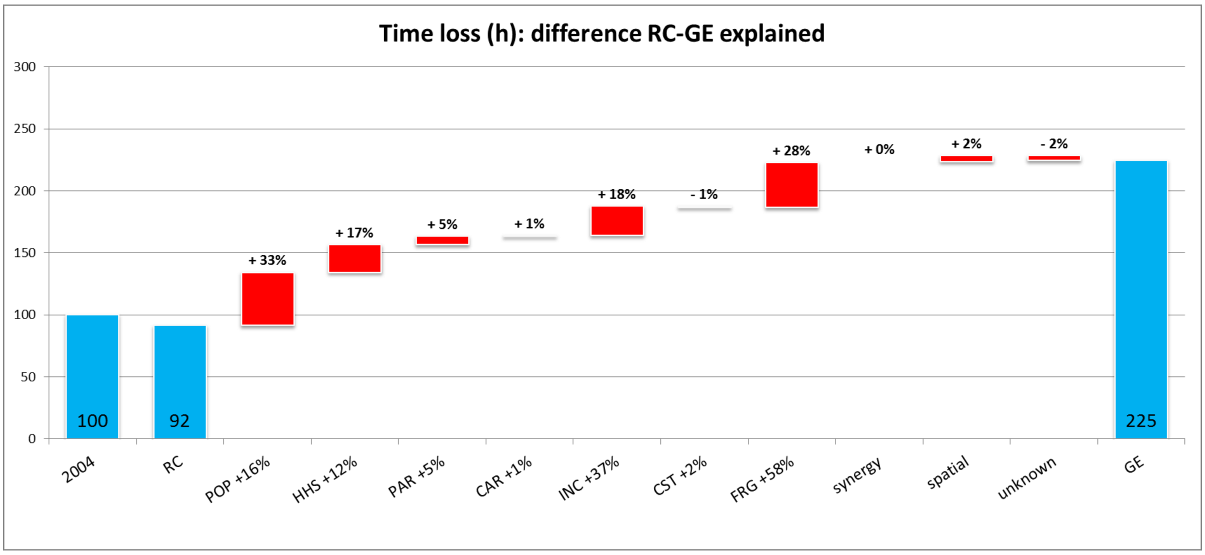
9.17 Appendix the difference in bandwidth explained

