Omdat ze het waard zijn
Scenario's en de reistijdbaten van infrastructuur investeringen

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Samenvatting

Onderzoek naar de gevoeligheid van reistijdbaten van infrastructuur investeringen voor veranderingen in achtergrondscenario's

Investeringen in het hoofdwegennet zijn kostbaar en voor lange termijn. Projecten moeten ver vooruit gepland worden omdat de realisatie veel tijd kost en de toekomst onzeker is. Beleidsmakers hebben daarom bij het maken van keuzes en het plannen van investeringen te maken met onzekerheid. De scenario's uit het rapport Welvaart en Leefomgeving (WLO) geven een bandbreedte voor nationale demografische en economische ontwikkelingen. Dit onderzoek wil meer inzicht geven in de invloed van specifieke scenario instellingen op de reistijdbaten[1] van investeringen.

Om de analyse uit te voeren worden de uiterste WLO scenario's, Regional Communities (RC, laag) en Global Economy (GE, hoog) als startpunt gebruikt, waarna het effect van specifieke scenariocomponenten wordt getest. De input voor de scenario's verschilt zeer. Naast inwonersaantallen en huishoudensgrootte verschillen vooral de huishoudinkomens en de vrachtkilometers. De olieprijs is gelijk verondersteld. In de referentie-situatie is het aantal auto-kilometers ongeveer 25% hoger in GE. De totale verliestijd is bijna 2,5 keer hoger dan in RC en het aantal congestie-uren is ruim 3 keer zo hoog. De gevoeligheid van de output voor inputvariabelen verschilt per indicator. Het aantal tours en gereisde afstand zijn vooral gevoelig voor populatie, grootte van de huishoudens en autobezit. Verliestijd en congestie-uren zijn daarnaast sterk afhankelijk van de arbeidsparticipatie en in mindere mate van het huishoudinkomen en vrachtverkeer.

Voor deze studie is een investeringspakket ontworpen op het hoofdwegennet van 20 miljard tussen 2020-2030. De reistijdbaten zijn in het hoge scenario maar liefst 3 keer zo hoog als in het lage. Ze zijn het meest gevoelig voor het aantal inwoners en autobezit. Met behulp van de gevonden gevoeligheden en verschillen in de input kunnen de verschillen in output tussen GE en RC verklaard worden. Populatie, huishoudensgrootte, het inkomen en vrachtverkeer zijn daarbij de belangrijkste verklarende variabelen voor het verschil in baten.

De conclusie is dat het reistijdverlies in files en mede daardoor de reistijdbaten van weginvesteringen erg gevoelig zijn voor het omgevingsscenario. De analyse geeft inzicht in de bijdrage van scenario componenten aan dit grote verschil. Tevens is nagegaan hoe welke componenten van de scenario's het meest bepalend zijn voor het rendement van investeringen in weginfrastructuur. Vanwege grote verschillen in uitkomst is het gebruik van verschillende scenario's in kosten-baten studies belangrijk en vooral de populatie, huishoudensgrootte, inkomensniveaus en vrachtverkeer verdienen aandacht bij het opstellen van nieuwe scenario's.

[1] De reistijdbaten zijn het welvaartseffect van kortere reistijden of kortere routes

1. Introduction

Infrastructure and the accompanying regional mobility and accessibility are a necessary condition for social welfare and economic development. 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 and competitiveness of the Netherlands the government invests in the main road network. These investments are very expensive. 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). Until recently, uncertainty was about the size and pace of economic and demographic growth. However, recent analyses show that for many regions it is uncertain if they will grow or decline (PBL 2011). This development differs in time and per scenario and highly affects transport demand. It is important to know more about these uncertainties and to come up with a good strategy to deal with a transitory peak in transport demand (eg. in 2020 or 2030) that will decline afterwards. The risk of over-investments is high and the cost of more careful decision making and incremental investments will increasingly outweigh this risk. This research aims to provide insight on the uncertainty of travel time benefits of investments in the main road network by analyzing their sensitivity to variation in specific scenario settings. The 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?

1.1 Policy context

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). One of the main goals is to improve accessibility by investing in infrastructure. The long term investment program of the government is called the Long-Term Program for Infrastructure, Spatial Planning and Transport (in Dutch: Meerjarenprogramma Infrastructuur, Ruimte en Transport, or MIRT). 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). It is necessary to plan projects far ahead because they take some time to implement. According to the Elverding committee, the time interval between establishing preparatory research and the first actual use of infrastructure is for large Dutch infrastructure projects on average 14 years. (Elverding 2008). The SVIR aims to improve accessibility by 'smart investments', 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. To determine profitability of projects cost benefit analysis (CBA) is mandatory for all large infrastructure projects carried out by the government (Visser and Korteweg 2008). The CBA is conducted in accordance with the OEI-guideline (Overview of the Effects of Infrastructure, in Dutch: Overzicht Effecten Infrastructuur). As said before, the 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 on 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.

According to the OEI-guideline, the robustness of the modeling results for the assumptions should be analyzed. The use of a high and low scenario, respectively Global Economy (GE) and Regional Communities (RC) is recommended (VenW 2008). These scenarios are developed by CPB, MNP and RPB (2006) in the study Welfare, Prosperity and Quality of the Living Environment (Welvaart en Leefomgeving, or WLO). The WLO-scenarios were built around two key uncertainties. These are the willingness to cooperate internationally and 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 1: Four futures of Europe

As my research focuses on the GE and RC scenarios, I will elaborate a little bit further on them. In the scenario Global Economy the European Union expands further eastwards. The scenario is characterized by high population growth (mainly because of immigrants), strong individualization and high economic growth. In the scenario Regional Communities countries keep their own sovereignty. The public sector will hardly be reformed. Labor productivity does not grow, economic growth is low and unemployment is relatively high. There is a population decline after 2020 and less individualization. Recent research on the validity the WLO-scenarios shows that there have been strong fluctuations, but largely within the bandwidth of the four scenarios and the conclusion is that the scenarios are still valid (Hilbers and Snellen 2010). In the spatial outlook 2011 PBL shows the (possible) future development of the Dutch regions. For some regions it is clear that they will grow or show a decline, for other regions this is uncertain (PBL 2011). Therefore policy makers should take more caution to invest in infrastructure by prioritizing projects, using adaptive planning and monitor demographic and economic developments.

This paper describes the research that I did for my master thesis graduation project and answers the research question from the introduction. The paper is structured around three topics. The first concerns the drivers for passenger mobility. The key variables are distinguished and then the scenarios are compared. Next the passenger mobility in 2030 is calculated for the two scenarios regarding tours, distance, time loss and congestion hours. The sensitivity of these indicators to the key variables is analyzed. Finally, the benefits of an investment package of 20 billion on the main road network in the period 2020-2030 are calculated and again the sensitivity to the key variables. The topics are discussed in the chapters method and results.

2. Method

Starting point for this research are two WLO scenarios: RC (population decrease and lowest economic growth and mobility) and GE (highest economic growth). They provide the input for the Dutch National Transport Model (LMS) that I use to forecast passenger 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. The analysis covers only relevant variables 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 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 analyses 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 passenger mobility, an evaluation framework and the designed investment package.

2.1 Drivers of passenger mobility

The first step in the analysis is to identify the key variables 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?

Jong, Daly et al. (2007) performed an extensive literature review on uncertainty in traffic forecasts. They 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. Combined with the available input data and findings during this research, I selected the 7 key variables that were analyzed in this research. The research 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). A summary and description of the variables is presented in the table below.

Description of input variables		
		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
Freight traffic	FRG	The freight traffic is defined by the number of kilometers traveled on the network for the travel purpose freight

Figure 2: Description of the key variables

These 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 built new consistent scenarios, keeping relations between dependent variables constant. Comparison of the zonal input data and a simplification on the labor market resulted in the following figure:

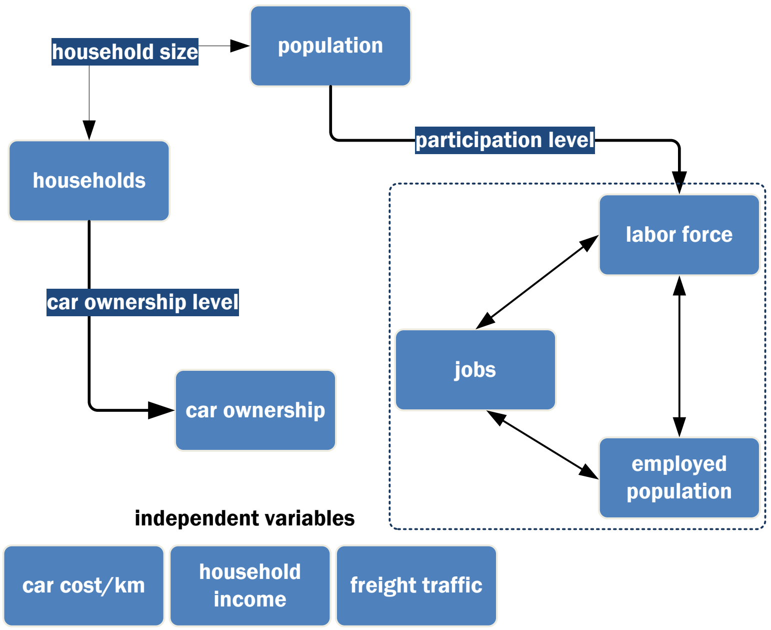

Figure 3: Relations between the key variables

Population (POP) is strongly related to the labor market via the participation level (PAR). The labor market was simplified for this research so that labor force, employed population and jobs are always adjusted simultaneously. The number of households is also directly related to the population via the household size (HHS). Car ownership level (CAR) is defined as the average number of cars per household and therefore the number of cars are linked to the number of households and population. Oil prices influence the variable car costs per kilometer (CST), which is an independent variable. This is also the case for freight traffic (FRG). Income levels (INC) should be related to car ownership level and to participation, but for this research this is also an independent variable. The differences between the two scenario's on the input for these drivers were extensively analyzed.

2.2 Evaluation framework for passenger mobility

The next step is to calculate the sensitivity of the output to these variables. 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 reach unrealistic values. For the research I designed 7 new scenarios. 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	√	√	√	√	√	√	√	√	√

Figure 4: Overview model runs and adjusted variables

For example, in the POP scenarios not only population was adjusted, but also households, cars and labor market. The last scenario is an integrated scenario where all key variables in GE were adjusted to the level of RC, to check if they together can explain the difference in output. 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 traveled 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 and therefore also in this study is the Dutch National Transport Model (LMS, in Dutch: Landelijk Model Systeem). The LMS is a strategic traffic model. It is a forecasting model for the mid to long term, 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). This model was used to forecast passenger mobility in 2030 in this research. The model output consists of a number of aspects, including differentiation to time of day and travel purpose.
Besides the socioeconomic scenarios I also designed a spatial scenario (SPA) where nothing changed to the input variables besides the spatial distribution. The GE scenario with the spatial distribution pattern of RC was implemented.

2.3 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 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 (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.

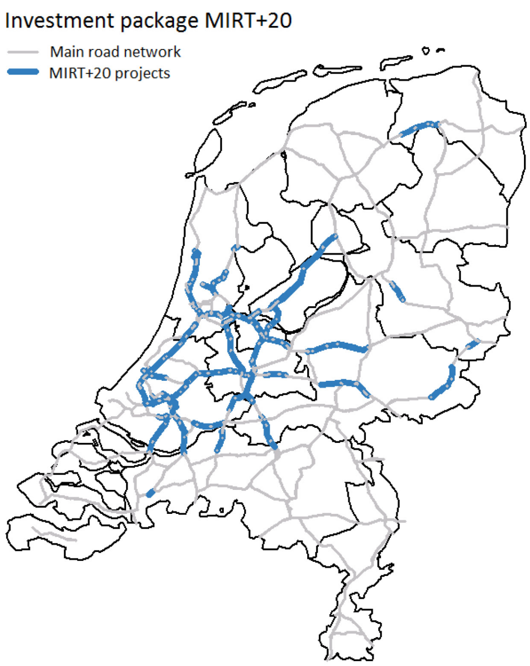

Figure 5: Investment package MIRT+20

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

Figure 6: Details on the MIRT+20 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 is explained in a paper by Rijkswaterstaat (2008). The values of time that were used are shown in the table below. The value of time represents the value that we attribute to one hour of travel time. Note that GE has about 15% higher values.

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

Figure 7: Overview values of time

3. Results

This chapter presents the results of my research. First the scenarios are compared for the key variables. Then passenger mobility in 2030 is calculated and compared according to the evaluation framework and the influence of specific scenario settings is analyzed. The benefits of the MIRT+20 investment package are described in the third paragraph, again including sensitivity to the input variables. Finally the difference between GE and RC is explained by the results of previous analysis.

3.1 Comparing the scenarios

The first important step is to see for the chosen key variables how uncertain they are. The following tables show aggregated data on the input variables for both scenarios.