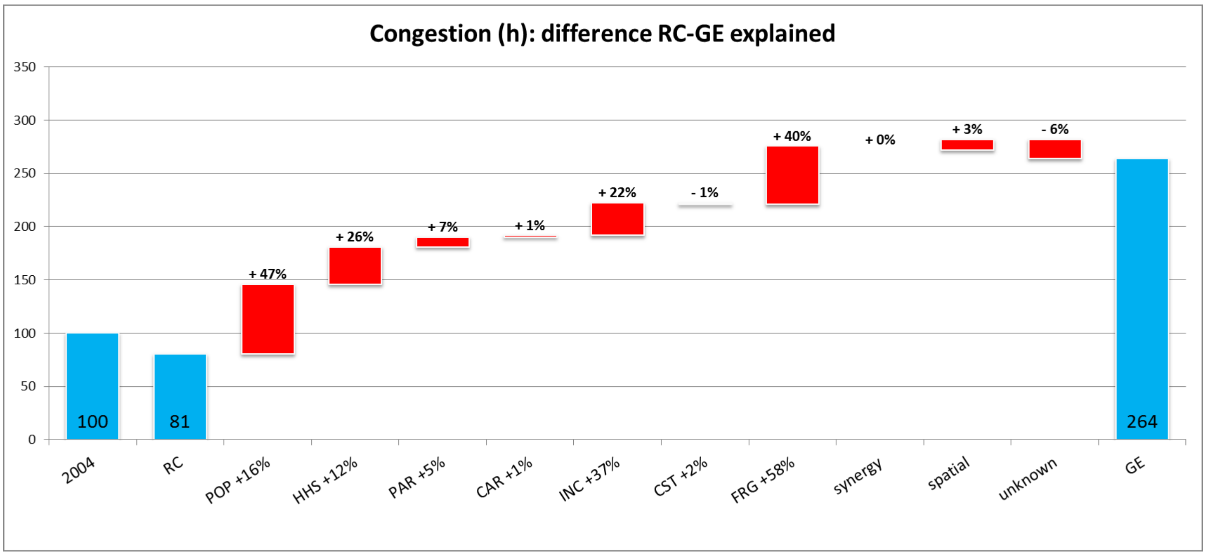
From RC to GE

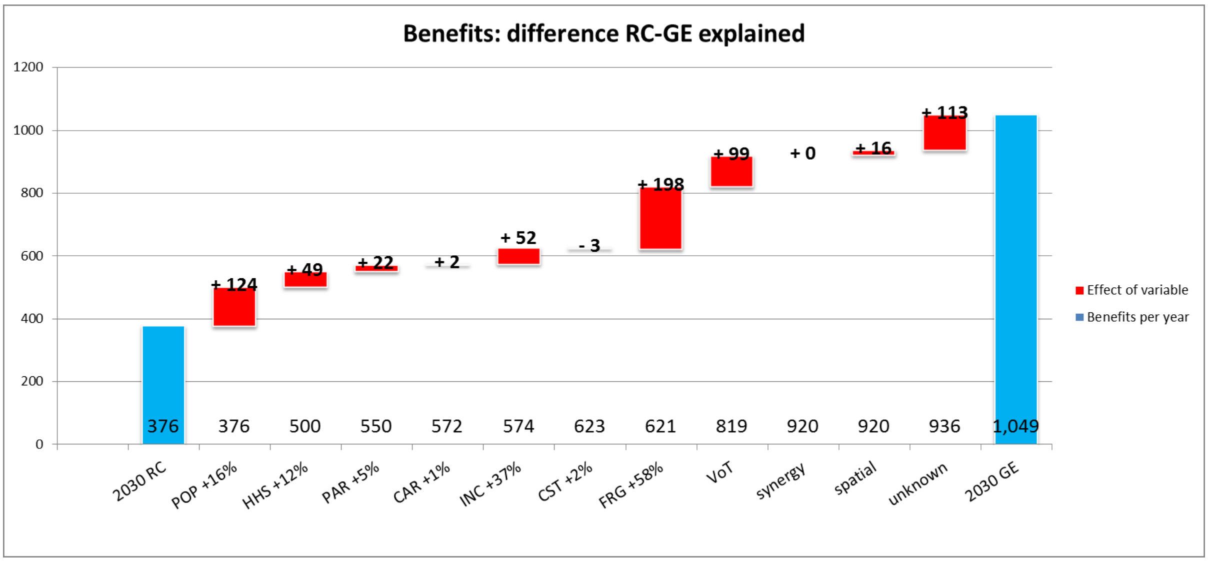
From RC to RC in 10 steps	Tours	Distance (km)	Time loss (h)	Congestion (h)	Benefits
2030 RC	8,074,000	232,305,000	153,000	59,000	376
1 POP +16%	+ 16%	+ 13%	+ 33%	+ 47%	+ 23%
2 HHS +12%	+ 7%	+ 7%	+ 17%	+ 26%	+ 9%
3 PAR +5%	+ 1%	+ 1%	+ 5%	+ 7%	+ 4%
4 CAR +1%	+ 0%	+ 0%	+ 1%	+ 1%	+ 0%
5 INC +37%	+ 1%	+ 7%	+ 18%	+ 22%	+ 10%
6 CST +2%	- 0%	- 0%	- 1%	- 1%	- 0%
7 FRG +58%	- 1%	- 4%	+ 28%	+ 40%	+ 36%
predicted RC	10,102,000	290,765,000	373,000	200,000	920
8 synergy	+ 0%	+ 0%	+ 0%	+ 0%	+ 0%
INT	10,102,000	290,765,000	373,000	200,000	920
9 spatial	+ 0%	+ 0%	+ 2%	+ 3%	+ 2%
10 unknown	+ 0%	+ 0%	- 2%	- 6%	+ 12%
2030 GE	10,148,000	291,616,000	374,000	194,000	1049