The two scenarios compared regarding the key variables			
	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%	-3.9%
CAR	1,158	1,151	-0.6%
INC	€ 86,684	€ 63,340	-26.9%
CST	93	91	-2.2%
FRG	45,413,705	28,826,919	-36.8%

Figure 8: Comparing the two scenarios

Population will decrease in RC but grow in GE. The number of people per household will decrease in both scenarios and participation level increases in both scenarios. Statistical analysis of CBS Statline data showed comparable results, except for car ownership and variable car costs. Variable car cost per kilometer depends on oil prices and fuel efficiency of the car park. For both the WLO scenarios in this research an oil price of $70,- per barrel was assumed. However it is well known that the oil price is very uncertain (Verdonk and Wetzels 2012). The fuel efficiency of the car park is slightly higher in RC, which explains the lower variable car costs per kilometer in RC.

The car ownership per household is approximately the same for RC and GE, while the household gross income shows a large difference. This is highly unlikely as car ownership and income are highly correlated. In the process of the research is appeared that freight traffic was also a key variable that determines the output of the model. This was quite surprising as this variable was rarely or not mentioned in the literature. The variable is uncertain, only about 60% of the freight kilometers take place in RC compared to GE. Concluding, according to the input data the bandwidth of population, household size, income and freight traffic for 2030 is large. Additionally, car ownership and oil prices are also uncertain.

3.2 Passenger mobility in 2030

The data for the two scenarios was used to compute passenger mobility in the high and low scenario in 2030. As explained in the method the main indicators are tours, distance, time loss and congestion. The results are presented below.

overall results LMS runs				
	tours	distance (km)	time loss (h)	congestion (h)
2004	7,403,000	192,018,000	167,000	74,000
RC	8,074,000	232,305,000	153,000	59,000
GE	10,148,000	291,616,000	374,000	194,000
GE / RC	+ 26%	+ 26%	+ 145%	+ 227%

Figure 9: Passenger mobility in RC and GE 2030

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%. The next table shows the sensitivity of the indicators to the variables in GE, all scaled to a 10% variation.

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%
SPA RC	- 0.1%	- 0.1%	- 2.3%	- 3.3%

Figure 10: Sensitivity of the indicators to a 10% change in input

The sensitivity of the output varies per indicator. The total number of tours per car and the total distance is sensitive to a variation in population and also in household size and car ownership. Time loss and congestion are more sensitive to a 10% change in the input and besides population, household size and car ownership also to labor participation. Income levels and freight traffic have less impact, but still about 5%. The results for RC are similar, although sensitivity in RC is higher. This is because of the higher absolute values in GE.

3.3 Benefits of investments

The benefits of the MIRT+20 package also show large differences for the high and low scenario. In GE the total travel time benefits are 1049 million euros per year and in RC only 376. The benefits in GE are almost 3 times higher. The travel time benefits are sensitive for variation in the input. The most important explanatory variables 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. The following figure combines sensitivity of the variable 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.

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

Figure 11: Sensitivity of travel time savings for the input variables (per 10% variation)

3.4 Difference between scenarios explained

Using these results I should now be able to explain the difference between GE and RC by comparing the input on the key variables and using the results of the sensitivity analysis. In this paragraph I will show this on an aggregated level. From my research I know per variable their sensitivity to variation and the differences between RC and GE.

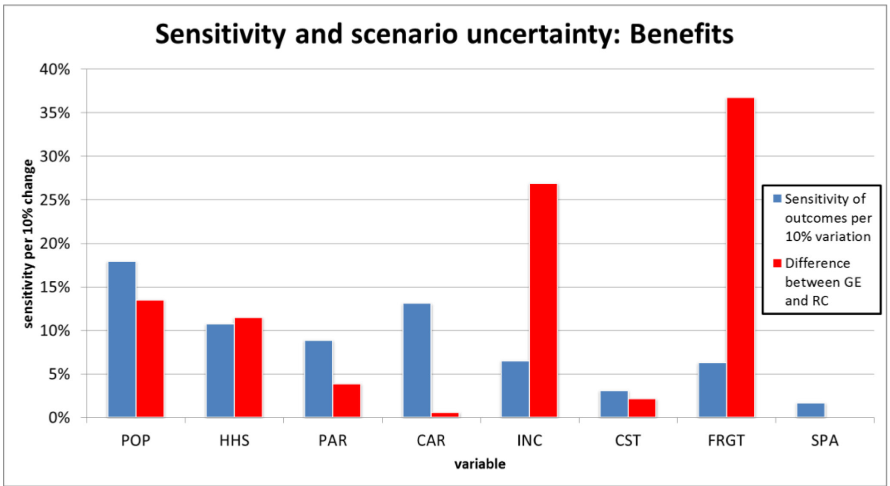

Figure 12: Sensitivity and scenario uncertaintie in GE

When multiplied they will show the effect on the output. The following figure 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 -4%	- 1%	- 1%	- 4%	- 5%	- 3%
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	8,131,000	238,459,000	157,000	62,000	356
8 synergy	- 1%	- 2%	+ 1%	- 0%	+ 4%
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

Figure 13: From GE to RC in 10 steps

As explained, the percentages are the result of a combination of sensitivity and uncertainty of the variables. Remember that the variable 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 same applies to the variable car costs (CST). Finally, it is important to realize that on a national level the differences are mainly volume differences, not spatial. Only 5% of the population is located in a different 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 gives a representation of the 10 steps.