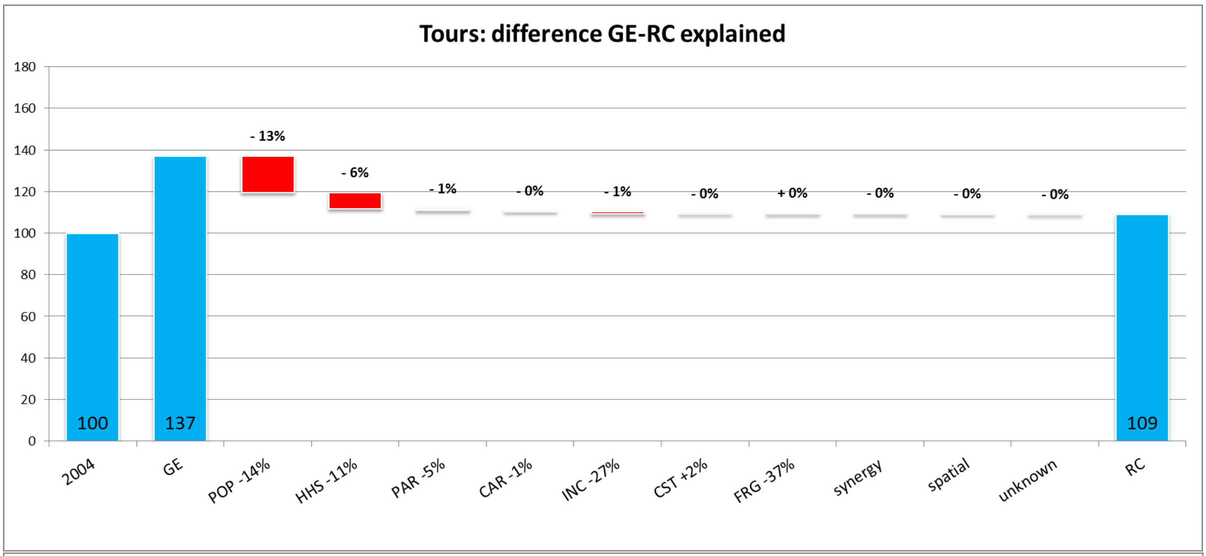

Time loss (h): difference RC-GE explained
300
250
200
150
100
50
0
100
92
+ 33%
+ 17%
+ 5%
+ 1%
+ 18%
- 1%
+ 28%
+ 0%
+ 2%
- 2%
225
2004
RC
POP +16%
HHS +12%
PAR +5%
CAR +1%
INC +37%
CST +2%
FRG +58%
synergy
spatial
unknown
GE

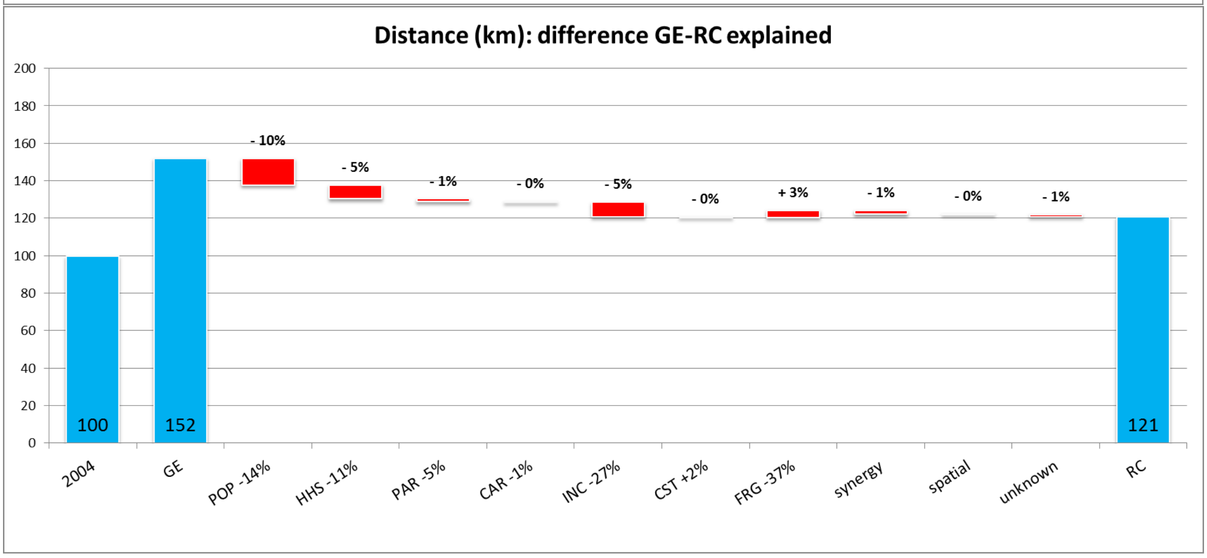

Congestion (h): difference RC-GE explained
350
300
250
200
150
100
50
0
100
81
+ 47%
+ 26%
+ 7%
+ 1%
+ 22%
- 1%
+ 40%
+ 0%
+ 3%
- 6%
264
2004
RC
POP +16%
HHS +12%
PAR +5%
CAR +1%
INC +37%
CST +2%
FRG +58%
synergy
spatial
unknown
GE

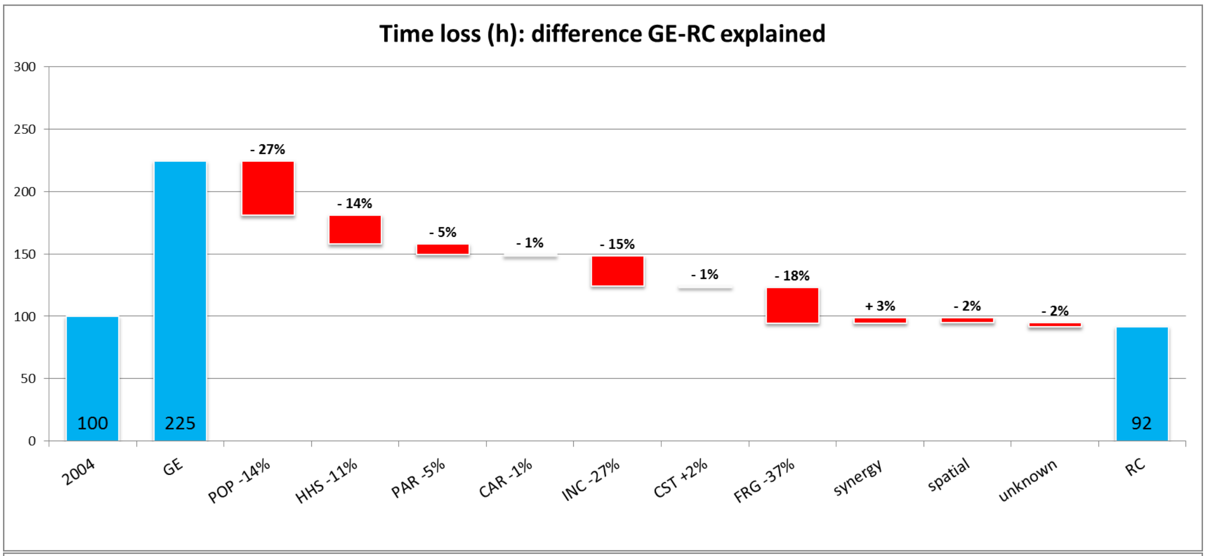

Benefits: difference RC-GE explained
1200
1000
800
600
400
200
0
+ 124
+ 49
+ 22
+ 2
+ 52
- 3
+ 198
+ 99
+ 0
+ 16
+ 113
376
376
500
550
572
574
623
621
819
920
920
936
1,049
2030 RC
POP +16%
HHS +12%
PAR +5%
CAR +1%
INC +37%
CST +2%
FRG +58%
VoT
synergy
spatial
unknown
2030 GE
Effect of variable
Benefits per year