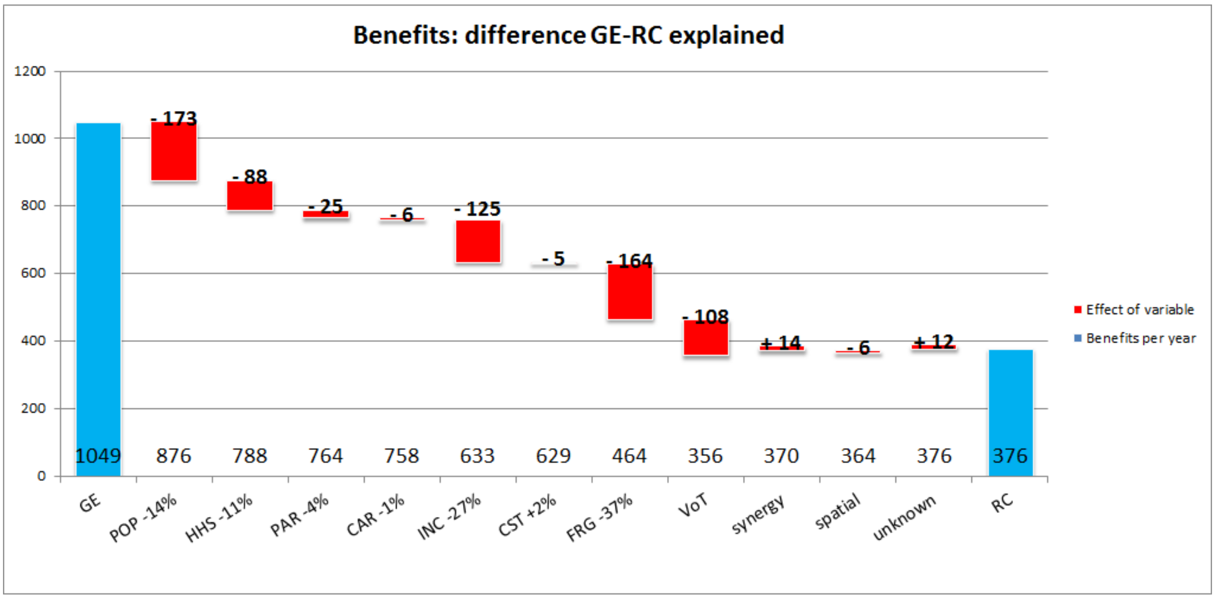

Figure 14: Explanation of the difference in benefits for GE and RC

The four variables that explain 70% of the difference are population, householdsize, income and freight traffic. Together with the new value of time this is 95%. The first 7 variables 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 variables (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 labor market or demographic differences in age or sex.

4. Conclusion and recommendations

This research shows that the key variables that were selected determine to a great extent the benefits of infrastructure investments. Population, household size, income and freight traffic explain most of the differences in output between the two scenarios. However car ownership and oil prices may be more uncertain than the scenarios suggest and therefore also cause uncertainty on the outcomes. The table below summarizes qualitatively how uncertain they are and to what extent they influence the benefits.

Uncertainty of input variables 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	++	+/-
Spatial distribution	-	-

Figure 15: Summary of uncertainty and sensitivity

4.1 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) (Jong, Daly et al. 2007). 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. This might be an interesting topic for future research. 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 variables uncertainty.

4.2 Recommendations

For the design of new scenarios in the future, the successors of the WLO, there are some recommendations. The variables that proved to have large impact of passenger mobility forecasts and benefits of the investment should be specified carefully in the new scenarios. Especially 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 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 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.

The main conclusion of this research is that there are large differences in mobility and congestion hours and especially in benefits of investments between scenarios. The differences are mainly due to population, households, income and freight traffic. The study suggests further exploration of uncertainty in cost-benefit studies at a time when the risk of over-investing increases. The large differences in benefits shows that the use of different scenarios in cost-benefit studies is important. We should only invest when we think that it’s worth it. Especially the population, household size, income levels and freight deserve attention in the design of new scenarios.

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