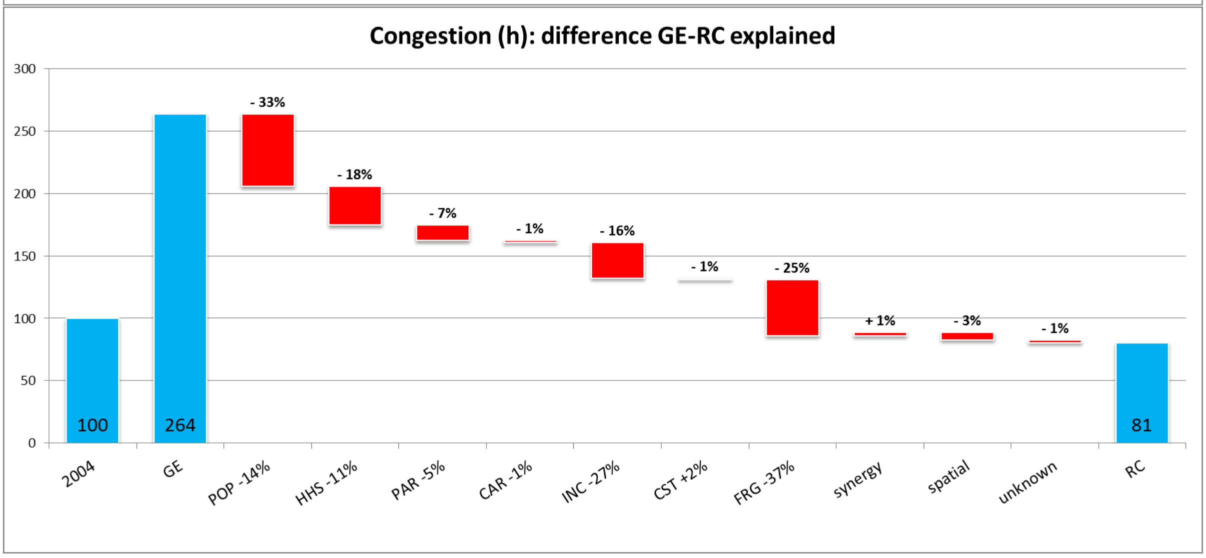
From GE to RC

From GE to RC in 10 steps	Tours	Distance (km)	Time loss (h)	Congestion (h)	Benefits
2030 GE	10,148,000	291,616,000	374,000	194,000	1049
1 POP -14%	- 13%	- 10%	- 27%	- 33%	- 24%
2 HHS -11%	- 6%	- 5%	- 14%	- 18%	- 12%
3 PAR -5%	- 1%	- 1%	- 5%	- 7%	- 5%
4 CAR -1%	- 0%	- 0%	- 1%	- 1%	- 1%
5 INC -27%	- 1%	- 5%	- 15%	- 16%	- 18%
6 CST +2%	- 0%	- 0%	- 1%	- 1%	- 1%
7 FRG -37%	+ 0%	+ 3%	- 18%	- 25%	- 23%
predicted RC	8,119,000	237,868,000	155,000	61,000	352
8 synergy	- 0%	- 1%	+ 3%	+ 1%	+ 5%
INT	8,089,000	234,382,000	159,000	62,000	370
9 SPRC	- 0%	- 0%	- 2%	- 3%	- 2%
10 unknown	- 0%	- 1%	- 2%	- 1%	+ 3%
2030 RC	8,074,000	232,305,000	153,000	59,000	376






Time loss (h): difference GE-RC explained
300
250
200
150
100
50
0
- 27%
- 14%
- 5%
- 1%
- 15%
- 1%
- 18%
+ 3%
- 2%
- 2%
100
225
92
2004
GE
POP -14%
HHS -11%
PAR -5%
CAR -1%
INC -27%
CST +2%
FRG -37%
synergy
spatial
unknown
RC


Congestion (h): difference GE-RC explained
300
250
200
150
100
50
0
- 33%
- 18%
- 7%
- 1%
- 16%
- 1%
- 25%
+ 1%
- 3%
- 1%
100
264
81
2004
GE
POP -14%
HHS -11%
PAR -5%
CAR -1%
INC -27%
CST +2%
FRG -37%
synergy
spatial
unknown
RC